A Comparison of Four Forest Inventory Tools in Southeast Arkansas
Brandon Tallant and Dr. Matthew Pelkki

Abstract

During the summer of 2003, timed measurements on 6,469 trees and 422 fixed radius plots were collected in an operational setting of a fixed radius plot forest inventory in the Gulf Coastal Plain of Arkansas. This project tested the efficiency of the Haglof Vertex III and a Suunto percent/degree clinometer in combination with a combination loggers’/diameter tape and 30 inch metal tree calipers when used in conducting a forest inventory.

The study found calipers to be faster than a loggers’ tape when measuring tree diameter at breast height. The sonar-based hypsometer was found to be faster than manual hypsometers when measuring tree height. The sonar-based hypsometer was faster than a loggers' tape when establishing 1/5 acre fixed plot radii. Also, the caliper/sonar-based hypsometer was the fastest tool combination to conduct a forest inventory. A general linear model was also estimated to predict plot time that had an adjusted $R^2$ of 0.79. It was found that the increased efficiency (27%) of the caliper/sonar-based hypsometer offset its high initial cost, with a break even point of 1,009 plots.

**Key words**: forest inventory, plot time, time study, tools
New technology is constantly becoming available to assist managers in performing forest inventories. This new technology comes at a substantially higher initial cost than that of traditional equipment, and there is little or no evidence of equipment ease of use, efficiency, or accuracy. This project tested the efficiency of the Haglof Vertex III (sonar-based hypsometer) and a Suunto percent/degree clinometer (manual hypsometer) in combination with the combination loggers’/diameter tape (loggers’ tape) and 30 inch metal tree calipers (calipers) when used in fixed radius circular plot forest inventories in the Gulf Coastal Plain of Arkansas.

Diameter Measurement

The most common tree measurement made by foresters is diameter at breast height. A variety of tools exist to measure this tree attribute with varying degrees of accuracy, precision, cost, operational simplicity, etc. (Clark and others 2000). The diameter measurement tools used in this study were a combination loggers-diameter tape and a 30-inch metal tree caliper. Moran and Williams (2002) noted that when irregularly shaped trees are measured with d-tapes, convex deficits occur where the tape passes over areas of the tree surface that have depressions. When compared to caliper measurements, Brickell (1970) found that d-tape girth measurements result in cross-sectional area bias larger than calipers. This is because measurements made with the d-tape are based on the perimeter of a circle and any departure from true circular form increases the ratio between the circumference and area according to the amount of departure from the circular form (McArdle 1928). When using tree calipers, it is common practice to record the diameter as the arithmetic mean of the two readings. Clark and others (2000) found that both tools, when used properly, provide comparable results with the majority of the bias caused by mathematical models that do not accurately represent stem cross sections.

Height Measurement

An important part of a timber inventory is the accurate determination of tree height. This is costly and often difficult to obtain; the general policy thus far has been to select the method that gives the lowest acceptable level of accuracy (Rennie 1979). The hypsometers used in this study are the Suunto clinometer (manual hypsometer) and the Haglof Vertex III. Both the manual and sonar hypsometers use trigonometric principles to determine tree height. Several studies have compared the accuracies of different hypsometers. Rennie (1979) found the Suunto manual hypsometer to be more precise and faster than the Abney level, the Christen hypsometer, or the Blume-Leiss hypsometer, all with 100-foot tapes. A study by Williams and others (1994) found the manual hypsometer to show significant negative bias only in the 0-33 ft height class. Wing and others (2004) found the Haglof Vertex to estimate tree height within 4.25 feet for 70 to 90 foot tall trees. They also found its average distance error to be less than 0.70 feet for targets ranging from 24 to 100 feet.

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Time Studies

Binot and others (1995) found the d-tape to be faster than the calipers. Based on an average of 34 trees, average person-seconds required to use the instruments were reported as 755 for diameter tape and data collector, 826 for diameter tape and tally sheet, 876 for caliper and data collector, and 917 for caliper and tally sheet. In other words, the time required for the d-tape and data collector required 755 seconds per 34 trees or 22 seconds per tree of two persons combined. The d-tape was faster than the calipers, because it only required one measurement versus two with calipers.

Hunt (1959) timed each height measurement with a stop watch to one-tenth second. The time required to measure a tree was determined as follows:
1) The operator assumed his position over the stake corresponding to the tree measured.
2) As he raised the instrument to his eye, the recorder started the watch.
3) The operator called out the instrument reading to the tree base and then to the first live limb.
4) The watch stopped when the recorder received the latter reading.
5) The two readings and the consumed time were recorded.

When using a tape, Rennie (1979) found the use of the Suunto clinometer with tape to be a faster instrument to determine tree height than the Abney level or Blume-Leiss. The average times required to measure 94 trees using different pieces of equipment were 200 minutes for the Abney level with tape, 146 minutes for the Blume-Leiss with tape, 125.5 minutes for the Suunto manual hypsometer with tape, 173.5 minutes for the Suunto manual hypsometer with pole, 79 minutes for the hand-held Christen hypsometer, and 107 minutes for the Christen hypsometer on a staff.

None of the research conducted thus far has combined the inventory instruments and studied how they work when used together, how much time they require in an operational setting when used together, or how stand conditions affect the time requirements in operational settings. This study will combine both height and diameter measurement inventory instruments, use them in an actual forest inventory, time the entire process, and make conclusions on their efficiency through time studies to include the initial cost of the equipment. This information will then be used to create a regression equation that will include the diameter and height measurement instruments used, as well as stand conditions to compute the time required to complete a forest inventory.

METHODS

Study Area

The study included four stand of timber in Ashley, Bradley, and Drew Counties, Arkansas. The first stand, located in Drew County, was a mature pine stand that had recently been thinned of most hardwoods and contained mostly mature pine trees; initially it was an old field plantation. The second stand, located in Bradley County, was an uneven-aged pine/hardwood stand that had not been actively managed. The next stand, also located in Bradley
County, was a middle aged pine plantation. The final stand was located in Ashley County. It was an uneven-aged pine stand that had recently been thinned of all hardwoods. This stand was an old forest that was put into production in 1994 as an uneven-aged pine forest. As the stands were all located in the Coastal Plain of Arkansas, there was little to no elevation changes in the topography.

**Inventory Methods**

All stands were inventoried at 7.5% intensity using 1/5th acre circular plots in the summer of 2003. Each stand was inventoried four consecutive times using different combinations of inventory tools. All inventories of each stand were completed using the same distance between cruise lines and plots on a line. At the beginning of each cruise method, the distance to the starting line and distance to the first plot of each line were randomly selected. Every tree with a diameter at breast height (DBH) greater than 4.6 inches was measured. Trees were measured to the nearest 1/10th inch; those with a diameter between 4.6 and 8.5 inches were considered pulpwood. Pine trees with a DBH greater than 8.6 inches were considered sawtimber sized trees, and hardwood trees with diameters greater than 11.6 inches were considered sawtimber sized trees. Three attributes of each tree that fell within the 1/5th acre circular plot were recorded, they included diameter at breast height to the nearest 1/10 inch, total height to the nearest foot, and an ocular estimation of the number of merchantable height (10-ft pulpwood sticks or 16-ft sawlogs). Merchantable pulpwood above sawtimber was not estimated.

Trees per acre and stand volumes were determined using these measurements. Each of the four inventories was completed using a different combination of the following diameter and height measurement tools:

- **Diameter**
  - Loggers’ Tape (combination loggers/diameter tape)
  - Calipers (30 inch metal tree calipers)
- **Height**
  - Sonar-based hypsometer (Haglof Vertex III)
  - Manual hypsometer (Suunto percent and degree clinometer).

A particular equipment combination was used until the entire inventory was completed. Also, research personnel (4 persons) rotated positions daily according to a randomized schedule.

Equations developed by Clark and others (1986) were used to determine the top diameters of trees. The cubic foot volume of pine trees in the mature pine stand were determined using equations from Van Deusen and others (1981) because the stand was old-field plantation grown loblolly pine. All other stand pine volumes were determined using equations from Amateis and Burkhart (1987). This equation was used because it was developed for loblolly pine trees in cutover site-prepared plantations. Hardwood tree volumes were determined using equations from Clark and others (1991).

**Inventory crew**

An inventory crew consisted of two individuals. The first role was that of the cruiser, this person measured tree attributes and determined plot boundaries for all plots. Tree attributes included diameter at breast height, total tree height, and merchantable height. The next person on the inventory crew was the tallyperson. This person was responsible for pacing from plot to plot, determining cruise lines, determining plot center, recording temperature, brushiness, weather, recording information called out by the cruiser, and recording the total time required to complete individual plots. Brushiness was a subjective ocular estimation of the brush in the plot; it was used to help determine if brush was a contributing factor to the time required to complete
steps in the inventory process. Weather was recorded as hot, windy, rainy, or normal. The difference between hot and normal weather was determined by the tallyperson.

Two additional persons followed the inventory crew and recorded times for all activities completed by the cruiser. Timer A and Timer B recorded the time required to complete the activities of the cruiser and the tallyperson. Timer A measured the time to find the starting line, plot radius determination, DBH, total height, and recovery time. Timer B measured travel time, acquisition time, separation, and merchantable height.

Timing Process

In addition to tree attributes, times (in seconds) to complete each task in the inventory process were recorded. The inventory process was divided into three levels of work that consisted of a total of 13 tasks. The order of tasks in an actual field setting may vary from the order of tasks used in this study. This set order was necessary in order for the timers to gather the information required for this project. Figure 1, presents a timber inventory operation process chart that depicts processes and measurements made in a forest inventory regardless of the instrument used.

Each day the total work time was recorded. It was started when the group left the designated corner of the property and ended when the group walked back to that same point. This designated corner did not change from day to day or from tool combination to tool combination. All breaks taken during the process were also recorded, so they could be accounted for in the plot total time and total daily time. With the exception of equipment failures, the times to complete inventory plots are delay-free times.

Regressions

The data were then randomly split into a regression dataset and a validation data set to develop and validate the regression equations. Residuals that were three standard deviations away from the mean were considered outliers and eliminated before regression models were fit. SAS® was used to fit a regression model that estimated the time required to inventory a plot. Mallows Cp and PRESS statistics were used to narrow regression models.

RESULTS/DISCUSSION

A total of 422 1/5th acre plots collectively containing 6,469 trees were used in means testing and model fitting. Out of this sample, 105 plots and 1,608 trees were randomly selected and included in the validation dataset. The remaining 317 plots and 4,861 trees were used in fitting and testing all regression equations. Table 1 shows the time to measure inventory plots with different equipment combinations summary statistics.

Table 1. Time to measure 1/5th acre fixed radius inventory plots with different equipment combinations summary statistics.

<table>
<thead>
<tr>
<th>Combination</th>
<th>N</th>
<th>Mean (min.)</th>
<th>Std. Dev.</th>
<th>Std. Err.</th>
</tr>
</thead>
</table>

27
Time Study

A t-test showed a significant difference in the hypothesis that time to measure the DBH of a tree using the loggers’ tape was less than or equal to the time with calipers for all species combined (p-value <0.0001, α=0.05). Data support rejecting the null hypothesis and concluding...
that it is faster to measure a tree once with tree calipers than with a logger’s tape. Table 2 shows the summary statistics and two-sample t-test on the means of DBH measurement times using different equipment. The mean times to measure a tree with calipers and logger’s tape are 2.0 and 6.5 seconds respectively.

**Table 2.** DBH times summary statistics and means tests.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (sec.)</th>
<th>Std. Dev.</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>All species combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caliper</td>
<td>3167</td>
<td>2.0</td>
<td>2.22</td>
<td>0.04</td>
</tr>
<tr>
<td>Loggers’ Tape</td>
<td>3303</td>
<td>6.5</td>
<td>5.47</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.18</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Tree calipers are faster than logger’s tapes because of the positioning motions required to operate them. Operators in this study only measured tree diameters once. As seen in Table 2, the standard error of time is higher for the logger’s tape than of tree calipers regardless of the species group being measured. Tree calipers require less time and have a smaller standard error. This is because regardless of tree size or any vines that may be on the tree, the process of measuring that tree with a caliper does not vary. The standard error is higher with the logger’s tape which is due to not only tree size but also vines or other obstacles to the worker. When using a logger’s tape, the tape must be placed around the tree underneath any vines that may be in the way which requires more time. Also, some operators must walk around larger trees if their arms will not reach around the DBH of the tree. Both of these situations increase the time required to measure a tree.

Table 3 shows the summary statistics and t-test on the times recorded during the tree height measurement processes using the manual and sonar-based hypsometers for all species combined. The sum of tree height times included separation, total height, merchantable height, and recovery of equipment for any given tree. A p-value of <0.0001 at α=0.05 rejected the null hypothesis that the time to measure the total height of a tree with a manual hypsometer is less than or equal to the time to measure the total height of a tree with the sonar-based hypsometer.
Table 3. Tree height measurement process times (all species combined) summary statistics and means test using the manual and sonar-based hypsometers.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (sec.)</th>
<th>Std. Dev.</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of tree height times</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual hypsometer</td>
<td>3213</td>
<td>53.2</td>
<td>16.50</td>
<td>0.29</td>
</tr>
<tr>
<td>Sonar-based hypsometer</td>
<td>3256</td>
<td>41.1</td>
<td>13.28</td>
<td>0.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.417</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

The mean times to measure the height of a tree with the manual hypsometer and sonar-based hypsometer were 53.2 and 41.1 seconds, respectively. As seen in Table 3, on average the sonar-based hypsometer was twelve seconds faster at measuring height than manual hypsometers. Upon further investigation, every process in measuring a tree was significantly faster with the sonar-based hypsometer when all species were combined.

Table 4 shows the summary statistics and means tests for the plot boundary establishment times. It would seem as though the loggers’ tape would require more time to establish plot radius than the sonar-based hypsometer, because the operator is required to return to the plot center after every distance measurement. Data suggest the loggers’ tape is faster with a mean time of 273.8 seconds versus 324.9 seconds when using the sonar-based hypsometer.

Quite often in forest inventories there is brush, trees, and other obstructions between the operator and the plot center. Although the sonar based hypsometer will take readings through some brush, it will not work on areas that have very dense vegetation between the sonar based hypsometer and transponder. These obstructions interfere with the sonar-based hypsometer and require the operator to maintain the same position, but move the instrument vertically or horizontally before a distance measurement is taken.

Table 4. Plot boundary establishment times (all stands combined) summary statistics and means test using loggers’ tape and sonar-based hypsometer.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (min.)</th>
<th>Std. Dev.</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loggers’ Tape</td>
<td>209</td>
<td>4.58</td>
<td>2.963</td>
<td>0.205</td>
</tr>
<tr>
<td>Sonar-based hypsometer</td>
<td>206</td>
<td>5.54</td>
<td>3.936</td>
<td>0.274</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.815</td>
<td>0.0026</td>
</tr>
</tbody>
</table>

Plot Level Regression

The final model form of the equation that best predicted total plot time is as follows:

\[
\hat{T}_{pi} = b_0 + b_1S2 + b_2M3 + b_3B + b_4\text{PSTPA} + b_5\text{NPSTPA}
\] (1)
where: $\hat{T}_p = $ predicted time to measure plot $i$ in minutes,

$b_0, b_1, b_2, b_3, b_4,$ and $b_5$ = parameter estimates,

$S2 =$ pine hardwood stand,

$M3 =$ caliper/sonar-based hypsometer,

$B =$ heavy brush,

$PSTPA =$ pine sawtimber trees per acre, and

$NPSTPA =$ non-pine sawtimber trees per acre.

Table 5 shows the regression coefficients and fit statistics for Equation 1. This equation had an adjusted $R^2$ of 0.7997 and the lowest PRESS value of any other potential plot level equations. A paired t-test showed a significant difference in the hypothesis that the actual time to measure a plot was less than or equal to the predicted time (p-value = 0.0297). Table 6 shows the summary statistics and the paired t-test for the means of actual versus predicted total plot time in minutes.

The intercept term in the plot level regression (Equation 1) is 7.33 minutes. This regression was normalized on the mature pine stand and loggers’ tape/manual hypsometer tool combination and does not include breaks taken in the plots. Regardless of the number of trees in the plot, the technician was still required to determine which trees were in the plot and which

Table 5. **Regression coefficients and fit statistics for the plot level equation**

(Equation 6).

<table>
<thead>
<tr>
<th>Parameter Coefficient</th>
<th>Parameter</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>Pr &gt; t</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>Intercept</td>
<td>7.33</td>
<td>0.774</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>$b_1$</td>
<td>pine/hardwood stand</td>
<td>4.09</td>
<td>1.055</td>
<td>0.0001</td>
</tr>
<tr>
<td>$b_2$</td>
<td>caliper/sonar hypsometer</td>
<td>-3.79</td>
<td>0.756</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>$b_3$</td>
<td>brush</td>
<td>2.47</td>
<td>0.740</td>
<td>0.0010</td>
</tr>
<tr>
<td>$b_4$</td>
<td>PSTPA</td>
<td>0.21</td>
<td>0.016</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>$b_5$</td>
<td>NPSTPA</td>
<td>0.19</td>
<td>0.006</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Adjusted $R^2 = 0.7997$

Table 6. **Actual versus predicted total plot time summary statistics and paired t-test using plot level regression.**

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (min.)</th>
<th>Std. Dev.</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Time</td>
<td>103</td>
<td>21.9</td>
<td>14.52</td>
<td>1.43</td>
</tr>
<tr>
<td>Predicted Time</td>
<td>103</td>
<td>23.0</td>
<td>11.79</td>
<td>1.16</td>
</tr>
</tbody>
</table>
trees were outside the plot, which on average required 5.06 minutes (Table 4). Plot boundary establishment explains a portion of the intercept term.

Simply being in a pine/hardwood stand would increase the time to complete a plot by 4.09 minutes. The presence of hardwood trees also had a positive influence on time in the tree-level regression. The significance of this stand may be due to its very large trees, both pine and hardwood. Due to the large size of both pine and hardwood trees in this stand, an operator would be required to walk around the large trees diameter in order to determine DBH.

Next, if the operator employed the use of the caliper/sonar-based hypsometer combination of equipment, the plot would be measured 3.79 minutes faster than if any other combination of tools were used. This is due to the faster tree measurement time as discussed in the tree level equation. All other tool combinations were found to be insignificant predictors of plot time.

Brush contributed 2.47 minutes to the time required to inventory a plot. Brush interferes with the equipment and makes the technician work harder to move through and take measurements through it. It was expected that brush would have a positive impact on total plot time.

Every tree in any given plot adds time to the total plot time. Pine sawtimber trees required more time to measure than any other tree. Consequently, every pine sawtimber tree per acre added 0.21 minutes to the total plot time. Each additional non-pine sawtimber tree per acre added 0.19 minutes to the total plot time. A model with trees per acre of all species combined was attempted but it only explained 17% of the variation in the total plot time.

The plot level regressions predicted total plot time was significantly different than the actual observed time. Even though the predicted time is not the same as an actual observed time, forest managers can still use the equal in a forest inventory planning setting if the time is adjusted appropriately. When averaged over the 107 plots in the validation dataset, the plot level regression overestimated the actual time by 1.05 minutes per plot. The average time of the validation dataset was 21.05 minutes while the test dataset average was 23.04 minutes. The difference in these averages could explain why the regression overestimates the validation dataset. Since the dataset was randomly chosen, the different average times were unavoidable.

To calculate the economic efficiency of including the sonar-based hypsometer and tree calipers in a forest inventory, the plot level regression results of two inventories, one with the sonar-based hypsometer/caliper combination and one with manual hypsometer/loggers' tape, where simulated in a pine stand using normal weather conditions, heavy brush, 37 pine sawtimber trees per acre, and 5 non-pine sawtimber trees per acre. The estimated time required with the manual hypsometer/loggers' tape was 15.6 minutes, while the estimated time required with the sonar-based hypsometer/tree calipers was 11.7 minutes.

If two forest technicians worked 8 hours, they could complete 27 plots in a day's time using the manual hypsometer/loggers' tape if they averaged 3 minutes travel time between plots. Under the same conditions, the same forest technicians could complete 34 plots in a day's time if they employed the use of the sonar-based hypsometer and tree calipers. The annual costs of the inventory methods are shown in Table 7. Using the sonar-based hypsometer/caliper combination a forest manager could decrease the cost per plot by $1.28 over the course of a year’s time and expect a 27% increase in worker production. The additional investment in the sonar-based

<table>
<thead>
<tr>
<th>t-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.205</td>
<td>0.0297</td>
</tr>
</tbody>
</table>
hypsometer would be returned in the first 1,094 plots after the original 6,000 plots expected under the use of loggers’ tape/manual hypsometer combination in the forest inventory.

Table 7. Annual costs of different inventories using the plot level regression.

<table>
<thead>
<tr>
<th>Inventory Method</th>
<th>Plots/ yr</th>
<th>Work Hrs/ yr</th>
<th>Annual Technicians’ Salary</th>
<th>Cost/ plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual hypsometer/loggers’ tape</td>
<td>6,500</td>
<td>2,000</td>
<td>$40,000</td>
<td>$5.95</td>
</tr>
<tr>
<td>Sonar-based hypsometer/caliper</td>
<td>8,000</td>
<td>2,000</td>
<td>$40,000</td>
<td>$4.67</td>
</tr>
</tbody>
</table>

Conclusions

The sonar-based hypsometer is a viable alternative to manual hypsometers that does increase the efficiency of those employing its use. Results presented in this study were based on data collected in the growing season when foliage was at its maximum. It seems likely that measurements taken in the winter, when foliage is at its minimum, would further increase time savings of the sonar-based instrument. Forest managers employing technicians to inventory stands on a continual basis should consider the use of sonar-based instruments.

From a planning perspective, the equation to estimate plot time should prove useful to forest managers. Predicting time to perform inventories should allow managers to more accurately plan how much inventorying can be completed by technicians. Equations can also act as quality control measures, ensuring that the inventory personnel are working efficiently.

The biggest strength of this study was that it focused on the times required to inventory forests in an operational setting, including all aspects of the inventory. It was designed around the inventory without modifying the motions or movements of forest workers. For this reason, the results of the study can be used by forest managers with confidence. No portion of the inventory was modified for ease in collecting data. Future research should concentrate on the use of more technologically advanced dendrometers and hypsometers in an operational setting. Many new pieces of equipment are tested for accuracy and precision, but not for improved efficiency of forest workers.

LITERATURE CITED


