Decline in Values of Slash Pine Stands Infected with Fusiform Rust

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ABSTRACT: *Losses in product values due to fusiform rust, caused by* Cronartium quercuum *(Berk.) Miyabe ex Shirai f. sp.* fusiforme, *were estimated from four, 25-yr-old slash pine,* Pinus elliotii *Engelm., plantations planted in southern Mississippi over a range of sites with different growth potential and expected rust infection levels. The percentage infected stems ranged from 2.5% to 62% at age 2.5. The conversion-return method (Davis 1966) was used to take into account logging, transportation, and milling costs. Estimated stand values between infected and noninfected stands were compared to determine the losses in product value due to fusiform rust. Decline in estimated stand stumpage values ranged from 5.6% to 15.5% at age 25. Stand stumpage values at age 25 declined 0.26% per 1% increase in stem rust infection at both ages 5 and 2.5. The strong linear relationship between the percentage of stems infected at age 5 and decline in stand stumpage values provides a useful tool for land managers who need to estimate the reduction in value of slash pine stands at harvest based on rust infection at age 5. Combining this information with estimates of losses from rust-associated mortality and reduced growth of infected stems (from other studies) permits land managers to estimate the value of slash pine stands at harvest at early ages and decide among management alternatives.*
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Key Words: Conversion-return, valuation, stand values.

Fusiform rust, caused by infections from *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *Fusiforme* is an important pest of both loblolly pine (*Pinus taeda* L.) and slash pine *(P. elliotii* Engelm. var. *elliottii).* Fusiform rust causes mortality in both species but is generally more severe on slash pine. Although there is generally no significant growth reduction in infected loblolly pines (Klatwitter 1957, Lloyd 1982, Geron and Hafley 1988), rust-infected slash pines that survive grow more slowly than noninfected trees (Froelich et al. 1983, Belanger et al. 2000). Infected trees of both species that survive have lower value than noninfected trees, primarily because of the reduced volume and/or value of solid wood products manufactured from them. In loblolly pine, the reduction in value is a function of site quality, the rust infection history for the stand, rust-associated mortality, the management system, and the desired products (Bridgwater and Smith 1997). Several authors have established that reductions in stand volumes are directly related to fusiform rust related mortality (Sluder 1977, Schmidt and Klapproth 1982, Lowe and van Buijtenen 1991, and Belanger et al. 2000). Losses in slash pine stand values due to fusiform rust have been modeled as a function of the number of trees established at age 5, the percentage with fusiform rust-infected stems at age 5, and the site index (Busby and Haines 1988). However, this analysis was based on expected yields from a growth and yield model and did not take into account loss in product value from rust-infected stems. More recently, the impact of fusiform rust was modeled for both loblolly and slash pines (Pye et al. 1997). This effort did take into account loss in product value from merchandising rust-infected stems, but information on numbers and positions of galls was not based on empirical data. This article reports estimated losses in product values on surviving stems due to fusiform rust from four, 25-yr-old slash pine plantations in southern Mississippi that were planted over a range of sites with different expected rust infection levels.

Materials and Methods

This study was based on four plantations located in Jackson County, Mississippi within 3 1 miles of the Gulf of

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Mexico. These plantations were four of nine planted in 1974 that survived through the 1998 growing season (25 growing seasons). The nine plantations were chosen to represent a wide range of site hazard potentials for fusiform rust. The four surviving plantations were determined to represent high hazard (plantation 2), intermediate hazard (plantation 1) and low hazard (plantations 3 and 4), based on cumulative infections at age 5 (Froelich and Snow 1986). Plantings were randomized complete block experimental designs with 6 ft within rows x 10 ft between rows (I .8 m x 3.0 m) established in January of 1974. Each plantation had 25 rows of 30 trees each. Each set of 3 interior rows, e.g., 3 to 5, was a complete block with trees from one of three seed sources planted in each row. Rows 3 through 23 represented 7 blocks in each planting. Rows 1, 2, 24, and 25 and trees 1, 2, 29, and 30 were considered border rows and were not included in analyses of growth data, but were used in determining survival and percentages of fusiform rust infection. Two seed sources were from two different seed production areas, the third from an open pollinated seed orchard. Total tree heights were measured at ages l-6, 11, and 25. Diameters at breast height (dbh) were measured at odd-numbered ages from 5 through 17 and at 2.5. Detailed observations were made on fusiform rust annually from ages I-1 6 and at age 25. These included location of each gall above ground and distance from the main stem, years after planting when: (1) galls were first observed, (2) branch galls spread into the main stem, (3) more than 50% of the main stem was girdled (4) rust- and nonrust-related mortality occurred.

Analyses of variance for the age 25 growth variables and the percentage of trees with stem galls were performed using a model that included plantations, blocks, seed sources, and the interactions among them as classes of variation. Sources were considered fixed effects while all other class variables were considered random. The plantation x source interaction was used as the error term to test for differences among plantations and seed sources.

Heights and dbh's of the ten tallest trees with and without rust in each plantation were compared using a reduced model for a nested design with plantations and trees in plantations as sources of variation.

Merchandiser

A computer algorithm was developed to merchandise trees into logs of variable lengths from 8 ft to 20 ft by 2 ft increments beginning at a stump height of 0.3 ft. We used the taper function to estimate inside bark diameters at each end of a log and the volume equation for slash pine to estimate log volumes provided in Thomas and Parresol (199 1). The merchandiser checked each 2 ft segment beginning at the stump height for the presence of a gall. If any portion of a gall occurred within a 2 ft segment, that segment was assigned to rust volume. If there were one or more 8 ft to 20 ft logs between 0.3 ft and the base of the first cankered segment, or between cankered segments, the merchandiser assigned those logs to pulpwood, chip-n-saw, or log volume, depending on the estimated small-end diameter of the log (pulpwood > 4 in., 4 in. > c-n-s < 6 in., sawlogs > 6 in.).

Valuation

Value of logs was the primary consideration in valuation of stands because it incorporates volume and quality into one metric. Estimating value takes into account the position of cankers within a stem, which can be a major component of stem value. For example, a 2 ft segment merchandised from a butt log would reduce stem and stand value more than a segment of the same volume from a second or third log.

The value of lumber in logs was determined as follows. The free-on-board (f.o.b.) price of lumber was determined from a sample of 47 logs from an earlier study (Bridgwater 1984) that came from trees that fell within the range of sizes in the present study. The value of each board was taken from Random Lengths© 1999 annual averages (Random Lengths© Publications, Inc. P.O. Box 876, Eugene, OR 97440-0867). Lumber from the original study was not graded, therefore the grade proportions for number 1, 2, and 3 lumber from butt, second, and top logs determined by Biblis (1990) in a study of slash pine at age 27 were used. The value of lumber in each log was calculated for butt, second, and top log proportions and regression equations were developed for each log type :

$$\text{Butt Log Value} = 0.023544 \times LEN \times SEDIB^2 \quad (1)$$

$$\text{Second Log Value} = 0.02\,1\,178 \times LEN \times SEDIB^2 \quad (2)$$

$$\text{Top Log Value} = 0.020558 \times LEN \times SEDIB' \quad (3)$$

where *LEN* = log length (ft) and *SEDIB* = diameter inside bark at the small end of the log (in.). R^2 values are not meaningful for models with no intercept, but the standard errors for the slopes were 2% or less of the estimate for all three equations. These equations were then used to estimate the value of logs in the current study.

Logging and manufacturing costs were estimated as in Bridgwater and Smith (1997) from equations adapted from Deal (1986).

$$\text{Logging Costs} = e^{(-2.3801+5.37/DBH^{-0.7838})+0.15\times MERCHVOL} \times I$$

where DBH = diameter at breast height of the tree-length-log, *MERCHVOL* = the merchantable volume of the log (ft^3) to a 4 in. top, and I= cost adjustment for the change in the average annual Consumer Price Index for lumber from 1986 (110.5) to 1999 (187.9) (USDL Bureau of Labor Statistics 1999).

$$\text{Manufacturing Costs} = \left(\frac{6.31 - 116.53\times SEDIB^{-2} + 2.13\times LN}{100}\right) + M_{86}\times I$$

where *LEN* and *SEDIB* and I are as before, and M_{86} = the estimated manufacturing costs ($) in 1986, which includes risk and profit.

The value of each log was then calculated from:

$$\text{Delivered Pulpwood Value (\$)} = \frac{CVOL}{76} \times \$61.38$$

Table 1. Cumulative mortality for four slash pine plantations with different rust hazards and surviving trees at age 25.

Plantation	No. of trees alive at age 1	Cumulative mortality* associated with: Rust	Other	No. of trees alive at age 25	Trees/ac at age 25
		(%)			
1	435	24	19	250	242
2	245	26	19	132	128
3	401	11	17	289	280
4	331	9	18	239	231

* Mortality and tree counts included border row trees. Values are based on the percentage of trees alive after 1 yr in the field

where *CVOL* = the volume (ft^3) of each log, 76 = the average volume (ft^3) in a cord of pulpwood, and $61.38 = the value of a cord of pulpwood delivered at the mill (Harris 1999). The sawlog and pulpwood values were compared for each log and the greater of the two was assigned to the log. This is consistent with the assumption that integrated producers will use a log for its highest value product. This objective is not likely to be achieved in actual practice, but is the goal of any manufacturer. In general, butt and second logs with small end diameters greater than seven inches were more valuable as sawlogs while only butt logs with small end diameters of 6 in. and at least 16 ft in length were worth more as sawlogs.

Volumes for bark and sawdust were estimated as a percentage of total log volume (Clark and McAlister 1998). Bark and sawdust volumes of 8% and 11%, respectively, were approximately correct for trees of the dimensions in the present study (Clark and Taras 1975). The volume of chips from residuals was estimated to be 81% of residual volume from logs. Residual volume was estimated for the sample of 47 logs described earlier by subtracting the volume of lumber produced from each log from the total log volume and a prediction equation was developed for use in the present study:

$$\textit{Residual Volume}\ (ft^3) = 0.002228\ LEN\ SEDIB^2$$

The standard error of the estimated slope was 3% of the estimate.

The value of bark, sawdust, and chips from residual volume were all estimated by assuming 67 lb/ft^3 and $15/ton for both bark and sawdust and $28/ton for chips (Clark and McAlister 1998).

Estimating Losses in Value Due To Merchandising Rust Infected Stems

Decline in stand value from merchandising rust infected values was estimated by simply comparing values of logs from the same trees merchandised as if they had no rust and again by removing galled sections.

Results

Differences among seed sources were not significant, nor was the interaction between plantations and blocks, therefore all further analyses were done using a reduced model: Y = P + B + e where: P = plantations, B = blocks within plantations, and e = error.

Initially, 750 trees were planted at each planting site, but mortality was quite high during the first planting year at all four locations (Table 1). Survival after 1 yr in the field was 58%, 33%, 53%, and 44% for the four plantations, respectively. Plantation 2 was classified as a high rust hazard site, Plantation 1, intermediate, and Plantations 3 and 4, low hazard (Froelich and Snow 1986). Mortality from fusiform rust after age 1 for Plantations 1 and 2 was more than double that for Plantations 3 and 4 (Table 1). Rust mortality combined with mortality from other causes (essentially the same for all four plantations) resulted in 136 to 298 trees per acre remaining at age 25 (Table 1).

Site hazard assignments were accurately reflected in the percentages of trees that survived to age 25 with stem galls. Plantation 2 had significantly greater percentages of trees with at least one stem gall (62%) than the other three plantations. Plantation 1 had a significantly greater percentage of galled trees (40%) than plantations 3 and 4 (28% and 25%, respectively), which were not significantly different from one another (Table 2).

The potential for growth varied significantly among the four sites (Table 2). Plantations 1 and 4 had higher site indexes at base age 25 (71.7 and 77.9, respectively) than the other two sites. These potentials were reflected in the average values for heights of all trees. Mean dbh of the surviving trees was greater at Plantation 2 which had a lower site index than Plantations 1 and 4 because there were many fewer surviving trees (Table 1), thus more growing space for survivors. Mean heights of the 10 tallest trees was significantly greater for nongalled trees than for galled trees at Plantations 1, 3, and 4

Table 2. Stand parameters for four slash pine plantations measured at age 25.

Plantation	Trees with stem galls*	Dbh (in.)	Height	10 tallest trees: Height, No stem galls	Height, With stem galls	Dbh, No stem galls	Dbh, With stem galls
	%		(ft)			(in.)	
1	40 b†	8.3 b	59.8 ab	71.7* ††	69.4	10.0	10.0
2	62 a	9.2 a	58.8 b	67.2	67.2	11.1*	10.2
3	28 c	7.2 c	53.8 c	65.5*	61.6	9.4	8.7
4	25 c	8.3 b	60.9 a	77.9*	70.0	11.0*	9.6

* Border trees were included in the calculations for percentages of trees with stem galls.
† Values followed by the same letters indicate plantations that were not significantly different at $P < 0.05$.
†† Values followed by * indicate that values were different for galled and nongalled trees at $P < 0.05$.

Table 3. Merchantable yields (per acre) from four slash pine plantations with and without rust .*

Plantation	No. of merchantable stems: No stem galls	No. of merchantable stems: Stem galls	Sawlog volume Mbf (scribner): No stem galls	Sawlog volume Mbf (scribner): Stem galls	Sawlog volume (ft³): No stem galls	Sawlog volume (ft³): Stem galls	Galled volume	Pulpwood volume: No stem galls	Pulpwood volume: Stem galls
							........................(ft³)........................		
1	149	142	5.4	4.3	1,434	1,137	73	1,004	1,020
2	89	70	3.5	2.3	966	652	60	425	504
3	98	88	2.4	2.0	661	550	43	1,003	949
4	118	116	5.4	4.7	1,453	1,278	38	799	771

* Yields with and without rust were estimated by comparing the same trees merchandised ignoring rust galls and again by merchandising out infected portions of the stems.

and mean dbh for the 10 tallest trees was significantly greater for Plantations 2 and 4.

Gross yields varied widely among the four plantations (Table 3). The impact of rust, both from rust-induced mortality and losses from merchandising out rust galls, are confounded with differences in site index and numbers of merchantable stems at age 25. For example the number of merchantable stems was highest at Plantation 1, which had the second highest incidence of galled stems. This occurred largely because survival at age 1 was greater for Plantation 1 than for the other three (Table 1). Plantation 4 had the second greatest number of merchantable stems even though the number of surviving trees at age 1 was intermediate. This occurred, in part, because Plantation 4 had the greatest growth potential (Table 2). However, the impact of fusiform rust galls on sawlog volume is clear (Table 3) and follows the same trend as the percentage of trees with stem galls at harvest (Table 2). Sawlog volume was reduced by 15%, 27%, 17%, and 12% for stands 1-4, respectively.

The reduction in sawlog volume occurred as a result of fewer logs being produced as the average log dimensions showed only minor and statistically non-significant differences among plantations (Table 4).

Higher frequencies of galled stems also resulted in a reduction in log grade. Since most galls occurred lower on stems, the frequency of butt logs was reduced in stands with more rust (Table 5). Second and third logs had lower value (Equations 1-3 above). The reduction in stand value was dramatic with increasing percentages of galled stems. For the plantation with the greatest frequency of stem galls (Plantation 2), the number of butt logs was nearly halved (Table 5).

Total estimated stumpage values were substantially reduced by the presence of galled stems in all four plantations (Table 6). The percentage reduction was strongly linearly related to increasing proportions of galled stems. The slopes of regressions through the origin were 0.26 for the percentage of galled stems both at age 5 and age 25. Both values were significantly greater than zero at a probability less than 0.00 1 even with so few degrees of freedom. Thus, stand value declined 0.26% for each 1% increase in the percentage of stems infected at age 5 or 25. Reductions in stand values were strongly dependent on the proportion of galled stems because the reduced values reflect only the losses due to merchandising rust galls out of infected stems. These reductions do not reflect losses due to differences in rust-associated mortality or growth losses on infected stems. Reductions in stand

Table 4. Average log parameters for four slash pine plantations with and without rust.*

Plantation	No. of logs: No rust	No. of logs: Rust	Sawlog volume (bd ft): No rust	Sawlog volume (bd ft): Rust	Sawlog volume (ft³): No rust	Sawlog volume (ft³): Rust	Small end diameter: No rust	Small end diameter: Rust	Log length: No rust	Log length: Rust
1	170	148	23.7	23.5	6.3	6.2	6.2	6.2	16.7	16.8
2	108	81	24.4	23.4	6.7	6.5	6.3	6.3	16.5†	15.9
3	91	82	19.7	19.6	5.4	5.4	6.1	6.1	15.2	15.2
4	154	149	26.5	25.6	7.1	6.9	6.4	6.4	17.0	16.7
Overall			23.6	23.0	6.4	6.3	6.2	6.2	16.4	16.2

* Yields with and without rust were estimated by comparing the same trees merchandised ignoring rust galls end again by merchandising out infected portions of the stems.

† Means for No Rust and Rust statistically different at $P < 0.05$. No other means were different at $P < 0.05$.

Table 5. Number and frequencies (in parentheses) of slash pine logs by plantation and log position for logs with and without rust .*

Plantation	Log position† 1: No rust (frequency)	1: Rust (frequency)	2: No rust (frequency)	2: Rust (frequency)	3: No rust (frequency)	3: Rust (frequency)
1	121 (71.2)	92 (62.2)	49 (28.8)	55 (37.2)	0 (0.0)	1 (0.7)
2	72 (66.7)	37 (45.7)	36 (33.3)	43 (53.1)	0 (0.0)	1 (1.2)
3	79 (86.8)	67 (81.7)	12 (13.2)	15 (18.3)	0 (0.0)	0 (0.0)
4	96 (62.3)	86 (57.7)	54 (35.1)	57 (38.3)	4 (2.6)	6 (4.0)

* Yields with and without rust were estimated by comparing the same trees merchandised ignoring rust galls and again by merchandising out infected portions of the stems.

† Log Position 1 butt log, 2 second log, 3 third log.

Table 6. Total estimated stand values for four slash pine plantations with different percentage galled stems with and without rust.*

Plantation	Stand value (per ac)		Reduction	Galled stems	
	No rust	With rust		Age 5	Age 25
	($)		(%)		
1	2,494	2,258	9.5	37	40
2	1,487	1,257	15.5	65	62
3	1,625	1,502	7.6	21	28
4	2,423	2,286	5.6	17	25

* Yields with and without rust were estimated by comparing the same trees merchandised ignoring rust galls and again by merchandising out infected portions of the stems.

values from rust-associated mortality and growth losses can be substantial. Fusiform rust accounted for 55% of volume losses in 15-yr-old progeny test plantings of slash pine in Georgia (Sluder 1977). The percentages of stem infections at age 5 were used to predict volume losses at age 15 (Schmidt and Klapproth 1982). Lowe and van Buijtenen (199 1) found that for tests with 30% or more rust infection at age 5, the percentage of rust infection was a better predictor of stand volume at age 15 than volume at age 5. A long-term study of ten slash pine plantations in the Coastal Plain of Georgia and South Carolina revealed that rust-associated mortality accounted for 78% of the total volume losses (Belanger et al. 2000). Reductions in stand values in 20-yr-old slash pine stands due to rust-associated mortality and growth losses have been modeled (Busby and Haines 1988). These predicted values were functions of site index, the numbers of trees planted, the percentage of infected stems and harvest age. However, these predictions did not take into account degrade from processing infected stems. Our results are simple to use in conjunction with this or other models to estimate the losses due to product degrade since these losses are strongly dependent on the percentage of infected stems at age 5.

Our general result that stand value declined 0.26% for each 1% increase in the percentage of stems infected at age 5 or 25 should be robust for most markets throughout the south as long as the relative values between solidwood and pulpwood and residual products does not change dramatically. The solidwood/pulpwood value ratio from our valuation was 4.5: I, the median value across the south in 1999. Solidwood/pulpwood ratios have historically varied (1989 to 1999) from 3: 1 to 5: 1 across the south except for one quarter, when the ratio was less than 3: 1. Since our analysis was done using a ratio near the historical maximum, we repeated our analysis adjusting the solidwood/pulpwood ratio to 3:1 and found that the slope of the relationship between the percentage reduction in stand value at age 25 and the percentage of galled stems at age 5 or age 25 fell only to 0.23. Thus we are confident that our results are robust over the historical range of value ratios for solidwood and pulpwood. Our valuation was based on the assumption that decisions will be made by a knowledgeable land manager whose goal is to maximize economic return. We recognize that there are periods when mill operators sacrifice maximum return for the sake of short-term mill supply requirements. Should land managers choose to repeat our procedure with different lumber price structures they would be required only to derive new equations to estimate log values as in Equations (1)-(3). All other information necessary to make new estimates (i.e., Tables 1–5) is provided.

Conclusions

Estimated loss in product value from 25-yr-old slash pine plantations is strongly related to the percentage of infected stems at age 5 and 25. Stand values at age 25 declined 0.26% per 1% increase in rust-infected stems both at age 5 and 25. In conjunction with losses expected from rust-associated mortality and reduced growth of infected stems (from other models), the strong linear relationship between reduced stand value and the percentage of infected stems at age 5 permits land managers to decide whether to carry stands to final harvest or replant with rust-resistant planting stock.

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