EVALUATION OF A RED PINE CRUISE IN MICHIGAN

TO INCLUDE CURRENT VOLUME EQUATIONS

USED IN TSALE

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MDNR FOREST MANAGEMENT DIVISION

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Management Summary

Red pine cruising in Michigan to include current volume-basal area (VBAR) and volume equations used in TSALE was evaluated for a 29-acre timber sale in the Gaylord Forest Management Unit, Cheboygan County, Michigan. This sale was approved by the Forest Management Division of the Michigan Department of Natural Resources (MDNR) on April 30, 1998. This 29-acre sawtimber stand of red pine was cruised as one strata using prism cruising with cumulative tally with a BAF 20 prism. In accordance with current MDNR guidelines, 29 sample points were taken. Stand area was estimated with a GPS receiver. The original MDNR cruise yielded the following estimates: (1) basal area per acre (BA) = 125, (2) total International ¼-in. bd.-ft. volume = 574 M, (3) total pulpwood volume = 220 cords, and (4) mean cords per acre = 46.3 with coefficient of variation (C.V.) = 44.8% and achieved error (A.E.) = 16.6%.

Two check cruises were run on this timber sale to compare with the original MDNR cruise and with each other. The first cruise was a prism cruise in 4 strata using a BAF 20 prism, consisting of 56 sample points. The second cruise was a fixed-plot cruise in the same 4 strata using 0.05-ac. circular plots, consisting of 36 sample plots. The data from these cruises were also used to compare the red pine and other VBAR and volume equations used in TSALE. Four representative red pine trees immediately to the west of the timber sale had their DBH and merchantable sawtimber height (SH) measured before standing tree measurements were made using a Barr and Stroud dendrometer. These 4 trees were then felled, bucked into 100-in. sticks, and the diameter inside and outside bark measured for each stick. The data from these trees were used to compare standing tree and felled tree measurements and actual sawtimber volume with sawtimber volume predicted using the equations in TSALE.

The results of this study show:

1. No serious errors in the original MDNR cruise of the red pine timber sale studied.
2. All estimates of total International ¼-in. bd.-ft. volume using the Fowler/Hussain (FH), Jones based on Gevorkiantz and Olsen's Table 2 [Jones (G&O)], and Jones adjusted for red pine [Jones (RP)] volume equations, and FH and MDNR volume-basal area ratios

(VBARs) and cumulative VBARs, were 0.4-6% less than the total sawtimber estimate for the original MDNR cruise.

3. The FH VBAR and cumulative VBAR estimates of total cord volume were 6-11% lower than the total cord volume for the original MDNR cruise.
4. The MDNR VBARs and cumulative VBARs based on Carlson's formula were both 31.3% larger than the total cord volume for the original MDNR cruise.
5. For prism cruising, stratified estimates were from 2.5 to 3.8 percentage points lower than non-stratified estimates for total sawtimber and pulpwood volumes.
6. All estimates of total cord volume from the fixed-plot cruise (i.e., mark and tally) were 22-28% more than the total cord estimate from the original MDNR cruise.
7. All estimates of mean cords per ac. were within ±6% of the mean cords per acre estimate from the original MDNR cruise.
8. All estimates of basal area per acre (BA) from the prism cruise ranged from 115.1 to 117.4, the estimate of BA from the fixed plot cruise was 119.0, while the estimate of BA from the original MDNR cruise was 125.0.
9. For mean cords per acre, the coefficient of variation (C.V.) for the estimates based on prism cruising varied from 42.2 to 43.4%, which was somewhat smaller than C.V.=44.8% from the original MDNR cruise.
10. For mean cords per acre, the achieved error (A.E.) for the estimates based on prism cruising varied from 11.5 to 11.7%, which was considerably smaller than A.E.=16.6% from the original MDNR cruise.
11. Point sample sawtimber volume estimates based on the FH red pine VBARs are no more than 2-3% larger than the sawtimber volume estimates based on the MDNR composite VBARs.
12. Mark and tally sawtimber volume estimates based on the FH red pine volume equation are no more than ±2-3% of the sawtimber volume estimates based on Jones' (RP) volume equation.

13. Point sample pulpwood volume estimates based on the FH VBARs are about 28 to 32% less than pulpwood volume estimates based on Carlson's formula, which is used in TSALE for most species.
14. The mark and tally pulpwood volume estimate based on the FH red pine sawtimber and pulpwood volume equations is 1.25% greater than the pulpwood volume estimate based on Jones' (RP) sawtimber and pulpwood volume equations.
15. VBARs and cumulative VBARs yield approximately the same volume estimates.
16. The FH red pine sawtimber volumes are larger than the Jones' (RP) sawtimber volumes for some combinations of DBH and (sawtimber height) SH, with the reverse being true for other combinations of DBH and SH.
17. Volume based on standing tree measurements are approximately the same as volumes based on felled tree measurements.
18. Mark and tally estimates of pulpwood volume are larger than estimates based on point sampling.
19. Overestimation of merchantable SH and pulpwood height (PH) can yield serious overestimation of volume.
20. Stratification of timber sales where the strata are variable yields more precise volume estimates.
21. Larger sample sizes yield more precise volume estimates.

Overall, there were no serious volume estimate differences among all of the VBAR and volume equations/tables used except for pulpwood volume estimates based on Carlson's VBARs. SH overestimation yielded considerably larger differences than the different VBAR and volume equations for sawtimber. Results for other stands with trees of different ages, densities, and spatial distributions, and different site quality may be different than those found for our example timber sale.

Based on the results of this study, we recommend the following:

1. Merchantable height estimation errors need to be minimized by periodic training and checking felled trees in the field at the time a timber sale is being cut.

2. Sampling intensity needs to be increased over current MDNR standards for valuable sawtimber stands by using a sequential process that yields achieved errors of 10%±2%. For widely variable stands, at least twice as many sample points will be needed.
3. When strata have distinct variation in volume and/or value, use stratified sampling.
4. Be very careful when estimating merchantable SH and PH, especially for taller trees. If your estimate is between two height classes (e.g., 5 and 6 sticks), round down.
5. Cumulative tally for point sampling can be used with confidence.
6. For mark and tally cruising with less than 100% tally, volume and BA adjustments need to be made if the percent cruise is not an integer as TSALE will only accept an integer.
7. The use of Carlson's formula in TSALE for sawtimber stands with sawtimber trees with residual pulpwood and some pulpwood trees should be reexamined (and even for just pulpwood stands).
8. In most cases, the FH sawtimber and pulpwood VBAR and volume equations give volume estimates relatively close to volume estimates based on MDNR VBARs and Jones' (RP) equations. Overall, they can be used with confidence.
9. Any VBAR or volume equation will tend to give volume values larger and smaller than other volume equations for certain DBH and SH or PH combinations (i.e., the FH sawtimber volume equation yields larger volume than Jones' (RP) volume equation for DBH=13 and SH=5 or 6, and DBH=14 and SH=6). For such cases, TSALE could be modified to give values that are the average of the FH and Jones' (RP) volumes.
10. Product standards for timber sales should clearly state that the minimum top DIBs for sawtimber and pulpwood are 7.6- (or 9.6-in. in the U.P.) and 3.6-in., respectively, and that sawtimber volume is calculated for 100-in. sticks (i.e., 8-ft. logs) and not 16-ft. logs for all FH aspen and red pine equations).
11. All VBAR and volume equations used (or to be used) in TSALE should be reexamined to include FH equations for aspen, jack pine, paper birch, oak, and northern hardwoods.

MICHIGAN
DEPARTMENT OF NATURAL RESOURCES
FOREST MANAGEMENT DIVISION

SUBJECT - **TIMBER CRUISING PROCEDURES**

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TITLE - **Evaluation of a Red Pine Cruise in Michigan to Include Current Volume Equations Used in TSALE**

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Introduction

The Forest Management Division of the Michigan Department of Natural Resources (MDNR) uses a variety of cruising procedures and volume equations/tables to estimate forest stand parameters, primarily volume, in timber sales in Michigan. Current volume equations/tables used in TSALE for red pine were developed by Fowler and Hussain (1987a, 1987b, 1989a, 1989b, 1989c) and modified by Robert Ziel of the MDNR and David Hamlin of White Pine Forest Systems for use in TSALE. Since these red pine volume equations/tables have been used in TSALE for some time and some timber contractors have shown concern over possible overestimation of some types of volume, it is appropriate at this time to evaluate red pine cruising and volume equation/table procedures used by the MDNR.

The purpose of this study is to evaluate the cruising procedures and volume equations/tables used for red pine on a representative MDNR timber sale where there is considerable sawtimber volume. The specific objectives are:

1. Examine the cruising procedures used in the original MDNR cruise to see if there are any major errors in area and volume estimation;
2. Determine if there are any large differences between the volume estimates of the original cruise and the two check cruises related to achieved error;

3. Evaluate the accuracy of the red pine volume equations/tables used in TSALE for volume estimation on the examined timber sale; and
4. Make any appropriate recommendations related to changing or modifying cruising procedures and/or volume equations/tables.

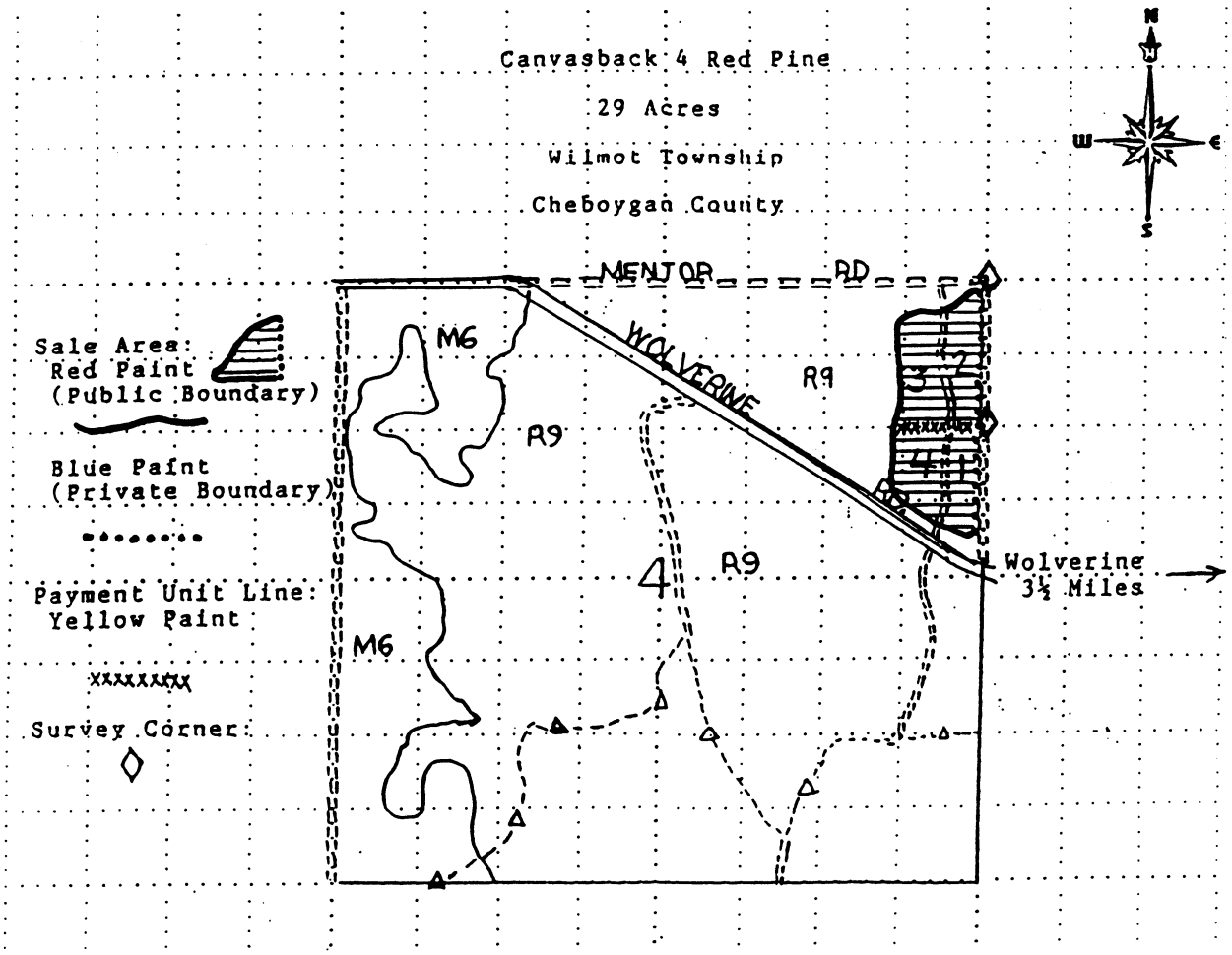
Timber Sale Examined

This study was done in the Canvasback 4 Red Pine Timber Sale (51-022-98-01) in the E½, NE¼, Sec. 4, T33N, R3W, Cheboygan County, Michigan in the Gaylord Forest Management Unit. See Figure 1 for a map of this timber sale. This 29-acre area was cruised as one strata using point sampling (i.e., prism cruising) using cumulative tally with a BAF 20 (PRF=1.94) prism. Current DNR guidelines were used to determine the 29 points taken in the cruise. The area of this sale was determined using a GPS receiver, so stand area is assumed reasonably accurate.

The original cruise yielded the following estimates:

1. Area = 29 acres
2. No. of sample points = 29
3. Stand age = 60 years
4. SI = 58
5. Basal area per acre = 125
6. Forest type = R9
7. Type of cut = Final Harvest
8. Estimated total Int. ¼=in. bd. ft. sawtimber volume = 574 M
9. Estimated total pulpwood volume = 220 cords

Figure 1. MDNR timber sale map of the Canvasback 4 Red Pine Sale in Cheboygan County, Michigan in the Gaylord Forest Management Unit.



*Note that we have divided the sale area into 4 units or strata. This was not done for the original MDNR cruise.

10. Sample statistics for total cordwood volume (sawtimber volume was converted to cords by multiplying 2 times 574).

    A. Mean = 46.3 cords/acre

    B. Standard deviation = 20.7

    C. Coefficient of variation = 44.8%

    D. Achieved error = 16.6%

    The appraised value of the stand was $189.00 per MBF of sawtimber and $34.35 per cord for pulpwood, while the bid price was $308.75 per MBF and $45.00 per cord.

All results from the two check cruises will be compared with the above estimates from the original MDNR cruise.

Methods and Materials

We spent the period 20-22 April 99 at the Canvasback 4 Red Pine Timber sale to: (1) run a point sample check cruise, (2) run a fixed-plot check cruise, and (3) take standing and felled tree measurements on the same 4 red pine trees immediately to the west of the timber sale. The 29-acre timber sale was stratified into 4 strata (units) for purposes of sampling (Figure 1). The acreage was estimated for each stratum using the total length of parallel horizontal lines in each stratum, yielding approximate areas of 5.5, 7.5, 8.9, and 7.0 acres for strata 1, 2, 3, and 4, respectively.

Point Sample Check Cruise

Cruise lines were spread out evenly throughout the 29-acre stand, yielding a total sample of 56 points (17, 12, 12, and 15 points in strata 1, 2, 3, and 4, respectively). A prism with a BAF 20 (PRF=1.94) was used to select "in" trees at each point. If a tree appeared "borderline" in the prism, the horizontal distance from the point to the center of the tree was measured with a fiberglass tape to

the nearest 0.1 of a foot (MD), and the DBH of the tree was measured with a D-tape to the nearest 0.1 of an inch. If the $MD < TD = DBH \bullet PRF$, then the tree was an "in" tree. The number of 100-in. sawtimber sticks (i.e., 8′ logs) to a 7.6-in. minimum top diameter (SH) and the number of residual pulpwood 100-in. sticks to a 3.6-in. minimum top diameter (RPH) was estimated for each "in" tree. If there were no sawtimber sticks, the number of pulpwood sticks to a 3.6-in. minimum top diameter was estimated (PH). A tree had to have a $DBH \geq 4.6$-in. to be considered merchantable. Trees that were of merchantable DBH but with no merchantable sticks were included in the sample (only one tree had no sticks).

Fixed Plot Check Cruise

The same cruise lines used for the point sample cruise were used for the fixed plot cruise with a sample of 36 plots spread out regularly over all cruise lines. Plot size was 0.05 acres with radius 26.3′. A rope 26.3′ in length was used to check for borderline trees. The DBH of each tree in the plot was measured with a D-tape to the nearest 0.1 of an inch, and SH, RPH, and PH were estimated as for the point sample check cruise. Once again, a tree had to have a $DBH \geq 4.6$-in. to be considered merchantable. There were 4 merchantable trees in the sample that had no sticks.

Standing/Felled Tree Measurements

Four representative red pine trees were selected immediately to the west of the timber sale. DBHs were selected in the range of 13-17 in. since (1) this is the range of DBHs where much of the concern over volume overestimation centers, and (2) there are many sawtimber sticks in each tree. We measured the DBH of each tree with a D-tape to the nearest 0.1 of an inch, and estimated the SH and RPH in 100-in. sticks to minimum top diameters of 7.6- and 3.6-in., respectively. Then a Barr and Stroud Dendrometer was used to take standing tree measurements on each tree at stump height

(12″), DBH height, top of the 2nd stick, two taper breaks, the approximate 3.6-in. minimum top diameter, and the top of the tree.

The 4 trees were then felled with a stump height of 12 inches. Each tree was bucked into 100-inch sticks to a 3.6-in. minimum top diameter. The DOB and DIB was measured at the end of each stick with a metal ruler to the nearest 0.05 of an inch (the average of two diameter measures was used for each DIB and DOB measurement). The distance from the top of the last stick to the tree top was measured with a fiberglass tape to the nearest 0.05 of a foot.

Results and Discussion

The results include (1) a comparison of the two check cruises and associated estimates with the original MDNR cruise and estimates, (2) the effects of overestimating SH on sawtimber volume estimates, (3) an examination of the volume-basal area ratios (VBARs) and individual tree volume equations used in TSALE, (4) a comparison of actual felled tree measurements and predicted standing tree measurements (based on Barr and Stroud Dendrometer measurements) and associated stick and tree sawtimber volume, (5) a comparison of actual tree sawtimber volumes with predicted volumes from the equation used in TSALE and two other contemporary sawtimber volume equations/tables, and (6) the effect of SH overestimation on predicted volumes as compared to actual volumes.

Two Check Cruises and the MDNR Cruise

The number of points and plots, and number of trees, number of trees per point or plot, and DBH in inches for sawtimber (ST), pulpwood (PW), and all trees (TOT.) for the two check cruises are shown in Table 1. Somewhat fewer trees and considerably more pulpwood trees per plot were sampled in the fixed-area plot cruise compared to the point sampling cruise.

Table 1. Number of points or plots, and number of trees, number of trees per point or plot, and DBH in inches for sawtimber (ST), pulpwood (PW), and all trees (TOT.) for the 2 check cruises.

Cruise Method	No. of Points or Plots	No. of Trees			No. of Trees Per Point or Plot			DBH (in.)		
		ST	PW	TOT.	ST	PW	TOT.	ST	PW	TOT.
Point Sampling	56	313	14	327	5.59	0.25	5.84	——	——	——
Plot Sampling	36	162	34	196	4.50	0.94	5.44	15.19	7.52	13.86

Table 2 shows the number of trees and average sawtimber (SH), residual pulpwood (RPH), pulpwood (PH), and total merchantable (MH) height in 100-in. sticks for the two check cruises. Average SH, RPH, PH, and MH were greater, less, greater, and greater, respectively, for point sampling compared to plot sampling. The greater number and smaller average height of pulpwood trees for plot sampling is due to the fact that more smaller trees are sampled in plot sampling.

Table 2. Number of trees and average sawtimber (SH), residual pulpwood (RPH), pulpwood (PH), and total merchantable (MH) height in sticks for the two check cruises.[1]

Cruise Method	ST			PW		TOT.	
	No. Trees	SH	RPH[3]	No. Trees	PH[2]	No. Trees	MH[2]
Point Sampling	313	5.53 (1-7)	1.62 (0-5)	14	3.64 (0-5)	327	7.00 (0-8)
Plot Sampling	162	5.34 (1-7)	1.70 (0-4)	34	2.65 (0-4)	196	6.28 (0-8)

[1] Ranges of merchantable height are given in parentheses.

[2] There were one and 4 pulpwood trees with no merchantable sticks for point and plot sampling, respectively.

[3] There were 3 and one ST trees with no residual pulpwood sticks for point and plot sampling, respectively.

TSALE uses VBAR and cumulative VBAR equations to estimate sawtimber International ¼-in. bd.-ft. and pulpwood cord volumes in point sampling. The Fowler/Hussain (FH) (1987b, 1989b,c) VBAR equations/tables are used for red pine sawtimber and pulpwood volumes. The MDNR Composite Sawtimber VBAR table (Tally Sheet R4145) and Carlson's formula (MDNR) are used for most other species. Cumulative VBAR equations make it easier to tally trees in the field.

TSALE also uses individual tree volume equations for ≤100% mark and tally procedures. We will use these equations for plot sampling. The FH (1987a, 1989a,c) volume equations are used for red pine. Jones' (1965) formula based on a fit of the composite sawtimber table in Gevorkiantz and Olsen (1955) and the use of species adjustment factors is used for most other species (e.g., the species adjustment factor for red pine is 1.04). A species adjustment factor of 1.00 yields bd.-ft. volumes approximately equal to those in Table 2 of Gevorkiantz and Olsen (G&O). The FH equation assumes a minimum top diameter of 7.6 in. while G&O assumes a minimum top diameter of 6.0 inches. FH volumes are estimates assuming 8-ft. bolts while G&O assumes 16-ft. logs. Residual pulpwood volume in cords is estimated by multiplying 0.42 by the number of M bd. ft. for all conifer species. Pulpwood volume in cords is estimated for red pine by using the FH pulpwood volume equation (Fowler and Hussain 1987a), while Jones' (1965) formula is used for most other species. Since TSALE assumes an integer % for mark and tally procedures, estimates must be adjusted for %'s that are not integers.

Table 3 compares the estimates for the 29-acre timber sale based on the MDNR original cruise and the two check cruises. The estimation procedures compared are:

Table 3. Type of cruise, ST volume equation used, sample size, total ST and PW volume, mean cords per acre, coefficient of variation (C.V.), achieved error (A.E.), and basal area per acre (BA) for the MDNR original cruise and the 2 check cruises.

Estimation Procedure	Type of Cruise	ST Volume Equation Used	Sample Size	Total ST Vol. (MBF)	Total PW Vol. (Cds.)	Mean Cords Per Ac.	C.V. (%)	A.E. (%)	BA $\left(\frac{Ft.^2}{Ac.}\right)$
MDNR Cumulative	SYS[1]	FH	29	574	220	46.3	44.8	16.6	125
FH VBAR	STR[2]	FH	56	553.7	196.1	43.7	42.2	11.5	115.3
		MDNR		539.4	288.8	45.6	42.7	11.7	115.3
FH Cumulative	STR[2]	FH	56	552.0	206.6	44.2	42.3	11.6	115.1
		MDNR		542.0	288.8	45.6	42.7	11.6	115.1
	SYS[1]	FH	56	566.8	212.5	45.2	42.9	11.5	116.8
		MDNR		557.0	297.2	46.8	43.4	11.6	117.4
FH Fixed Plot (Mark & Tally)	SYS[1]	FH	36	571.7	282.1	49.2	——	——	119.0
		Jones (G&O)		546.0	267.9	46.9	——	——	119.0
		Jones (RP)		567.9	278.6	48.8	——	——	119.0

[1] SYS – systematic sampling of entire 29-acre timber sale.

[2] STR – stratified systematic sampling of the timber sale with 4 strata.

1. MDNR Cumulative VBAR based on one systematic sample from the sale (SYS) using FH equations/tables for red pine;
2. FH VBARs based on a systematic sample from each of 4 strata (STR) using FH tables for red pine and the MDNR composite table and Carlson's formula;
3. Cumulative FH VBARs based on a systematic sample from each of 4 strata (STR) using the FH equations and the MDNR composite equation and Carlson's formula;
4. Cumulative FH VBARs based on one systematic sample from the sale (SYS) using the FH equations and the MDNR composite equation and Carlson's formula;
5. FH Fixed Plot (Mark and Tally) based on one $\left(\frac{36x0.05}{29}\right)x100 = 6.206897\%$ sample by area from the sale using FH, Jones (G&O-species adjustment factor = 1.00), and Jones (RP-species adjustment factor = 1.04) formulas.

The percentage that volume estimates from the 2 check cruises were of the volume estimates from the original MDNR cruise are shown in Table 4. Results indicate the following:

1. There are no serious errors in the original MDNR cruise;
2. The C.V.'s of the point sampling check cruise was somewhat lower than the C.V. of the original MDNR cruise;
3. The A.E. of the point sampling check cruise was considerably lower than that of the original cruise, due mainly to increased sample size;
4. Stratification in the point sampling check cruise did not decrease A.E. appreciably compared to no stratification.
5. The estimates of BA per acre were 4.8 to 7.9% less for the 2 check cruises compared to the original MDNR cruise.
6. All estimates of total Int. ¼-in. bd.-ft. volume for the 2 check cruises were less than the estimate for the original MDNR cruise, ranging from 0.4 to 6.0% less.
   A. FH estimates for point sampling were somewhat larger than MDNR estimates, ranging from 1.8 to 2.7% higher.
   B. Stratified estimates for point sampling were less than estimates based on no stratification (i.e., 2.6 and 2.7% less for FH and MDNR, respectively).
   C. The FH and MDNR cumulative estimates for point sampling were very close to the respective VBAR estimates.
   D. FH estimates for fixed-plot sampling were 4.7 and 0.7% more than Jones (G&O) and Jones' (RP) estimates, respectively, and Jones' (RP) estimate was 4.0% larger than Jones' (G&O) estimate.

Of Course!

Table 4. Percentage volume estimates from the 2 check cruises were of the volume estimates from the original MDNR cruise.

Estimation Procedure	Type of Cruise	ST Volume Equation Used	Total ST Vol. (MBF)	Total PW Vol. (Cds.)	Mean Cords Per Ac.
FH VBAR[1]	STR	FH	96.5	89.1	94.4
		MDNR	94.0	131.3	98.5
FH Cumulative[1]	STR	FH	96.2	93.9	95.5
		MDNR	94.4	131.3	98.5
	SYS	FH	98.7	96.6	97.6
		MDNR	97.0	135.1	101.3
FH Fixed Plot[2] (Mark & Tally)	SYS	FH	99.6	128.2	106.3
		Jones (G&O)	95.1	121.8	101.3
		Jones (RP)	98.9	126.7	105.4

[1] Point sampling check cruise.

[2] Plot sampling check cruise.

7. Mixed results were obtained for total pulpwood cord volume.

   A. FH estimates for point sampling were lower than the original MDNR cruise estimates, ranging from 3.4 to 10.9% less, while MDNR estimates for point sampling were larger than the original MDNR cruise estimates, ranging from 31.3 to 35.1% higher.

   B. Stratified estimates for point sampling were less than estimates based on no stratification (i.e., 2.8% less for both FH and MDNR).

   C. The FH and MDNR cumulative estimates for point sampling were 5.4 and 0.0% larger than the respective VBAR results.

   D. All fixed plot estimates were considerably larger than the original MDNR cruise estimate, ranging from 21.8 to 28.2% higher.

      1. FH estimates were 5.3 and 1.2% more than Jones' (G&O) and Jones' (RP) estimates, respectively.

2. Jones' (RP) estimate was 4.0% larger than Jones' (G&O) estimate.

8. Mixed results were also obtained for mean cords per acre even though all estimates were relatively close to each other. In general, VBAR and cumulative point sampling estimates were less than the estimate from the original MDNR cruise, ranging from 5.6% less to 1.3% more. The fixed-plot estimates were larger than the original MDNR cruise estimate, ranging from 1.3 to 6.3% higher.

Overestimation of ST Height

Since estimation of merchantable height is a common and serious measurement error, the effect of overestimation of ST height on sawtimber volume estimation was examined for the 29-acre timber sale.

Table 5 shows the effect of decreasing the number of ST sticks by one from the ST height estimates made in the point sample check cruise for ST total International ¼-in. bd.-ft. volume. ST height was reduced by one stick for all and half of the trees for SH≥7, 6, 5, and 4. SH≥7 means that all or half of the trees with SH≥7 sticks, had their SH reduced by one stick. The volume estimate decreased by 1.0 to 14.5% going from SH≥7 to ≥4 for all trees decreased by one stick. The volume estimate decreased by 0.6 to 7.1% going from SH≥7 to ≥4 for half of all trees decreased by one stick. For half of the trees results, each tree had a probability of 0.5 of having SH decreased by one stick.

Table 6 shows the effect of decreasing the number of ST sticks by one from the ST height estimates made in the fixed-plot sample check cruise for ST total International 1/4-in. bd.-ft. volume. ST height was reduced by one stick for all and half of the trees for SH≥7, 6, 5, and 4. The volume estimate decreased by 1.2 to 16.5% going from SH≥7 to ≥4 for all trees decreased by one

Table 5. The effect of overestimation of ST International ¼-in. bd.-ft. volume for point sampling with no stratification using the FH estimates by decreasing the ST height by one stick for all and half of the trees for various subsets of merchantable height.

MHs Used in Estimation of Volume		Total ST Volume (MBF)	% of Volume Based on MHs as Measured
Decrease SH by 1	No. of Trees		
No Decrease	All Trees	566.7	
SH=7	All SH=7 trees	560.9	99.0
SH≥6	All SH≥6 trees	505.7	89.2
SH≥5	All SH≥5 trees	490.2	86.5
SH≥4	All SH≥4 trees	484.7	85.5
SH=7	Half SH=7 trees	563.4	99.4
SH≥6	Half SH≥6 trees	533.3	94.1
SH≥5	Half SH≥5 trees	529.3	93.4
SH≥4	Half SH≥4 trees	526.3	92.9

Table 6. The effect of overestimation of ST International ¼-in. bd.-ft. volume for fixed-plot sampling with no stratification using the FH estimates by decreasing the ST height by one stick for all and half of the trees for various subsets of merchantable height.

MHs Used in Estimation of Volume		Total ST Volume (MBF)	% of Volume Based on MHs as Measured
Decrease SH by 1	No. of Trees		
No Decrease	All Trees	576.2	
SH=7	All SH=7 trees	569.1	98.8
SH≥6	All SH≥6 trees	512.4	88.9
SH≥5	All SH≥5 trees	491.4	85.3
SH≥4	All SH≥4 trees	481.0	83.5
SH=7	Half SH=7 trees	573.1	99.5
SH≥6	Half SH≥6 trees	549.4	95.3
SH≥5	Half SH≥5 trees	534.0	92.7
SH≥4	Half SH≥4 trees	528.1	91.7

stick. The volume estimate decreased by 0.5 to 8.3% going from SH≥7 to ≥4 for half of all trees decreased by one stick. The same probability model used for point sampling was used for fixed-plot sampling for the half of the trees results. Note that the total ST volume for the case where no ST heights were reduced (Table 6) is somewhat higher than the TSALE results (Table 3). This is

because the computer program written for the results here used DBHs to the nearest 0.1 of an inch while TSALE uses DBHs to the nearest inch.

VBAR and Volume Equations/Tables Used in TSALE

In order to examine the accuracy of the red pine VBAR and volume equations/tables used in TSALE, the FH equations/tables were compared with contemporary VBAR and volume equations/tables.

VBAR Equations/Tables

The sawtimber FH VBARs and cumulative VBARs used for red pine are compared to the MDNR VBARs and cumulative VBARs used for most other species in TSALE in Table 7. All VBARs are the number of International ¼-in. bd. ft. per sq. ft.

Cumulative VBARs are very close to VBARs for both FH and MDNR except for No. of sticks (SH)=1. FH and MDNR VBARs and cumulative VBARs are very close to each other except for SH=1 where FH underestimates for VBAR and overestimates for cumulative VBAR. FH values, in general, slightly overestimate MDNR values with the overestimation decreasing as SH increases. Remember that the MDNR values are composite while the FH values were developed for red pine.

The average number of sawtimber sticks for the two check cruises of the 29-acre timber sale were somewhat over 5. For SH=5, the FH VBAR is 3.2% higher than the MDNR VBAR, and the FH cumulative VBAR is 2.2% higher than the MDNR cumulative VBAR (Table 7).

Table 8 compares the pulpwood FH, Carlson's, and MDNR VBARs and cumulative VBARs. All VBARs are the number of cords per sq. ft. FH and Carlson's values are used in TSALE.

Table 7. International ¼-in. bd.-ft. VBARs and cumulative VBARs (CUM) for FH and MDNR estimates and associated percentages for SH 1 to 10.

No. of Sticks	FH		MDNR		% FH VBAR is of		% MDNR VBAR	% FH CUM is
	VBAR	CUM	VBAR	CUM	HF CUM	MDNR VBAR	is of MDNR CUM	of MDNR CUM
1	37	49.9	42	43.8	74.1	88.1	95.9	113.9
2	75	77.4	72	72.0	96.9	104.2	100.0	107.5
3	105	104.9	102	100.1	100.1	102.9	101.9	104.8
4	134	132.3	130	128.2	101.3	103.1	101.4	103.2
5	161	159.8	156	156.4	100.8	103.2	99.7	102.2
6	188	187.2	183	184.5	100.4	102.7	99.2	101.5
7	214	214.7	210	212.7	99.7	101.9	98.7	100.9
8	241	242.2	237	240.8	99.5	101.7	98.4	100.6
9	267	269.6	264	269.0	99.0	101.1	98.1	100.2
10	294	297.1	291	297.1	99.0	101.0	97.9	100.0

Table 8. Pulpwood cord VBARs and cumulative VBARs (CUM) for FH, Carlson, and MDNR estimates and associated percentages for PH=1 to 10.

No. of Sticks	FH		Carlson		MDNR	% FH is of Carlson		% FH is of MDNR		% Carlson is of MDNR
	VBAR	CUM	VBAR	CUM	VBAR	VBAR	CUM	VBAR	CUM	VBAR & CUM
1	.083	.137	.100	.100	.086	83.0	137.0	96.5	159.3	116.3
2	.171	.181	.150	.150	.144	114.0	120.7	118.8	125.7	104.2
3	.227	.224	.200	.200	.201	113.5	112.0	112.9	114.4	99.5
4	.271	.266	.250	.250	.251	108.4	106.4	108.0	106.0	99.6
5	.311	.307	.300	.300	.296	103.7	102.3	105.1	103.7	101.4
6	.348	.348	.350	.350	.333	99.4	99.4	104.5	104.5	105.1
7	.383	.387	.400	.400	.368	95.8	96.8	104.1	105.2	108.7
8	.417	.426	.450	.450	.391	92.7	94.7	106.6	109.0	115.1
9	.455	.463	.500	.500	——	91.0	92.6	——	——	——
10	.493	.500	.550	.550	——	89.6	90.9	——	——	——

FH cumulative VBARs are very close to FH VBARs except for No. of sticks (PH)=1, with FH cumulative VBARs overestimating for PH=1, 2, and 7-10, and underestimating for PH=3-5. Carlson's VBARs and cumulative VBARs are the same as Carlson's formula is a linear equation. FH VBARs are larger than Carlson's VBARs for PH=2-5, and smaller for PH=1 and 6-10. FH cumulative VBARs are larger than Carlson's cumulative VBARs for PH≤5, and smaller for PH>5. FH VBARs are smaller than MDNR VBARs for PH=1, and larger for PH>1. Carlson's VBARs are,

in general, larger than MDNR VBARs, especially for PH>5. Remember that the MDNR values are composite, Carlson's formula is a general one, and FH values are for red pine.

Individual Tree Volume Equations

The sawtimber FH, Gevorkiantz and Olsen (G&O), Jones' (G&O), and Jones' (RP) International ¼-in. bd.-ft. volumes for DBHs from 13 to 16 inches and SHs from 3 to 6 sticks are compared in Tables 9-11. Jones' (G&O) values are from Jones' formula based on G&O Table 2, and Jones' (RP) values are obtained from Jones' (G&O) values using the RP species adjustment factor of 1.04. TSALE uses FH volumes for red pine and Jones' (G&O) volumes with species adjustment factors for most other species. We will use a species adjustment factor of 1.00 [Jones' (G&O)] and 1.04 [Jones' (RP)] for our comparisons.

Table 9 compares the volumes from G&O with the volumes from Jones' (G&O). In general, the 2 sets of volume values are quite close with Jones' (G&O) values being smaller for SH=3, 4, and 6, with mixed results for SH=5. The 2 sets of values are very close for SH=5 and 6, moderately close for SH=4, and less close for SH=3. Jones' (G&O) values vary from 4.5% less to 2.2% more than G&O values.

Table 9. International ¼-in. bd.-ft. volumes from Table 2 in Gevorkiantz and Olsen (top value) and Jones' equation based on Table 2 (bottom value) for various DBH & SH combinations.

DBH	SH			
	3	4	5	6
13	96/91.7	118/115.4	134/137.0	149/156.3
14	110/107.4	140/135.0	163/160.5	184/183.7
15	128/124.4	160/156.3	188/186.2	214/213.5
16	148/142.9	180/179.5	213/213.9	247/245.7

Jones' (RP) and G&O volume values are compared in Table 10. Except for DBH=13 and SH=3, Jones' (RP) values are larger than G&O values, varying from 0.3 to 9.1% larger. Jones' (RP) values are always 4% larger than Jones' (G&O) values.

Table 11 compares FH volume values with G&O and Jones' (RP) volume values. FH values are less than both G&O and Jones' (RP) values for MH=3 and 4 except for DBH=13 and MH=4, with the difference increasing as DBH increases and SH decreases. On the other hand, FH values are larger than both G&O and Jones' (RP) values for SH=5 and 6 except for DBH=16 and SH=5 for Jones' (RP), with the difference increasing as SH increases and DBH decreases. The differences are larger for G&O compared to G&O (RP). Large differences are found for DBH=13 and SH=5 and 6, and DBH=14 and SH=6. Remember that G&O values are composite and G&O (RP) and FH values are for red pine.

Table 10. International ¼-in. bd.-ft. volumes from Jones' equation based on Table 2 of Gevorkiantz and Olsen adjusted for RP (top value) and percentages of respective values in Table 2 of Gevorkiantz and Olsen (bottom value) for various DBH and SH combinations.

DBH	SH			
	3	4	5	6
13	95.4 (99.4%)	120.0 (101.7%)	142.5 (106.3%)	162.6 (109.1%)
14	111.7 (101.5%)	140.4 (100.3%)	166.9 (102.4%)	191.0 (103.8%)
15	129.4 (101.1%)	162.6 (101.6%)	193.6 (103.0%)	222.0 (103.7%)
16	148.7 (101.2%)	186.7 (103.7%)	222.5 (104.5%)	255.5 (103.4%)

Table 11. International ¼-in. bd.-ft. volumes from Fowler and Hussain (FH) (top value), percentages of respective values in Table 2 of Gevorkiantz and Olsen (middle value), and percentages of respective values from Jones' equation adjusted for red pine (bottom value) for various DBH & SH combinations.

DBH	SH			
	3	4	5	6
13	93.3 (97.2%) (97.8%)	122.6 (103.9%) (102.2%)	151.6 (113.1%) (106.4%)	180.2 (120.9%) (110.8%)
14	106.3 (96.6%) (95.2%)	139.7 (99.8%) (99.5%)	172.6 (105.9%) (103.4%)	205.2 (111.5%) (107.4%)
15	119.9 (93.7%) (92.7%)	157.6 (98.5%) (96.9%)	194.8 (103.6%) (100.6%)	231.6 (108.2%) (104.3%)
16	134.3 (91.4%) (90.3%)	176.5 (98.1%) (94.5%)	218.2 (102.4%) (98.1%)	259.4 (105.0%) (101.5%)

The average number of ST sticks for the two check cruises of the 29-acre timber sale were somewhat over 5 and the average DBH of sawtimber for the fixed-plot check cruise was somewhat over 15 inches. For DBH=15 and SH=5, FH volume is 3.6 and 0.6% larger than G&O and Jones' (RP) volumes, respectively. Jones' (RP) volume is 3.0 and 4.0% larger than G&O and Jones' (G&O) volumes, respectively.

Felled and Standing Tree Results

Four red pine trees just outside the west boundary of the timber sale were measured with the Barr and Stroud Dendrometer, felled and cut into 100-in. sticks with a 1-ft. stump, and the DOB and DIB measured at the end of each stick to the nearest 0.05 of an inch. The height in ft. from the top of the last stick to the tree top was also measured. Sawtimber (ST) and residual pulpwood sticks had to have a minimum top DIB of 7.6- and 3.6-in., respectively.

Actual (i.e., based on felled tree measurements) and predicted (i.e., based on Barr and Stroud measurements) measurements for various tree characteristics for the 4 trees are shown in Table 12. Average actual and predicted DBH was 14.95 and 14.3 inches, respectively. Both average actual and predicted sawtimber (ST) and pulpwood (PW) merchantable heights were 4.5 and 6.5 sticks, respectively. Thus, there was an average of 2 residual PW sticks. Average actual and predicted DIB in inches of the last ST stick in a tree were 9.25 and 9.15, respectively. Average actual and predicted DIB in inches of the last PW stick in a tree were 4.625 and 4.55, respectively. Average actual and predicted total height in feet were 67.4 and 68.5, respectively. Average actual and predicted GFC at 17.67 ft. were 82.7 and 84.4, respectively.

Table 12. Actual and predicted values for DBH and minimum DIB for Sawtimber (ST) and Pulpwood (PW) in inches, ST and PW merchantable heights (M) in 100-in. sticks, total height (TH) in feet, and GFC.

Tree Characteristic	Tree 1		Tree 2		Tree 3		Tree 4	
	Actual	Pred.	Actual	Pred.	Actual	Pred.	Actual	Pred.
DBH	15.2	14.4	14.2	13.3	13.1	13.0	17.3	16.5
MH_{ST}	5	5	4	4	4	4	5	5
MH_{PW}	7	7	6	6	6	6	7	7
Min. DIB_{ST}	9.2	9.2	9.2	8.8	9.0	8.8	9.6	9.8
Min. DIB_{PW}	4.5	4.1	4.6	4.9	4.8	4.6	4.6	4.6
TH	66.0	72.1	66.2	66.0	63.9	65.4	73.6	70.5
GFC	84.7	84.1	81.0	83.2	83.6	88.9	81.5	81.6

Table 13 shows the actual and predicted DOB, DIB, and double bark thickness (DBT) values in inches at stump height and the top of each stick for the 4 trees. Differences between the 2 sets of values are due to measurement errors. For DBT, differences are also due to the bark factor (BF) prediction equation

Table 13. Actual and predicted DOB, DIB, and DBT values in inches at stump height(S) and at the top of each 100-in. stick for the 4 felled trees.

A. Tree 1

Stick	DOB		DIB		DBT	
	Actual	Pred.	Actual	Pred.	Actual	Pred.
S	17.0	16.9	15.4	15.7	1.6	1.2
1	14.0	13.7	13.2	13.2	0.8	0.5
2	13.5	12.5	12.9	12.1	0.6	0.4
3	11.8	11.6	11.3	11.2	0.5	0.4
4	10.8	10.6	10.4	10.4	0.4	0.2
5	9.6	9.4	9.2	9.2	0.4	0.2
6	7.5	7.0	7.0	6.8	0.5	0.2
7	5.0	4.2	4.6	4.1	0.4	0.1

B. Tree 2

Stick	DOB		DIB		DBT	
	Actual	Pred.	Actual	Pred.	Actual	Pred.
S	16.5	16.3	15.1	15.1	1.4	1.2
1	13.0	12.7	12.2	12.2	0.8	0.5
2	12.1	11.5	11.5	11.1	0.6	0.4
3	11.1	10.4	10.4	10.1	0.7	0.3
4	9.4	9.0	9.2	8.8	0.2	0.2
5	7.5	7.3	7.2	7.1	0.3	0.2
6	5.1	5.0	4.9	4.9	0.2	0.1

C. Tree 3

Stick	DOB		DIB		DBT	
	Actual	Pred.	Actual	Pred.	Actual	Pred.
S	14.7	15.3	13.6	14.1	1.1	1.2
1	12.5	12.6	11.6	12.1	0.9	0.6
2	11.6	11.9	11.0	11.6	0.6	0.3
3	10.8	10.7	10.3	10.4	0.5	0.3
4	9.2	9.0	9.0	8.8	0.2	0.2
5	7.1	7.0	6.7	6.9	0.4	0.1
6	4.7	4.7	4.5	4.6	0.2	0.1

D. Tree 4

Stick	DOB		DIB		DBT	
	Actual	Pred.	Actual	Pred.	Actual	Pred.
S	19.6	19.2	17.8	17.7	1.8	1.5
1	15.6	15.5	14.8	14.9	0.8	0.6
2	14.7	13.9	14.1	13.5	0.6	0.4
3	13.6	12.7	12.8	12.4	0.8	0.3
4	12.4	11.4	11.9	11.2	0.5	0.2
5	10.2	10.1	9.6	9.8	0.6	0.3
6	7.6	7.4	7.2	7.2	0.4	0.2
7	4.8	4.7	4.6	4.6	0.2	0.1

(1) $\hat{BF} = 0.9405 - 0.01637/TH + 0.009954 \ln(TH)$ (Fowler and Damschroder 1988).

Actual and predicted International ¼-in. bd.-ft. volumes for each 100-in. stick and the entire tree for the 4 trees are shown in Table 14. The formula for the Int. ¼-in. volume of an 8′ log is

(2) $\hat{V} = 0.905\left(0.44D^2 - 1.20D - 0.30\right)$,

where D is DIB at the small end of the log in inches (Husch et al. 1982). Average actual and predicted volumes were 181.4 and 176.4 bd. ft., respectively. The predicted volumes were 96.7, 94.2, 106.4, and 94.4% of the actual volumes for trees 1, 2, 3, and 4, respectively, with an average of 97.9%. The weighted average is 97.1%. The correlation between the predicted and actual values was 0.993 (t-test, p=0.007). There was a significant simple linear regression between the predicted and actual volumes (t-test, p=0.007). The intercept was not significantly different from zero (t-test, p=0.333), and the slope was not significantly different from one (t-test, p≈0.2). The mean differences between the predicted and actual volumes was not significantly different from zero (paired t-test, p=0.357).

Table 14. Actual and predicted Int. ¼-in. bd.-ft. volumes for each 100-in. stick and the entire tree for the 4 felled trees.

Stick	Int. ¼-in. Bd.-Ft. Volume							
	Tree 1		Tree 2		Tree 3		Tree 4	
	Actual	Pred.	Actual	Pred.	Actual	Pred.	Actual	Pred.
1	54.8	54.8	45.8	45.5	41.1	45.2	71.4	72.2
2	51.8	45.2	39.9	36.8	35.6	40.3	63.6	57.2
3	38.1	37.9	31.9	29.2	30.8	31.2	51.5	47.1
4	31.5	31.2	23.3	21.1	21.9	21.0	43.2	37.3
5	23.3	23.7	——	——	——	——	26.2	27.6
Tot.	199.4	192.8	140.8	132.7	129.4	137.7	255.9	241.4

Results indicated that predicted sawtimber volumes based on Barr and Stroud measurements of the 4 trees are not significantly different than respective volumes based on felled tree measurements. On the average, the predicted volumes were 97.9% of the actual volumes for the 4 trees studied.

Felled Tree and Predicted Volumes

Table 15 shows the DBH, SH, GFC, actual minimum top diameter of the last sawtimber stick, actual International ¼-in. bd.-ft. volume based on felled tree measurements, and FH and Jones' (RP) predicted volumes for the 4 felled trees. Average GFC of the 4 trees was 82.7%. The average GFC of the trees used to develop the FH volume equation was 83.6%, while the average GFC related to Table 2 of G&O, on which the Jones' (RP) equation was based, was 78 to 79%. FH volumes assume a minimum top diameter of 7.6-in. while G&O and Jones' (RP) assume a minimum top diameter of 6.0 in. The average predicted FH and Jones' (RP) volumes were 1.13% less and 0.5% more, respectively, than the average actual volume. FH underpredicted on 3 trees and overpredicted on one tree, while Jones (RP) underpredicted on 2 trees and overpredicted on 2 trees.

Table 15. DBH, SH, GFC, minimum DIB, actual International ¼-in. bd.-ft. volume based on felled tree measurements, and predicted FH and Jones' (RP) volumes for the 4 felled trees.

Tree	DBH	SH	GFC	Min. DIB	Int. ¼-in. Bd.-Ft. Vol.			% of Actual Vol.	
No.	(in.)	(sticks)	(%)	(in.)	Actual	FH	Jones (RP)	FH	Jones (RP)
1	15.2	5	84.7	9.175	199.42	199.38	199.17	99.98	99.87
2	14.2	4	81.0	9.175	140.80	143.17	144.67	101.68	102.75
3	13.1	4	83.6	9.625	129.40	124.30	121.96	96.06	94.25
4	17.3	5	81.5	8.95	255.88	250.16	263.30	97.76	102.90
Mean	14.95	4.5	82.7	9.23	181.38	179.25	182.28	98.83*	100.50*

*Weighted mean.

average Jones' (RP) volumes (Tables 17-20). For no SH estimation errors, G&O average volumes were slightly less than FH and Jones' (RP) average volumes (Table 16). When SH was overestimated, G&O average volumes were less than FH and Jones' (RP) average volumes (Tables 18 and 20). FH, Jones' (RP), and G&O average volumes were larger than average actual volume when SH was overestimated with the difference increasing as the number of trees with overestimated SH increased. The above results should be expected since the FH equation assumes a minimum top diameter of 7.6 in. while Jones' (RP) and G&O assume a 6.0 in. minimum top diameter, and Jones' (RP) volumes are 1.04 of Jones' (G&O) volumes, which in turn, are approximations of G&O volumes.

Conclusions and Recommendations

The results of this study show (1) no serious errors in the original MDNR cruise of the red pine timber sale studied, (2) point sample sawtimber volume estimates based on the Fowler/Hussain (FH) red pine VBARs are no more than 2-3% larger than volume estimates based on the MDNR composite VBARs, (3) mark and tally sawtimber volume estimates based on the FH red pine volumes are no more than ±2-3% of the volume estimates based on Jones' (RP) volumes, (4) point sample pulpwood volume estimates based on the FH red pine VBARs are about 28 to 32% less than volume estimates based on Carlson's formula, (5) the mark and tally pulpwood volume estimate based on the FH red pine sawtimber and pulpwood volumes is 1.25% greater than the pulpwood volume estimate based on Jones' (RP) sawtimber and pulpwood volumes, (6) VBARs and cumulative VBARs yield approximately the same volume estimates, (7) the FH red pine sawtimber volumes are larger than the Jones' (RP) sawtimber volumes for some combinations of DBH and SH, with the reverse being true for other combinations of DBH and height, (8) volumes based on standing tree measurements are approximately the same as volumes based on felled tree

measurements, (9) mark and tally estimates of pulpwood volume are larger than estimates based on point sampling, (10) overestimation of merchantable SH and/or PH can yield serious overestimation of volume, (11) stratification of timber sales where the strata are variable yields more precise volume estimates, and (12) larger sample sizes yield more precise volume estimates. Overall, there were no serious volume estimate differences among all of the VBAR and volume equations/tables used except for pulpwood volume estimates based on Carlson VBARs. SH overestimation yielded considerably larger differences than the different VBAR and volume equations for sawtimber. These results apply to the 29-acre timber sale studied here. Results for other stands with trees of different ages, densities, and spatial distributions, and different site quality, may be different.

Based on the results of this study, we recommend the following:

1. Merchantable height estimation errors need to be minimized by periodic training and checking trees felled in the field at the time a timber sale is being cut.
2. Sampling intensity needs to be increased over current DNR standards for valuable sawtimber stands by using a sequential process that yields achieved errors of 10% ±2%. For widely variable stands, at least twice as many sample points will be needed.
3. When strata have distinct variation in volume and value, use stratified sampling;
4. Cumulative tally for point sampling can be used with confidence.
5. Be very careful when estimating merchantable ST and PW height, especially for taller trees.
6. For mark and tally cruising with less than 100% tally, volume and BA adjustments need to be made if the percent cruise is not an integer as TSALE will only accept an integer. The current version of TSALE should be revised to solve this problem.

7. The use of Carlson's formula in TSALE for sawtimber stands with sawtimber trees with residual pulpwood and some pulpwood trees should be reexamined (and even for just pulpwood stands).
8. In most cases, the FH sawtimber and pulpwood VBAR and volume equations give results relatively close to MDNR VBARs and Jones' (RP) equations. Overall, they can be used with confidence.
9. Any VBAR or volume equation will tend to give volume values larger and smaller than other volume equations for certain DBH and SH or PH combinations (e.g., the FH sawtimber volume equation yields larger volumes than the Jones' (RP) volume equations for DBH=13 and SH=5 or 6, and DBH=14 and SH=6). For such cases, TSALE could be modified to give volume values that are an average of the FH and Jones' (RP) volumes.
10. Product standards for timber sales should clearly state that the minimum top DIBs for sawtimber and pulpwood are 7.6- (and 9.6-in. for the U.P.) and 3.6-in., respectively, and that sawtimber volume is calculated for 100-in. sticks (i.e., 8-ft. logs) and not 16-ft. logs for all FH aspen and red pine equations.
11. All VBAR and volume equations used (or to be used) in TSALE should be reexamined to include FH equations for aspen, jack pine, paper birch, oaks, and northern hardwoods.

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	(906) 246-3245	Felch Field Office, PO Box 188, Felch, MI 49831
Dennis Nezich	(906) 786-2354	**ESCANABA FOREST MANAGEMENT UNIT**, 6833 Hwy 2, 41 & M-35, Gladstone, MI 49837
	(906) 753-6317	Stephenson Field Office, West 5420 River Road, Stephenson, MI 49887
Bill Brondyke	(906) 346-9201	**GWINN FOREST MANAGEMENT UNIT**, 410 West M-35, Gwinn, MI 49841
	(906) 485-1031	Ishpeming Field Office, 1985 US 41 Hwy West, Ishpeming, MI 49849
	(906) 249-1497	Marquette Field Office, 110 Ford Road, Marquette, MI 49855
Gilbert Joy	(906) 293-3293	**NEWBERRY FOREST MANAGEMENT UNIT**, Box 428, 5666 M 123 S., Newberry, MI 49868
Dean Reid	(906) 635-5281	**SAULT STE MARIE FOREST MANAGEMENT UNIT**, Box 798, 2001 Ashmun, Sault Ste Marie, MI 49783
(send Dean Reid mail to Naubinway)	(906) 477-6048	Naubinway Field Office, PO Box 287, US 2, Naubinway, MI 49762
	(906) 297-2581	Detour Field Office, PO Box 92, M134, Detour, MI 49725
Jeff Stampfly	(906) 452-6227	**SHINGLETON FOREST MANAGEMENT UNIT**, M-28 West, PO Box 67, Shingleton, MI 49884
	(906) 499-3346	Seney Field Office, Corner of M-77 & M-28, PO Box 72, Seney, MI 49883
	(906) 341-2518	Wyman Nursery, Rt No 2, Box 2004, Manistique, MI 49854

NORTHERN LOWER PENINSULA - Jim McMillan (Roscommon Office) 517-275-5151

	(517) 732-3541	Gaylord Office, 1732 West M-32, Box 667, Gaylord, MI 49734
	(616) 775-9727	Cadillac Office, 8015 Mackinaw Trail, Cadillac, MI 49601
	(517) 826-3211	Mio Office, 191 S. Mt. Tom Rd, Box 939, Mio, MI 48647
	(517) 275-5151	Roscommon Office, 8717 N. Roscommon Rd, Box 128, Roscommon, MI 48653
Dayle Garlock	(517) 785-4251	**ATLANTA FOREST MANAGEMENT UNIT**, 13501 M-33, Atlanta, MI 49709
	(517) 354-7822	Alpena Field Office, 4343 M-32 West, Alpena, MI 49707
	(517) 733-8775	Onaway Field Office, Hwy M-211, Box 32, Onaway, MI 49765
Bill O'Neill	(517) 731-5806	**GAYLORD FOREST MANAGEMENT UNIT**, 1732 West M-32, Box 667, Gaylord, MI 49734
	(616) 533-8341	Bellaire Field Office, 701 E. Cayuga St., PO Box 278, Bellaire, MI 49615
	(616) 238-9314	Indian River Field Office, PO Box 10, 6984 Wilson, Indian River, MI 49749
	(616) 539-8564	Pellston Field Office, 304 Stimson, Box 126, Pellston, MI 49769
Joe Jarecki	(517) 983-4101	**PIGEON RIVER COUNTRY FOREST MANAGEMENT UNIT**, 9966 Twin Lakes Rd, Vanderbilt, MI 49795
Dennis Vitton	(616) 775-9727	**CADILLAC FOREST MANAGEMENT UNIT**, 8015 Mackinaw Trail, Cadillac, MI 49601
	(616) 745-4651	Baldwin Field Office, Route 2, Box 2810, Baldwin, MI 49304
	(616) 824-3591	Manton Field Office, 521 N. Michigan, Manton, MI 49663
	(616) 734-5840	Evart Field Office, 951 W. 7th Street, Evart, MI 49631
	(616) 861-5636	Oceana Field Office, 1757 E. Hayes Rd, M-20, Shelby, MI 49455
Joe Fields	(616) 922-5280	**TRAVERSE CITY FOREST MANAGEMENT UNIT**, 970 Emerson, Traverse City, MI 49686
	(616) 258-2711	Kalkaska Field Office, 2089 N. Birch St., Kalkaska, MI 49646
	(616) 325-4611	Platte River Field Office, 15210 U.S. 31 Hwy, Beulah, MI 49617
Courtney Borgondy	(517) 426-9205	**GLADWIN FOREST MANAGEMENT UNIT**, 801 N. Silverleaf, PO Box 337, Gladwin, MI 48624
	(517) 539-6411	Harrison Field Office, 708 N. First St., Harrison, MI 48625
	(517) 846-4104	Standish Field Office, 527 N. M76, Box 447, Standish, MI 48658
Susan Thiel	(517) 687-7771	Sanford Field Office, 118 W. Saginaw, MI 48657
	(517) 348-6371	**GRAYLING FOREST MANAGEMENT UNIT**, 1955 N. I-75 BL, Grayling, MI 49738
	(517) 736-8336	Lincoln Field Office, 408 Main St, PO Box 122, Lincoln, MI 48742
	(517) 826-3211	Mio Field Office, 191 S. Mt. Tom Rd, Box 939, Mio, MI 48647
Don Torchia	(517) 275-4622	**ROSCOMMON FOREST MANAGEMENT UNIT**, Box 218, Roscommon, MI 48653
	(517) 422-2897	Houghton Lake Field Office, 180 S. Harrison Rd, Houghton Lake, MI 48629
	(517) 345-0472	West Branch Field Office, 2389 South M-76, West Branch, MI 48661

SOUTHERN LOWER PENINSULA - Ben Kinsey (Lansing-Knapp's Centre) 517-241-9048

	(517) 241-9048	Southern Lower Peninsula, PO Box 30028, Knapp's Centre, 3rd Floor, Lansing, MI 48909
Ken Alto	(517) 675-5111	Rose Lake Warehouse and Repair Shop, 9870 W. Stoll Rd, Haslett, MI 48840
	(517) 872-4009	Cass City Field Office, 4017 E. Caro Rd, Cass City, MI 48726
Kim Dufresne	(616) 685-6851	Plainwell Office, 621 N. 10th Street, Plainwell, MI 49080
	(616) 788-5062	Muskegon Field Office, 7550 E. Messinger Rd, Twin Lake, MI 49457
	(616) 673-5819	Allegan Field Office, 4590 118th Avenue, Allegan, MI 49010
	(616) 795-9393	Yankee Springs Field Office, 420 Bassett Lake Road, Middleville, MI 49333
Tim Tennis	(517) 780-7901	Jackson Office, 301 E. Louis Glick Hwy, Jackson, MI 49201
	(810) 724-4804	Imlay City Field Office, 571 East Borland, Imlay City, MI 48444
	(810) 229-5762	Brighton Field Office, 6360 Chilson Rd, Howell, MI 48843

revised March 2, 1999

Forest Management Division

15 Resource Management Units

effective 1/25/98

● - *Resource Management Unit Office*

▌ - *Resource Management Unit Boundaries*

| - *County Boundaries*