DEVELOPMENT OF DIMENSION LUMBER GRADE AND YIELD ESTIMATES FOR YELLOW-POPLAR SAWLOGS AND TREES

by

Joseph Denig

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APPROVED:

E. M. Wengert, Chairman

K. H. Hinkelmann

G. Ifju

W. B. Stuart

M. S. White

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Blacksburg, Virginia

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1.0 INTRODUCTION

The projected increased demands for forest products and the dwindling softwood supplies are expected to lead to increased pressure on the hardwood raw material base. This increased pressure presents a challenge in terms of traditional hardwood utilization schemes to supply a wide range of many new hardwood products from a resource of variable quality and size.

1.1 Problem Statement

The Eastern United States' hardwood region offers a great potential for supplying the nation's growing demand for wood based products. The problem in realizing this potential is that eastern hardwoods in general, and yellow-poplar (*Liriodendron tulipifera* L.) in particular, are underutilized (Table 1.1); that is, their net annual growth exceeds their annual removal level.

Recent U.S. Forest Service survey data show that in the Eastern United States there is approximately 11.2 billion cubic feet of yellow-poplar growing stock. The net annual growth rate is 600 million cubic feet while the annual removal rate is 200 million cubic. Under custodial forest management (i.e., a minimal level), the annual harvest of yellow-poplar can be increased from 234 to 500 million cubic feet (Boyce and McClure 1978).

1.2 Broad Objective

The broad objective of this dissertation is to explore and define the value relationships for processing yellow-poplar logs into various

Table 1.1. Growing stock, net annual growth and annual removals of yellow-poplar and other hardwoods in the eastern U.S. in 1978.

	Million Cubic Feet
Growing Stock	
Yellow-poplar	11,173
Other hardwoods	198,845
Net Annual Growth	
Yellow-poplar	620
Other hardwoods	7,077
Annual Removals	
Yellow-poplar	234
Other hardwoods	4,265

Source: Boyce and McClure (1978).

end products. By defining this relationship, it is believed that the potential for profitable processing of yellow-poplar will be increased, and in turn, this will increase the utilization of this species and assist in fulfilling our country's increased demand for wood.

End products used in this evaluation are veneer logs, factory lumber, chips and manufacturing residues, all of which are presently being marketed, and dimension lumber, a potential but yet unmarketed (from yellow-poplar) product. It is hypothesized that yellow-poplar logs can also be stratified into dimension lumber yield classes.
The potential value when manufactured into dimension lumber can then be contracted with values when manufactured into other currently marketed products. Log classes presently exist that can be used to establish a potential, estimated value for a log when processed into these various currently marketed products.

1.3 Specific Objectives

At present, dimension (nominal 2-inch thick) lumber used in light frame construction is almost exclusively manufactured from softwood species. Overlooking the market effects of the present economic down turn, there is a growing need for construction lumber for family housing at reasonable prices. Recent literature, research, and conferences have pointed to the possibility and feasibility of using yellow-poplar dimension lumber. It is an accepted species for light framing in the grading rules of the Northern Hardwood and Pine Manufacturers Association (1982). Yet, if utilization of yellow-poplar as a dimension lumber species is to be realized, lumber yields and residue volumes for various grade and size classes of yellow-poplar trees must be available in order to allow land managers to assess the value of standing yellow-poplar timber, develop sound management objectives for the species, and encourage its wide use. Similar yield and residue information for yellow-poplar sawlogs is also needed to allow sawmill operators to evaluate the economic feasibility of producing dimension lumber (in lieu of the other, more typical products) from yellow-poplar logs. However, it must be recognized that many of the sawmills in the yellow-poplar region are quite small, and, therefore, will require explicit information on the profitability of sawing yellow-poplar because they do not maintain an extensive staff for developing their own data.

In order to develop a sound basis for evaluating the economic potential for producing yellow-poplar dimension lumber, the following specific objectives are incorporated into this disseration:

1) Develop practical log grading specifications for yellow-poplar in order to identify those logs economically suitable for producing construction dimension lumber.

2) Develop equations and tables for predicting dimension lumber volume yields and associated chippable residue and sawdust yields from yellow-poplar logs and trees of various size and quality classes.

3) Collect basic log and tree data so that results from the above objectives could be integrated with existing product yield and biomass prediction models to aid in the development of multi-product tree classification systems.

After these specific objectives are met (Chapters 3 to 5), then the broad objective is addressed (Chapter 6).

2.0 LITERATURE REVIEW

2.1 Yellow-poplar Raw Material

2.1.1 Yellow-poplar tree

Yellow-poplar, a member of the magnolia family, is a rapid-growing, shade-intolerant eastern hardwood capable of obtaining heights of 120 feet and diameters of 18 to 24 inches in 50 years on good sites (Harlow and Harrar 1969). Its natural range is the Eastern United States, from central Florida northward to Massachusetts and from the Atlantic coast westward to the Mississippi River.

In the Appalachian region, yellow-poplar sites range from sea level to 4500 feet in elevation (Vick 1973). For good growth, yellow-poplar requires moist, well-drained loose textured soil such as found in coves and on moist slopes.

Yellow-poplar is a constituent of 16 forest cover types, being the major species in pure yellow-poplar forest cover type; yellow-poplar, white oak and northern red oak type; yellow-poplar and hemlock; and yellow-poplar and sweetgum (Vick 1973).

The species is known as a prolific seeder, producing from 200,000 to 300,000 seeds per acre (Harlow and Harrar 1969, and Vick, 1973). However, only five to ten percent of the seeds are viable, these requiring contact with mineral soil and full sunlight for germination.

2.1.2 Yellow-poplar wood

Yellow-poplar is a diffuse porous wood with its growth rings delineated by marginal parenchyma. The sapwood of yellow-poplar is narrow and varied in color. The heartwood color ranges from tan to brown, purple, blue and yellow. These varied colorations have no apparent effect on the strength properties (Vick 1973).

The specific gravity of yellow-poplar is 0.42 based on ovendry weight and volume at twelve percent moisture content (Vick 1973).

Yellow-poplar is easily worked with handtools. It also glues easily and holds paint well. Yellow-poplar lumber has been used for furniture, boxes, pallets, millwork, musical instruments and miscellaneous products. Veneer from yellow-poplar has been used for produce boxes, for plywood in furniture and as a corestock material (Panshin and DeZeeuw 1970).

Koch (1978) examined the wood properties in relationship to structural use and concluded, "clear yellow-poplar compares favorably in specific gravity, bending strength and stiffness with softwood species commonly used for structural purpose".

This is supported by the comparison of specific gravity, and moduli of rupture and elasticity of yellow-poplar and of several softwood species commonly used for dimension lumber listed in Table 2.1. Yellow-poplar specific gravity and strength values are somewhat less than those of Douglas-fir and loblolly pine and comparable to ponderosa pine and spruce. (Allowable design values for yellow-poplar are discussed in Section 2.3.1).

Table 2.1. Properties of yellow-poplar and selected softwood species used for dimension lumber.

Species	Specific Gravity	MOR (psi)	MOE (10^6 psi)
Yellow-Poplar	.42	10,100	1.58
Douglas Fir (Coast)	.48	12,400	1.95
Loblolly Pine	.51	12,800	1.79
Ponderosa Pine	.40	9,400	1.29
Spruce	.44	10,400	1.23

Source: USDA Forest Service (1974). Based on small clear specimens at 12% MC.

2.2 Yellow-poplar Markets

2.2.1 Present yellow-poplar markets

A traditional major use of yellow-poplar is as corestock and cross band veneer for furniture (Smith 1978). As the furniture industry has increased its use of particleboard for corestock, the demand for yellow-poplar lumber has decreased. In 1953, approximately 135 million board feet of yellow-poplar lumber were used by the North Carolina furniture industry; the use declined to 55 million board feet in 1968 (Smith 1978) and continued to decline over the last 10 years[1/].

The demand by the furniture industry for yellow-poplar rotary cut veneer and plywood (and, therefore, the demand for the higher quality logs and trees) continues. Therefore, it is a major concern of the U.S. Forest Service for wise use of the forest resource that an active use and market be found for the lower quality logs and trees which had been previously marketed for corestock.

2.2.2 Market outlook for yellow-poplar dimension lumber

Yellow-poplar has been used as a local construction material in the past, but present building code requirements for graded lumber have eliminated most of this use. As stated earlier, one suggested potential use of yellow-poplar is in the manufacturing of dimension lumber. This

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[1/] Dr. Fred M. Lamb, personal communication, October 16, 1982, Virginia Tech, Blacksburg, Virginia.

would utilize the lower quality material and probably would not interfere with the markets established for the higher quality material.

Schick (1978) conducted a potential market survey for yellow-poplar studs in West Virginia prior to the acceptance of yellow-poplar dimension lumber grading rules by the Northern Hardwood and Pine Manufacturers Association (1982). The results indicated that the majority of wholesalers (70%), retailers (80%) and homebuilders (86%) surveyed would consider selling or using yellow-poplar dimension lumber if the wholesale price was as much as up to ten percent lower than comparable softwood products. A majority of wholesalers (62%), retailers (67%) and home-builders (70%) agreed with the statements, "properly dried and manufactured poplar framing lumber is structurally substitutable for traditional softwood framing lumber".

Schick also indicated that yellow-poplar has a high probability of being accepted as a construction material. He concluded that the softwood-dominated dimension lumber market may be penetrated with a competitive price strategy for yellow-poplar. Recent experience with aspen studs have shown that hardwoods have the potential to penetrate the dimension lumber market at the same price as softwoods (at the same grade)[2/].

[2/] John Snyder, personal communication, July 1982, Cascade Forest Industries, Milwaukee, Wisconsin.

Table 2.2. Stumpage, delivered log and delivered chip prices for yellow-poplar in 13 Southern states for the period from January, 1980, to June, 1982.

Product	Unit	Location	Average Price Per Unit		
			Average	Low	High
Stumpage, Veneer	MBF[1]	Woods	$127	$110	$142
Stumpage, Sawlogs	MBF[1]	Woods	$ 60	$ 55	$ 64
Stumpage, Pulpwood	Cord	Woods	$ 3	$ 3	$ 4
Veneer Logs	MBF[1]	FOB Mill[2]	$205	$173	$229
Sawlogs	MBF[1]	FOB Mill	$125	$117	$134
Chipping Logs	MBF[1]	FOB Mill	$101	$89	$115
Roundwood	Cord	FOB Mill	$ 31	$ 30	$ 32
Chips, Clean	Ton	FOB Mill	$ 15	$ 14	$ 16
Chips, Whole Tree	Ton	FOB Mill	$ 11	$ 11	$ 12

[1]Doyle Scale.

[2]FOB Mill denotes delivered to manufacturing mill.

Source: Timber Mart South (last 8 issues, 1980; 12 issues, 1981; first 4 issues, 1982).

2.2.3 Yellow-poplar price information

Current average prices for yellow-poplar stumpage, logs delivered and residues delivered to the mill yard are listed in Table 2.2. The importance of marketing a product to its full potential value is seen in the difference in price of yellow-poplar sawlogs selling for $125 per thousand board feet (log scale) versus veneer logs selling for $205 per thousand board feet (log scale). However, there are restrictions to markets, such as geographical considerations, that do not allow the realization of the full value of the product.

Prices for furniture grade yellow-poplar are listed FOB sawmill lumber in Table 2.3. Prices for spruce-pine-fir dimension lumber delivered to the wholesaler in the eastern United States are listed in Table 2.4. (It is expected that yellow-poplar dimension lumber would penetrate the market niche held by spruce-pine-fir, being comparable in mechanical properties and design values.)

The cost of freight is an important factor for a sawmill to consider in establishing the price of dimension lumber to the lumber wholesaler. Typical rail freight cost for one thousand board feet of spruce-pine-fir dimension lumber from Prince George, Canada to New York is $104 (Random Lengths Publications 1982). Because yellow-poplar dimension lumber would be manufactured in the Appalachian region and could be sold in Pittsburgh and Washington, D.C. areas, a more appropriate freight charge may be $20 to $30 per thousand board feet[3/]. The prices listed

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3/ Based on a typical charge of $.25 per mile per MBF by truck for a 120 mile radius or rail freight from Augusta, GA to New York of $31-35/MBF for southern yellow pine 2 x 4's (Random Lengths, June 18, 1982).

Table 2.3. Prices (FOB Sawmill) for 4/4 and 8/4 yellow-poplar lumber per thousand board feet manufactured in the Appalachian region for the period of January 4, 1981, to June 5, 1982.

Hardwood Grade	Price per Board Foot		
	Average	Low	High
	4/4 Lumber		
FAS	$418	$400	$420
1 Com.	$279	$265	$283
2A Com.	$170	$167	$178
2B Com.	$157	$152	$160
	8/4 Lumber		
FAS	$453	$435	$455
1 Com.	$305	$290	$310
2A Com.	$184	$180	$185
2B Com.	$158	$155	$160

Source: Lemsky (52 issues in 1981, 23 issues in 1982).

Table 2.4. Prices for spruce-pine-fir dimension lumber delivered to wholesalers in the northeastern United States for the period from January 9, 1981, to August 13, 1982.

Size	Softwood Grade	Price Per MBF		
		Average	Low	High
2 x 4	Standard and Better	$217	$185	$260
2 x 4	Utility	$167	$138	$190
2 x 6	No. 2 and Better	$228	$205	$270
2 x 6	No. 3	$163	$140	$185
2 x 8	No. 2 and Better	$232	$210	$275
2 x 8	No. 3	$164	$150	$185

Source: Random Lengths Publications (40 issues in 1981, 25 issues in 1982).

for the spruce-pine-fir minus $30 per thousand board feet may be a reasonable estimate of the prices obtainable for yellow-poplar lumber.

2.3 Saw-Dry-Rip (S-D-R)

In recent years, the U.S. Forest Products Lab has researched and developed a new manufacturing process for producing hardwood dimension lumber in order to overcome the problem of excessive warp in conventional manufacturing schemes (Hallock and Bulgrin 1978, Maeglin et al. 1981, and Maeglin and Boone 1981). This new process is called the Saw-Dry-Rip (S-D-R) process. Logs are live sawn into 1-3/4 inch thick flitches. The flitches (which may be lightly edged after sawing) are then kiln dried using schedule T10-D3 (Rasmussen 1961) after which they are equalized for 48 hours at 15 percent equilibrium moisture content (EMC). The dry flitches are ripped into nominal dimension lumber widths and then planed to final size.

Out of 369 dimension lumber pieces manufactured in Hallock and Bulgrin's first study of the S-D-R processes, 99 percent met the warp limitations specified by Stud grade. (See Section 2.4.1 for grade information.)

In a follow-up economic study of the S-D-R system, Maeglin, Bulgrin and Hallock (1981) found the volume yield when producing 4/4 lumber to be only 70 percent of the yield when producing either conventionally or S-D-R sawn studs. The value yield of logs sawn into 4/4 lumber was only 73% of the value when sawn into dimension lumber.

Maeglin and Boone (1981) conducted a further study comparing studs manufactured by conventional sawing with S-D-R sawing in combination

Table 2.5. Yellow-poplar studs failing to meet warp requirements for stud grade.

Treatment	Warp			Number of Studs
	Crook	Bow	Twist	
	--------Percent--------			
Conventionally sawn, Conventionally dried	16	1	1	355
Conventionally sawn, High-temperature dried	9	1	1	373
S-D-R live sawn, Conventionally dried	2	1	0	403
S-D-R live sawn, High-temperature dried	0	0	0	418

Source: Maeglin and Boone (1981).

Maximum warp limits: crook, ¼ inch in 8-ft. length; bow, ½-inch in 8-ft. length; twist, 3/8 inch in 8-ft. length.

with a conventional kiln schedule (T11-D4; Rasmussen 1961) and a high-temperature schedule. The high temperature schedule was 235°F for 28 hours followed by an equalization period of 48 hours at a 10 percent EMC. It was concluded that the S-D-R system produces studs with much less warp than conventional sawing methods and also that the number of studs rejected by excessive warp is further reduced (although only slightly) by high-temperature drying (Table 2.5). The authors theorized that the benefits from high-temperature drying result because above 212°F the lignin plasticizes, allowing the stressed fibers (i.e., the fibers are under stress due to the naturally occurring growth stresses in the tree) to slip, thus relieving the growth stress that would probably cause warp in conventional sawing and drying. However, no evidence to support this conclusion was given. In fact, the major benefits (i.e., reduced warp as shown in Table 2.5) appear to arise mostly from the sawing pattern rather than the drying method.

2.4 Grades, Yields and Economic Assessments

2.4.1 Grades

The purpose of grading or stratifying logs and lumber into classes is to estimate value based on anticipated end product use.

2.4.1.1 Lumber

Hardwood factory lumber (i.e., lumber intended to be cut or machined into small pieces such as for furniture parts) is graded based on the amount of defect free surface area. The National Hardwood Lumber Association (1978) publishes the lumber grading rules for

Table 2.6. Strength and stiffness allowable design values (extreme fiber in bending, F_b, and modulus of elasticity, E) for yellow-poplar dimension lumber at 19% moisture content.[1]

		Allowable Design Value	
Grade	Dimensions (nominal)	F_b (psi)	E (psi)
Select Structural	2 to 3 inches	1500	1,500,000
No. 1	thick and	1250	1,500,000
No. 2	2 to 4 inches	1050	1,300,000
No. 3	wide	575	1,200,000
Stud		575	1,200,000
Construction	2 to 4 inches	750	1,200,000
Standard	thick and	425	1,200,000
Utility	4 inches wide	200	1,200,000
Select Structural	2 to 4 inches	1300	1,500,000
No. 1	thick and	1100	1,500,000
No. 2	5 inches and	900	1,300,000
No. 3	wider	525	1,200,000
Appearance		1100	1,500,000
Stud		525	1,200,000

[1]To adjust for 15 percent maximum moisture content multiply F_b by 1.08 and E by 1.05.

Source: National Forest Products Association (1980).

hardwood factory lumber.

On the other hand, dimension lumber is usually visually graded based on expected strength-reducing criteria (i.e., knots, checks, shake and slope of grain), although its alternative, mechanically stress rating (MSR), is gaining in importance.

Grading rules for yellow-poplar structural lumber are described by the Northern Hardwood and Pine Manufacturers Association (1982). Design values for yellow-poplar dimension lumber have been established (Table 2.6) under the Northern Hardwood and Pine Manufacturers Association grading rules. These compare closely to spruce-pine-fir (Koch 1978).

2.4.1.2 Logs and trees

Traditional hardwood log grades as established by the U.S. Forest Service are based on the relationship between log characteristics (most typically knots) and factory lumber yields (Vaughan, et al. 1966). Therefore, their usefulness in determining hardwood dimension lumber yields are questionable, since as stated above, factory lumber grades are based on the amount of clear cuttings and structural grades are based on strength-reducing defects.

Hardwood tree grades developed by the U.S. Forest Service are based on grading the best 12-foot section of the 16-foot butt log (Hanks 1976) or, as sometimes practiced, based on the entire standing tree which is mentally divided into 16 foot logs and then each log graded individually.

Southern pine log grades developed by Schroeder, Campbell and Rodenbach (1968) (for logs to be sawn into dimension lumber) are based on the number of clear faces (i.e., knot-free) on the log. Regression equations were developed for percent lumber yield by lumber grade for each log grade as a function of log diameter. Even though the unexplained variances of the clear face grading system were similar to an older "knot count" grading method, the clear face system was recommended because it was much simpler to apply.

Southern pine tree grades (for structural lumber) developed by Schroeder, Campbell and Rodenbach (1968) are based on the number of clear faces system. Regression equations were developed to predict the percent lumber grade yield for each individual tree grade as a function of tree diameter at breast height and merchantable height.

2.4.2 Grade and factory lumber yield

2.4.2.1 Trees

Hanks (1976) developed regression equations for predicting factory lumber yields from yellow-poplar trees graded by the U.S. Forest Service hardwood tree grading system. Hanks selected 159 yellow-poplar trees, measured merchantable height and diameter at breast height (DBH), and then graded the trees with the U.S. Forest Service grade rules. The trees were then felled, bucked into sawlogs, and sawn into factory lumber. An identification system was maintained so that each piece of lumber could be traced back to a particular tree. The lumber was graded by a National Hardwood Lumber Association certified inspector.

Multiple regression equations were developed that predict dry lumber yields for each lumber grade within each tree grade as a function of DBH^2, merchantable height, and DBH^2 times merchantable height.

Predictive regression equations for estimating yellow-poplar tree weight and volume of chippable residue, bark, factory lumber, and sawdust as a function of DBH^2 times merchantable height were developed by Clark, Taras and Schroeder (1974).

Green factory lumber volume in board feet (Y) may be estimated for yellow-poplar trees by the following equation (Clark, et al.):

$$Y = -14.61814 + 0.2085\ (DBH)^2(Mh)$$

$$R^2 = 0.99$$

where:

DBH = diameter in inches measured at breast height.

Mh = sawlog merchantable height measured normally during a timber cruise.

These equations fulfilled the need for information on weight and volume of lumber and residue that could be used to estimate tree volume; tree grade and lumber grades were not incorporated into the equations.

2.4.2.2 Sawlogs

Tables for yellow-poplar logs graded by U.S. Forest Service rules showing the average lumber yield in various 4/4 factory lumber grades were reported by Cassens (1980). The factory lumber yield, although not quantified by a regression equation, was presented as a function of log grade and diameter based on a 420 log sample. These data are used in the economic analysis of Chapter 6.

2.4.2.3 Subfactory logs

Hanks (1973) developed yield tables for subfactory class logs for several different hardwood species including yellow-poplar. Subfactory logs are those that fail to meet U.S. Forest Service log grade 3 requirements but have at least an 8-inch scaling diameter. The tables Hanks presented were derived from regression equations with the lumber yield as a function of both the scaling diameter and the scaling diameter squared.

2.4.3 Economic feasibility of processing yellow-poplar logs by the S-D-R system

Harpole, Maeglin and Boone (1981) conducted and economic feasibility study of processing low- to medium-density hardwoods into dimension lumber using the Saw- Dry- and Rip (S-D-R) system. The mill studied would manufacture 60.4 million board feet of dimension lumber a year and have a capital cost estimated at $11,500,000. A sawmill of this size is probably unrealistic for the Appalachian region. Nevertheless, the study does provide the basic format of a feasibility analysis for a potential investor.

One important difficulty in easily applying the results of Harpole, et al. (1981) is in evaluating Return on Sales:

$$\text{Return on Sales} = \frac{LR - PC - RC + RR}{LR}$$

where:

LR = lumber revenue

PC = processing cost

RC = roundwood cost

RR = residue revenue.

The difficulty is in determining accurate estimates of the terms in this equation. Processing cost (PC) will vary from sawmill to sawmill, being dependent on capital and operating cost. Thus, for each case, PC must be carefully measured or estimated. Likewise, the roundwood cost (RC), lumber revenue (LR) and revenue from residues (RR) have a strong dependence on each other. This means that the return on sales will vary with log grades and with market prices and, therefore, will be a highly dynamic situation. If lumber and residue revenues, which are in turn dependent on raw material quality (i.e., log grades), can be stratified along with raw material price, then the situation can be made more stable and the S-D-R method of dimension lumber manufacturing more accurately assessed.

3.0 DIMENSION LUMBER YIELD ASSESSMENT: METHODS, MATERIALS AND PROCEDURES

In order to estimate dimension lumber yields, sample trees were graded, manufactured into logs, graded as logs, manufactured into 2 x 4's using the S-D-R method and graded. Lumber yields were related to tree grades, log grades, and other characteristics in order to obtain useful prediction equations.

3.1 Data Collection

A total of 53 yellow-poplar trees were selected from two sites located in the Monongahela National Forest near Richwood, West Virginia. The distribution of the sample trees (Table 3.1) was chosen to meet the predetermined sampling pattern which is a function of the U.S. Forest Service southern pine tree grades (Table 3.2) (Schroeder, et al. 1968) and the diameter classes (measured at breast height, DBH, 4.5 geet above ground level).

After selection and before felling, the tree grade was also determined using the U.S. Forest Service hardwood tree grading system (Table 3.3). Modifications to the diameter limits and log lengths were made to the U.S. Forest Service hardwood tree and log grades in order to allow the stratification of smaller logs by the grading system[1/].

The trees were then felled. Height measurements were taken from the stump end to a four-, six- and eight-inch top diameter (outside bark)

[1/] James Schroeder, personal communication and recommendation, U.S. Forest Service, Asheville, North Carolina.

Table 3.1. Number of trees within each southern pine tree grade and diameter class selected for study.

Diameter Class	U.S.F.S. Southern Pine Tree Grades		
	A	B	C
8.0 - 9.9 inches	0	3	5
10.0 - 11.9	1	3	3
12.0 - 13.9	2	3	3
14.0 - 15.9	4	5	5
16.0 - 17.9	2	2	2
18.0 - 19.9	3	1	0
20.0 - 21.9	2	1	2
22.0 - 23.9	1	0	0
	$n_A = 15$	$n_B = 18$	$n_C = 20$
	Total number of trees = 53		

Table 3.2. U.S.F.S. southern pine tree grade specifications.

Grade Factor	Tree Grade A	Tree Grade B	Tree Grade C
Number of Clear Faces	3 or 4	1 or 2	None

Notes:

1. A face is one-fourth the circumference of the 16-foot grading section and extends the full length of the grading section. Clear faces are those free from knots measuring more than ½ inch in diameter, overgrown knots of any size, and holes more than ¼ inch in diameter. Faces may be rotated, if necessary, to obtain the maximum number of clear faces on the grading section.

2. Sweep. Lower any tentative Grade A or B tree by one grade if sweep in the lower 12 feet of the grading section amounts to 3 or more inches and equals or exceeds one-fourth the diameter at breast height.

3. Heart rot. Lower any tentative Grade A or B tree one grade if conks, punk knots or other evidence of advanced heart rot is found anywhere on the tree stem.

4. No tree can be lowered below Grade C, provided the total scaling deducations for sweep and/or rot do not exceed two-thirds the gross scale of the tree. Trees with total scaling deducations in excess of two-thirds gross scale are classified as cull.

Source: Schroeder, Campbell and Rodenbach (1968).

Table 3.3. U.S.F.S. hardwood tree grades as modified for yellow-poplar dimension lumber yield study.[1]

Grade Factor	Tree Grade 1	Tree Grade 2	Tree Grade 3
Length of grading zone (feet)	Butt 16	Butt 16	Butt 16
Length of grading section (feet)	Best 12	Best 12	Best 12
Dbh, minimum (inches)	16	None	None
Clear cuttings (on the three best faces):			
Length, minimum (feet)	5	3	2
Number on face (maximum)	2	3	
Yield in face length (minimum)	5/6	4/6	3/6
Cull deduction, including crook and sweep but excluding shake, maximum within grading section (percent)	9	9	50

[1]Minimum DBH and minimum diameter inside bark at top of grading section for grades 2 and 3 were eliminated.

Source: Hanks (1976).

and to the apex of the tree. The trees were then skidded to the landing where they were bucked into 16-foot 8-inch logs and transported to the Brooks Forest Products Center, Blacksburg, Virginia. During bucking, the logs were numbered to identify their location within a particular tree. The exposed tree and log ends were end coated with a commercial wax emulsion in order to reduce end drying and limit end checking.

3.1.1 Log measurement

Upon arrival at the Brooks Center, the 16-foot 8-inch logs were bucked in half with a one-inch disk removed from the freshly sawn end of one of the log halves. From this disk, a 60 degree (approximate) wedge shape section, radiating from the center, was cut and used as a moisture content (MC) sample to estimate the green moisture content of the two adjoining bolts. The moisture content of the wedge shaped pieces was determined using the ovendrying method. For the sake of clarity and brevity, the nominal 8-foot sawlogs will be referred to as "logs" from hereon. The freshly bucked logs were numbered to continue to identify their origin. Log diameters at the small and large end, inside and outside the bark, were recorded. The logs were then graded using both the U.S. Forest Service hardwood and southern pine log grading rules, as listed in Table 3.4 and 3.5, respectively.

Log defects and characteristics--knot size, knot type, sweep percent, crook percent, cull percent, number of burls, number of epicormic branches, seams, scars, extent of bird peck and end defects--were also measured and recorded. The definations, means and ranges of

Table 3.4. U.S.F.S. hardwood log grades, modified for yellow-poplar dimension lumber yield study.[1]

Log Grade	Minimum Diameter (Inches)	Maximum No. of Cuttings Allowed	Minimum Length of Cuttings (Feet)	Minimum Yield of Clear Face Length	Maximum Sweep and Crook Allowed	Maximum Cull Allowed
1	13	2	7	5/6	15%	40%
2	11	3	3	2/3	30%	50%
3	None	No Limit	2	1/2	50%	50%

[1]Requirement for minimum diameter was eliminated for grade 3 and for minimum length was eliminated for all grades.

Notes:

$$\text{Sweep } \% = \frac{\text{Total Sweep} - 1}{\text{Scaling Diameter}}$$

$$\text{Grade } \% = \frac{\text{Deflection}}{\text{Diameter}} \times \frac{\text{Length of Crook}}{\text{Log Length}}$$

Source: Rast, Sonderman and Gammon (1973).

Table 3.5. U.S.F.S. southern pine log grade specifications.

Grade Factor	Log Grade 1	2	3
Number of Clear Faces	3 or 4	1 or 2	None

Notes:

1. Clear faces. A face is one-fourth the circumference of the log surface and extends the full length of the log. Clear faces are those free from knots measuring more than ½ inch in diameter, overgrown knots of any size, and holes more than ¼ inch in diameter. Faces may be rotated, if necessary, to obtain the maximum number of clear faces on the log.
2. Sweep. Lower any tentative Grade 1 or 2 log one grade if sweep is 3 inches or more and equals or exceeds one-third the scaling diameter of the log.
3. Heart rot. Lower any tentative Grade 1 or 2 log one grade if conks, massed hyphae, punk knots, or other evidence of advanced heart rot are found.
4. No log will be lowered below Grade 3 if its net scale is at least one-third the gross log scale after deductions have been made for sweep and/or rot. Logs with total scaling deductions for sweep and rot exceeding two-thirds the gross scale of the log will be classified cull.

Source: Schroeder, Campbell and Rodenbach (1968).

the log defect and descriptive variables are listed in Table 4.1.

3.1.2 Log sawing

Immediately prior to sawing, the logs were weighed. Logs were not debarked. Then the logs were oriented on the saw carriage with a better face as the opening face, except for those logs containing sweep or crook. Those logs that contained sweep or crook were oriented so that the curvature in the log was oriented up or down on the saw carriage. The reasoning behind the orientation of the logs with sweep and crook is two-fold: obtain maximum usable material that can be sawn from the log and reduce the chance of warping.

Logs were held with two knees and dogs seven feet apart. The saw was a 54-inch diameter circular saw with a 9/32-inch nominal kerf. The opening face was a minimum of 4-inches wide in order to allow a minimum of one nominal four inch wide board to be manufactured from the first flitch. The log was live sawn into 7/4 flitches (1.750 inches plus 0.125 inch shrinkage allowance) as prescribed by the Saw-Dry-Rip (S-D-R) system (Maeglin and Bulgrin 1978) successively from the opening face to approximately half the log's diameter. The log was then rotated 180 degrees and the remainder of the flitches were sawn from the log. There was no taper setting, so the final flitch was of full thickness[2/].

[2/] Robert Maeglin, personal communication and recommendation, U.S. Forest Service, Forest Products Laboratory, Madison, Wisconsin.

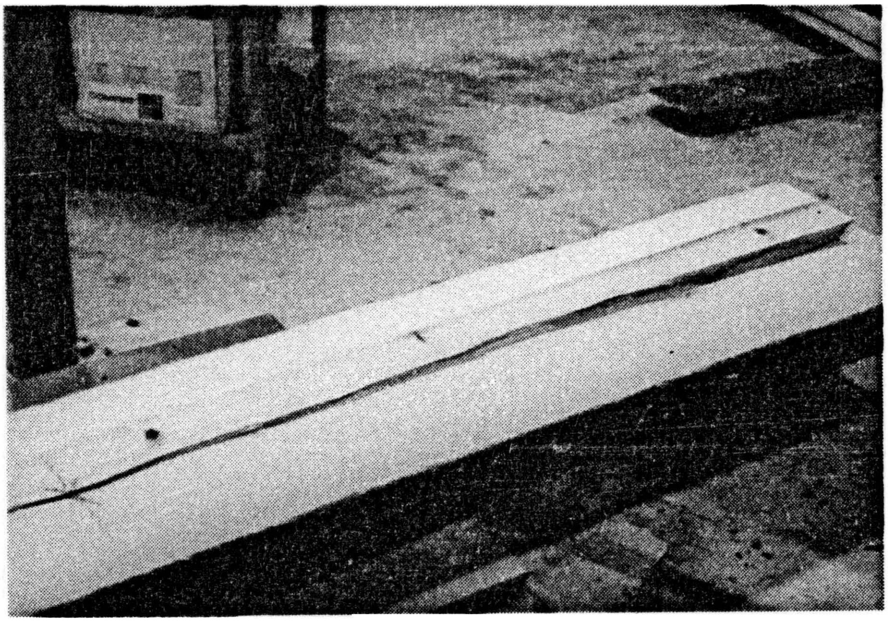

Figure 3.1. Split caused by growth stresses in flitch containing pith.

During the sawing of the first several logs, it was noticed that the last flitch sawn from a log--i.e., the dog board--(which would be near the center of the log) was approximately 0.2-inches scant in thickness midway along its length, apparently due to growth stresses and the use of only two knees to hold the log at its ends. To compensate for this affect, an 8/4 setting was used for this last flitch on the rest of the logs. The final flitch was, therefore, 8/4 at the ends and approximately 7/4 in the center.

It was also noticed during the sawing that those flitches from the larger logs (scaling diameter > 12.0 inches) and that contained the pith, or were adjacent to it, would invariably develop an end split for a distance of several feet along the grain up to the entire length of the flitch (Figure 3.1). This end split would occur while the flitch was still on the carriage or moments after the flitch had left the carriage. This is typical for behavior for logs with large growth stresses.

All flitches were numbered so that their position in the log and log from which they came could be identified later. The flitches and slabs were weighed separately. The moisture content of the wood in the slab was determined for each log by selecting a one inch sample from the slabbing material and ovendrying this sample.

3.1.3 Drying

The flitches were kiln dried at 235°F (113°C) for 28 hours and then equalized at 10 percent EMC for 48 hours, a schedule recommended for S-D-R yellow-poplar lumber by Maeglin and Boone (1981).

Flitches were then weighed and measured for MC with an electrical resistance type moisture meter.

3.1.4 Ripping

Dimension lumber grade yields were determined by lumber grades from Timber Products Inspection (TPI) agency using the Northern Hardwood and Pine Manufacturers Association grading rules.

Two grading procedures were followed:

1) In the first case, before ripping, the lumber grader estimated the yield of structural light framing dimension lumber up to 2 x 8 nominal size, maximizing the width of the dimension lumber, and the yield of No. 2 and Better lumber[3/]. A rip saw kerf of 0.281 inches was assumed. This initial grading before ripping was done in order to obtain yield estimates for lumber other than the 2 x 4's that were actually produced.

2) After this first step, then the flitches were ripped into nominal 2 x 4 dimension lumber (3.625 inches in width). The kerf of the edger was 9/32-inch. The lumber from each flitch was tallied, graded and weighed. This data was used for development of the yield equations and the economic discussions that follow.

The edgings were weighed and their MC determined from a 1-inch sample.

[3/] In most of the Appalachian area, light framing dimension lumber is sold on the basis of Grade No. 2 and Better. Hence, the importance of this grade for yellow-poplar.

3.2 Residue Yield Calculations

The following method was used to calculate residue yield.

Sawdust Yield. Sawdust yield (ovendry weight) from the breakdown of the logs into flitches is determined by:

$$\text{Sawdust} = (\text{Log wt.} - \text{Flitch wt.} - \text{Slab wt.}) \times \left(\frac{1}{1 + MC}\right)$$

where

Log wt. = green weight of the log

Flitch wt. = total green weight of the flitches from a log

Slab wt. = weight of the slabs from a log

MC = moisture content of the sawdust from headrig sawing of a log.

Sawdust yield (ovendry weight) from the ripping operation is determined by:

$$\text{Sawdust} = (\text{Flitch wt.} - \text{Lumber wt.} - \text{Edging wt.}) \times \left(\frac{1}{1 + MC}\right)$$

where

Flitch wt. = total weight of the dried fltiches from a log

Lumber wt. = total weight of the dried lumber from a log

Edging wt. = total weight of the dried edgings from a log

MC = moisture content of the flitches from a log.

The total sawdust yield (ovendry weight) from a log is the sum of the weights from the two operations.

Edgings and Slabbing. The (ovendry) weight of the wood in the slabs from a log is determined by:

$$\text{Wood wt.} = (\text{Slab wt. x Wood content}) \times (\frac{1}{1 + MC})$$

where

Slab wt. = weight of the slabs from a log

Wood content = the ratio of the weight of the dry wood in the slabs to the total weight of the slabs (determined by separating the wood from the bark in small selected sections of the slabs of each log).

MC = moisture content of the wood in the slabs from a log.

The (ovendry) weight of the wood in the edgings from a log is determined by:

$$\text{Wood edging wt.} = (\text{Edging wt. x Wood content}) \times (\frac{1}{1 + MC})$$

where

Edging wt. = weight of the edgings from a log

Wood content = the ratio of weight of the dry wood in the edgings to the total weight of the slab edgings

MC = moisture content of the wood in the slabs from a log.

The total (ovendry weight) of wood residue yield from a log is the sum of the wood components of the slabbings and edgings.

4.0 RESULTS, ANALYSIS AND DISCUSSION OF LOG YIELD STUDY

4.1 Pooled Log Data Analysis

The complete log data set consists of 337 logs from 53 trees. The means and ranges of the various log defects and descriptive variables that were measured prior to sawing are presented in Table 4.1. The means and ranges of data collected during and after log sawing are presented in Table 4.2.

To gain a perspective on those log characteristics that influence the quality yield of dimension lumber from a given yellow-poplar log sample, a stepwise regression model with 18 independent variables was evaluated by selecting the independent variables that contribute the most to the coefficient of multiple determination (R^2) for each step (i.e., the number of independent variables included) of the equation developed. These 18 variables were chosen because they would affect yield volume or quality or both.

The dependent variable is the yield (board feet) of nominal two by fours, eight feet long, structural light framing (NHPMA 1982) grade No. 2 and Better, 2 + Btr., from individual logs. The model used in this analysis is written as:

$$2 + \text{Btr. yield} = f\begin{bmatrix}\text{LDIB, LDOB, SDIB, LKNT1, LKNT2,}\\ \text{LKNT3, DKNT1, DKNT2, DKNT3, BURLS,}\\ \text{SWEEP, CROOK, EBRNCH, SCARS, EDFCT,}\\ \text{CULL, BPECK, SEAM.}\end{bmatrix} \quad [4.1]$$

The independent variables are defined in Table 4.1. Table 4.3 contains the results of the first ten regression equations developed from this exploratory model (Equation 4.1). In terms of explaining the variation of

Table 4.1. Means and ranges of log defects and descriptive variables.

Variable	Description	Mean	Minimum	Maximum
SDIB	Small end diameter inside the bark or scaling diameter (inches)	11.1	6.0	21.3
LKNT1	Count of live knots larger or equal to two inches	0.83	0	9
LKNT2	Count of live knots larger than one inch and less than two	0.16	0	4
LKNT3	Count of live knots smaller than or equal to one inch	0.27	0	7
DKNT1	Count of dead knots larger or equal to two inches	0.72	0	20
DKNT2	Count of dead knots larger than one inch and less than two	1.36	0	30
DKNT3	Count of dead knots smaller than or equal to one inch	3.69	0	41
BURLS	Count of burl knots	0.86	0	28
SWEEP	Sweep (%)[1]	3.6	0	41
CROOK	Crook (%)[1]	2.1	0	33
EBRNCH	Count of epicormic branches	3.4	0	31
SCARS	Depth of scar: 0 = none 1 = bark grain deviation 2 = surface scar 3 = deep scar	0.15	0	2
EDFCT	End defect: 0 = none 1 = park pocket 2 = unsound wood on one end 3 = unsound wood on both ends	0.04	0	3
CULL	Cull (%)	0.0	0	10
BPECK	Amount of bird peck present	0.14	0	3
SEAM	Total length of seam (feet)	0.15	0	8
LOGWT	Log weight (pounds)	369.7	100	1400
LOGMC1	Log moisture content (%)	90.3	59	130

[1]See Table 3.4.

Table 4.2. Means and ranges of individual log variables.

Variable	Description	Mean	Maximum	Minimum
	<u>FLITCHES</u>:			
	Green weight of sawn flitches, nominal two inches thick (pounds)	273.5	39	833
	Weight of dried flitches (pounds)	155.2	22	490
	MC of dried flitches (%)	8.8	6	30
	<u>SLABS</u>:			
	Green weight of slabs (pounds)	41.0	2	386
	Ratio of weight of the wood in the slabs to the total weight of the slabs	0.57	0.98	0.01
	MC of the bark from slabs (%)	88.1	42	175
	MC of the wood from slabs	108.2	41	191
	<u>EDGINGS</u>:			
	Weight of the edgings (pounds)	49.5	8	158
	The ratio of the weight of the wood component of the edgings versus total weight of the edgings from $\log_n$	0.82	0.0	0.99
	MC of the wood component of the edgings (%)	8.0	4	19
	MC of the bark component of the edgings (%)	6.3	5	14
	<u>LUMBER</u>:			
LUMWT	Weight of the lumber (pounds)	90.9	11	330
CONE	Cubic feet of structural light framing grade No. 1	13.9	0.0	66.7
CTWO	Cubic feet of structural light framing grade No. 2	13.1	0.0	69.3
CTHR	Cubic feet of structural light framing grade No. 3	9.8	0.0	112.0
CECON	Cubic feet of economy grade for $\log_n$	9.4	0.0	72.0
ONES	Board feet of structural light framing grade No. 1	15.9	0.0	90.6

Table 4.2. (continued). Means and ranges of individual log variables.

Variable	Description	Mean	Maximum	Minimum
TWO	Board feet of structural light framing grade No. 2	6.8	0.0	32.0
THREE	Board feet of structural light framing grade No. 3	7.7	0.0	42.7
ECON	Board feet of economy grade	13.9	0.0	80.0

Table 4.3. Results of stepwise regression using the 18-variable model (Equ. 4.1) for predicting 2+Btr. yield from yellow-poplar logs.

Step	Variables	R^2
Step 1	SDIB	0.63
Step 2	SDIB, DKNT1	0.65
Step 3	SDIB, DKNT1, CROOK	0.69
Step 4	SDIB, LKNT1, SWEEP, CROOK	0.70
Step 5	SDIB, LKNT1, DKNT1, SWEEP, CROOK	0.72
Step 6	SDIB, LKNT1, DKNT1, SWEEP, CROOK, EDFCT	0.73
Step 7	SDIB, SDOB[a], LKNT1, DKNT1, SWEEP, CROOK, EDFCT	0.73
Step 8	SDIB, SDOB[a], LKNT1, DKNT1, BURLS[a], SWEEP, CROOK, EDFCT	0.74
Step 9	SDIB, SDOB[a], LKNT1, DKNT1, DKNT3[b], BURLS[a], SWEEP, CROOK, EDFCT	0.74
Step 10	SDIB, SDOB[a], LKNT1, DKNT1, DKNT2[b], DKNT3[a], BURLS[a], SWEEP, CROOK, EDFCT	0.74

Note: Variables without superscript are significant at 0.01 level; "a" superscript at 0.05 level; and "b", not significant at 0.05 level. Variable names are identified in Table 4.1.

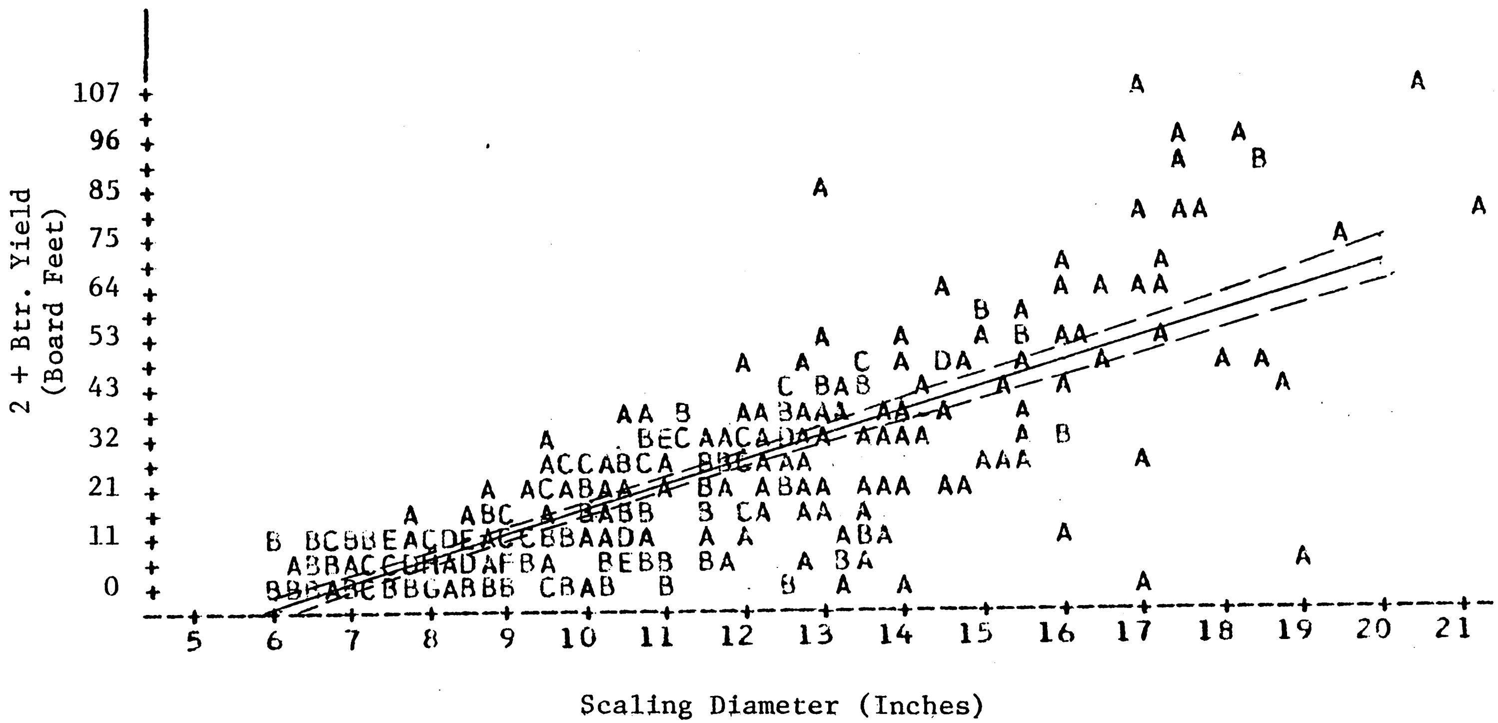

Figure 4.1. 2 + Btr. yield as a function of scaling diameter. (The solid line is -38.1539 + 5.4710(scaling diameter) and the dashed lines are the 95% confidence limits.)
LEGEND: A = 1 observation, B = 2 observations, etc.

2 + Btr. yield (board feet) per log among the observations, the scaling diameter was selected as the single most important independent variable for the best one variable equation:

$$2 + \text{Btr. yield} = -38.1539 + 5.4710\ (\text{Scaling dia.}) \qquad [4.2]$$

$$R^2 = 0.63$$

This equation is referred to at the "pooled results" in later sections.

Equation [4.2] and the 95 percent confidence limits for the mean are graphed (Figure 4.1) along with the individual log yields. This graph confirms the strong relationship between the scaling diameter and the 2 + Btr. yield. The importance of scaling diameter is supported by previous log and lumber grade recovery studies, for both factory and dimension lumber (Cassens 1980, Hanks 1973 and Schroeder, et al. 1968).

Large knots (both dead and live) were selected early in the stepwise model development (steps 2 and 4, Table 4.3); the smaller dead knots were selected later (steps 9 and 10, Table 4.4) in the model development and their slopes were not statistically different from zero. This importance of knots is to be expected as the grading rules for grade No. 2 lumber permit, without penalty, edge knots on the wide face of lumber with diameters up to one and one-quarter inches for nominal four inch width lumber and knots up to two inches in width located on the centerline of the wide face.

Crook was selected in the stepwise regression development process prior to sweep (step 3 versus step 4, Table 4.3). This is expected as crook, by definition, is a more severe deviation of the straightness of a log than sweep. Both crook and sweep would be important variables as they

1) lower the volume of eight foot long lumber that can be generated from a sweepy or crooked eight foot cylinder and 2) directly affect the slope of grain in the lumber which in turn affects the 2 + Btr. yield. The grade requirements for grade No. 2 specify that the slope of grain may not exceed one in eight for a four-inch wide piece.

Few logs in the sample exhibited end defects. However, on those logs that had end defects, the 2 + Btr. yield was lower (step 6, Table 4.3).

Burls were selected relatively late (step 8, Table 4.3), the slope being statistically insignificant (i.e., not varying significantly with yield). The late selections of burls and shallow slope is consistent with the observation made during sawing that burls in yellow-poplar generally were a log surface defect, as opposed to an interior defect which would affect lumber quality.

4.2 Evaluation of Log Grades

Reiterating a hypothesis presented earlier: either of the present-day log grading systems, the U.S. Forest Service Hardwood or Southern Pine log grading rules, is applicable for stratifying yellow-poplar logs into 2 + Btr. dimension lumber yield classes. Such grading must have an R^2 higher than pooled results (Equation 4.2) if grading is to be beneficial. This hypothesis will be evaluated both quantitatively and intuitively.

4.2.1 Quantitative analysis

In order to evaluate the stratification of yellow-poplar logs by both the hardwood and southern pine grading schemes into 2 + Btr.

Table 4.4. Results of Duncan's Multiple Range Test on the quality ratio variable, Q, for the hardwood and southern pine log grading schemes. Means of Q with the same grouping letter are not significantly different (α = 0.05).

HARDWOOD LOG GRADING:

Hardwood Grade	$\bar{Q}$	Grouping
1	0.1564	A
2	0.1444	A
3	0.0954	C

SOUTHERN PINE LOG GRADING:

Southern Pine Grade	$\bar{Q}$	Grouping
1	0.1561	A
2	0.1210	B
3	0.0922	C

dimension lumber yield classes, a variable measuring quality yield was needed. Therefore, a quality ratio variable, Q, was defined for an individual log as the ratio of the 2 + Btr. yield (board feet) to the log's estimated ovendry weight. This ratio was used to test the stratification, as opposed to board feet yield because the ratio standardized the yield on a wood unit weight, thereby eliminating any bias introduced by diameter limitations in the hardwood log grades.

A nested analysis of variance (ANOVA) was conducted to determine if there was a difference in Q among the log grade levels (for both the hardwood and southern pine log grades separately) with the diameter classes (integer values of the scaling diameter) nested within the grade classes. The results of this nested ANOVA rejected the null hypothesis ($\alpha = 0.001$) for both the hardwood and southern pine grades that Q among the grade levels are the same. To define the difference in Q indicated in the nested ANOVA, a Duncan's Multiple Range Test ($\alpha = 0.05$) was conducted among the grade levels (Table 4.4).

The results indicate that there was no discernable difference of Q between hardwood log grades one and two. The hardwood log grades did not adequately stratify the yellow-poplar logs into salable dimension lumber yield classes as well as hoped. On the other hand, Duncan's Multiple Range Test indicated that the southern pine log grades did stratify the yellow-poplar logs with Q decreasing for lower log grades. This indicates the practical potential for the southern pine grades.

Table 4.5. Regression equations by log grades predicting the 2+Btr. yield (board feet) per log as a function of the scaling diameter.

HARDWOOD LOG GRADES:

Grade	Intercept	Slope	R^2	PR > F
1	-63.7404	7.5146	0.52	0.0001
2	-38.6542	5.5112	0.28	0.0001
3	-23.7652	3.8809	0.45	0.0001

SOFTWOOD LOG GRADES:

Grade	Intercept	Slope	R^2	PR > F
1	-47.9985	6.6764	0.77	0.0001
2	-33.2037	5.0398	0.51	0.0001
3	-23.6770	3.8183	0.44	0.0001

Regression equations were developed for each log grade (Table 4.5) for both the hardwood and southern pine log grades to predict the board feet yield of grade No. 2 and Better lumber, 2 + Btr., as a function of scaling diameter.

The coefficients of determination for the individual regression equations based on hardwood log grades were expected to be low because the hardwood grading rules containing diameter limitations which will result in a shorter range of the independent variable, scaling diameter.

A difficulty arises in the comparison of the amount of variation explained (coefficient of determination) by the individual yield equations (Table 4.5) to the amount explained by the pooled results (Equation 4.2). To solve this problem, a coefficient of determination for the following model for each log grading scheme will be evaluated:

2 + Btr. yield = f(log grade, scaling dia., log grade x scaling dia.)

The coefficient of determination from this model, referred to as Total R^2, will be used for comparisons. The Total R^2 for the hardwood grading scheme ($R^2 = 0.68$) and southern pine grading scheme ($R^2 = 0.69$) are larger than the R^2 of the pooled model, ($R^2 = 0.63$).

Selected means and 95 percent confidence limits for 2 + Btr. yield from the equations presented in Table 4.4 for the hardwood and softwood log grades are presented in Table 4.6. The overlapping confidence intervals between grades indicate that the hardwood grades have a difficult time distinguishing differences in 2 + Btr. yield among each other. This agrees with the results of the Duncan's Multiple Range Test mentioned earlier.

Table 4.6. Means and 95 percent confidence limits for 2+Btr. yield (bd. ft.) per log from equations in Table 4.4.

HARDWOOD:

Scaling Diameter (inches)	Grade 1 Lower 95% CL	Grade 1 Mean	Grade 1 Upper 95% CL	Grade 2 Lower 95% CL	Grade 2 Mean	Grade 2 Upper 95% CL	Grade 3 Lower 95% CL	Grade 3 Mean	Grade 3 Upper 95% CL
8							5.5	7.3	9.1
12				22.7	27.5	32.2	21.0	22.8	24.6
16	50.9	56.5	62.1	39.9	49.5	59.1	34.8	38.3	41.8
20	74.9	86.6	98.2	52.0	71.6	91.2	48.3	53.9	59.4
24	96.1	116.6	137.1	63.7	93.6	123.6	61.7	69.4	77.0

SOUTHERN PINE:

Scaling Diameter (inches)	Grade 1 Lower 95% CL	Grade 1 Mean	Grade 1 Upper 95% CL	Grade 2 Lower 95% CL	Grade 2 Mean	Grade 2 Upper 95% CL	Grade 3 Lower 95% CL	Grade 3 Mean	Grade 3 Upper 95% CL
8	-0.6	5.4	11.4	-5.0	2.07	9.2	4.8	6.9	8.7
12	28.7	32.1	35.6	23.6	27.3	31.0	20.2	22.1	24.1
16	54.7	58.8	63.0	41.3	47.4	53.6	33.6	37.4	41.2
20	78.3	85.5	92.7	57.1	67.6	78.1	46.6	52.7	58.7
24	101.4	112.2	123.0	72.6	87.8	102.9	59.6	68.0	76.3

Note: Underlining between grades indicates confidence intervals overlap at that diameter.

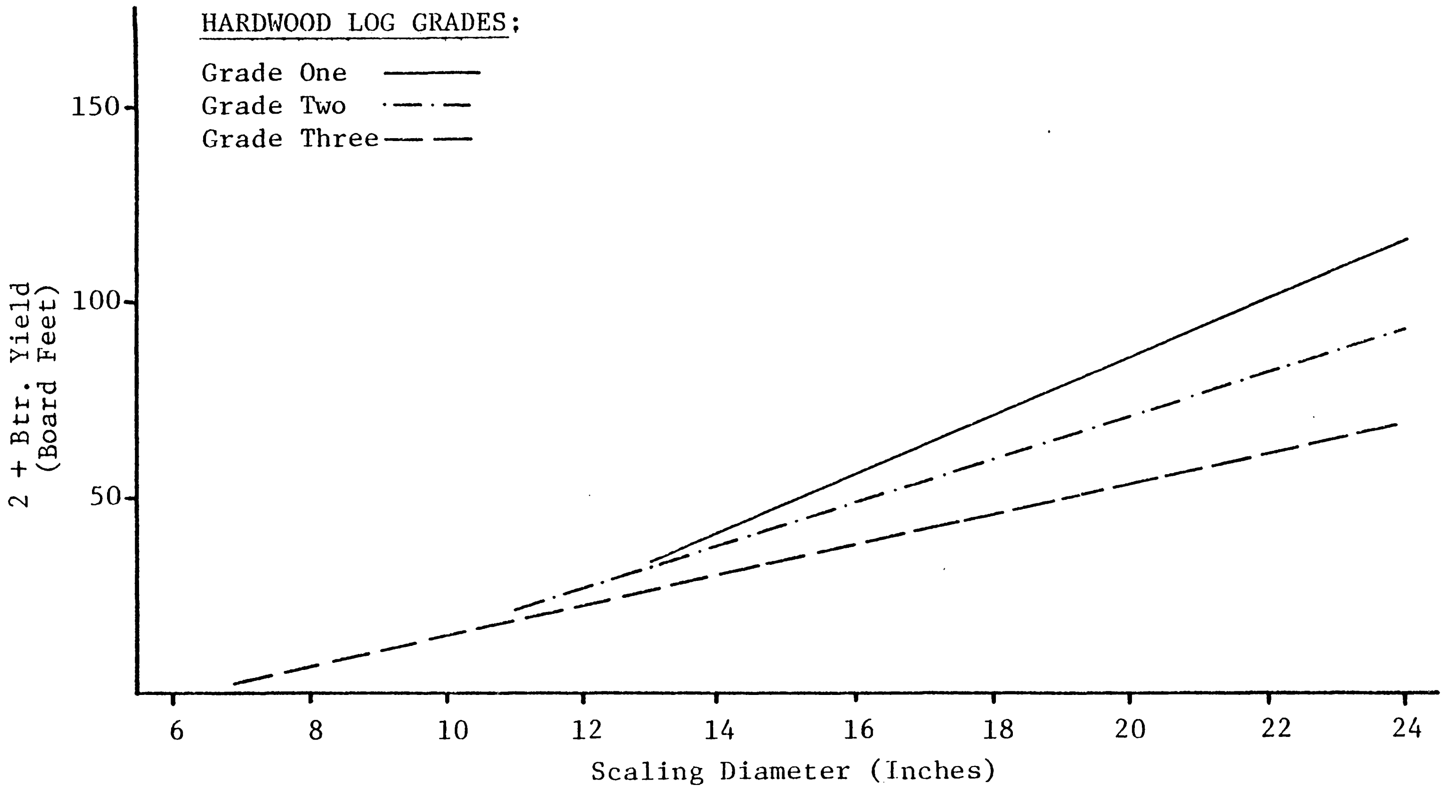

Figure 4.2. Regression lines (from Table 4.5) developed for estimating 2 + Btr. yield from yellow-poplar logs using U.S. Forest Service hardwood log grades.

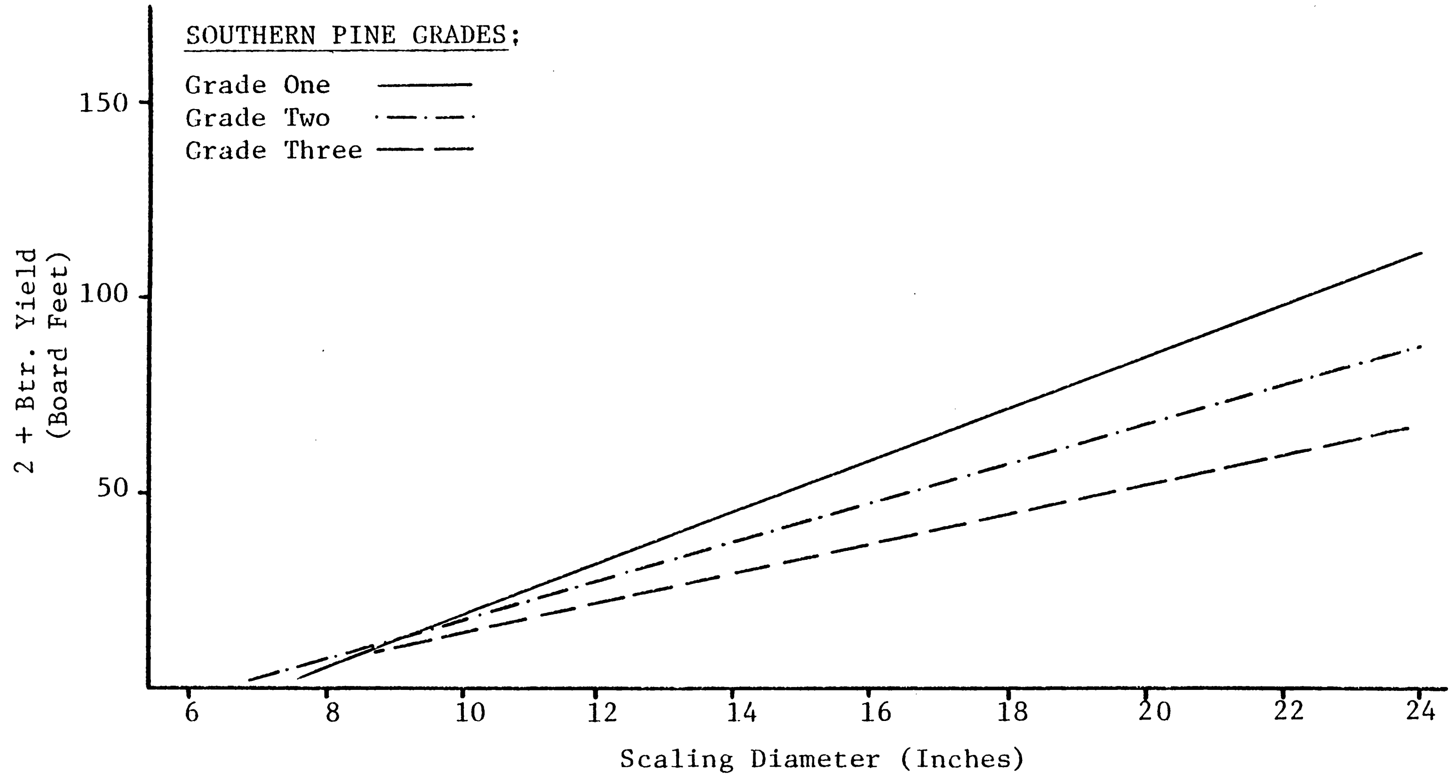

Figure 4.3. Regression lines (from Table 4.5) developed for estimating 2 + Btr. yield from yellow-poplar logs using U.S. Forest Service southern pine log grades.

At smaller scaling diameters, the softwood grade prediction equations provide confusing or meaningless results (see 8-inch scaling diameter, Table 4.6 or Figure 4.3), because these 2 + Btr. yield equations intersect at approximately nine inches. Below this diameter, the higher quality logs have a smaller predicted yield than the low quality logs. The over-lapping of the confidence intervals at the larger diameters with the southern pine grades can be explained by 1) the expanding nature (i.e., larger variability of the data) of confidence limits and 2) few data points at these diameters.

The 2 + Btr. yield equations for both the hardwood and southern pine grades are graphed on Figure 4.2 and 4.3, respectively. Figure 4.3 illustrates the intersection of the southern pine 2 + Btr. yield equations at the lower diameter limits. Both Figure 4.2 and 4.3 suggest the need for a "below grade" classification to explain those yields falling below the grade three 2 + Btr. yield equations.

The results of the nested ANOVA, Duncan's Multiple Range Test, the 2 + Btr. yield equations (especially in light of their respective coefficients of determination (R^2), and the Total R^2's) suggest that neither log grade scheme has an overwhelming advantage over the other in separating yellow-poplar into dimension lumber yield classes. However, the traditional log grading systems explain more variation (Total R^2) than the pooled (or one grade) system.

Table 4.7. Lower exclusion limits for the southern pine grades. Logs in each grade must meet clear face requirements of that grade as well.

Characteristic	Southern Pine Grade One	Southern Pine Grade Two	Southern Pine Grade Three
Scaling diameter	12	10	
Large dead knots (> 2 inches)	1	3	18
Crook %	6%	7%	12%
Sweep %	12%	16%	25%
Large live knots (> 2 inches)	None	3	8
End defect	None	None	Rot may be found on both ends
Burls	2	3	7
Small dead knots (< 1 inch)	2	2	24
Medium dead knots (> 1 but < 2 inches)	1	1	10

Note: See Table 4.1 for further definition of characteristics.

Table 4.8. Regression equations for 2+Btr. yield developed for Modification Two southern pine log grades.

<table>
<tr><th rowspan="2">Modification</th><th colspan="4">Grade Level</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>1
(Total R^2 = 0.72)</td><td>Intercept = -51.8646
Slope = 6.9289
R^2 = 0.60</td><td>Intercept = -22.6743
Slope = 4.6302
R^2 = 0.51</td><td>Intercept = -31.1885
Slope = 4.7391
R^2 = 0.55</td><td></td></tr>
<tr><td>2
(Total R^2 = 0.73)</td><td colspan="2">Intercept = -41.6265
Slope = 6.1926
R^2 = 0.62</td><td>Intercept = -31.1885
Slope = 4.7391
R^2 = 0.56</td><td>Intercept = 2.5146
R^2 = 0.01</td></tr>
<tr><td>3
(Total R^2 = 0.75)</td><td colspan="2">Intercept = -42.4641
Slope = 6.2548
R^2 = 0.67</td><td>Intercept = -43.4020
Slope = 5.6607
R^2 = 0.49</td><td>Intercept = 5.9648
R^2 = 0.00</td></tr>
</table>

Note: All equations are in the form of 2+Btr. yield = a + b (scaling diameter).

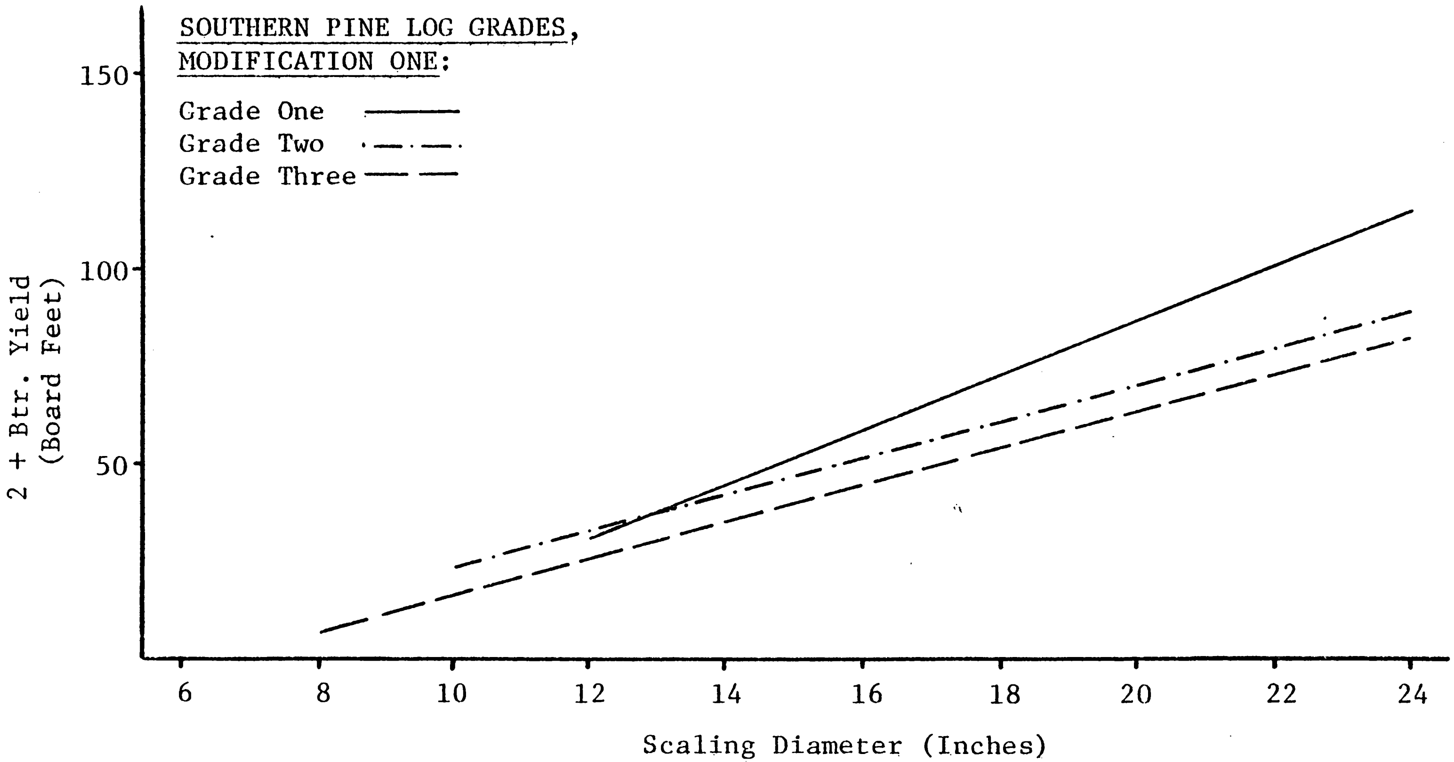

Figure 4.4. Regression equations developed for estimating 2 + Btr. yield from yellow-poplar logs using Modification One of the southern pine grades.

4.2.2 Applicability of traditional log grades

Due to the ease of application of the southern pine log grading method, further analysis is directed toward modification and application of these grades. (The basis for this decision is supported by the work of Schroeder, Campbell and Rodenbach (1968) who found no clearcut best method of grading southern pine logs quantitatively; however, they choose their method due to ease of application. This decision is also supported by the results of the Duncan's Multiple Range Test performed on the quality ratio and also by results of the analysis of the confidence limits of the 2 + Btr. yield equations for each individual grade.)

4.3 Southern Pine Log Grade Modification

In examing the 2 + Btr. yield data, it was noticed that several logs in each southern pine grade category met the criterion for the particular log grade, however, the 2 + Btr. yield was below average for the indiviudal log for a specific grade and scaling diameter. It was felt that if lower log defect exclusion limits were used in conjunction with the southern pine grades, there would be a reduction in the variation of 2 + Btr. yield for a particular log grade, thereby reducing the overlapping of the confidence intervals.

From the data obtained on the influences of various log characteristics and defects on 2 + Btr. yield (Section 4.1), lower exclusion limits were developed for the important characteristics and incorporated with the existing southern pine log grades (Table 4.7). Also, lower limits on scaling diameter were established for grades one and two to prevent the 2 + Btr. yield equations from intersecting each other at the smaller diameters.

Using all the lower exclusion limits (Table 4.7), regression equations were developed to estimate 2 + Btr. yield from yellow-poplar logs. The resulting equations are listed as Modification One, Table 4.8. The Total R^2 was 0.72 or three percentage points higher than the southern pine Total R^2 and nine percentage points higher than the pooled R^2.

A plot of the yield equations developed for Modification One, (Figure 4.4), indicates that there was little practical differentiation (5.33 board feet or one 2 by 4) among the 2 + Btr. yield equations for log grade one and two. Therefore, the observations for log grades one and two were combined, using the exclusion limits for log grade two as set forth in Table 4.7. This is termed "Modification Two". An estimate of the volume of 2 + Btr. generated from the below grade logs (those logs that failed to meet log grade three exclusion limit, Table 4.7) was determined in order to evaluate their potential economic return. The below grade logs are classified as grade four. The resulting 2 + Btr. yield equations for Modification Two are given in Table 4.8. Total R^2 for Modification Two was one point above Modification One.

From the plot of Modification Two data points (Figure 4.5), it appeared that the smaller diameter logs, scaling diameter less than 9, could be grouped in the grade four classification on the basis of their small 2 + Btr. yield. This would allow a single point estimate of 2 + Btr. yield for grade 4 logs without respect to scaling diameter. The sweep limitation for grade two was also reduced from 25 percent to

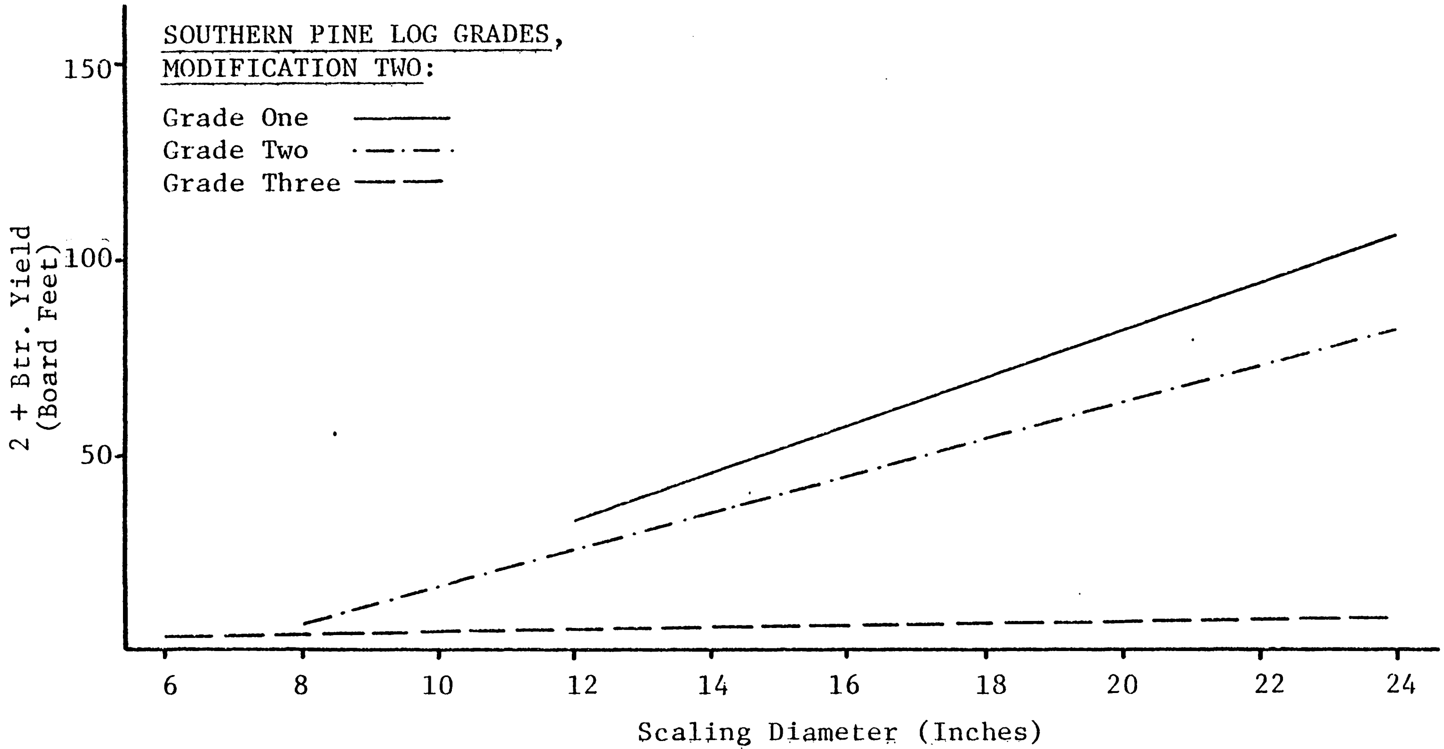

Figure 4.5. Regression equations for estimating 2 + Btr. yield from yellow-poplar logs using Modification Two of the southern pine log grades.

20 percent. The grading criteria with the two above changes was termed "Modification Three" (Table 4.8). The 2 + Btr. yield regression equations developed using Modification Three accounted for 75 percent (Total R^2 = 0.75) of the variation in the yield of 2 + Btr., this was an improvement of 12 percentage points over the equation utilizing the pooled (one grade) system and six percentage points over the traditional southern pine log grades.

Other modifications consisting of manipulation of the lower defect limits were tried, however, none yielded a Total R^2 equal to or higher than Modification Three.

The confidence limits for Modification Three (Table 4.9) overlap only at the extreme high end of the independent variable range (scaling diameter = 20) where there are only a few data points. Comparing the length of the 95 percent confidence interval (Table 4.10) shows a clear advantage of Modification Three in terms of predicting 2 + Btr. yield over the present day hardwood grading and southern pine grading systems. Note that Modification Three has traditional southern pine log grade levels one and two combined, yet the length of the confidence limits are as short or shorter than for the traditional log grading schemes.

4.3.1 Summary of southern pine log grade information

Modification Three of the southern pine log grading scheme appears to meet the criteria for a log grading system for yellow-poplar logs that will be used to manufacture dimension lumber for the following reasons: 1) It stratifies yellow-poplar logs into statistically different dimension lumber yield classes with very little overlap, as verified by

Table 4.9. Mean and 95 percent confidence limits generated from the regression equations developed from Modification Three of the southern pine grades.

	Grade Level								
	1			2			3		
SDIB	Lower 95% CL	Mean	Upper 95% CL	Lower 95% CL	Mean	Upper 95% CL	Lower 95% CL	Mean	Upper 95% CL
8							5.0	6.1	7.1
12	29.0	32.6	36.1	22.5	24.5	26.6			
16	54.0	57.6	61.2	42.7	47.1	51.6			
20	75.7	82.6	89.5	61.8	69.8	77.8			

Note: Underlining means confidence limits overlap.

Table 4.10. Length of 95 percent confidence intervals for 2+Btr. yield equations developed for hardwood, southern pine and Modification Three grading schemes.

Scaling Diameter (inches)	Hardwood Grades			Southern Pine Grades			Modification Three Grades		
	1	2	3	1	2	3	1 & 2	3	4
12	20.5	9.5	3.6	6.9	7.4	3.9	7.1	4.1	NA
16	11.2	19.2	7	8.3	12.3	7.6	7.2	8.9	NA

the 95 percent confidence limits; 2) it accounts for much of the variation in the 2 + Btr. yield (Total $R^2 = 0.75$) and 3) they are easy to apply.

For clarity, Modification Three of the southern pine log grades will from hereon be known as the yellow-poplar dimension lumber log grades. For brevity, these log grades will be termed Y-P grades. The combination of southern pine log grade one and two of Modification Three will be represented by Y-P log grade one. Modified southern pine log grade three will be represented by Y-P log grade two and modified southern pine grade four (below grade) will be represented by Y-P log grade three. The requirements for the Y-P log grade classes are summarized in Table 4.11.

4.4 Yields from Y-P Log Grades

4.4.1 Lumber

The 2 + Btr. yield as a function of scaling diameter for the yellow-poplar dimension lumber log grade class 1 may be described by the following regression equation:

$$2 + \text{Btr. yield} = -42.4641 + 6.2548\ (\text{Scaling dia.}) \qquad [4.3]$$

$$R^2 = 0.67$$

The regression equation for 2 + Btr. yield for yellow-poplar dimension lumber log grade class 2 being:

$$2 + \text{Btr. yield} = -43.4020 + 5.6607\ (\text{Scaling dia.}) \qquad [4.4]$$

$$R^2 = 0.49$$

Table 4.11. Lower exclusion limits for the yellow-poplar dimension lumber log grades.

Characteristic	Grade 1	Grade 2	Grade 3
Clear faces	2	0	0
Scaling diameter	9	9	
Large dead knots (> 2 inches)	4	18	
Crook %	7%	12%	
Sweep %	12%	25%	
Live knots (> 2 inches)	3	8	No Limits
End defect	None	Rot may not be found on both ends	
Burls	3	8	
Small dead knots (< 1 inch)	2	25	
Medium dead knots (> 1 but < 2 inches)	1	11	

The regression equation for 2 + Btr. yield for yellow-poplar dimension lumber log grade class 3 being:

$$2 + \text{Btr. yield} = 5.9648 \qquad [4.5]$$

$$R^2 = 0.00$$

The slopes of equations [4.3] and [4.4] were significantly different than zero at the 0.0001 probability level. However, for Y-P log grade 3, the coefficient for the scaling diameter term was not significantly different from zero, so the intercept alone is used as a single value estimate of 2 + Btr. yield (equation 4.5).

Using equations [4.3] and [4.4], a difference of 6.3 board feet is found for the 2 + Btr. yield from a log with a scaling diameter of nine inches. This difference increases with larger diameters. Thus the level of log stratification between Y-P grades 1 and 2 provides useful differences in yield. (Note that a difference of only 1.6 board feet was found for the 2 + Btr. yield for equations [4.4] and [4.5] with a scaling diameter of nine inches, however, this does not present a problem because the equations diverge from each other from this point. Further, because the yield of dimension lumber is so small, it is reasonable to expect that such small logs will have a more economical use than dimension lumber (e.g., chips).

Estimates of the average 2 + Btr. yield for a range of scaling diameters, using equations [4.3], [4.4] and [4.5] and their associated confidence limits are provided in Appendix A.

Up to this point, only the yield of 2 + Btr. has been discussed, as this product category is the most marketable and probably the most profitable. Other dimension lumber, Grade No. 3 and Economy, may be produced. Using the Y-P log grades, regressions were run for these lumber grades.

The yield (board feet) of nominal two by four inches, eight feet long structural light framing grade No. 3 lumber as a function of scaling diameter for Y-P log grade 1 is described by the following regression equation:

$$\text{Gr. 3 yield} = -14.9691 + 1.7854 \text{ (Scaling dia.)} \qquad [4.6]$$

$R^2 = 0.29$

For Y-P log grade 2, the yield is:

$$\text{Gr. 3 yield} = 5.1277 + 1.744 \text{ (Scaling dia.)} \qquad [4.7]$$

$R^2 = 0.13$

For Y-P log grade 3, the yield is:

$$\text{Gr. 3 yield} = 1.7331 + 0.7823 \text{ (Scaling dia.)} \qquad [4.8]$$

$R^2 = 0.12$

The slopes of these equations are all significant at the 0.0001 probability level. The coefficients of determination (R^2) are low due to the low volume of Grade No. 3 generated from a log (1.0) board feet per nine inch scaling diameter grade 1 log and the high variability.

The yield (board feet) of nominal two by four inches, eight feet long Economy grade lumber as a function of scaling diameter for Y-P log grade is described by the following regression equation:

Economy yield = -14.6133 + 2.1684 (Scaling dia.) [4.9]

$R^2 = 0.27$

For Y-P log grade 2 the yield is:

Economy yield = -13.0382 + 2.4098 (Scaling dia.) [4.10]

$R^2 = 0.21$

For Y-P log grade 3, the yield is:

Economy yield = -34.3074 + 5.3437 (Scaling dia.) [4.11]

$R^2 = 0.68$

The slopes of equations [4.9], [4.10] and [4.11] were significant of the 0.0001 probability level.

The total (Economy and Better) dimension lumber yield (board feet) separated by Y-P log grades as a function of scaling diameter is graphed in Figure 4.6. Y-P log grades 1 and 2 have very similar total lumber volume yields, while Y-P log grade 3 yields substantially less in volume. This is likely due to the great amount of crook and sweep contained in the Y-P grade 3 logs.

The International 1/4-inch rule predicts lumber volume yield more consistently for Y-P log grades one and two than the Doyle Rule. This is likely due to tendency inaccuracies of Doyle rule caused by large slab deductions for small logs. However, both the International 1/4-inch and Doyle rule over-predict the dimension lumber yield for Y-P log grades one and two at large scaling diameters (> 20 inches). This is expected due to the loss of usable lumber volume because of the splitting of the center flitches from larger logs by the growth stresses in the log.

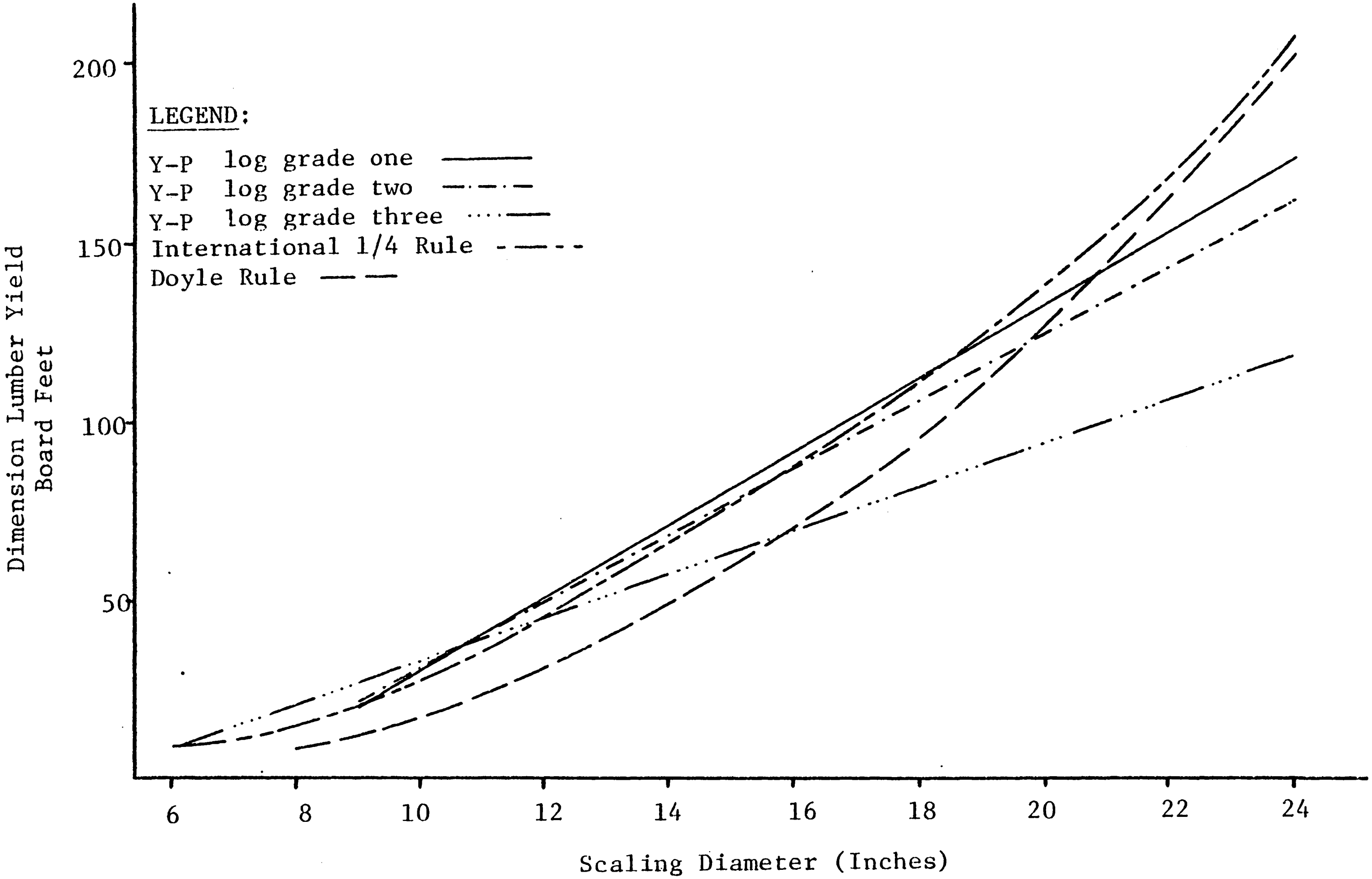

Figure 4.6. Total dimension lumber yield per yellow-poplar dimension lumber (Y-P) log grade as a function of scaling diameter and Yield of International 1/4-inch and Doyle Rule superimposed on the yields of the log grades,

(See Section 3.1.2). In summary, the dimension lumber yield by grade as a function of scaling diameter is graphed for Y-P log grades 1, 2 and 3 (Figures 4.7, 4.8 and 4.9 respectively). The higher the Y-P log grade, the higher percentage dimension lumber yield.

4.4.2 Non-lumber products

The ovendry weight (pounds) of sawdust generated in the primary log breakdown and ripping operation as a function of scaling diameter for Y-P log grade 1 is described by the following regression equation:

$$\text{Sawdust wt.} = -75.5340 + 11.1356 \text{ (Scaling dia.)} \qquad [4.12]$$

$R^2 = 0.76$

For Y-P log grade 2, the sawdust yield is:

$$\text{Sawdust wt.} = -29.8106 + 8.2649 \text{ (Scaling dia.)} \qquad [4.13]$$

$R^2 = 0.38$

For Y-P log grade 3, the sawdust yield is:

$$\text{Sawdust wt.} = -104.3591 + 17.6873 \text{ (Scaling dia.)} \qquad [4.14]$$

$R^2 = 0.71$

The slopes for these equations are significant at the 0.0001 probability level.

The ovendry weight (pounds) of the slabs in primary log breakdown and edgings in ripping as a function of scaling diameter for Y-P log grade 1 is described by:

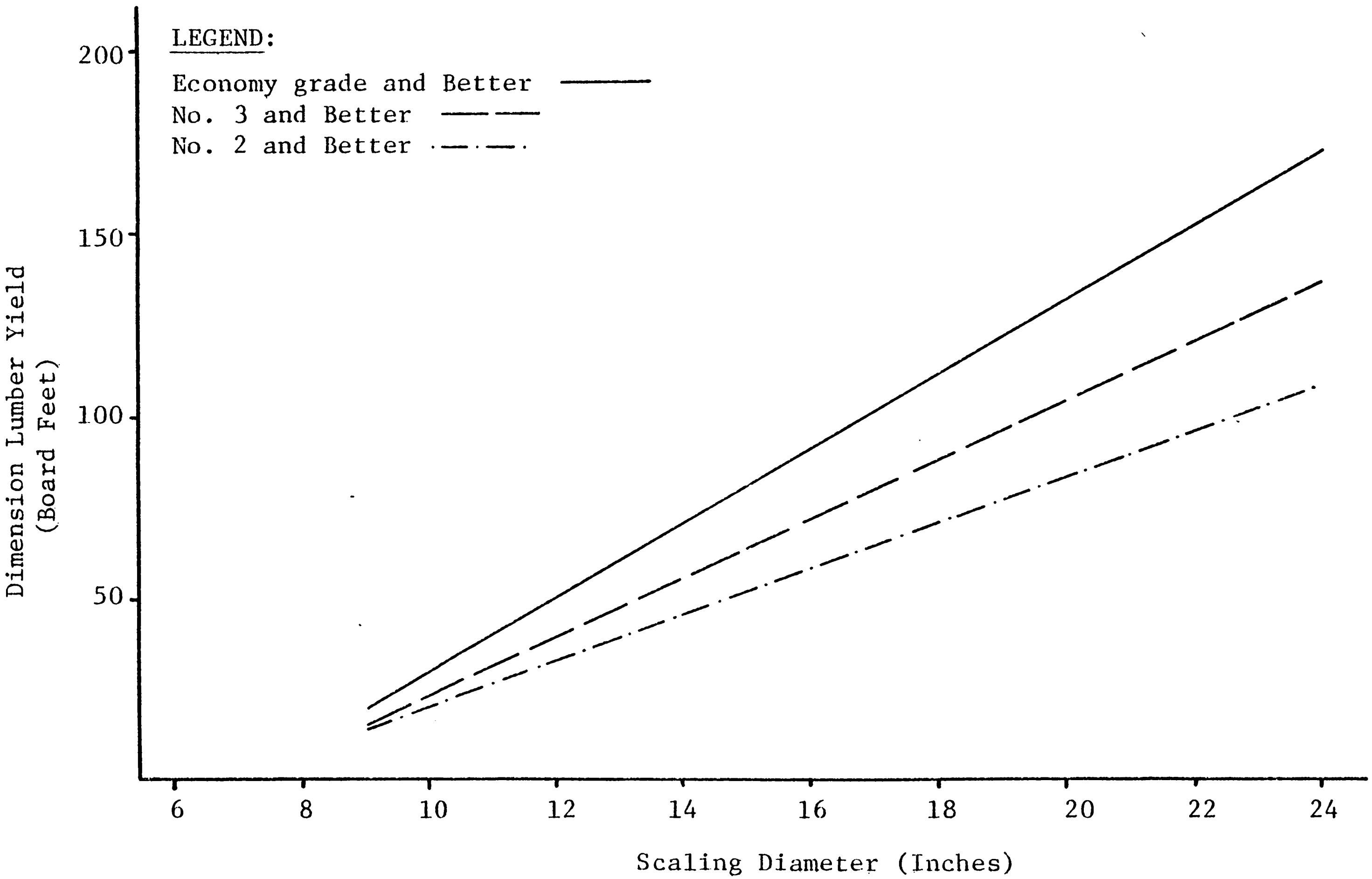

Figure 4.7. Dimension lumber yield by grade as a function of scaling diameter for Y-P log grade 1.

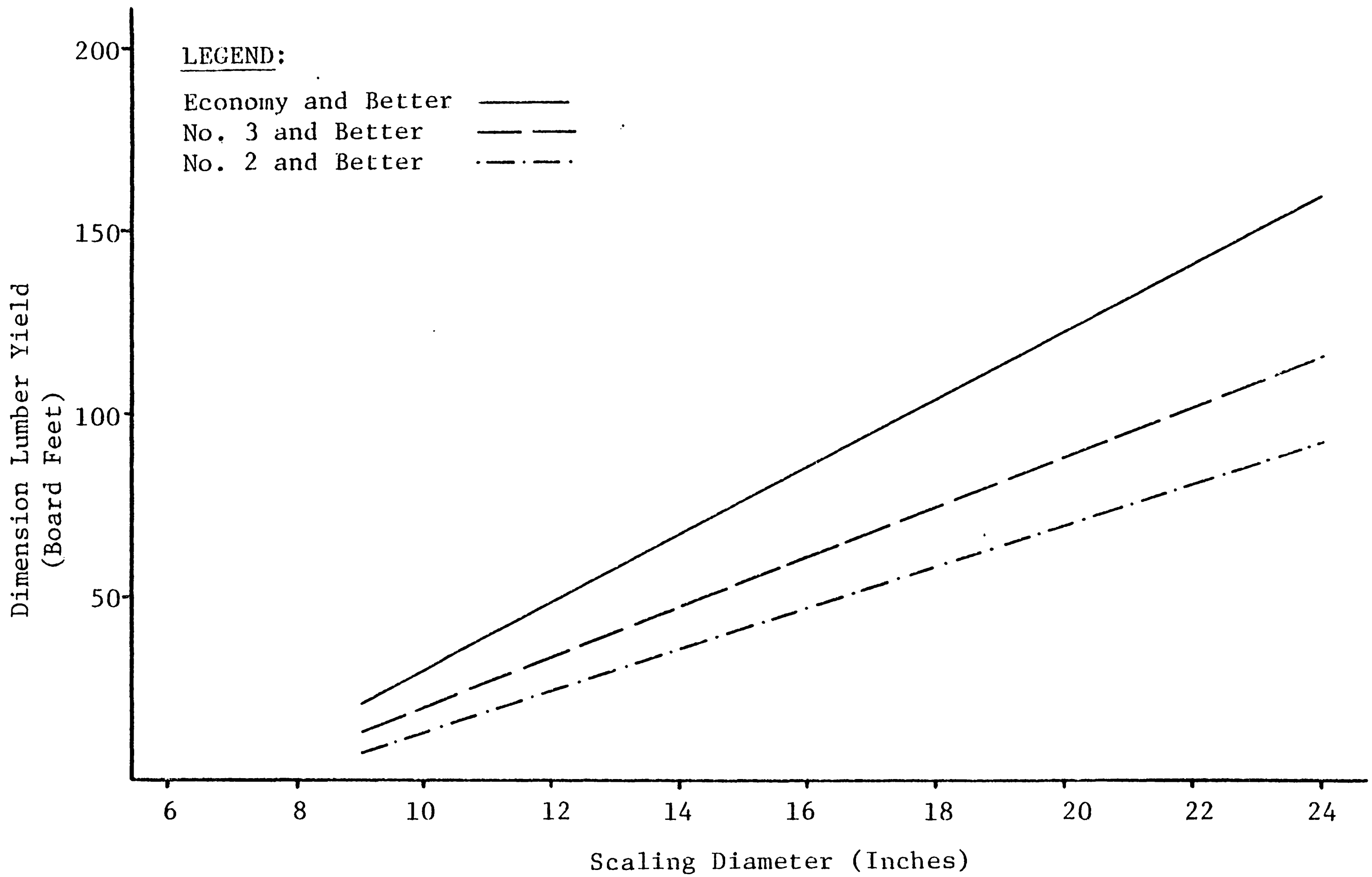

Figure 4.8. Dimension lumber yield by grade as a function of scaling diameter for Y-P log grade 2.

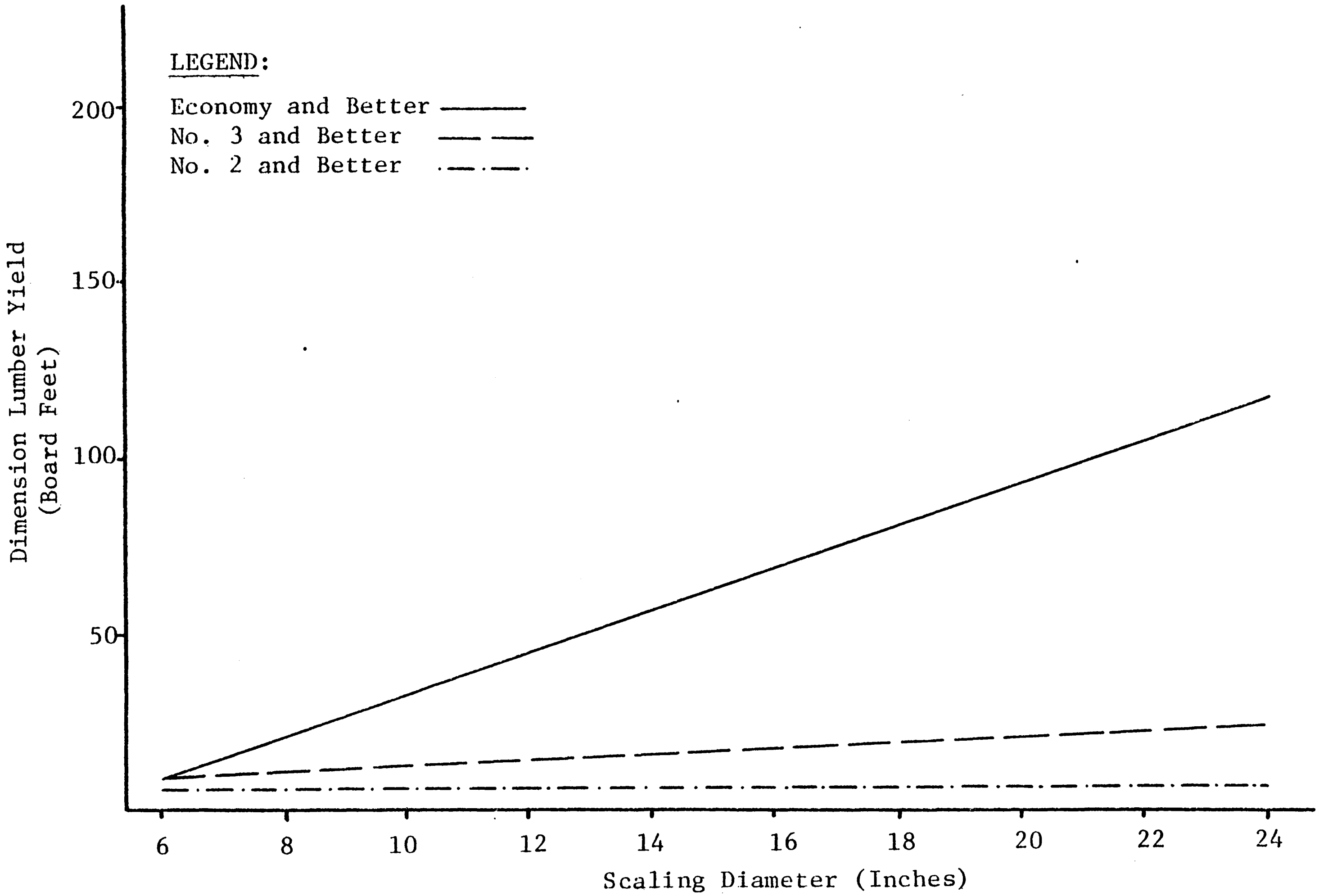

Figure 4.9. Dimension lumber yield by grade as a function of scaling diameter for Y-P log grade 3.

Slab and edging wt. = -56.0099 + 8.4263 (Scaling dia.) [4.15]

$R^2 = 0.55$

For Y-P log grade 2, the weight is:

Slab and edging wt. = -34.3073 + 7.3553 (Scaling dia.) [4.16]

$R^2 = 0.47$

For Y-P log grade 3, the weight is:

Slab and edging wt. = -60.1884 + 11.6857 (Scaling dia.) [4.17]

$R^2 = 0.78$

The slopes for these equations are significant at the 0.0001 probability level.

The ovendry weight, W, (pounds) of the slabs, edgings, and Economy grade lumber[1/] from a log as a function of scaling diameter for Y-P log grade 1 is described by the following regression equation:

W = -76.3888 + 11.5284 (Scaling dia.) [4.18]

$R^2 = 0.68$

For Y-P log grade 2, the weight is:

W = -49.9460 + 10.5698 (Scaling dia.) [4.20]

$R^2 = 0.49$

[1/] The ovendry weight of the structural light framing grade three and economy grade yield were estimated using an assumed specific gravity of 0.42 obtained from the Wood Handbook (USDA 1974).

For Y-P log grade 3, the weight is:

$$W = -106.9804 + 18.9821 \text{ (Scaling dia.)} \qquad [4.21]$$

$R^2 = .84$

The slopes of these equations are significant at the 0.0001 probability level.

The ovendry weight (pounds) of the slabs, edging, Economy grade and structural light framing grade 3 lumber (products that might be most profitably used for chips) from a log, chippable weight, as a function of scaling diameter for Y-P log grade 1 is described by the following regression equation:

$$\text{Chippable wt.} = -96.4324 + 11.9622 \text{ (Scaling dia.)} \qquad [4.22]$$

$R^2 = 0.75$

For Y-P log grade 2, the weight is:

$$\text{Chippable wt.} = -56.4603 + 12.1592 \text{ (Scaling dia.)} \qquad [4.23]$$

$R^2 = 0.53$

For Y-P log grade 3, the weight is:

$$\text{Chippable wt.} = -108.79 + 20.0655 \text{ (Scaling dia.)} \qquad [4.24]$$

$R^2 = 0.87$

The slopes of these equations are significant at the 0.0001 probability level.

Of the regression equation sets developed for the various wood waste components, the equations for Y-P grades 1 and 2 within each set intersect at larger diameters (15.9-inches for sawdust, 20.3-inches for slab weight, 27.6-inches for slabs, edgings and Economy and 22.2-inches for chippable material the Y-P grade 3 logs consistently produced a larger waste component than the other two higher grades. These observations verify the suitability of the Y-P log grades. It should also be noted that the amount of variation explained in the various residue yields was always less from Y-P log grade 2.

4.4.3 Summary of log grade development

The effects of various log characteristics on dimension lumber yield were examined. This examination along with the comparison of the current traditional log grading systems led to a suggested yellow-poplar dimension lumber log grading system. This log grading system incorporates the clear face concept from the southern pine log grading system combined with limiting defects established from the study of the influences of various log characteristics on dimension lumber yield. Using the Y-P log grading system, yield equations were established for dimension lumber and residues from the log sample, with R^2 values frequently greater than 0.6.

5.0 TREE DATA ANALYSIS

The complete tree data set consisted of 53 trees; the definitions, mean and ranges of the various tree characteristics and tree yield variables are listed in Table 5.1. Only 50 trees were used in the analysis, however, because of incomplete data on three trees.

5.1 Pooled Data Model

A stepwise regression model was developed that maximized the coefficient of (multiple) determination (R^2). This procedure was used in order to evaluate the influence of various tree characteristics on yield (board feet) of structural light framing (NHPMA 1978) grade No. 2 and Better (2 + Btr.) from an individual tree and also was used to establish a basis for evaluating 2 + Btr. yield equations developed when the tree sample data was stratified by the current tree grading methods. The stepwise model was:

$$2 + \text{Btr. yield} = f\begin{bmatrix}\text{DBH, HGT, 4'' HGT, 6'' HGT, 8'' HGT,}\\ \text{LOGHGT, DBH}^2\text{, VOL, DBH * 8'' HGT}\end{bmatrix} \qquad [5.1]$$

In terms of explaining the variation of 2 + Btr. yield among the individual trees, [DBH * 8" HGT] (R^2 = 0.88) was selected as the single most important independent variable (Table 5.2). As the stepwise equation development progressed, the other independent variables added into the equation contributed very little in terms of R^2, and were often statistically insignificant.

The first level yield equation developed by the stepwise process is:

$$2 + \text{Btr. yield} = -41.26638 + 0.20578\ (\text{DBH * 8'' HGT}) \qquad [5.2]$$

$R^2 = 0.88$

Table 5.1. Definition, mean and ranges for selected tree characteristic and yield variables.

Variable	Description	Mean	Minimum	Maximum
DBH	Tree diameter measured at breast height (inches)	14.4	8.0	23.2
HGT	Maximum tree height (feet)	88.8	35.0	154.0
4" HGT	Tree height measured to a four-inch top diameter[1] (feet)	70.6	19.0	98.0
6" HGT	Tree height measured to a six-inch top diameter[1] (feet)	62.5	17.0	91.0
8" HGT	Tree height measured to an eight-inch top diameter[1] (feet)	53.1	5.0	87.0
LOGHGT	Total length of logs utilized in study (feet)	50.8	8.3	83.0
DBH^2	DBH * DBH			
TDBH	DBH * 8" HGT			
VOL	DBH * DBH * 8" HGT			

[1]Measured outside bark.

Table 5.2. Results of first five levels of stepwise regression process for developing 2+Btr. yield equations for yellow-poplar trees.

Step	Variable(s)	R
1	DBH * 8" HGT	0.88
2	LOGHGT, VOL	0.90
3	LOGHGT[a], DBH2[b], VOL	0.90
4	6" HGT[b], LOGHGT[a], DBH2[b], VOL	0.90
5	HGT[b], 6" HGT[b], LOGHGT[a], DBH2[b], VOL	0.90

Note: Variables without superscript are significant at 0.01 level; "a" superscript at 0.05 level; and "b" superscript, not significant at 0.05 level.

Note that DBH * 8" HGT is the product of two relatively easily and economically obtained tree measurements which can be obtained before a tree is felled using conventional forestry equipment.

The 2 + Btr. yields and the 95 percent confidence limits derived from equation [5.2] are listed in Table 5.3 for selected values of DBH and 8" HGT. Note that the confidence intervals are often shorter than 20 percent of the 2 + Btr. yield and are relatively consistent (±10 to 15 bd. ft.) in length throughout the DBH and 8" HGT ranges.

5.2 Traditional Tree Grading

As a basis for evaluation, any tree grading scheme should explain the variation in yield as well as or better than the pooled data equation (Equation 5.2). Likewise, the 95 percent confidence intervals should be as short or shorter than those listed for the pooled data (Table 5.3).

A stepwise exploration model (Equation 5.1) was evaluated for the three tree grades of both the U.S. Forest Service hardwood and southern pine tree grading schemes. The results of this stepwise analysis for the hardwood and southern pine grading schemes are provided in Table 5.4.

As with the stepwise 2 + Btr. regression models developed for the pooled tree data, there was a rapid rate of diminishing returns for the addition of variables beyond step 2 to the model in terms of increase of the coefficient of multiple determination. Also, as variables were added, they rapidly lost their statistical significance in the model.

The variable 8" HGT was selected as the variable that contributes the most to the coefficient of determination for the one step regression

Table 5.3. Selected 2+Btr yields and 95 percent confidence limits developed using equation [5.2].

DBH	DBH * 8" HGT	Lower 95% CLM	2+Btr Yield	Upper 95% CLM
10	20	-17.2	-0.1	17.0
	40	27.0	41.0	55.0
	60	70.5	82.2	93.9
	80	112.7	123.2	134.3
12	20	-8.3	8.1	24.5
	40	44.5	57.5	70.5
	60	96.0	106.9	117.8
	80	145.3	156.3	167.3
14	20	0.6	16.4	32.1
	40	61.9	74.0	86.1
	60	120.9	131.6	142.3
	80	176.9	189.2	201.5
16	20	9.4	24.6	39.7
	40	79.0	90.4	101.8
	60	145.3	156.3	167.3
	80	207.7	222.1	236.5
18	60	169.0	181.0	192.9
	80	238.2	255.1	271.9
20	60	192.4	205.7	218.9
	80	268.4	288.0	307.5
22	60	215.4	230.4	245.3
	80	298.4	320.9	343.4
24	60	238.1	255.1	271.9
	80	328.3	353.8	379.4

Table 5.4. Independent variables selected for the first three steps using the model [equation 5.1] with the data stratified by the hardwood tree data.

	Hardwood Tree Grades		
Step	1	2	3
1	VOL (R^2 = 0.59)	DBH * 8" HGT (R^2 = 0.88)	DBH * 8" HGT (R^2 = 0.82)
2	DBH LOGHGT (R^2 = 0.79)	LOGHGT VOL (R^2 = 0.89)	LOGHGT VOL (R^2 = 0.86)
3	4" HGT LOGHGT VOL (R^2 = 0.89)	HGT LOGHGT VOL (R^2 = 0.90)	4" HGT LOGHGT VOL (R^2 = 0.87)
	Southern Pine Tree Grades		
	A	B	C
1	DBH * 8" HGT (R^2 = 0.93)	VOL (R^2 = 0.72)	DBH * 8" HGT (R^2 = 0.87)
2	DBH LOGHGT (R^2 = 0.95)	6" HGT[b] DBH * 8" HGT (R^2 = 0.73)	DBH[a] DBH * 8" HGT (R^2 = 0.90)
3	DBH HGT[b] LOGHGT[b] (R^2 = 0.96)	HGT[a] 4" HGT[a] DBH * 8" HGT (R^2 = 0.82)	HGT[b] DBH^2[a] DBH * 8" HGT (R^2 = 0.90)

Note: Variables without superscript are significant at 0.01 level; "a" superscript, at 0.05 level; and "b", not significant at 0.05 level.

Table 5.5. First three steps of stepwise equations developed from model [equation 5.1] to predict 2+Btr. yield for data stratified by both the hardwood and southern pine tree grades.

Hardwood Tree Grade 1:

2+Btr. = 5.78520 + 0.00991 (VOL) [5.2]

2+Btr. = 977.89305 + 39.14445 (DBH) + 7.27716 (LOGHGT) [5.3]

2+Btr. = 237.74107 - 6.50253 (4" HGT) + 9.98035 (LOGHGT) + 0.01382 (VOL) [5.4]

Hardwood Tree Grade 2:

2+Btr. = 57.58085 + 0.22857 (DBH * 8" HGT) [5.6]

2+Btr. = 51.58804 + 1.88249 (LOGHGT) + 0.00732 (VOL) [5.7]

2+Btr. = -85.02552 + 0.76114 (HGT) + 1.25204 (LOGHGT) + 0.00711 (VOL) [5.8]

Hardwood Tree Grade 3:

2+Btr. = -21.07565 + 0.15294 (DBH * 8" HGT) [5.9]

2+Btr. = 26.78239 + 1.20536 (LOGHGT) + 0.00526 (DBH * 8" HGT) [5.10]

2+Btr. = -10.29974 - 0.70470 (4" HGT) + 1.93649 (LOGHGT) + 0.00494 (VOL) [5.11]

Southern Pine Tree Grade A:

2+Btr. = -62.47201 + 0.23812 (DBH * 8" HGT) [5.12]

2+Btr. = -331.25976 + 25.99029 (DBH) + 1.92432 (LOGHGT) [5.13]

2+Btr. = -271.32902 + 26.33242 (DBH) - 1.32974 (HGT) + 2.97525 (LOGHGT) [5.14]

Southern Pine Tree Grade B:

2+Btr. = 6.80687 + 0.00859 (VOL) [5.15]

2+Btr. = 33.35896 - 1.28128 (6" HGT) + 0.20098 (DBH * 8" HGT) [5.16]

2+Btr. = -142.14828 + 7.31953 (HGT) - 7.64564 (4" HGT) + 0.19007 (DBH * 8" HGT) [5.17]

Southern Pine Tree Grade C:

2+Btr. = -35.05711 + 0.18982 (DBH * 8" HGT) [5.18]

2+Btr. = 56.34789 - 9.71819 (DBH) + 0.25875 (DBH * 8" HGT) [5.19]

2+Btr. = 48.92709 - 0.95959 (HGT) - 0.53078 (DBH^2) + 0.34198 (DBH * 8" HGT) [5.20]

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model of 2 + Btr. yield for two out of the three grades for both the hardwood and southern pine tree grades. An explanation of this observation lies in the fact that dimension lumber yield from logs is accurately estimated by the log diameter. With trees (trees being considered a series of logs) diameter is multiplied by height to estimate dimension lumber volume.

Using the variables developed in the first level of the stepwise equation development for both the hardwood and softwood tree grading schemes (except for the softwood grade C the second level variables were utilized) estimates for the mean yield of 2 + Btr. and 95 percent confidence limits for the means were developed (Table 5.7).

These equations were chosen on a basis of their coefficients of determination and that they required the same tree diameter and height measurements (DBH and 8" HGT).

The means and 95 percent confidence limits developed for the hardwood tree grading system, Table 5.6, indicate there is little practical differentiation between grades two and three below 16 inches DBH (grade 1 by definition must have a DBH equal to or greater than 16 inches), in terms of board feet yield differences of the means and overlapping confidence intervals. Greater than 16 inches in diameter the differentiation of grades two and three means becomes greater, yet there is still a large overlap in the confidence intervals of the means. Hardwood tree grade 1 yields greater recovery of 2 + Btr. than grades 2 and 3, however, the confidence intervals overlap each other for the various hardwood tree grades frequently.

Table 5.6. Mean yield of 2+Btr and 95 percent confidence limits for the means developed for the hardwood tree grades using equations [5.2] for Grade 1, [5.6] for Grade 2 and [5.9] for Grade 3.

		Hardwood Tree Grades								
		1			2			3		
DBH	ETHGT	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM
10	20	-191.9	14.0	220.0	-22.4	12.7	47.8	-3.5	9.8	23.2
	40	-157.7	33.8	225.4	17.0	44.9	72.7	29.7	40.3	50.9
	60	-123.6	53.7	230.9	54.6	77.1	99.5	60.0	70.8	81.6
	80	-89.6	73.5	236.5	88.8	109.3	129.8	87.5	101.3	115.1
12	20	-176.9	22.7	222.4	-14.4	19.1	52.7	3.3	15.9	28.5
	40	-127.7	51.3	230.3	32.4	57.8	83.1	42.3	52.5	62.8
	60	-78.7	79.8	238.3	75.6	96.4	117.2	76.7	89.1	101.5
	80	-30.0	108.3	246.7	112.9	135.0	157.1	108.3	125.7	143.0
14	20	-159.1	33.0	225.2	-6.5	25.6	57.6	10.1	22.0	34.0
	40	-92.3	71.9	236.1	47.3	70.6	93.9	54.2	64.7	75.2
	60	-25.9	110.7	247.4	95.1	115.7	136.4	92.7	107.4	122.0
	80	39.6	149.6	259.5	134.8	160.8	186.8	128.7	150.1	171.4
16	20	-138.6	44.9	228.5	1.4	32.0	62.6	16.7	28.1	39.5
	40	-51.6	95.7	242.9	61.8	83.5	105.2	65.7	76.9	88.1
	60	34.3	146.4	258.4	112.9	135.0	157.1	108.3	125.7	143.0
	80	117.7	197.1	276.5	155.2	186.5	217.9	148.9	174.4	200.0
18	60	101.1	186.8	272.5	129.5	154.3	179.2	123.6	144.0	164.3
	80	198.0	251.0	304.0	174.8	212.3	249.8	168.9	198.8	228.8

Table 5.6. (continued) Mean yield of 2+Btr and 95 percent confidence limits for the means developed for the hardwood tree grades using equations [5.2] for Grade 1, [5.6] for Grade 2 and [5.9] for Grade 3.

		Hardwood Tree Grades								
		1			2			3		
DBH	ETHGT	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM
20	60	171.4	232.0	292.6	145.1	173.7	202.2	138.8	162.2	185.7
	80	258.9	311.2	363.6	193.9	238.1	282.2	188.8	223.2	257.6
22	60	234.3	281.9	329.5	160.2	193.0	226.8	153.9	180.5	207.2
	80	291.8	377.8	463.8	212.7	263.8	315.0	208.6	247.6	286.5
24	60	273.9	336.6	399.3	174.8	212.3	249.8	168.9	198.8	228.8
	80	316.0	450.7	585.5	231.5	289.6	347.9	228.4	272.0	315.5

Note that the 2 + Btr. yield estimates developed for the hardwood tree grading scheme increases the width of the confidence limits as the tree grades progress in quality. This is partially because in the hardwood tree grading scheme, the diameter limits decrease the range of the independent variable.

The southern pine tree grade estimates of mean 2 + Btr. yield and their associated 95 percent confidence limits, Table 5.7, reveals problems also with using the southern pine tree grades to stratify yellow-poplar trees into salable dimension lumber class in order to help obtain value estimates of the standing tree.

Below 16 inches in DBH, the equation developed for southern pine tree grade A predicted less 2 + Btr. than that for grade C. In the 2 + Btr. equation development of the souther pine tree grade A, the smallest tree in terms of DBH was 11.6 inches with the average DBH being 16.4 inches. Thus, the predictions for 2 + Btr. for grade A logs exceeded the range of the data resulting in unrealistic estimates. This is due to the fact that the southern pine tree grades do not incorporate diameter limits.

In general, the length of the confidence limits of the 2 + Btr. yield equations developed for the southern pine tree grades are more consistent with expectations, the higher quality grades and larger diameters having shorter confidence limits.

5.2.1 Current tree grading methods versus pooled data estimates

Comparing the 2 + Btr. yield estimates based on tree grades (Table 5.6 and 5.7) versus the pooled data estimates, the estimates for

Table 5.7. Mean yield of 2+Btr and 95 percent confidence limits for the means developed for the southern pine tree grades using equation [5.12] for Grade A, [5.15] for Grade B and [5.19] for Grade C.

		Southern Pine Tree Grades								
		A			B			C		
DBH	ETHGT	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM
10	20	-59.1	-14.8	29.4	-1.2	30.5	62.1	-8.8	10.5	29.8
	40	-4.1	32.8	69.6	17.4	45.7	74.0	38.3	62.2	86.0
	60	50.6	80.4	110.2	35.5	60.9	86.3	79.6	113.8	148.1
	80	104.5	128.0	151.5	53.1	76.1	99.2	118.8	165.5	212.2
12	20	-48.1	-5.3	37.4	7.1	37.2	67.3	-18.3	1.6	21.6
	40	17.8	51.8	85.8	33.4	59.1	84.7	47.9	63.6	79.4
	60	83.1	109.0	134.9	58.5	81.0	103.4	99.5	125.6	151.8
	80	146.7	166.1	185.5	81.9	102.9	123.8	146.3	187.6	228.9
14	20	-37.1	4.2	45.5	16.7	45.1	73.5	-36.7	-7.2	22.2
	40	39.7	70.9	102.1	51.7	74.9	98.1	49.5	65.1	80.6
	60	115.2	137.5	159.9	83.8	104.7	125.6	117.1	137.4	157.8
	80	187.4	204.2	221.0	112.0	134.5	157.0	172.5	209.7	247.0
16	20	-26.1	13.7	53.5	27.6	54.2	80.8	-58.3	-16.1	26.1
	40	61.4	89.9	118.4	71.8	93.1	114.5	43.0	66.5	90.1
	60	146.7	166.1	185.5	109.9	132.1	154.3	130.1	149.2	168.4
	80	225.8	242.3	258.8	142.4	171.0	199.6	196.9	231.9	266.9
18	60	177.5	194.7	211.9	136.1	163.1	190.1	137.7	161.0	184.3
	80	261.8	280.4	299.0	174.0	212.4	250.8	219.1	254.0	289.0

Table 5.7. (continued) Mean yield of 2+Btr and 95 percent confidence limits for the means developed for the southern pine tree grades using equation [5.12] for Grade A, [5.15] for Grade B and [5.19] for Grade C.

		Southern Pine Tree Grades								
		A			B			C		
DBH	ETHGT	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM	Lower 95% CLM	2+Btr Mean	Upper 95% CLM
20	60	206.9	223.4	239.6	163.0	197.8	232.5	142.2	172.8	203.4
	80	296.1	318.5	340.1	207.7	258.6	309.6	239.1	276.1	313.2
22	60	235.0	251.8	268.6	191.4	236.1	280.9	145.2	184.6	224.0
	80	329.4	356.6	383.4	244.1	309.7	375.4	257.2	298.3	339.3
24	60	261.8	280.4	299.0	221.6	278.1	334.6	147.5	196.4	245.2
	80	362.1	394.7	427.3	283.5	365.7	447.9	274.0	320.4	366.8

the 2 + Btr. yield from the pooled data are very close to the average of the tree grade data for both the hardwood and southern pine grading schemes. For example, at 14 inches DBH and 60-foot height, the pooled data estimate of 2 + Btr. is 131.6 board feet, 126.5 board feet for the average southern pine grade estimates and 111.3 board feet for the average hardwood grades estimates.

The confidence limits for the pooled data estimates of 2 + Btr. yield are shorter and more consistent in length versus those developed for the current tree grading methods. The hardwood and southern pine tree grading schemes appear, therefore, to have problems in stratifying the sample data into usable estimates of salable dimenion lumber. In contrast, the pooled data equation explains the variability in 2 + Btr. yield to a high degree (R^2 = 0.88) and results in confidence limits that appear are acceptable for value estimation of a yellow-poplar tree for dimension lumber production.

In making this conclusion, it must be remembered that tree grades would not be used to select specific trees during the stumpage sale. However, value estimates are derived from end product prices. This is in constrast to log grades, which is used to stratify the logs into product yield classes in order to estimate log value and in turn encourage delivery of logs to the log yard for a specific end use through monetary incentive.

Thus, estimating the return on a pooled estimate of an end product would not be of serious consequences for tree valuation. However, a tool is needed for foresters to identify potential trees for a specific end product.

5.3 Influence of Defects on Yields

A stepwise exploration model was developed in order to evaluate the influences of visible tree defects in the bottom eight foot log. The stepwise regression model is:

$$\%\ 2 + \text{Btr. yield} = f \begin{bmatrix} \text{LIVE KNOTS, DEAD KNOTS, BURLS, SWEEP,} \\ \text{CROOK, BRANCH, SCARS, END DEFECT,} \\ \text{CULL, SEAM} \end{bmatrix} \quad [5.21]$$

where,

% 2 + Btr. yield = No. 2 and Better lumber yield as a percent of total dimension lumber yield from a tree.

LIVE KNOTS = number of live knots larger than two inches in diameter (count).

DEAD KNOTS = number of dead knots larger than two inches in diameter (count).

BURLS = number of burls (count).

SWEEP = percent sweep (See Section 4.1).

CROOK = percent crook (See Section 4.1).

BRANCH = number of epicormic branches (count).

SCARS = size of scar.

END DEFECT = size of end defect located at stump height.

CULL = percent cull based on scaled volumes.

SEAM = length of seam(s).

Table 5.8. Results of stepwise regression process evaluating the influences of outward tree defects found in bottom eight-foot log of an individual tree on the percent yield of dimension lumber grade No. 2 and Better versus total dimension lumber yield.

Level	Defect	Coefficient	H_o: B = 0[1/]	R^2
1	SCARS	-0.086	0.0197	0.15
2	DEAD KNOTS	-0.049	0.0950	0.21
	SCARS	-0.087	0.0167	
3	DEAD KNOTS	-0.051	0.0826	0.25
	SCARS	-0.084	0.0195	
	END DEFECT	-0.058	0.2186	
4	DEAD KNOTS	-0.046	0.1115	0.29
	BRANCH	0.006	0.2178	
	SCARS	-0.070	0.0583	
	END DEFECT	-0.094	0.0924	
5	LIVE KNOTS	-0.163	0.2850	0.36
	DEAD KNOTS	-0.044	0.1467	
	SWEEP	-0.648	0.5281	
	BRANCH	0.006	0.2903	
	SCARS	-0.056	0.1595	
	END DEFECT	-0.259	0.1337	
	CULL	3.766	0.4863	
	SEAM	0.033	0.3855	

[1/] Level of significance.

The results of the above stepwise process (Equation 5.21) are given in Table 5.8. Care must be taken in interpreting the results in Table 5.8, because the defects utilized in the equation development had a low rate of occurrence in the study trees and were from discrete distributions. The reason for this caution can be seen on independent variable level eight, where the slope coefficients are positive for branches, cull and seams.

The coefficient of (multiple) determination, R^2, in Table 5.8 indicates that visible tree defects have only a small influence on the yield of No. 2 and Better lumber as a percentage of total dimension lumber yield from a tree.

Scars were selected as the one variable that contributed the most to the explanation of the variation of percent 2 + Btr. yield. This is as expected because scars indicate that a tree is damaged and will likely contain unsound wood. Dead knots over two inches in diameter, was added next to the stepwise model. This coincides with what was to be expected from the experience gained in investigating the influence of log defects on 2 + Btr. yield, and may be explained by knot size restrictions as defined by dimension lumber grade No. 2. End defects were added as the third independent variable to the stepwise model. The selection of end defects early in the model development supports the importance that the amount of sound wood has on the yield.

5.4 Summary of Tree Data Analysis

A model for predicting the yield of No. 2 and Better lumber from yellow-poplar trees was developed using the pooled data set. The data set was then stratified using both the hardwood and southern pine tree grading systems and individual yield model for No. 2 and Better lumber developed for each grade. The models developed from the stratified data sets were found to do a poorer job of estimating yield of No. 2 and Better lumber as opposed to the pooled equation. This indicated that for usable estimates of dimension lumber yields from yellow-poplar trees, stratification by tree grades was not required.

Further, a weak relationship between the percentage yield of No. 2 and Better dimension lumber yield versus total dimension lumber yield of a tree and visible tree defects was found.

The pooled data dimension lumber and residue yield equations for yellow-poplar trees, means and 95 percent confidence limits for the means can be found in Appendix B.

6.0 A METHOD OF ECONOMIC EVALUATION

The purpose of this chapter is to present a method of examining the value relationship for processing yellow-poplar logs into various end products that are presently marketed versus dimension lumber. The evaluation presented in this chapter is for specific assumptions and may not represent a particular situation accurately. However, a simple method of economic evaluation is presented so that sawmill operators and entrepreneurs will be encouraged to evaluate the potential of producing dimension lumber from yellow-poplar sawlogs versus other currently marketed end products. Computer programs that use the evaluation method presented are available, these having the advantage of easily manipulating input variables, thereby exploring many possible alternatives (Sinclair 1980).

In order to assess how a log may be best utilized in terms of maximizing a sawmill owners profit, the approach of the logs' break-even point will be taken in this chapter. The break-even point, as used in this chapter, may be defined as the log diameter for a particular quality class (i.e., hardwood log grade one) utilized for a specific purpose (i.e., factory lumber) at which all manufacturing costs, including the log cost, are covered by the value of the end product(s) but no profit is realized.

Thus, a log whose end product value exceeds the manufacturing cost will have a net revenue that exceeds the break-even point, contributing positively to the sawmill's profit.

6.1 Assumptions and Conditions

The dimension lumber yields used in calculations are the yields estimated by the Y-P log grade equations modified for product upgrading as described in Appendix C.

Prices are those presented in Section 2.1.5. Prices used for dimension lumber were adjusted downward by $30.00 per thousand board feet ($/mbf) to account for freight charges. Thus, the price for structural light framing No. 2 and Better is $187.00/MBF and for No. 3 is $137.00/MBF. Prices for economy grade dimension lumber were assumed to be $100.00/MBF[1/].

Production costs for dimension lumber are given as lower and upper limits of a range of estimated costs. The lower limit is $66.93/MBF for producing hardwood dimension lumber in an efficient softwood stud mill manner as described by Harpole, Boone and Maeglin (1981). The upper limit of the dimension lumber production costs are the cost per MBF of producing factory lumber, $65.61 (White 1980), plus $30.00/MBF[2/] for the estimated cost of drying and planing the dimension lumber.

Prices for the factory lumber grade class 2B, 3A, and 3C are assumed to be $125.00/MBF and $100.00/MBF for the 3C lumber grade class. The value yield for factory lumber was determined using the yield of the Doyle scale. Production costs are assumed to be $65.61/MBF distributed on a diameter basis by a time study analysis done by White (1980).

[1/] Prices for economy grade are difficult to estimate since markets for the material are scarce.

[2/] Drying costs are estimated at $22.70/MBF (Wengert 1977), the remainder going for planing.

Table 6.1 lists the prices and costs used to find the net revenue yields of logs presented in the evaluation. For an example: the net revenue yield of a 13-inch scaling diameter, hardwood log grade 1 (HWD grade 1) yellow-poplar sawlog being manufactured into 4/4 factory lumber may be found by the following formula:

		4/4 Lumber		Conventional Mill		Sawlog
Net Revenue Yield Per Log	=	Value Yield HWD Grade 1	-	Production Cost	-	Delivered Price

$$= 9.31 - 4.97 - 5.13$$

$$= \$-0.79/\text{log}$$

The net revenue would be -0.79 $/log or a loss of -0.79 to the mill profit picture for manufacturing the log.

6.2 Analysis of Log Net Revenue

The best utilization of yellow-poplar logs, in terms of contributing to a sawmill's profit, will be analyzed in this section using graphs of the net revenue of a particular quality log utilized for a specific purpose versus the logs scaling diameter. Three log quality classes, high, low and medium will be used in analysis.

6.2.1 High quality yellow-poplar logs

In examining the alternative uses for the high quality (relatively free of external log defects such as knots, rot and sweep) three utilization scenarios are addressed, they are manufacturing the sawlogs into veneer, factory lumber and dimension lumber (Figures 6.1, 6.2 and 6.3 respectively).

Table 6.1. Prices and costs used in determining logs net revenue yield as a function of log diameter (SDIB).

SDIB	Dimension Lumber Value Yield $/Log YPDL Grade 1[1]	Dimension Lumber Value Yield $/Log YPDL Grade 2[2]	Dimension Lumber Value Yield $/Log YPDL Grade 3[3]	Factory Lbr. Value Yield $/Log Hardwood Grade 1[4]	Factory Lbr. Value Yield $/Log Hardwood Grade 2[5]	Factory Lbr. Value Yield $/Log Hardwood Grade 3[6]	Chipping Logs Delivered $/Log[7]	Saw Logs Delivered $/Log[8]	Veneer Logs Delivered $/Log[9]	Production Costs for Conventional Mill[10]	Production Costs for SDR Using Conventional Mill[11]	Production Costs for SDR Mill[12]
6			1.60							2.68*	.86	.60
7			2.09							2.91*	1.22	.86
8			2.90			1.25	0.81	1.00	1.64	3.12*	1.82	1.27
9	3.38	3.34	3.72			1.93	1.31	1.63	2.67	3.40	2.41	1.69
10	5.13	4.91	4.49			2.94	1.82	2.25	3.69	3.69	2.99	2.09
11	6.81	6.45	5.29		5.46	4.20	2.53	3.13	5.13	3.98	3.84	2.69
12	8.56	8.00	6.09		6.33	5.76	3.23	4.00	6.56	4.25*	4.83	3.38
13	10.25	9.53	6.86	9.31	8.75	7.07	4.14	5.13	8.41	4.97	5.82	4.06
14	11.68	11.06	7.67	13.95	10.66	7.03	5.05	6.25	10.25	5.70	6.77	4.74
15	13.71	12.62	8.46	15.47	13.15	11.00	6.16	7.63	12.51	6.43	7.74	5.42
16	15.43	14.18	9.29	20.38	16.84	13.59	7.27	9.00	14.76	7.15*	8.73	6.11
17	17.16	15.70	10.07	23.56	17.05		8.59	10.63	17.43	8.33	9.70	6.79
18	18.87	17.24	10.85	28.97	19.25		9.90	12.25	20.09	9.51	10.68	7.48
19	20.61	18.37	11.63	33.69	21.45		11.41	14.13	23.17	10.69	11.66	8.17
20	22.32	20.20	12.95	46.10	31.77		12.93	16.00	26.24	11.87	12.62	8.84
21	24.03	21.91	13.26	39.24	31.75		14.65	18.13	29.73	13.05	13.61	9.52
22	25.76	23.43	14.03	41.64	37.62		16.36	20.25	33.21	14.23*	14.58	10.21
23	27.47	24.08	14.84	53.87	37.89		18.28	22.63	37.11	16.76	15.55	10.90
24	29.20	26.52	15.62	56.64			20.20	25.00	41.00	19.30	16.53	11.57

1, 2, 3 Yields derived from Appendix A, upgraded using Appendix C and prices as described in Section 6.1.

4, 5, 6 Yields derived from Casnens (1980) and Doyle scale, prices as described in Section 6.1.

7, 8, 9 Prices as described in Sections 2.1.5 and 6.1 allocated on Doyle Scale basis.

10 Production cost with asterisk from White (1980), others derived from linear interpolation.

11 $65.61/MBF processing cost (White, 1980) plus $30.00/MBF drying and planing cost.

12 Harpole, Boone and Haeglin (1981).

Note: SDIB = Scaling diameter.

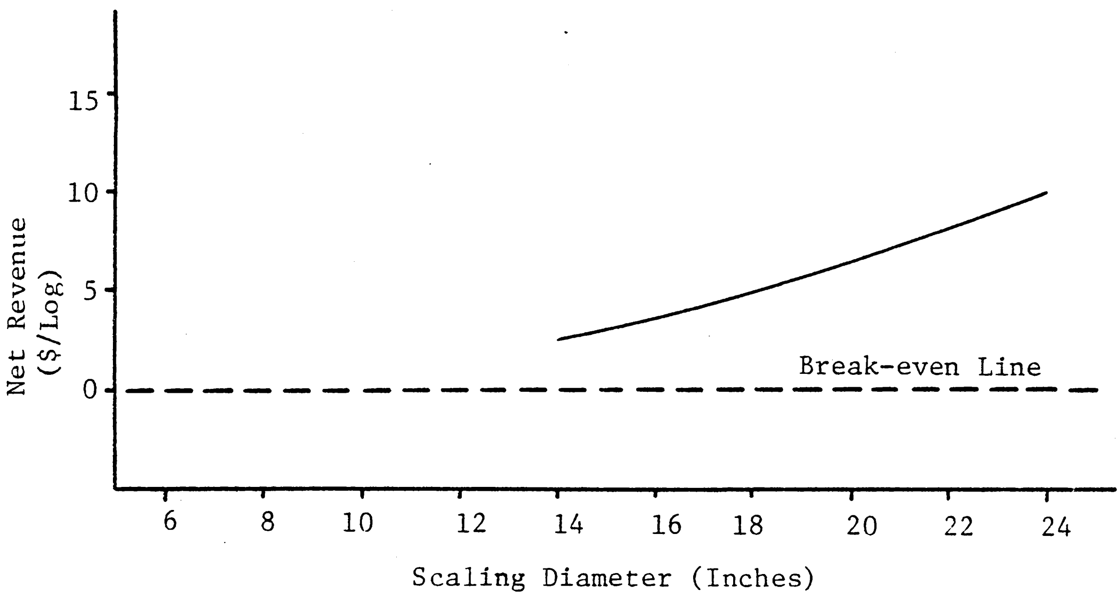

Figure 6.1. Net revenue curve of yellow-poplar sawlogs sold as veneer logs.

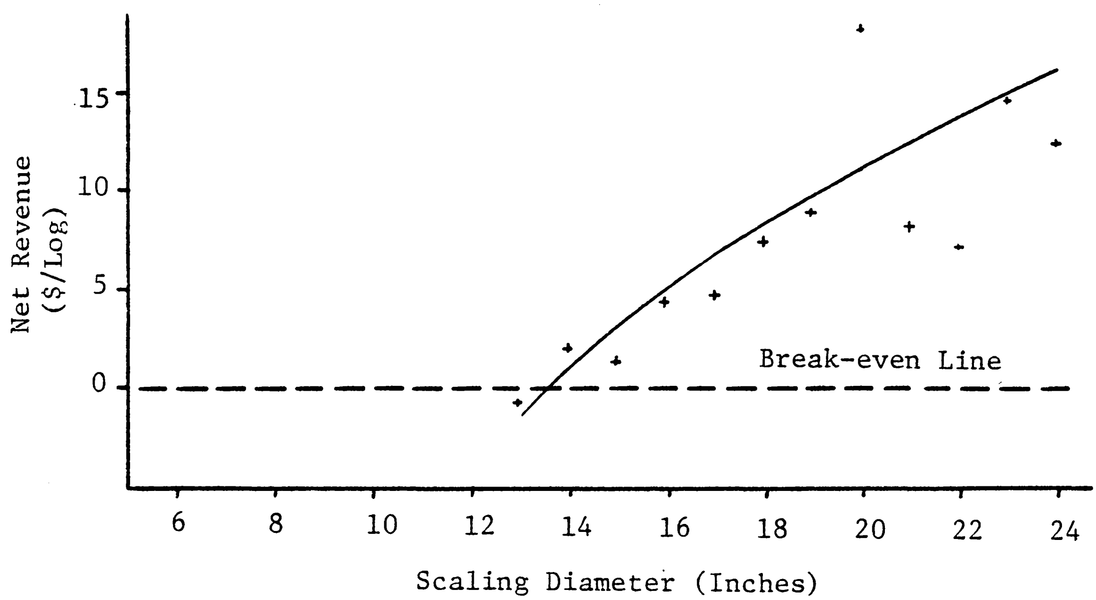

Figure 6.2. Net revenue curve of yellow-poplar sawlogs, Hardwood Log Grade One, manufactured into factory lumber.

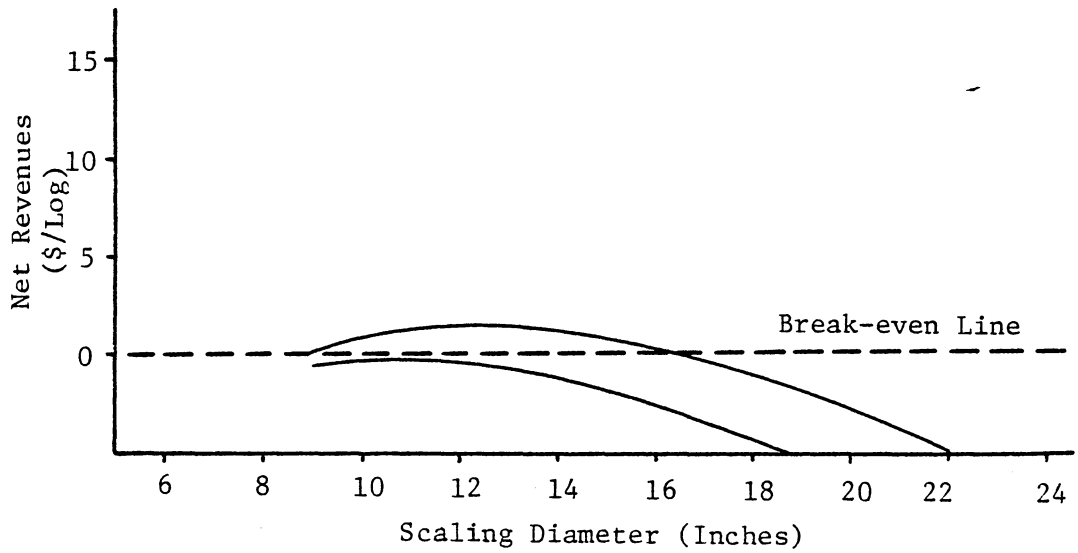

Figure 6.3. Net revenue curves of yellow-poplar sawlogs, Y-P Log Grade One, manufactured into dimension lumber using low and high estimates of production costs.

In the veneer utilization scenario, Figure 6.1, yellow-poplar sawlogs that meet veneer log standards[3/] (free of any visible defects and a minimum of 14 inches in scaling diameter) are delivered to the sawmill's logyard at sawlog prices, separated from the other logs, loaded on trucks and delivered to the veneer mill. Using this system, the sawmill operator can realize a profit from approximately $5.00/log for logs with a 14-inch scaling diameter to approximately $20.00/log for those with a 24-inch scaling diameter.

In Figure 6.2, high quality yellow-poplar logs (assumed to meet the hardwood log grade one standards) are manufactured into 4/4 lumber. At the lower diameter limits of the hardwood number one log specifications the manufacturing of 4/4 is unprofitable, however, as diameter increased so does profitability at a rapid rate exceeding the profitability of selling the logs for veneer at approximately 16-inches scaling diameter.

One may argue that selling the logs that meet veneer standards instead of manufacturing 4/4 lumber may involve less risk, however, the separation and selling of veneer quality logs from a group of hardwood grade one logs would tend to shift the net revenue curve downward for manufacturing lumber and increase the risk at the same time.

The third option presented for the high quality yellow-poplar logs is the manufacturing of dimension lumber (Figure 6.3). This appears to be a viable alternative for logs up to approximately 15-inches in scaling diameter for yellow-poplar dimension lumber grade one logs.

[3/] Personal communication with the log buyer of Lane Furniture.

The size limitation of manufacturing dimension lumber from yellow-poplar logs in part may be due to the linear relationship of dimension lumber versus scaling diameter caused by the volume loss in larger logs due to splits induced by growth stresses and production costs may have been over-estimated or assigned to the various diameters incorrectly. Also, the percentage of salable dimension lumber, 2 + Btr., versus total dimension lumber decrease as scaling diameter increased. This, opposed to factory lumber production, in which generally lumber quality is a direct relationship to scaling diameter.

For quality yellow-poplar logs, it appears a two stage manufacturing operation may be feasible, manufacturing dimension lumber from the smaller diameter logs and factory lumber from the larger diameter logs.

6.2.2 Medium quality yellow-poplar logs

The scenario for the medium quality yellow-poplar logs would include the alternatives of manufacturing the logs into factory lumber or dimension lumber.

The manufacturing of yellow-poplar logs hardwood log grade two (Figure 6.4) into factory lumber proves much less profitable than hardwood log grade one logs. The break-even point being approximately 20-inches in scaling diameter.

The second option for the medium quality yellow-poplar sawlogs is the manufacturing of dimension lumber, Figures 6.3 and 6.5. Yellow-poplar dimension lumber log grade one logs are included in both the high and medium quality classes by definition (Chapter 4). The net revenue curve for the manufacturing of dimension lumber for Y-P grade two logs (Figure 6.5) is shifted downward from the Y-P grade one logs (Figure 6.5). This is

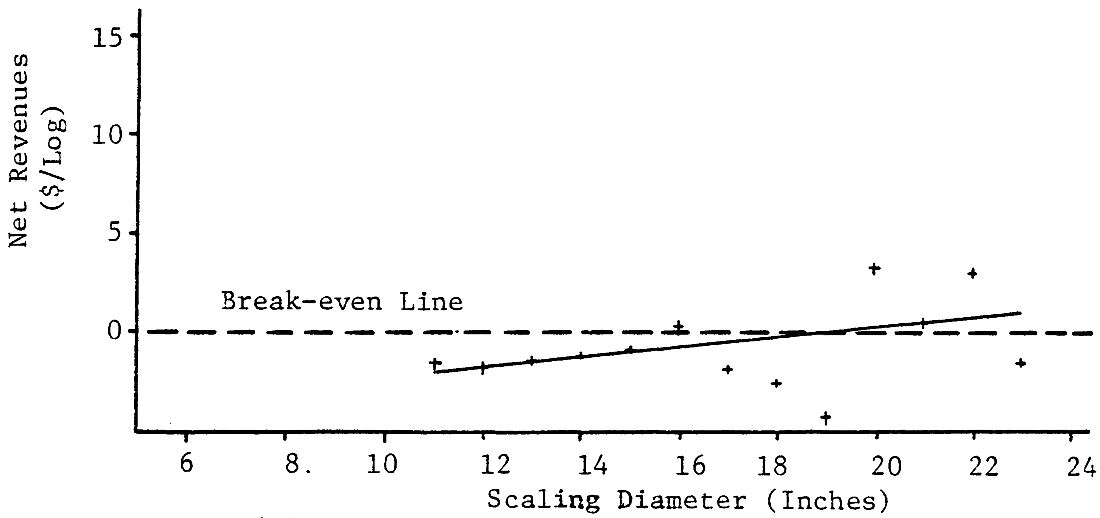

Figure 6.4. Net revenue curve of yellow-poplar sawlogs, Hardwood Log Grade Two, manufactured into factory lumber.

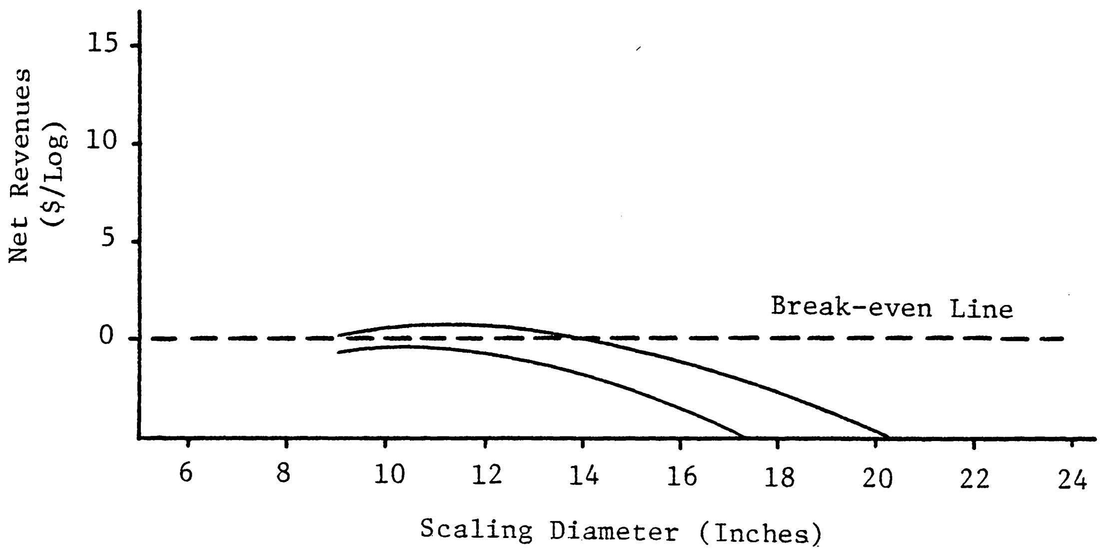

Figure 6.5. Net revenue curves of yellow-poplar sawlogs, Y-P Log Grade Two, manufactured into dimension lumber using low and high estimates of production costs.

reflected by the lowering of the maximum diameter for profitable production for Y-P grade two logs to approximately 13-inches scaling diameter.

If one considers that the Y-P grade two logs may be purchased as chiplogs and manufactured into dimension lumber (Figure 6.6), the net revenue curve shifts upwards and approximates the net revenue curve for Y-P grade one logs (Figure 6.3).

6.2.3 Low quality yellow-poplar logs

The low quality scenario includes the manufacturing of 4/4 lumber from hardwood log grade three and the manufacturing of dimension lumber from Y-P grade three logs, with the logs purchased either as sawlogs or chiplogs.

Using the assumptions presented, the manufacturing of 4/4 lumber from hardwood grade three yellow-poplar logs is an unprofitable proposition, even when these logs are obtained at chiplog prices (Figures 6.7 and 6.8).

On the other hand, production of dimension lumber is profitable at the smaller scaling diameters.

6.3 Dimension Lumber Residue Yields

Total estimated residue yield (sawdust, slabbings and edgings) by log diameter class for manufacturing yellow-poplar dimension lumber using the S-D-R system were obtained from Appendix A. Residues were assigned a value of \$11.23/ton, the value of whole tree energy chips, Section 2.1.5. The value of \$11.23/ton is a conservative estimate in comparison to

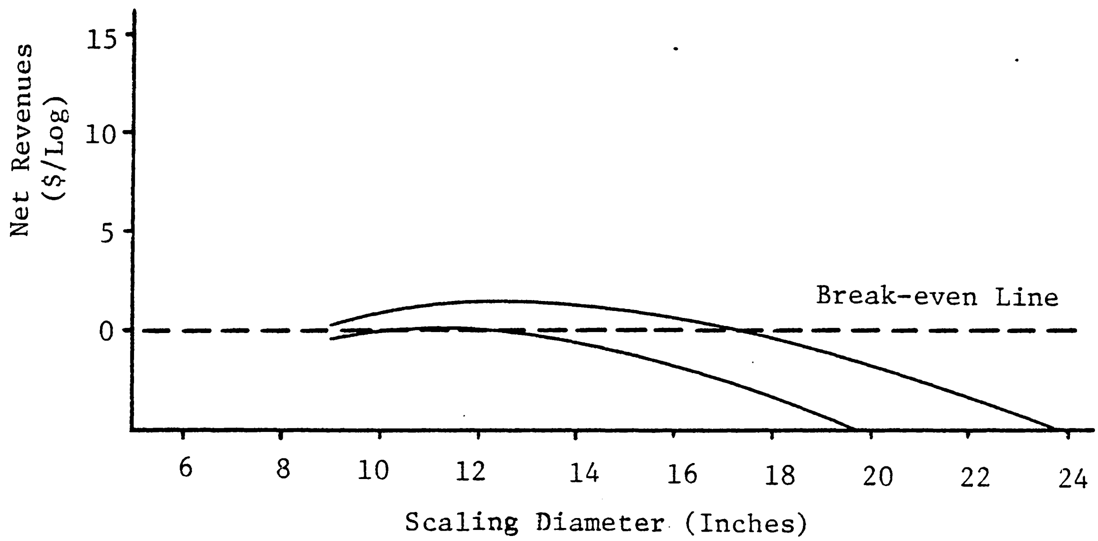

Figure 6.6. Net revenue curves of yellow-poplar chiplogs, Y-P Log Grade Two, manufactured into dimension lumber using low and high estimates of production costs.

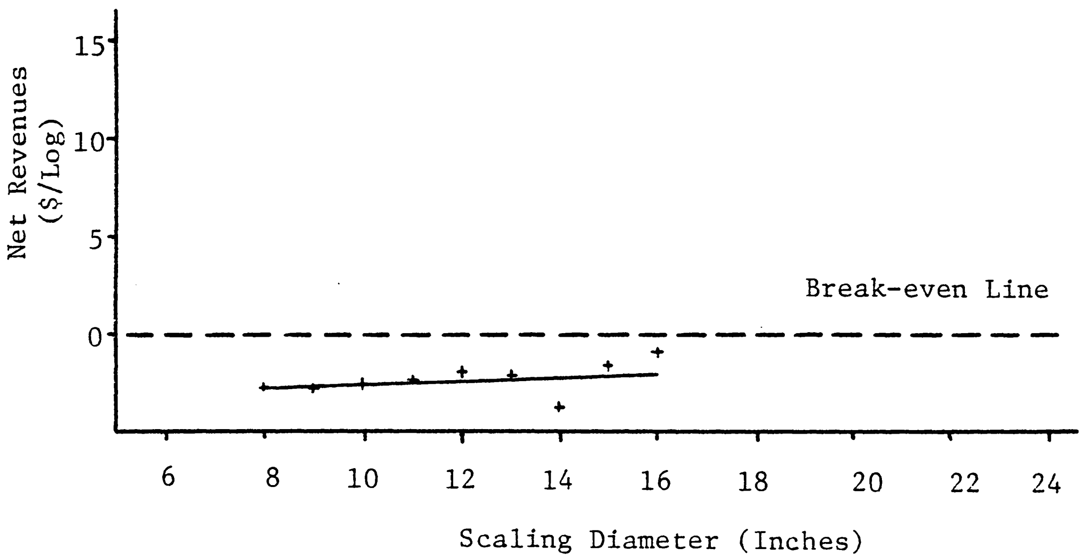

Figure 6.7. Net revenue curve of yellow-poplar sawlogs, Hardwood Log Grade Three, manufactured into factory lumber.

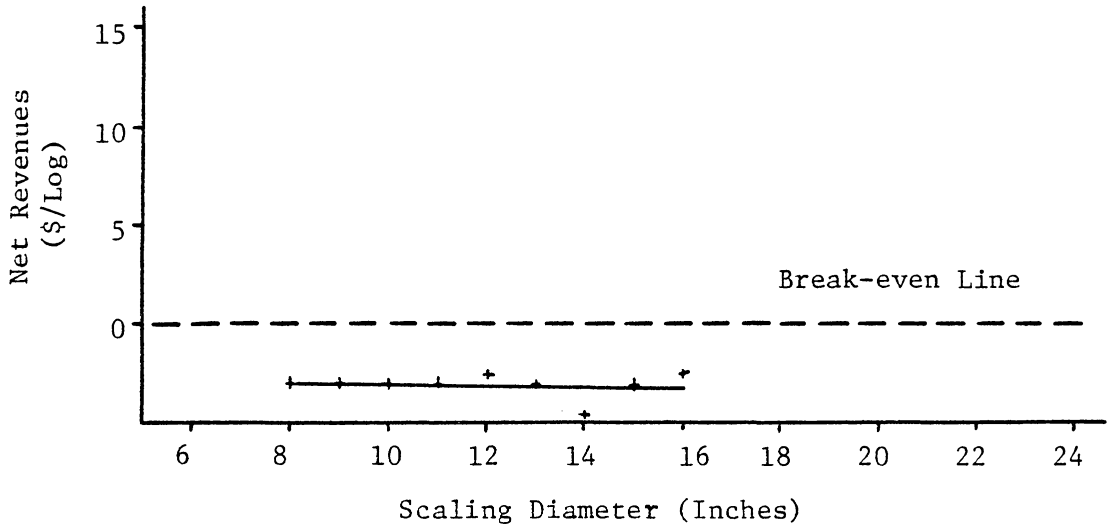

Figure 6.8. Net revenue curve of yellow-poplar chiplogs, Hardwood Log Grade Three, manufactured into factory lumber.

Harpole, Maeglin and Boone (1981) who valued wood chips at $16.00/ton, dry sawdust and planer shavings at $14.00/ton and hogged fuel at $8.50/ton.

The product of the residue yield times the value assigned was graphed, by yellow-poplar dimension lumber (Y-P) log grade, in Figure 6.11. As expected from the graph of lumber yield as a function of diameter by grade, Figure 4.6, Y-P grade three had a much higher residue value yield versus Y-P grades one and two.

6.3.1 Effects of residue yield on net revenue graphs

The residue value yield shown in Figure 6.11 was combined with the net revenue graphs for dimension lumber production, Figures 6.3, 6.5 and 6.10 resulting in Figure 6.12. The effect of adding the residue yield values to the net revenue curves of yellow-poplar dimension lumber is the upward shift, or increase in profitability of the manufacturing of dimension lumber.

Figure 6.12 suggests again that the manufacturing of dimension lumber using the S-D-R system is a feasible small log process. In turn, the combination of manufacturing dimension lumber from small logs (scaling diameter < 15-inches) with production of factory lumber from the larger logs would economically utilize a range of yellow-poplar logs in terms of both size and quality.

6.4 Summary of the Economic Evaluation

Using net revenue, a method of analyzing the profitability of producing yellow-poplar dimension lumber from sawlogs in light of

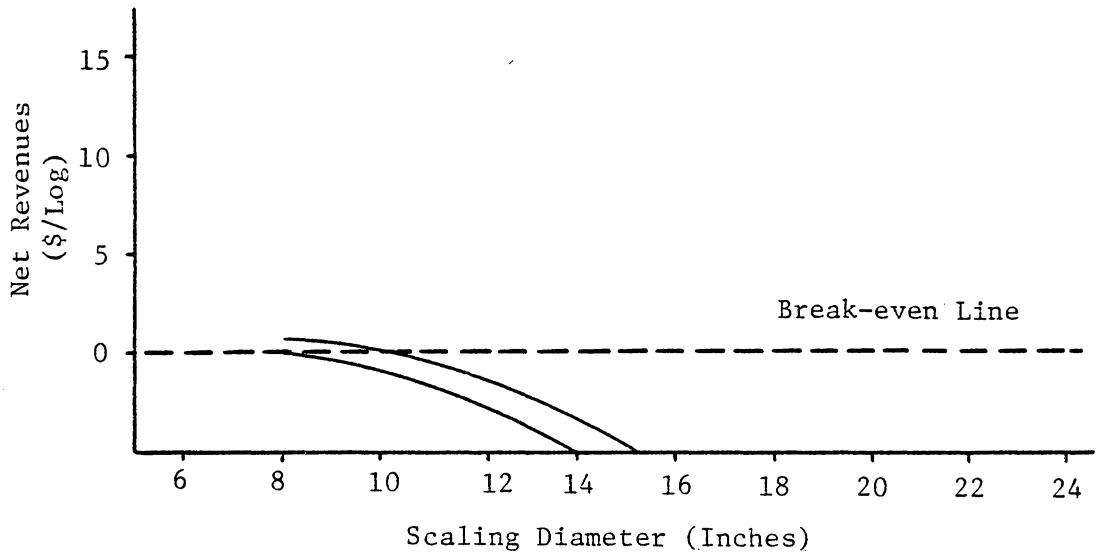

Figure 6.9. Net revenue curves of yellow-poplar sawlogs, Y-P Log Grade Three, manufactured into dimension lumber using low and high estimates of production costs.

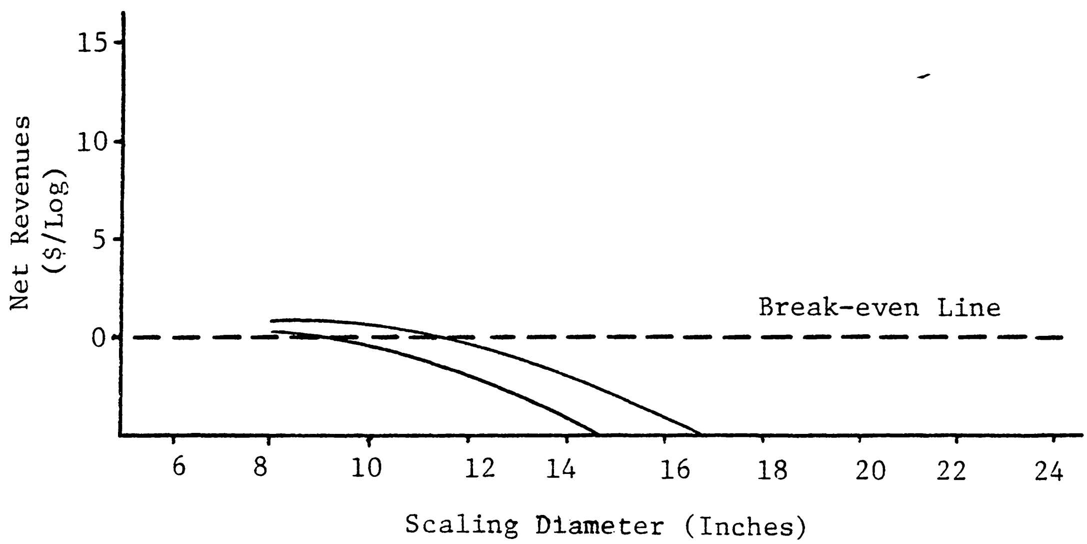

Figure 6.10. Net revenue curves of yellow-poplar chiplogs, Y-P Log Grade Three, manufactured into dimension lumber using low and high estimates of production costs.

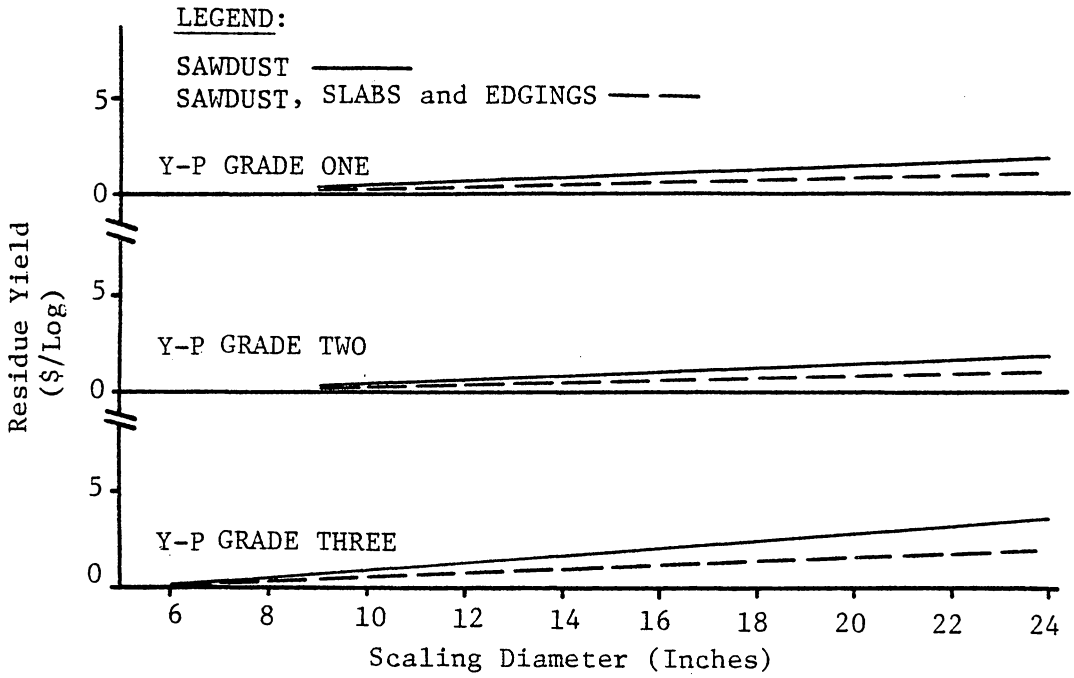

Figure 6.11. Residue yield using the S-D-R process for manufacturing dimension lumber as a function of scaling diameter.

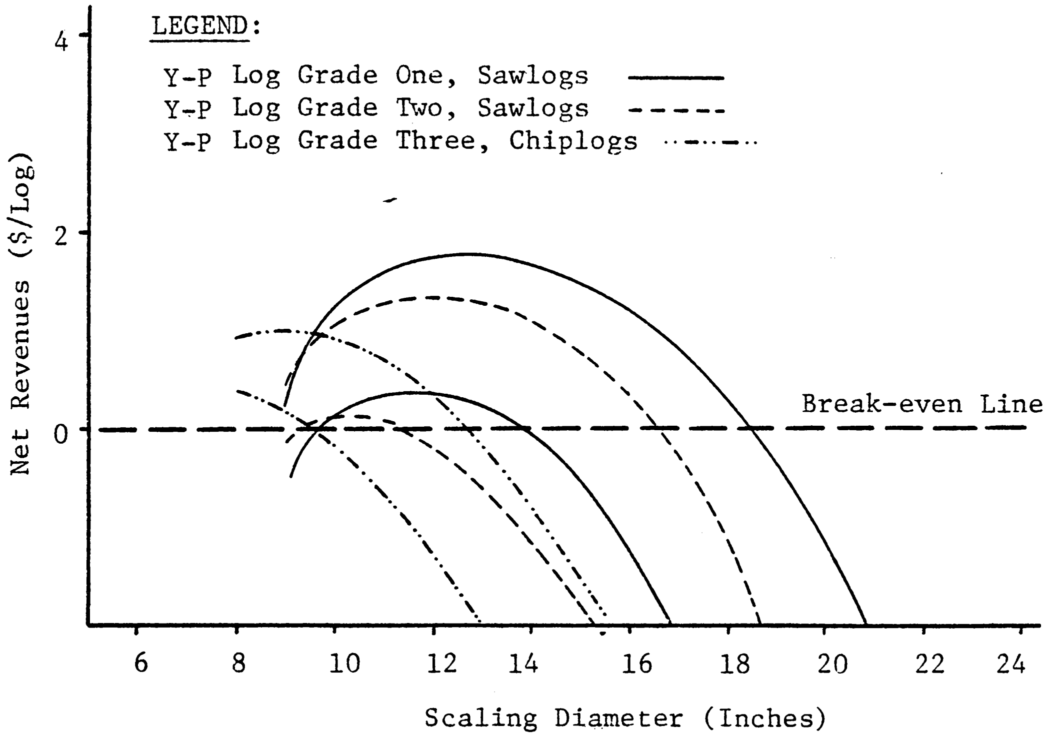

Figure 6.12. Net revenue curve for the three Y-P log grades manufactured into dimension lumber.

other alternative products was presented.

Using the assumptions stated, it was found that high quality yellow-poplar sawlogs with larger diameters could be profitably sold as veneer logs or manufactured as factory lumber, while the smaller and lower quality yellow-poplar logs could profitably be manufactured into dimension lumber using the S-D-R system. The shape of the net revenue curves for manufacturing dimension lumber suggest that further investigation is needed in determining the production costs for the Saw-Dry-Rip process and the relationship of dimension lumber value yield versus log cost. The addition of revenues from residues of the manufacturing of dimension lumber using the S-D-R system enchancing the profitability of the system.

7.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Yellow-poplar log grades were established to stratify yellow-poplar logs into salable dimension lumber classes when the lumber was manufactured by the Saw-Dry-Rip manufacturing system. These log grades are based on the southern pine log grades with log defect exclusion limits. Dimension lumber yield and residue yield for producing yellow-poplar dimension lumber were determined and are listed (Appendix A).

The use of various grading schemes for stratifying yellow-poplar trees into salable dimension lumber classes was evaluated. It was found that estimates of salable dimension lumber yield from pooled data yielded better results than estimates using tree grades for stratification. Estimates for the dimension lumber yield are listed (Appendix B).

A method evaluating the feasibility of producing dimension lumber from yellow-poplar logs of various diameters and quality classes was evaluated in light of producing alternate products using net revenue graphs (using various assumptions on costs and prices). The net revenue graphs suggested (based on the assumptions presented) that a sawmill should utilize the lower diameter (scaling diameter < 15-inches) and lower quality logs for dimension lumber production and on the other hand larger dimension and higher quality logs for factory lumber.

7.2 Conclusions

The following conclusions were made from the investigation;

1. Eight foot yellow-poplar logs sawn by the Saw-Dry-Rip process can be stratified into grades which reflect significant

differences in dimension lumber yield between the log grades.

2. A series of equations were developed that predict the dimension lumber and residue yields for the various yellow-poplar dimension lumber log grades and from trees.

3. Within the constraints of the preliminary data, yellow-poplar logs may reliably be separated according to the end product produced.

In addressing the broad-objective, the yellow-poplar dimension lumber log grades and associated yield equations allow reliable value estimates for dimension lumber end products to be made. However, further research is needed to study the estimation and allocation of production costs for logs of various grades and size classes in order to accurately assess the economic potential of the Saw-Dry-Rip system.

7.3 Recommendations

The following recommendations are made:

1. A study be conducted in which the estimation and allocation of production costs for the Saw-Dry-Rip system be determined.

2. It is recommended that once the Saw-Dry-Rip system has been commercially adopted for yellow-poplar dimension lumber, a follow-up study will be needed to confirm the log grades and their associated yield estimates and confirm the tree yield equations for various sites.

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APPENDIX A

Table A.1. Yield of No. 2 and Better dimension lumber, 2 + Btr., in board feet from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of 2 + Btr. (= -42.46415 + 6.25475(SDIB), $R^2 = 0.67$).

SDIB (Inches)	2 + Btr. (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	13.8	7.9	19.7
10	20.1	15.1	25.1
11	26.3	22.1	30.6
12	32.6	29.0	36.1
13	38.8	35.8	41.9
14	45.1	42.2	48.0
15	51.4	48.2	54.5
16	57.6	54.0	61.2
17	63.9	59.6	68.2
18	70.1	65.0	75.2
19	76.4	70.4	82.4
20	82.6	75.7	89.5
21	88.9	81.0	96.7
22	95.1	86.3	103.9
23	101.4	91.6	111.2
24	107.6	96.9	118.4
25	113.9	102.1	125.7
26	120.2	107.4	132.9

Note: SDIB = Scaling diameter.

Table A.2. Yield of No. 2 and Better dimension lumber, 2 + Btr., in board feet from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of 2 + Btr. (= -43.40198 + 5.66072(SDIB), R^2 = 0.49).

SDIB (Inches)	2 + Btr. (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	7.5	4.1	10.9
10	13.2	10.5	15.9
11	18.9	16.7	21.1
12	24.5	22.5	26.6
13	30.2	27.9	32.5
14	35.8	33.0	38.7
15	41.5	37.9	45.1
16	47.2	42.7	51.6
17	52.8	47.5	58.1
18	58.5	52.3	64.7
19	64.2	57.0	71.3
20	69.8	61.8	77.8
21	75.5	66.5	84.4
22	81.1	71.3	91.0
23	86.8	76.0	97.6
24	92.5	80.7	104.2
25	98.1	85.4	110.8
26	103.8	90.1	117.4

Note: SDIB = Scaling diameter.

Table A.3. Yield of No. 2 and Better dimension lumber, 2 + Btr., in board feet from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of 2 + Btr. (= 5.96482 + 0.011580(SDIB), R^2 = 0.00).

SDIB (Inches)	2 + Btr. (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	6.0	4.5	7.6
7	6.0	4.8	7.3
8	6.1	5.0	7.1
9	6.1	5.0	7.1
10	6.1	4.8	7.3
11	6.1	4.5	7.6
12	6.1	4.2	8.0
13	6.1	3.8	8.5
14	6.1	3.4	8.9
15	6.1	2.9	9.3
16	6.2	2.5	9.8
17	6.2	2.1	10.3
18	6.2	1.6	10.7
19	6.2	1.2	11.2
20	6.2	0.7	11.6
21	6.2	0.3	12.1
22	6.2	-0.1	12.6
23	6.2	-0.6	13.1
24	6.2	-1.0	13.5

Note: SDIB = Scaling diameter.

Table A.4. Yield of No. 3 dimension lumber (THREE) in board feet from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of THREE (THREE = -14.96905 + 1.78540(SDIB), R^2 = 0.29).

SDIB (Inches)	THREE (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	1.1	-2.6	4.8
10	2.9	-0.3	6.1
11	4.7	2.0	7.4
12	6.5	4.2	8.7
13	8.2	6.3	10.2
14	10.0	8.2	11.9
15	11.8	9.8	13.8
16	13.6	11.3	15.6
17	15.4	12.6	18.1
18	17.2	13.9	20.4
19	19.0	15.2	22.8
20	20.7	16.4	25.1
21	22.5	17.5	27.5
22	24.3	18.7	29.9
23	26.1	19.9	32.3
24	27.9	21.0	34.7

Note: SDIB = Scaling diameter.

Table A.5. Yield of No. 3 dimension lumber (THREE) in board feet from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of THREE (THREE = -5.12769 + 1.17439(SDIB), R^2 = 0.13)

SDIB (Inches)	THREE (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	5.4	3.7	7.2
10	6.6	5.2	8.0
11	7.8	6.7	8.9
12	9.0	7.9	10.0
13	10.1	8.9	11.3
14	11.3	9.8	12.8
15	12.5	10.6	14.4
16	13.7	11.4	16.0
17	14.8	12.1	17.6
18	16.0	12.8	19.2
19	17.2	13.5	20.9
20	18.4	14.2	22.5
21	19.5	14.9	24.2
22	20.7	15.6	25.8
23	21.9	16.3	27.5
24	23.1	17.0	29.2

Note: SDIB = Scaling diameter.

Table A.6. Yield of No. 3 dimension lumber (THREE) in board feet from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of THREE (THREE = -1.73313 + 0.78228(SDIB), R^2 = 0.12

SDIB (Inches)	THREE (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	3.0	1.7	4.2
7	3.7	2.7	4.7
8	4.5	3.7	5.4
9	5.3	4.4	6.2
10	6.1	5.1	7.1
11	6.9	5.6	8.2
12	7.7	6.1	9.2
13	8.4	6.5	10.4
14	9.2	6.9	11.5
15	10.0	7.4	12.6
16	10.8	7.8	13.8
17	11.6	8.2	14.9
18	12.3	8.6	16.1
19	13.1	9.0	17.3
20	13.9	9.4	18.4
21	14.7	9.8	19.6
22	15.5	10.2	20.7
23	16.3	10.6	21.9
24	17.0	11.0	23.1

Note: SDIB = Scaling diameter

Table A.7. Yield of Economy grade dimension lumber (ECON) in board feet from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for mean yield of ECON (ECON = -14.61328 + 2.16842(SDIB), R^2 = 0.27).

SDIB (Inches)	ECON (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	4.9	0.1	9.7
10	7.1	2.9	11.2
11	9.2	5.8	12.7
12	11.4	8.5	14.3
13	13.6	11.0	16.1
14	15.7	13.3	18.2
15	17.9	15.3	20.5
16	20.1	17.1	23.1
17	22.2	18.7	25.8
18	24.4	20.2	28.6
19	26.6	21.7	31.5
20	28.8	23.1	34.4
21	30.9	24.5	37.4
22	33.1	25.8	40.3
23	35.3	27.2	43.3
24	37.4	28.6	46.3

Note: SDIB = Scaling diameter.

Table A.8. Yield of Economy grade dimension lumber (ECON) in board feet from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for mean yield of ECON (ECON = -13.03818 + 2.40978(SDIB), R^2 = 0.21).

SDIB (Inches)	ECON (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	8.6	5.9	11.4
10	11.1	8.8	13.3
11	13.5	11.7	15.3
12	15.9	14.2	17.6
13	18.3	16.4	20.2
14	20.7	18.3	23.1
15	23.1	20.1	26.1
16	25.5	21.9	29.2
17	27.9	23.6	32.3
18	30.3	25.2	35.4
19	32.7	26.9	38.6
20	35.2	28.6	41.8
21	37.6	30.2	44.9
22	40.0	31.9	48.1
23	42.4	33.5	51.3
24	44.8	35.1	54.5

Note: SDIB = Scaling diameter.

Table A.9. Yield of Economy grade dimension lumber (ECON) in board feet from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for mean yield of ECON (ECON = -34.30735 + 5.34368(SDIB), R^2 = 0.68).

SDIB (Inches)	ECON (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	-2.2	-4.5	0.0
7	3.1	1.3	4.9
8	8.4	6.9	10.0
9	13.8	12.3	15.3
10	19.1	17.3	20.9
11	24.5	22.2	26.8
12	29.8	27.0	32.7
13	35.2	31.7	38.6
14	40.5	36.4	44.6
15	45.8	41.1	50.6
16	51.2	45.8	56.6
17	56.5	50.5	62.6
18	61.9	55.2	68.6
19	67.2	59.9	74.6
20	72.6	64.5	80.6
21	77.9	69.2	86.6
22	83.3	73.9	92.6
23	88.6	78.5	98.6
24	93.9	83.2	104.7

Note: SDIB = Scaling diameter.

Table A.10. Yield of SAWDUST in ovendry pounds from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for mean yield of SAWDUST (SAWDUST = -75.53398 + 11.13556(SDIB), R^2 = 0.76).

SDIB (Inches)	SAWDUST (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	24.7	16.4	33.0
10	35.8	28.8	42.8
11	47.0	41.1	52.8
12	58.1	53.3	62.9
13	69.2	65.0	73.4
14	80.4	76.3	84.4
15	91.5	87.0	96.0
16	102.6	97.3	108.0
17	113.8	107.3	120.2
18	124.9	117.2	132.6
19	136.0	127.0	145.1
20	147.2	136.8	157.6
21	158.3	146.5	170.1
22	169.4	156.2	182.7
23	180.6	165.8	195.3
24	191.7	175.5	207.9

Note: SDIB = Scaling diameter.

Table A.11. Yield of SAWDUST in ovendry pounds from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for mean yield of SAWDUST (SAWDUST = -29.81059 + 8.26487(SDIB), $R^2 = 0.38$).

SDIB (Inches)	SAWDUST (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	44.6	37.9	51.2
10	52.8	47.5	58.1
11	61.1	56.8	65.4
12	69.4	65.4	73.3
13	77.6	73.3	82.0
14	85.9	80.5	91.3
15	94.2	87.3	101.0
16	102.4	94.0	110.8
17	110.7	100.6	120.7
18	119.0	107.2	130.7
19	127.2	113.7	140.7
20	135.5	120.2	150.7
21	143.8	126.7	160.8
22	152.0	133.0	170.8
23	160.3	139.7	180.9
24	168.5	146.1	190.9

Note: SDIB = Scaling diameter

Table A.12. Yield of SAWDUST in ovendry pounds from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for mean yield of SAWDUST (SAWDUST = -104.34913 - 17.68727(SDIB), R^2 = 0.71).

SDIB (Inches)	SAWDUST (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	1.8	-6.3	9.8
7	19.5	13.0	25.9
8	37.1	31.7	42.6
9	54.8	49.5	60.2
10	72.5	66.4	78.7
11	90.2	82.6	97.8
12	107.9	98.5	117.3
13	125.6	114.2	137.0
14	143.3	129.7	156.8
15	161.0	145.3	176.7
16	178.6	160.8	196.5
17	196.3	176.2	216.5
18	214.0	191.7	236.4
19	231.7	207.1	256.3
20	249.4	222.5	276.3
21	267.1	237.9	296.2
22	284.8	253.3	316.2
23	302.5	268.7	336.2
24	320.1	284.1	356.2

Note; SDIB = Scaling diameter.

Table A.13. Yield of SLADG in ovendry pounds from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for mean yield of SLADG (SLADG = -56.00992 + 8.42633(SDIB), R^2 = 0.55).

SDIB (Inches)	SLADG (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	19.8	8.3	31.4
10	28.3	18.4	38.1
11	36.7	28.4	44.9
12	45.1	38.2	52.0
13	53.5	47.6	59.5
14	62.0	56.4	67.5
15	70.4	64.5	76.3
16	78.8	72.0	85.6
17	87.2	79.1	95.4
18	95.7	86.0	105.3
19	104.1	92.7	115.5
20	112.5	99.4	125.7
21	120.9	106.0	135.9
22	129.4	112.5	146.2
23	137.8	119.1	156.5
24	146.2	125.6	166.9

Note: SDIB = Scaling diameter.
SLADG = Slab and edging ovendry weight.

Table A.14. Yield of SLADG in ovendry pounds from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for mean yield of SLADG (SLADG = -34.30728 + 7.35535(SDIB), $R^2 = 0.47$).

SDIB (Inches)	SLADG (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	31.9	26.6	37.2
10	39.2	35.0	43.5
11	46.6	43.2	50.1
12	54.0	50.8	57.1
13	61.3	57.0	64.7
14	68.7	64.5	72.9
15	76.0	70.7	81.3
16	83.4	76.9	89.9
17	90.7	83.0	98.5
18	98.1	89.0	107.2
19	105.4	95.0	115.9
20	112.8	101.0	124.6
21	120.2	107.0	133.3
22	127.5	112.9	142.1
23	134.9	118.9	150.8
24	142.2	124.9	159.6

Note: SDIB = Scaling diameter.
SLADG = Slab and edging ovendry weight.

Table A.15. Yield of SLADG in ovendry pounds from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of SLADG (SLADG = -60.18837 + 11.68567(SDIB), R^2 = 0.78).

SDIB (Inches)	SLADG (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	9.9	5.6	14.2
7	21.6	18.2	25.0
8	33.3	30.4	36.2
9	45.0	42.1	47.9
10	56.7	53.2	60.1
11	68.4	64.1	72.6
12	80.0	74.7	85.3
13	91.7	85.3	98.1
14	103.4	95.8	111.0
15	115.1	106.3	123.9
16	126.8	116.8	136.8
17	138.4	127.3	149.7
18	150.2	137.7	162.6
19	161.8	148.1	175.5
20	173.5	158.6	188.5
21	185.2	169.0	201.4
22	196.9	179.4	214.4
23	208.6	189.9	227.3
24	220.3	200.3	240.3

Note: SDIB = Scaling diameter.
SLADG = Slab and edging ovendry weight.

Table A.16. Yield of WASTE in ovendry pounds from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of WASTE (WASTE = -76.38884 + 11.51842(SDIB), R^2 = 0.68).

SDIB (Inches)	WASTE (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	27.3	15.5	39.0
10	38.8	28.8	48.8
11	50.3	41.9	58.7
12	61.8	54.8	68.9
13	73.4	67.3	79.4
14	84.9	79.2	90.6
15	96.4	90.4	102.4
16	107.9	101.0	114.9
17	119.4	111.1	127.7
18	130.9	121.1	140.8
19	142.5	130.9	154.1
20	154.0	140.6	167.4
21	165.5	150.2	180.8
22	177.0	159.8	194.2
23	188.5	169.4	207.6
24	200.1	179.0	221.1

Note: SDIB = Scaling diameter.
WASTE = Ovendry weight of slabs, edgings and Economy grade lumber.

Table A.17. Yield of WASTE in ovendry pounds from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of WASTE
(WASTE = -49.94601 + 10.56975(SDIB), R^2 = 0.49).

SDIB (Inches)	WASTE (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	45.2	37.9	52.5
10	55.8	49.9	61.6
11	66.3	61.6	71.1
12	76.9	72.6	81.2
13	87.5	82.8	92.2
14	98.0	92.2	103.8
15	108.6	101.4	115.4
16	119.2	110.3	128.1
17	129.7	119.1	140.1
18	140.3	127.8	152.8
19	150.9	136.6	165.2
20	161.4	145.3	177.6
21	172.0	153.9	190.1
22	182.6	162.6	202.6
23	193.2	171.2	215.1
24	203.7	179.9	227.6

Note: SDIB = Scaling diameter.
WASTE = Ovendry weight of slabs, edgings and Economy grade lumber.

Table A.18. Yield of WASTE in ovendry pounds from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of WASTE (WASTE = -106.98044 + 18.98213(SDIB), R^2 = 0.84).

SDIB (Inches)	WASTE (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	6.9	1.3	12.5
7	25.9	21.4	30.4
8	44.9	41.0	48.7
9	63.9	60.0	67.7
10	82.8	78.3	87.3
11	101.8	96.2	107.4
12	120.8	113.9	127.7
13	139.8	131.4	148.2
14	158.8	148.8	168.7
15	177.8	166.2	189.3
16	196.7	183.6	209.8
17	215.7	201.0	230.4
18	234.7	218.4	251.0
19	253.7	235.7	271.7
20	272.7	253.0	392.3
21	291.6	270.4	312.9
22	310.6	387.7	333.5
23	329.6	305.0	354.2
24	348.6	322.4	374.8

Note: SDIB = Scaling diameter.
WASTE = Ovendry weight of slabs, edgings and Economy grade lumber.

Table A.19. Yield of WASTE2 in ovendry pounds from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of WASTE2 (WASTE2 = -96.43236 + 13.96220(SDIB), R^2 = 0.75).

SDIB (Inches)	WASTE2 (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	29.2	17.2	41.2
10	43.2	32.9	53.4
11	57.2	48.5	65.8
12	71.1	63.9	78.3
13	85.1	78.9	91.3
14	99.0	93.2	104.9
15	113.0	106.9	119.1
16	127.0	119.9	134.1
17	140.9	132.5	149.4
18	154.9	144.8	165.0
19	168.8	157.0	180.7
20	182.8	169.1	196.5
21	196.8	181.2	212.4
22	210.7	193.2	228.3
23	224.7	205.2	244.2
24	238.7	217.1	260.2

Note: SDIB = Scaling diameter.
WASTE2 = Ovendry weight of slabs, edgings, grade No. 3 and Economy lumber.

Table A.20. Yield of WASTE2 in ovendry pounds from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of WASTE2 (WASTE2 = -56.46028 + 12.15922(SDIB), R^2 - 0.53).

SDIB (Inches)	WASTE2 (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	53.0	45.2	60.8
10	65.1	58.9	71.4
11	77.3	72.2	82.4
12	89.5	84.9	94.0
13	101.6	96.6	106.6
14	113.7	107.6	120.0
15	125.9	118.2	133.7
16	138.1	128.6	147.6
17	150.2	138.8	161.6
18	162.4	149.1	175.7
19	174.6	159.2	189.9
20	186.7	169.4	204.1
21	198.9	179.5	218.2
22	211.0	189.6	232.4
23	223.2	199.7	246.7
24	235.4	209.8	260.9

Note: SDIB = Scaling diameter.
WASTE2 = Ovendry weight of slabs, edgings, grade No. 3 and Economy lumber.

Table A.21. Yield of WASTE2 in ovendry pounds from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of WASTE2 (WASTE2 = -108.79 + 20.0655(SDIB), R^2 = 0.87).

SDIB (Inches)	WASTE2 (Pounds)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	11.6	6.2	17.0
7	31.7	27.3	36.0
8	51.7	48.1	55.4
9	71.8	68.1	75.5
10	91.9	87.6	96.2
11	111.9	106.6	117.3
12	132.0	125.3	138.7
13	152.1	144.0	160.1
14	172.1	162.6	181.7
15	192.2	181.2	203.2
16	212.3	199.7	224.8
17	232.3	218.2	246.4
18	252.4	236.7	268.1
19	272.5	255.2	289.7
20	292.6	273.7	311.3
21	312.6	292.2	333.0
22	332.7	310.7	354.5
23	352.7	329.1	376.3
24	372.8	347.6	397.9

Note: SDIB = Scaling diameter.
WASTE2 = Ovendry weight of slabs, edgings, grade No. 3 and Economy lumber.

Table A.22. Yield of No. 2 and Better dimension lumber in cubic feet (CTBT) from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of CTBT (CTBT = -2.32226 + 0.34206(SDIB), R^2 = 0.67).

SDIB (Inches)	CTBT (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	0.76	0.43	1.08
10	1.10	0.82	1.37
11	1.44	1.21	1.67
12	1.78	1.59	1.98
13	2.12	1.96	2.29
14	2.47	2.31	2.63
15	2.81	2.64	2.98
16	3.15	2.95	3.35
17	3.49	3.26	3.73
18	3.83	3.56	4.11
19	4.18	3.85	4.50
20	4.52	4.14	4.90
21	4.86	4.43	5.29
22	5.20	4.72	5.68
23	5.55	5.01	6.08
24	5.89	5.30	6.48

Note: SDIB = Scaling diameter.

Table A.23. Yield of No. 2 and Better dimension lumber in cubic feet (CTBT) from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of CTBT (CTBT = -2.37355 + 0.30957(SDIB), R^2 = 0.49).

SDIB (Inches)	CTBT (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	0.41	0.23	0.60
10	0.72	0.57	0.87
11	1.03	0.91	1.15
12	1.34	1.23	1.45
13	1.65	1.52	1.78
14	1.96	1.80	2.12
15	2.27	2.07	2.47
16	2.58	2.34	2.82
17	2.89	2.60	3.18
18	3.20	2.86	3.54
19	3.51	3.12	3.90
20	3.82	3.38	4.26
21	4.13	3.64	4.62
22	4.48	3.90	4.98
23	4.75	4.16	5.34
24	5.07	4.41	5.70

Note; Scaling diameter.

Table A.24. Yield of No. 2 and Better dimension lumber in cubic feet (CTBT) from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of CTBT (CTBT = 0.32620 + 0.00063(SDIB), R^2 = 0.00).

SDIB (Inches)	CTBT (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	0.33	0.25	0.41
7	0.33	0.26	0.40
8	0.33	0.28	0.39
9	0.33	0.28	0.39
10	0.33	0.26	0.40
11	0.33	0.25	0.42
12	0.33	0.23	0.44
13	0.33	0.21	0.46
14	0.34	0.18	0.49
15	0.34	0.16	0.51
16	0.34	0.14	0.54
17	0.34	0.11	0.56
18	0.34	0.09	0.59
19	0.34	0.06	0.61
20	0.34	0.04	0.64
21	0.34	0.02	0.66
22	0.34	-0.01	0.69
23	0.34	-0.03	0.71
24	0.34	0.06	0.74

Note: SDIB = Scaling diameter.

Table A.25. Yield of No. 3 dimension lumber in cubic feet (CTHRS) from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of CTHRS CTHRS = -0.81862 + 0.09764(SDIB), R^2 = 0.29).

SDIB (Inches)	CTHRS (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	0.06	-0.14	0.26
10	0.16	-0.02	0.33
11	0.26	0.11	0.40
12	0.35	0.23	0.48
13	0.45	0.34	0.56
14	0.55	0.45	0.65
15	0.65	0.54	0.75
16	0.74	0.62	0.87
17	0.84	0.69	0.99
18	0.94	0.76	1.12
19	1.04	0.83	1.24
20	1.13	0.89	1.37
21	1.23	0.96	1.50
22	1.33	1.02	1.64
23	1.43	1.09	1.77
24	1.52	1.15	1.90

Note: SDIB = Scaling diameter.

Table A.26. Yield of No. 3 dimension lumber in cubic feet (CTHRS) from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of CTHRS
(CTHRS = -0.28042 + 0.06422(SDIB)
R^2 = 0.13).

SDIB (Inches)	CTHRS (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	0.30	0.20	0.39
10	0.36	0.29	0.44
11	0.43	0.36	0.49
12	0.49	0.43	0.55
13	0.55	0.49	0.62
14	0.62	0.54	0.70
15	0.68	0.58	0.79
16	0.75	0.62	0.87
17	0.81	0.66	0.96
18	0.88	0.70	1.05
19	0.94	0.74	1.14
20	1.00	0.78	1.23
21	1.07	0.81	1.32
22	1.13	0.85	1.41
23	1.20	0.89	1.50
24	1.26	0.93	1.59

Note: SDIB = Scaling diameter.

Table A.27. Yield of No. 3 dimension lumber in cubic feet (CTHRS) from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of CTHRS (CTHRS = -0.09478 + 0.04278(SDIB), R^2- 0.12).

SDIB (Inches)	CTHRS (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	0.16	0.09	0.23
7	0.20	0.15	0.26
8	0.25	0.20	0.29
9	0.29	0.24	0.34
10	0.33	0.28	0.39
11	0.38	0.31	0.45
12	0.42	0.33	0.51
13	0.46	0.36	0.57
14	0.50	0.38	0.63
15	0.55	0.40	0.69
16	0.59	0.42	0.75
17	0.63	0.45	0.82
18	0.68	0.47	0.88
19	0.72	0.49	0.94
20	0.76	0.51	1.01
21	0.80	0.54	1.07
22	0.85	0.56	1.13
23	0.89	0.58	1.20
24	0.93	0.60	1.26

Note: SDIB = Scaling diameter,

Table A.28. Yield of economy grade dimension lumber in cubic feet (CECON) from 8 foot, Y-P log grade 1, yellow-poplar logs and 95% confidence limits for the mean yield of CECON (CECON = -0.79916 + 0.11859(SDIB), R^2 = 0.27).

SDIB (Inches)	CECON (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Cu. Ft.)
9	0.27	0.00	0.53
8	0.39	0.16	0.61
10	0.51	0.32	0.70
11	0.62	0.46	0.78
12	0.74	0.60	0.88
13	0.86	0.73	0.99
14	0.98	0.84	1.12
15	1.10	0.94	1.26
16	1.22	1.02	1.41
17	1.34	1.11	1.56
18	1.45	1.19	1.72
19	1.57	1.26	1.88
20	1.69	1.34	2.04
21	1.81	1.41	2.21
22	1.93	1.49	2.37
23	2.05	1.56	2.53
24	2.17	1.64	2.70

Note: SDIB = Scaling diameter.

Table A.29. Yield of economy grade dimension lumber in cubic feet (CECON) from 8 foot, Y-P log grade 2, yellow-poplar logs and 95% confidence limits for the mean yield of CECON (CECON = -0.71303 + 0.13179(SDIB), R^2 - 0.21).

SDIB (Inches)	CECON (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
9	0.47	0.32	0.63
10	0.60	0.48	0.73
11	0.74	0.64	0.84
12	0.87	0.78	0.96
13	1.00	0.90	1.10
14	1.13	1.00	1.26
15	1.26	1.10	1.43
16	1.40	1.20	1.60
17	1.53	1.29	1.77
18	1.66	1.38	1.94
19	1.79	1.47	2.11
20	1.92	1.56	2.28
21	2.05	1.65	2.47
22	2.19	1.74	2.63
23	2.32	1.83	2.80
24	2.45	1.92	2.98

Note: SDIB = Scaling diameter.

Table A.30. Yield of Economy grade dimension lumber in cubic feet (CECON) from 8 foot, Y-P log grade 3, yellow-poplar logs and 95% confidence limits for the mean yield of CECON
(CECON = -1.87618 + 0.29223(SDIB)
R^2 - 0.68).

SDIB (Inches)	CECON (Cu. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
6	-0.12	0.24	-0.00
7	0.17	0.07	0.27
8	0.46	0.38	0.54
9	0.75	0.67	0.84
10	1.05	0.95	1.15
11	1.34	1.21	1.46
12	1.63	1.48	1.79
13	1.92	1.73	2.11
14	2.22	1.99	2.44
15	2.51	2.25	2.77
16	2.80	2.51	3.09
17	3.09	2.76	3.42
18	3.38	3.02	3.75
19	3.68	3.27	4.08
20	3.97	3.53	4.41
21	4.26	3.78	4.74
22	4.55	4.04	5.07
23	4.85	4.30	5.39
24	5.14	4.55	5.72

Note: SDIB = Scaling diameter.

APPENDIX B

Table B.1. Yield of No. 2 and Better dimension lumber in board feet (2 + Btr.) from yellow-poplar trees and 95% confidence limits of the mean yield of TTBT
(2 + Btr.) = -41.266382 + 0.205778(ETDBH).
R^2 = 0.88).

DBH (Inches)	ETHGT (Feet)	2 + Btr. (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
10	20	-0.1	-17.2	17.0
	40	41.0	27.0	55.0
	60	82.2	70.5	93.9
	80	123.4	112.7	134.0
12	20	8.1	-8.3	24.5
	40	57.5	44.5	70.5
	60	106.9	96.0	117.8
	80	156.3	145.3	167.3
14	20	16.4	0.6	32.1
	40	74.0	61.8	86.1
	60	131.6	120.9	142.3
	80	189.2	176.9	201.5
16	20	24.6	9.4	39.7
	40	90.4	79.0	101.8
	60	156.3	145.3	167.3
	80	222.1	207.8	236.5
18	60	181.0	169.0	192.9
	80	255.1	238.2	271.9
20	60	205.7	192.4	218.9
	80	288.0	268.4	307.4
22	60	230.4	215.4	245.3
	80	320.9	298.4	343.4
24	60	255.1	238.2	271.9
	80	353.8	328.3	379.4

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

Table B.2. Yield of No. 3 dimension lumber in board feet (THREE) from yellow-poplar trees and 95% confidence limits of the mean yield of (THREE (THREE = -6.511683 + 0.062401(ETDBH), R^2 = 0.78).

DBH (Inches)	ETHGT (Feet)	THREE (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
10	20	6.0	-1.7	13.6
	40	18.4	12.2	24.7
	60	30.9	25.7	36.2
	80	43.4	38.6	48.2
12	20	8.5	1.1	15.8
	40	23.4	17.6	29.3
	60	38.4	33.5	43.3
	80	53.4	48.4	58.3
14	20	11.0	3.9	18.0
	40	24.4	23.0	33.9
	60	45.9	41.0	50.7
	80	63.4	57.8	68.9
16	20	13.5	6.6	20.3
	40	33.4	28.3	38.5
	60	53.4	48.4	58.3
	80	73.4	66.9	79.8
18	60	60.9	55.5	66.2
	80	83.3	75.8	90.9
20	60	68.4	62.4	74.3
	80	93.3	84.5	102.1
22	60	75.9	69.1	82.6
	80	103.3	93.2	113.4
24	60	83.3	75.8	90.9
	80	113.3	101.8	124.8

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

Table B.3. Yield of Economy grade dimension lumber in board feet (ECON) from yellow-poplar trees and 95% confidence limits of the mean yield of ECON
(ECON = -13.577266 + 0.113077(ETDBH), R^2 = 0.73).

DBH (Inches)	ETHGT (Feet)	ECON (Bd. Ft.)	Lower 95% CLM (Bd. Ft.)	Upper 95% CLM (Bd. Ft.)
10	20	9.0	-6.5	24.6
	40	31.7	18.9	44.4
	60	54.3	43.6	64.9
	80	76.9	67.2	86.6
12	20	13.6	-1.4	28.5
	40	40.7	28.9	55.5
	60	67.8	57.9	77.8
	80	95.0	84.9	105.0
14	20	18.1	3.7	32.4
	40	39.4	38.8	60.7
	60	81.4	71.7	91.1
	80	113.1	101.8	124.3
16	20	22.6	8.8	36.4
	40	59.8	48.4	69.1
	60	95.0	84.9	105.0
	80	131.2	118.1	144.2
18	60	108.5	97.7	119.4
	80	149.3	134.0	164.5
20	60	122.1	110.0	134.2
	80	167.3	149.6	185.1
22	60	135.7	122.1	149.3
	80	185.4	165.0	205.9
24	60	149.3	134.0	164.5
	80	203.5	180.3	226.7

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

Table B.4. Yield of SAWDUST in ovendry pounds from yellow-poplar trees and 95% confidence limits of the mean yield of SAWDUST (SAWDUST = -32.963147 + 0.441244(ETDBH), R^2 = 0.90).

DBH (Inches)	ETHGT (Feet)	SAWDUST (Pounds)	Lower 95% CLM (Pounds)	Upper 95% CLM (Pounds)
10	20	55.3	20.6	89.9
	40	143.5	115.1	171.9
	60	231.8	208.2	255.4
	80	320.0	298.8	341.3
12	20	72.9	39.6	106.3
	40	178.8	152.6	205.1
	60	284.7	262.9	306.6
	80	390.6	369.0	412.3
14	20	90.6	58.6	122.6
	40	214.1	189.7	238.5
	60	337.7	316.6	358.8
	80	461.2	437.2	485.3
16	20	108.2	77.5	139.0
	40	249.4	226.5	272.3
	60	390.6	369.0	412.3
	80	531.8	503.9	559.7
18	60	443.6	420.3	466.8
	80	602.4	569.7	635.1
20	60	496.5	470.7	522.3
	80	673.0	634.9	711.1
22	60	549.5	520.5	578.5
	80	743.6	699.7	787.5
24	60	602.4	569.7	635.1
	80	814.2	764.3	864.2

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

Table B.5. Yield of SLADG in ovendry pounds from yellow-poplar trees and 95% confidence limits of the mean yield of SLADG (SLADG = -12.503840 + 0.312919(ETDBH), R^2 - 0.80).

DBH (Inches)	ETHGT (Feet)	SLADG (Pounds)	Lower 95% CLM (Pounds)	Upper 95% CLM (Pounds)
10	20	50.1	13.1	87.1
	40	112.2	82.3	143.0
	60	175.2	150.1	200.4
	80	237.8	215.2	260.5
12	20	62.6	27.1	98.2
	40	137.7	109.7	165.7
	60	212.8	189.5	236.1
	80	287.9	264.8	311.0
14	20	75.1	40.9	109.3
	40	162.7	136.7	188.8
	60	250.3	227.8	272.9
	80	338.0	312.3	363.6
16	20	87.6	54.8	120.5
	40	187.8	163.3	212.2
	60	287.9	264.8	311.0
	80	388.0	358.2	417.9
18	20	325.4	300.6	350.3
	40	438.1	403.1	473.1
20	60	363.0	335.4	390.6
	80	488.2	447.4	529.0
22	60	400.5	369.5	431.6
	80	538.2	491.2	585.3
24	60	438.1	403.1	473.1
	80	588.3	534.8	641.8

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.
SLADG = Weight of slabings and edgings.

Table B.6. Yield of WASTE in ovendry pounds from yellow-poplar trees and 95% confidence limits of the mean yield of WASTE (WASTE = -26.220763 + 0.466951(ETDBH), R^2 = 0.82).

DBH (Inches)	ETHGT (Feet)	WASTE (Pounds)	Lower 95% CLM (Pounds)	Upper 95% CLM (Pounds)
10	20	63.2	13.5	112.8
	40	152.6	111.8	193.3
	60	241.9	208.1	275.8
	80	331.3	300.9	361.7
12	20	81.0	33.3	128.8
	40	188.3	150.7	226.0
	60	295.6	264.3	326.8
	80	402.9	371.8	433.9
14	20	98.9	53.0	144.8
	40	224.1	189.1	259.0
	60	349.2	319.0	379.5
	80	474.4	439.9	508.8
16	20	116.8	72.7	160.9
	40	259.8	227.0	292.6
	60	402.9	371.8	433.9
	80	545.9	505.8	585.9
18	60	456.5	423.1	489.9
	80	617.4	570.4	664.4
20	60	510.1	473.1	547.2
	80	688.9	634.1	743.7
22	60	563.8	522.1	605.4
	80	760.4	697.3	823.5
24	60	617.4	570.4	664.4
	80	831.9	760.1	903.7

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.
SLADG = Weight of slabings, edgings and Economy grade lumber.

Table B.7. Yield of WASTE in ovendry pounds from yellow-poplar trees and 95% confidence limits of the mean yield of WASTE (WASTE = -31.927956 + 0.520359(ETDBH), R^2 = 0.83).

CBH (Inches)	ETHGT (Feet)	WASTE (Pounds)	Lower 95% CLM (Pounds)	Upper 95% CLM (Pounds)
10	20	72.1	16.4	127.9
	40	176.2	130.5	221.9
	60	280.3	242.3	318.3
	80	384.4	350.2	418.5
12	20	93.0	39.3	146.6
	40	217.8	175.6	260.1
	60	342.7	307.6	377.8
	80	467.6	432.8	502.4
14	20	113.8	62.2	165.3
	40	259.5	220.2	298.7
	60	405.2	371.2	439.2
	80	550.9	512.2	589.6
16	20	134.6	85.1	184.1
	40	301.1	264.3	337.9
	60	467.6	432.8	502.4
	80	634.1	589.2	679.1
18	60	530.1	492.6	567.5
	80	717.4	664.6	770.1
20	60	595.5	550.9	634.1
	80	800.6	739.1	862.2
22	60	654.9	608.1	701.7
	80	883.9	813.0	954.8
24	60	717.4	664.6	770.1
	80	967.2	886.5	1047.8

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.
WASTE2 = Weight of slabings, edgings, grade No. 3 and Economy lumber.

Table B.8. Yield of No. 2 and Better dimension lumber in which feet (CTBT) from yellow-poplar trees and 95% confidence limits of the mean yield of CTBT
(CTBT = -2.256756 + 0.011253(ETDBH), R^2 = 0.88).

DBH (Inches)	ETHGT (Feet)	CTBT (Cu. Ft.)	Lower 95% CLM (Cu. Ft.)	Upper 95% CLM (Cu. Ft.)
10	20	0.0	-0.9	0.9
	40	2.2	1.5	3.0
	60	4.5	3.9	5.1
	80	6.7	6.2	7.3
12	20	0.4	-0.5	1.3
	40	3.1	2.4	3.9
	60	5.8	5.2	6.2
	80	8.5	7.9	9.1
14	20	0.9	0.0	1.8
	40	4.0	3.4	4.7
	60	7.2	6.6	7.8
	80	10.3	9.7	11.0
16	20	1.3	0.5	2.2
	40	4.9	4.3	5.6
	60	8.5	7.9	9.1
	80	12.1	11.4	12.9
18	60	9.9	9.2	10.5
	80	13.9	13.0	14.9
20	60	11.2	10.5	12.0
	80	15.7	14.7	16.8
22	60	12.6	11.8	13.4
	80	17.5	16.3	18.8
24	60	13.9	13.0	14.9
	80	19.3	18.0	20.7

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

Table B.9. Yield of No. 3 dimension lumber in cubic feet (CTHRS) from yellow-poplar trees and 95% confidence limits of the mean yield of CTHRS (CTHRS = -0.356108 + 0.003413(ETHGT), R^2 - 0.78).

DBH (Inches)	ETHGT (Feet)	CTHRS (Cu. Ft.)	Lower 95% CLM (Cu. Ft.)	Upper 95% CLM (Cu. Ft.)
10	20	0.3	-0.1	0.7
	40	1.0	0.7	1.4
	60	1.7	1.4	2.0
	80	2.4	2.1	2.6
12	20	0.5	0.1	0.9
	40	1.3	1.0	1.6
	60	2.1	1.8	2.4
	80	2.9	2.6	3.2
14	20	0.6	0.2	1.0
	40	1.6	1.3	1.9
	60	2.5	2.2	2.8
	80	3.5	3.2	3.8
16	20	0.7	0.4	1.1
	40	1.8	1.5	2.1
	60	2.9	2.6	3.2
	80	4.0	3.7	4.4
18	60	3.3	3.0	3.6
	80	4.6	4.1	5.0
20	60	3.7	3.4	4.1
	80	5.1	4.6	5.6
22	60	4.1	3.8	4.5
	80	5.6	5.1	6.2
24	60	4.6	4.1	5.0
	80	6.2	5.6	6.8

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

Table B.10. Yield of Economy grade dimension lumber in cubic feet (CECON) from yellow-poplar trees and 95% confidence limits of the mean yield of CECON (CECON = 0.742507 + 0.006184(ETDBH), R^2 = 0.73).

DBH (Inches)	ETHGT (Feet)	CECON (Cu. Ft.)	Lower 95% CLM (Cu. Ft.)	Upper 95% CLM (Cu. Ft.)
10	20	0.5	-0.4	1.3
	40	1.7	1.0	2.4
	60	3.0	2.4	3.5
	80	4.2	3.7	4.7
12	20	0.7	-0.1	1.6
	40	2.2	1.6	2.9
	60	3.7	3.2	4.3
	80	5.2	4.6	5.7
14	20	1.0	0.2	1.8
	40	2.7	2.1	3.3
	60	4.5	3.9	5.0
	80	6.2	5.6	6.8
16	20	1.2	0.5	2.0
	40	3.2	2.6	3.8
	60	5.2	4.6	5.7
	80	7.2	6.5	7.9
18	60	5.9	5.3	6.5
	80	8.2	7.3	9.0
20	60	6.7	6.0	7.3
	80	9.2	8.2	10.1
22	60	7.4	6.7	8.2
	80	10.1	9.0	11.3
24	60	8.2	7.3	9.0
	80	11.1	9.9	12.4

Note: ETDBH = ETHGT * DBH
ETHGT = Height (in feet) to an eight inch top.

APPENDIX C

APPENDIX C

A study of 97 structural light framing grade number three and 248 economy grade 2 x 4's was conducted in order to 1) identify the limiting defects and their frequency of occurrence and 2) obtain an estimate of the board footage that can be upgraded by additional processing.

Tables 1 and 2 list the frequency of occurrence of the limiting defects for 2 x 4's graded structural light framing grade number three and economy grade respectively.

Wane occurred most frequently of the limiting defects, 23.7 percent for structural light framing grade number three and 69.4 percent for economy grade. Wane, the lack of wood in a board's specified dimensions, may occur more frequently in smaller logs because of a high surface to volume relationship versus larger diameter logs. Pieces containing wane may be upgraded by planning and triming or may be prevented by ripping boards other than nominal four inches in width from a flitch.

Grain deviation was the second most frequently occurring limiting defect, 19.6 percent of the structural light framing grade number three and 12.1 percent of the economy grade. Logs containing sweep, crook and defects such as knots may be indicative of grain deviation.

The second part of the study was to determine what board feet percentage of the structural light framing grade number three and economy grade can be upgraded by planning and triming, Tables 3 and 4, respectively. The percentages of upgradable lumber (Tables 3 and 4) may be used to upgrade dimension lumber yield estimates found in Appendix A to account for further processing. An example is given in Table 5.

Table C.1. Limiting defect of 2 x 4's, structural light framing grade No. 3.

Limiting Defect	Pieces	Percent
Grain Deviation	19	19.6
Knot	15	15.5
Wane	23	23.7
Decay	18	18.6
Shake	6	6.2
Split	16	16.4
	97	100.0%

Table C.2. Limiting defect of 2 x 4's, Economy grade.

Limiting Defect	Pieces	Percent
Wane	172	69.4
Knot	24	9.7
Crook	2	.8
Decay	1	.4
Split	14	5.6
Grain Deviation	30	12.1
Shake	3	1.2
Broken	2	8
	248	100.0%

Table C.3. Correction factors for upgrading yield estimates of structural light framing grade No. 3 to structural light framing grade No. 2 and Better by further processing.

New Grade	Length of Piece	(1) Number of Pieces	(2) Piece Volume (Board Feet)	(1 x 2) Volume (Board Feet)	Total (Percent)	Total Upgraded (Percent)
No. 3 (No change in grade)	8 ft.	55	5.333	293.315	60.7	0
	< 8 ft.			20.544		
No. 2 & Better	6 ft.	2	4.000	8.000	1.5	39.3
	7 ft.	24	4.666	111.984	21.7	
	92-5/8 in.	10	5.146	51.460	9.9	
	8 ft.	6	5.333	31.998	6.2	
		97		517.301	100.00	

Table C.4. Correction factors for upgrading yield estimates of Economy grade to structural light framing grade No. 3 and to grade No. 2 and Better by further processing of the lumber.

New Grade	Length of Piece	(1) Number of Pieces	(2) Piece Volume (Board Feet)	(1 x 2) Volume (Board Feet)	Total (Percent)	Total Upgraded (Percent)
Economy (No change in grade)	8 ft.	119	5.333	1061.267	64.8	0
	< 8 ft.			70.646		
No. 3	6 ft.	1	4.000	4.000	0.2	10.2
	7 ft.	25	4.666	116.65	6.7	
	92-5/8 in.	3	5.146	15.438	0.9	
	8 ft.	8	5.333	42.664	2.4	
No. 2	6 ft.	5	4.000	20.000	1.1	25.0
	7 ft.	65	4.666	303.29	17.4	
	92-5/8 in.	13	5.146	66.898	3.8	
	8 ft.	9	5.333	47.997	2.7	
		248		1748.850	100.00	

Table C.5. Method of upgrading dimension lumber yields presented in Appendix A to account for further processing (i.e., planning and triming).

PROCEDURE: Estimate the dimension lumber yield from a 24-inch in SDIB, 8 foot long, Y-P grade No. 1 log using Appendix A.

Operation	No. 2 and Better	No. 3	Economy
Estimate lumber yield from Appendix A	107.6 bd. ft.	27.9 bd. ft.	37.4 bd. ft.
Upgrade grade three	27.9 * .393 = 11.0	27.9 x .607 = 16.9	
Upgrade economy grade	37.4 * .250 = 9.4	37.4 * .102 = 3.8	37.4 * .648 = 24.2
Sum upgraded yields	128.0 bd. ft.	20.7 bd. ft.	24.2 bd. ft.

Note: SDIB = Scaling diameter.

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DEVELOPMENT OF DIMENSION LUMBER GRADE AND YIELD
ESTIMATES FOR YELLOW-POPLAR SAWLOGS AND TREES

by

Joseph Denig

(ABSTRACT)

The projected increased demands for forest products and the dwindling softwood supplies are expected to lead to increased pressure on the hardwood raw material base.

The Eastern United States' hardwood region offers a great potential for supplying the nation's growing demand for wood based products. The problem in realizing this potential is that eastern hardwoods in general, and yellow-poplar (*Liriodendron tulipifera* L.) in particular, are underutilized.

At present, dimension lumber used in light frame construction is almost exclusively manufactured from softwood species. Recent literature, research, and conferences have pointed to the possibility and feasibility of using yellow-poplar dimension lumber. It is an accepted species for light framing in the grading rules of the Northern Hardwood and Pine Manufacturers Association. Yet, if utilization of yellow-poplar as a dimension lumber species is to be realized, lumber yields and residue volumes for various grade and size classes of yellow-poplar trees must be available in order to allow land managers to assess the value of standing yellow-poplar timber, develop sound

management objectives for the species, and encourage its wide use. Similar yield and residue information for yellow-poplar sawlogs is also needed to allow sawmill operators to evaluate the economic feasibility of producing dimension lumber from yellow-poplar logs.

Yellow-poplar log grades were established to stratify yellow-poplar logs into salable dimension lumber classes when the lumber was manufactured by the Saw-Dry-Rip manufacturing system. These log grades are based on the southern pine log grades with log defect exclusion limits. Dimension lumber and residue yields for the yellow-poplar dimension lumber log grades are presented.

The use of various grading schemes for stratifying yellow-poplar trees into salable dimension lumber classes was evaluated. It was found that estimates of salable dimension lumber yield from pooled data yielded better results than estimates using tree grades for stratification. Estimates for the dimension lumber yield are listed.

Producing dimension lumber from yellow-poplar logs of various diameters and quality classes was evaluted in light of producing alternate products using net revenue graphs. The net revenue graphs suggested that a sawmill should utilize the lower diameter and lower quality logs for dimension lumber production.