SILVICULTURAL TREATMENT EFFECTS ON HARDWOOD TREE QUALITY ON THE VINTON FURNACE EXPERIMENTAL FOREST

John Brown, Janice K. Wiedenbeck, Rado Gazo, and Daniel A. Yaussy[†]

ABSTRACT.—This study examined the effects that silvicultural treatments have on the tree grade distribution of a mixed hardwood stand located on the Vinton Furnace Experimental Forest. Four stand treatments were established: a commercial clearcut, a commercial clearcut with timber stand improvement (TSI), a selection cut, and a selection cut with TSI. Trees were found to be of better quality in the selection cuts, where the odds of a tree being classified into the same reference grade or higher grade vs. lower than the reference grade were found to be 1.5 to 12.3 times the odds of a tree in the commercial clearcut being classified into the same reference grade or higher grade vs. lower than the reference grade. As a group, stands where TSI was applied had different odds for better quality trees than did stands without application of TSI. Within the commercial clearcut treatments, TSI had a significant positive effect on tree grade odds, but TSI did not prove beneficial within the selection cuts. Past potential tree grade measurements were also examined to determine their effectiveness in predicting future grade. It was found that between one-half to two-thirds of the trees in this study had the same potential tree grade in 2000 as they did in 1989.

In addition to quantitative tree measures such as DBH and height, managers of hardwood timber have the additional concern of determining the impact of silvicultural treatment upon tree grade. Much value can be lost if the system has detrimental effects on tree grade distribution, as lower quality trees will have lesser amounts of usable volume and/or poorer quality lumber extracted per unit tree. Understanding how specific treatments affect tree grade distribution can help to at least maintain or even improve quality in treated stands.

Erickson et al. (1990) found that a light improvement cut showed the greatest gains in grade 1 and 2 trees in a Michigan northern hardwood stand as compared to several diameter limit and selection system treatments. In a 40-year study of a Wisconsin northern hardwood stand, Strong et al. (1995) found that a medium intensity selection cut had the greatest improvements in tree grade versus light and heavy selection cuts, control, crop tree, and diameter limit treatments.

The first objective of this study is to examine any possible differences in potential tree grade (PTG) distribution between four silvicultural treatments: commercial clearcut, commercial clearcut with TSI, selection cut, and selection cut with TSI. Within this broad objective, there are several specific comparisons of interest. These PTG contrasts are: selection cut stands vs. clearcut stands; TSI stands vs. non-TSI stands; within commercial clearcuts, TSI vs. non-TSI; and within selection cuts, TSI vs. non-TSI. A second objective of this study is to examine how well past PTG measurements predicted current PTG measurements.

Study Site

The four plots included in this study are located on the Vinton Furnace Experimental Forest, near McArthur, Ohio with approximate coordinates of 39° 11.4' N. lat., 82° 24' W. long. Plot elevations range between 800 and 900 ft. Soils are Germano-Gilpin complex on southerly aspects and Steinsburg-Gilpin complex on northerly aspects. The pre-treatment stand was established in 1864 after clearcutting of timber for use as fuel for iron smelting. From this stand, six adjacent rectangular five-acre plots were assigned

[†]Mathematical Statistician (JPB) and Research Scientist (JKW), USDA Forest Service, Forestry Sciences Laboratory, 241 Mercer Springs Rd., Princeton, WV, 24740; Associate Professor, Purdue University, Dept. of Forestry and Natural Resources, 1200 Forest Products Building, West Lafayette, IN 47907-1200; and Project Leader (DAY), USDA Forest Service, Forestry Sciences Laboratory, 359 Main Rd., Delaware, OH 43015. JPB is corresponding author: to contact, call (304) 431-2741 or email at jpbrown@fs.fed.us

treatments as part of a study of management intensity on upland forests, with each plot having a 66-ft buffer zone surrounding it on all sides. Two plots were later removed from that study. The four remaining plots consisted of the following treatments:

- Commercial Clearcut – All trees containing at least one eight-ft log with a 10-in diameter inside bark (dib) top were harvested.
- Commercial Clearcut with TSI – Same treatment as Commercial Clearcut with all remaining trees of undesirable form or species being girdled, poisoned, or cut for pulpwood.
- Selection Cut – Mature, over-mature, diseased or damaged trees with at least one eight foot log (10 inches dib top) were harvested such that basal area was not reduced below 50 square feet per acre.
- Selection Cut with TSI – Same treatment as Selection Cut with all remaining trees that were diseased, non-commercial species, attacked by insects, or considered cull were girdled, poisoned, or cut for pulpwood. Additionally, crop trees were released from grapevines.

Treatments were installed between 1955 and 1957. Both Selection Cuts were treated in 1961, 1971-72, and 1985.

Material and Methods

Field Measurements

In 2000, four half-acre subplots were selected from each plot for ease of measurement. For each tree the following measurements were taken: dbh, actual tree grade (Hanks 1976), potential tree grade (Hanks 1976 without diameter restrictions), height to 4 in. and 8 in. top diameters, total height, sweep, and crook. Previously in 1989, these same measures were taken on the same trees. A total of 401 trees were included in the analysis.

Statistical Methods

A cumulative logistic regression model (CLR) was utilized to test for differences in treatment effects, due to the ordinal structure of PTG. The CLR model is a subset of the generalized logistic regression (GLR) model. Several forestry studies have utilized GLR models. For example, they have been used to estimate tree grade distribution for Northeast forests (Yaussy 1993), to predict veneer bolt grade for loblolly pine (Lynch and Clutter 1999), and to examine the relationship of dbh and bark nitrogen to beech bark disease severity (Latty et al. 2003).

For ordinal response variables with more than 2 levels, a dichotomy is introduced such that probabilities are modeled for only two classes: a same or increasing value class and a decreasing value class. A cumulative logistic regression model is of the form:

$$g(p_j)=f_j$$

where:

J=number of classes (ordinal)

$i=1 \ldots J = 4$ (1)

$j=1 \ldots J-1$ (2)

$p_j = \Pr(Y \leq i|x)$ *alternatively* $\sum_{i=1}^{j} p_i^*$ (3)

p_i^*=probability of being classified into the i^{th} category

β_k=regression coefficients (k=0 to n, with n=number of independent variables)

f_j =an additive function of the independent variables that is linear in its parameters,

i.e. $f_1=\beta_{10} + \beta_1 X_1 + \ldots \beta_n X_n$ (4)

$f_2=\beta_{20} + \beta_1 X_1 + \ldots \beta_n X_n$ etc. (functions differ only by intercept)

$$g(\bullet) = \text{logit function} = \log\left(\frac{p_j}{1-p_j}\right) \quad (5)$$

$$\left(\frac{p_j}{1-p_j}\right) = odds_j \quad (6)$$

$$\frac{odds_j}{odds_{j'}}\text{, = odds ratio } (j \neq j') \quad (7)$$

Note:

$$p_1 = p_1^* \quad (8)$$

$$\sum_{i=1}^{J} p_i^* = 1 \quad (9)$$

$$p_4^* = 1 - \sum_{j=1}^{J-1} p_j \quad (10)$$

so

$$\Pr(Y=1|x) = p_1^* \quad (11)$$

$$\Pr(Y=2|x) = p_2^* = \Pr(Y \leq 2|x) - \Pr(Y \leq 1|x) \quad (12)$$

$$\Pr(Y=3|x) = p_3^* = \Pr(Y \leq 3|x) - \Pr(Y \leq 2|x) \quad (13)$$

$$\Pr(Y=4|x) = p_4^* = 1 - \Pr(Y \leq 3|x) \quad (14)$$

In a CLR model, the odds ratio (OR) incorporates the ordinal nature of the response variable PTG, and is used to examine differences between categorical independent variables. The OR represents the ratio of the odds for one treatment vs. the odds for another treatment that a tree will be in a selected grade *or better,* e.g., the odds that a tree from the selection cut treatment will be categorized as grade 2 or 1 vs. the odds that a tree from the commercial clearcut treatment will be categorized as grade 2 or 1. The odds in this example are the dichotomy of the probability of being in *grades 2 and 1* vs. the probability of being in *grades 3 and 4*. Note that since the model is a CLR model, these odds are uniform regardless of which grade is selected for a reference; in the example the selected grade is *2*. Thus, the grades can simply be dichotomized as same or increasing (SI) and decreasing (D). Reference to these odds will be noted as SI/D.

When the confidence limit (CL) for the odds ratio estimate includes the value one, there is essentially no statistical difference in the probabilities between two treatments. For this study, interest centered on specific contrasts, as noted in the objectives. Tests of contrasts were Bonferroni adjusted in order to maintain the family-wide experimental error rate.

Cohen's Kappa statistic is utilized to determine the level of agreement between past PTG and current PTG. This statistic, which generally ranges from 0 to 1 but may result in a slightly negative value in rare instances, describes the strength of agreement between two raters of categorically defined cases. The statistic accounts for those cases of agreement that are due to random chance. The formula for Cohen's Kappa statistic is:

$$\kappa = \frac{P_A - P_C}{1 - P_C}$$

where:

P_A=proportion of cases for which raters agree

P_C=proportion of cases for which agreement is expected by chance, computed from marginal proportions.

All statistical analyses were performed using SAS®(SAS, Cary, NC).

Results and Discussion

Establishment Conditions

Data in Table 1 indicate the pre- and post-stand conditions at establishment. Greater numbers of stems larger than 12 inches and a concomitant amount of basal area were left in the two selection cuts than in the clearcuts, as would be expected. Compared to the other treatments, the commercial clearcut with TSI had the greatest reductions, with just a few stems and a very small amount of basal area left.

Previous Stand Removals

Beyond the establishment report, detailed stand records prior to 1976 were lost; only general summaries remain. Thinnings did occur in 1961 and the winter of 1971 and 1972. A third thinning occurred in 1985 (table 2). Thinnings in the commercial clearcut removed somewhat lower amounts of basal area, 17.2 ft^2/ac, as compared to the two selection cuts: 27.6 ft^2/ac for non-TSI and 23.2 ft^2/ac for TSI. Stems removed from the commercial clearcut stand had a mean dbh of 13.6 in, which is larger than those from either of the two selections cuts, which had dbh means of 8.9 in (non-TSI) and 9.1 in (TSI).

Table 1.—Original stand data (1953)[1].

Treatment	No. Trees ≥4" dbh (per acre)	No. Trees ≥ 12" dbh (per acre)	Basal Area Trees ≥4" (ft^2/ac)
Pre-treatment 1953			
Commercial Clearcut	151	55	93.4
Commercial Clearcut with TSI	123	60	95.8
Selection Cut	116	46	77.8
Selection Cut with TSI	101	52	87.5
Post-treatment 1956			
Commercial Clearcut	99	11	37.9
Commercial Clearcut w/TSI	7	1	3.7
Selection Cut	90	31	53.4
Selection Cut w/TSI	49	32	44.0

[1]Russell Walters, unpublished establishment report, 1958

Table 2.—Harvest removals and mortality (1985).

Treatment	Status	Trees per acre	Basal Area (ft^2/acre)	Mean DBH (in)
Commercial Clearcut	Harvest	16.8	17.2	13.6 (0.13)
	Logging Damage	7.2	1.7	6.4 (0.30)
	Total	*24.0*	*18.9*	
Selection Cut	Harvest	53.2	27.6	8.9 (0.25)
	Logging Damage	3.2	0.8	6.5 (0.49)
	Total	*56.4*	*28.4*	
Selection Cut with TSI	Harvest	34.8	23.2	9.1 (0.47)
	Logging Damage	5.6	1.9	7.1 (0.64)
	TSI	0.2	0.0	4.9
	Total	*40.6*	*25.1*	*21.1*
Commercial Clearcut with TSI	N/A	N/A	N/A	N/A

Current Stand Conditions

Major species in each of the stands consist of oaks (northern red, white, and chestnut), red maple, yellow-poplar, and some hickories. There is no dominant species on any stand. The greatest frequency of any species is red maple, which represents 41.3 percent of the commercial clearcut stand (fig. 1). Percentage representation by basal area (fig. 2) is generally similar in value to tree count percentage. The most notable exception is for white oak, which had an approximately 10 percent greater representation by basal area than by frequency count.

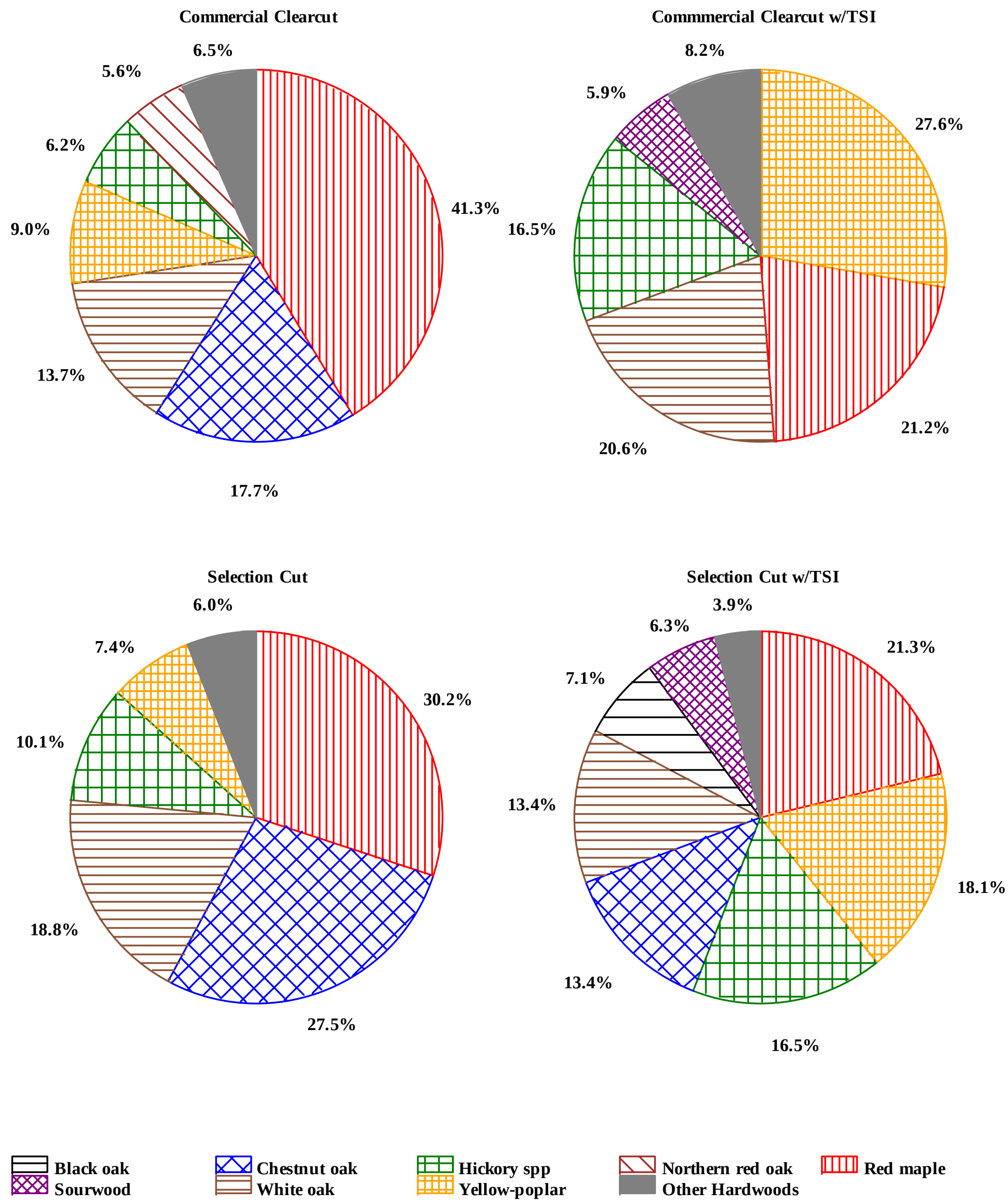

Figure 1.—Year 2000 percentages of trees (≥ 4.5 in. dbh) for each treatment summarized by counts.

Mean dbh across all species is lowest in the commercial clearcut stand, 9.6 in, and is highest in the selection cut stand, 12.9 in (table 3). The greatest density of stems (≥ 4 in dbh) is found in the commercial clearcut treatment, with 161 trees per acre (tpa). The selection cut with TSI had the least number of stems, having 64 tpa. Basal area ranged from 64.2 ft^2/ac to 88.5 ft^2/ac, for the selection cut with TSI and commercial clearcut treatments respectively. However, the number of stems (≥ 12 in dbh) was similar across treatments, ranging from 14-18 tpa.

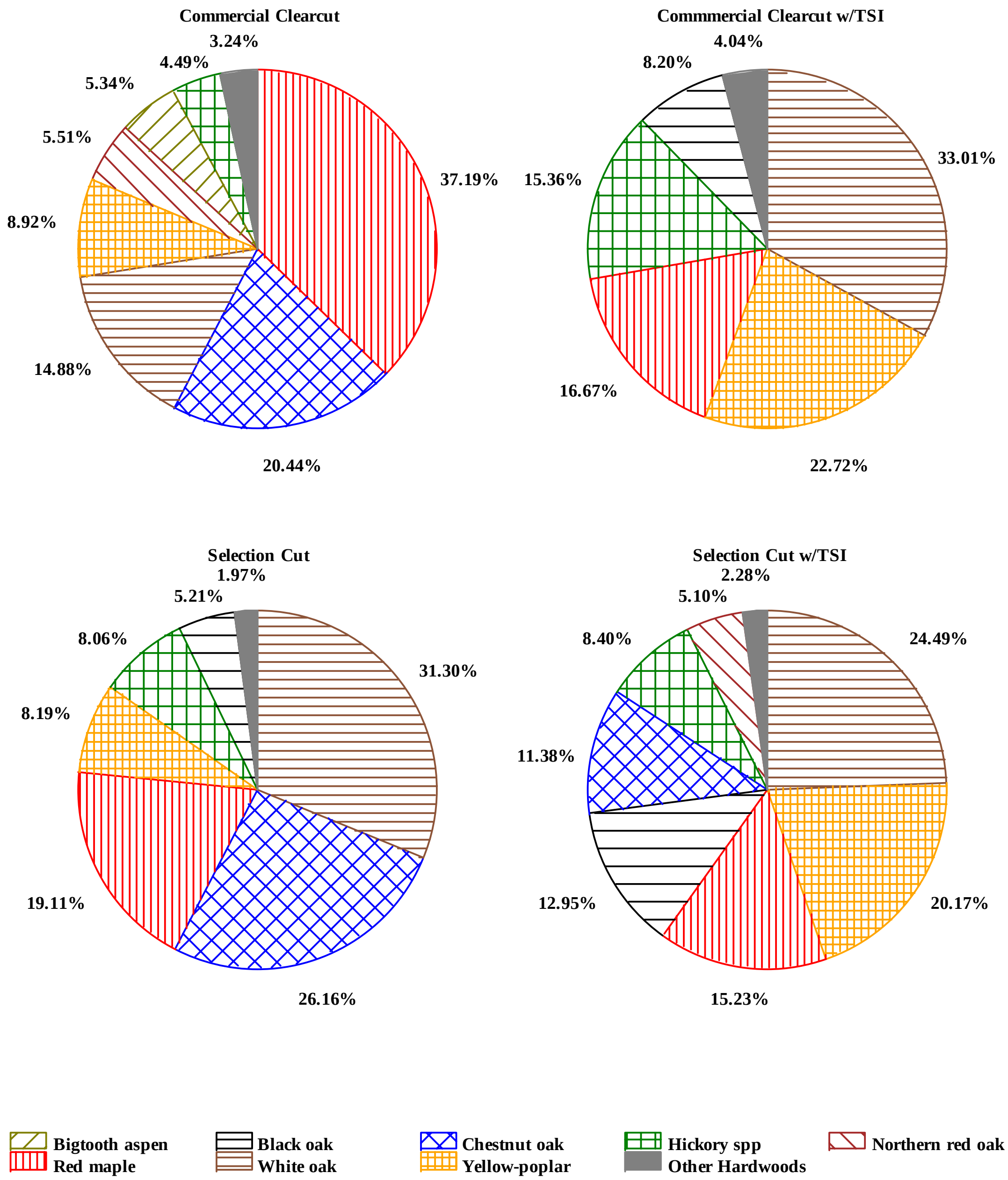

Figure 2.—Year 2000 percentages of trees (≥ 4.5 in. dbh) for each treatment summarized by basal area.

Table 3.—Current stand conditions (2000).

	No. Trees ≥4" dbh (per acre)			No. Trees ≥12" dbh (per acre)		
Treatment	n	Mean	se	n	Mean	se
Commercial Clearcut	4	161	20	4	18	1
Commercial Clearcut w/TSI	4	85	14	4	17	3
Selection Cut	4	75	14	4	18	4
Selection Cut w/TSI	4	64	11	4	14	1

	Basal Area (Trees ≥4")			DBH (Trees ≥4")		
Treatment	n	Mean (ft^2/ac)	se	n	Mean (in.)	se
Commercial Clearcut	4	88.1	6.3	322	9.6	0.17
Commercial Clearcut w/TSI	4	76.8	11.4	170	11.7	0.42
Selection Cut	4	78.8	11.9	149	12.9	0.43
Selection Cut w/TSI	4	63.7	7.3	127	12.3	0.50

Statistical Results

The score test for the proportional odds assumption was non-significant, p=0.775, indicating that proportional odds were satisfied. There was a significant effect of treatment on PTG, p<0.001.

In the tests of the four contrasts, only one contrast was non-significant, the comparison of TSI vs. non-TSI within selection cuts, p=0.601. The contrast of selection cut stands vs. commercial clearcut stands, of TSI stands vs. non-TSI stands, and of TSI vs. non-TSI within commercial clearcuts were all significant, p<0.001.

The first contrast to be considered is that of the selection treatments vs. the commercial clearcuts (significant at p<0.001). The odds ratio (table 4) for this contrast indicates that the SI/D odds of a tree in either of the selection cuts are 4.3 times the SI/D odds for a tree in either of the commercial clearcuts. Significantly greater SI/D odds for the selection cuts indicate the potential for better quality trees when utilizing selection cuts vs. commercial clearcuts. The PTG distribution for the commercial clearcuts contains twice as many grade four trees as do the selection cuts, while the selection cuts have twice as many grade 1 trees as do the commercial clearcuts (fig. 3).

The contrast between TSI and non-TSI stands is significant, p<0.001. The SI/D odds of the TSI stands are 5.9 times the odds of the non-TSI stands (table 4). There are 17 percent fewer grade 4 trees in the TSI

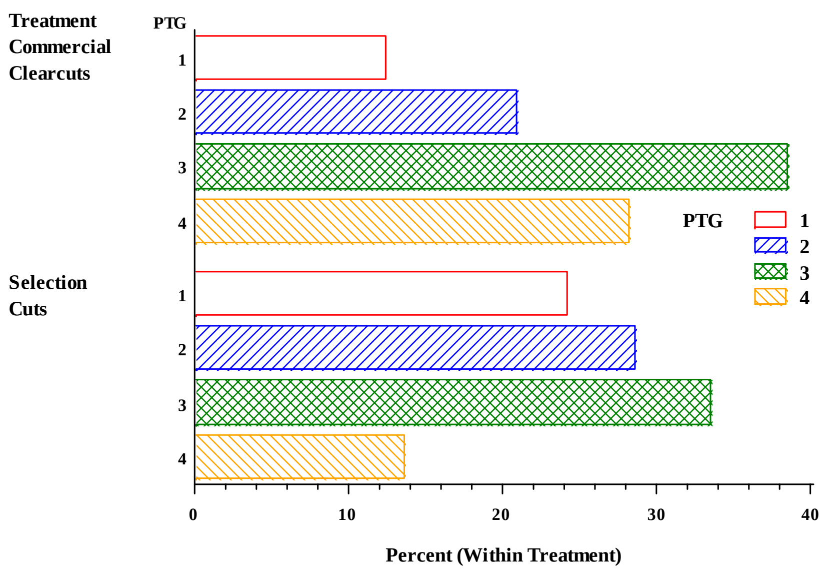

Figure 3.—Potential grade distribution of commercial clearcut stands vs. selection cut stands.

stands than in the non-TSI stands and nearly twice as many grade 1 trees in the TSI stands as than in the non-TSI stands (fig. 4).

Within commercial clearcuts, the contrast of TSI and non-TSI was also significant, p<0.001. The SI/D odds of a tree in the commercial clearcut with TSI were 5.1 times the SI/D odds of a tree in the non-TSI commercial clearcut (table 4). There are approximately 25 percent fewer grade 4 trees and nearly 20 percent more grade 1 trees in the TSI stand than in the non-TSI stand (fig. 5).

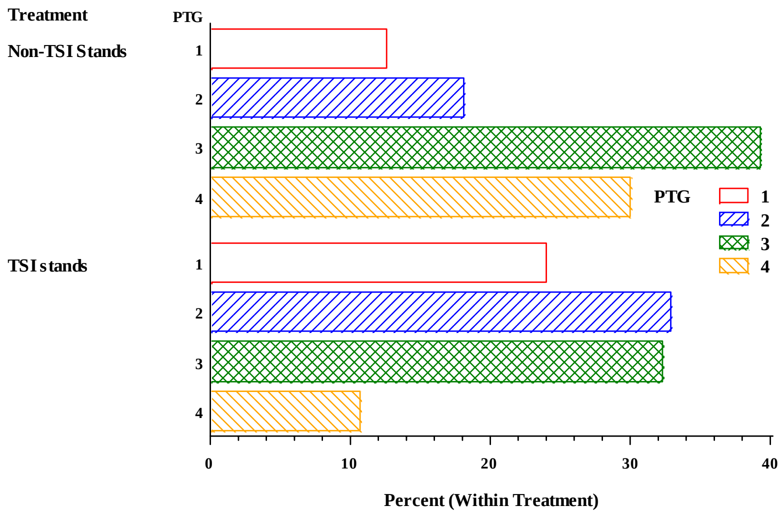

Figure 4.—Potential grade distribution of TSI stands vs. non-TSI stands.

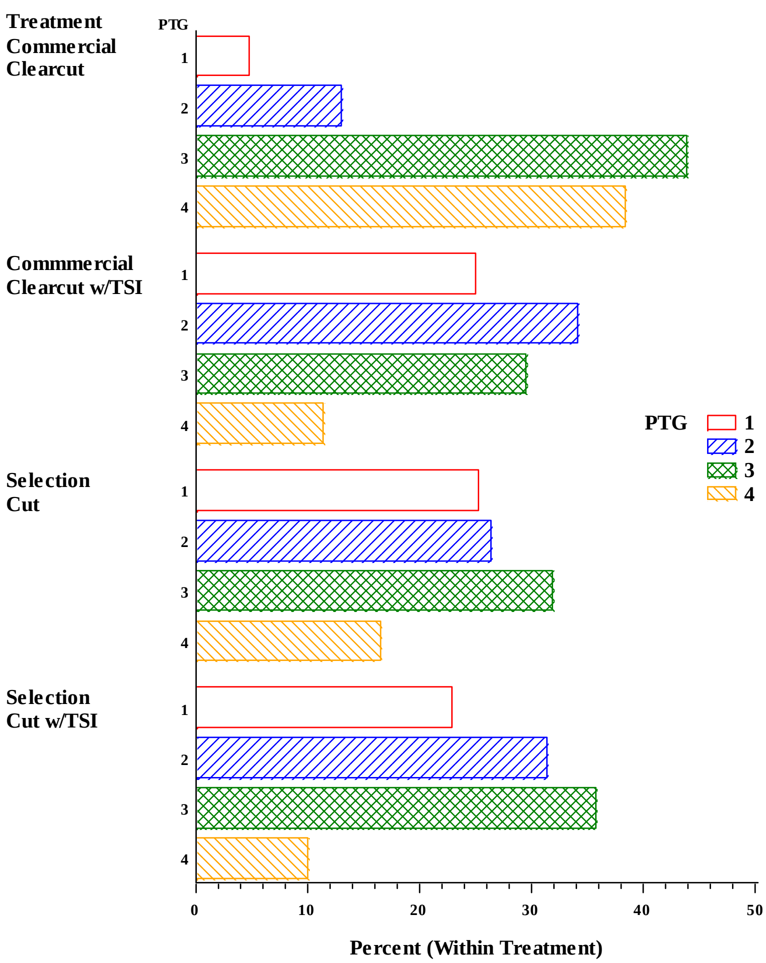

Figure 5.—Potential grade distribution of individual stands.

The lack of significance for the comparison of TSI vs. non-TSI within selection cuts is readily understandable. Selection cutting by definition attempts to remove trees of all sizes to achieve a uniform distribution of trees across age classes. As there was a harvest code to indicate TSI removed trees in 1985, scant trees were removed in order to apply TSI (table 2). The majority of removals were done for harvesting purposes, so a lack of difference in PTG within selection treatments is not surprising.

In order to assess the strength of agreement between 1989 PTG and 2000 PTG, Cohen's Kappa statistic was used. For this data, Kappa was equal to 0.42 (table 5), which would be rated moderate using Landis and Koch's (1977, p165) strength of agreement scale (see Appendix). As an alternative measure, a 95-percent CL on the proportion of matching PTG records is 0.48, 0.66, indicating that from one-half to two-thirds of the cases measured in 1990 were identical to those in 2000. Therefore, while PTG is a rough guide to future tree quality, additional measures could be useful to properly estimate future tree grade.

Table 4.—Odds Ratio estimates for selected contrasts.

Contrast	Odds Ratio*	Lower Limit	Upper Limit
Within Commercial Clearcuts, TSI vs. Non-TSI	5.1	2.5	10.2
Within Selection Cuts, TSI vs. Non-TSI	1.2	0.5	2.5
Selection Cuts vs. Commercial Clearcuts	4.3	1.5	12.3
TSI vs. Non-TSI	5.9	2.1	16.8

* Boldface odds ratios indicate significant differences at α=0.05

Table 5.—Potential tree grade frequency counts.

	2000			
PTG 1989	1	2	3	4
1	27	4	2	0
2	13	14	8	2
3	1	12	19	5
4	0	1	4	10

κ= 0.42

Conclusions

Results from this study indicate two successful strategies for improving grade in stands of similar composition. First, TSI improved grade distribution when comparing across the two silvicultural treatments and also within the commercial clearcut options. Second, selection cutting demonstrated marked increases in grade over commercial clearcutting, with SI/D odds between 1.5 to 12.3 times those for the commercial clearcuts. Future studies including other silvicultural treatments would be of great utility in determining additional comparisons of treatments.

In addition, judging from data spanning eleven years, estimating future tree grade using PTG appears to be only moderately successful. While slightly over half of the trees maintained their original grade, the remainder demonstrated quality changes over this time period. Adding PTG measurements to ongoing inventories would provide further opportunities to determine the scope of these changes.

Acknowledgments

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APPENDIX

Landis & Koch (1977, p.165) have suggested the following benchmarks for interpreting Kappa:

Kappa Statistic	Strength of Agreement
<0.00	Poor
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost Perfect