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PINEVOL: A User's Guide to a Volume Calculator for Southern Pines

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Cover photo: The PINEVOL title screen that introduces the program

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Abstract

Taper functions describe a model of the actual geometric shape of a tree. When this shape is assumed to be known, volume by any log rule and to any merchantability standard can be calculated. PINEVOL is a computer program for calculating the volume of the major southern pines using species-specific bole taper functions. It can use the Doyle, Scribner, or International ¼-inch log rules or calculate solid wood volume inside or outside of bark. This document describes the methods used in volume calculation in PINEVOL and is a program user's guide.

Keywords: Loblolly pine, longleaf pine, shortleaf pine, slash pine, stem profile equations, taper functions.

Introduction

Tree volume is an important determinant of timber value. Information about tree volume is also important to those who evaluate alternatives to cutting and important forest characteristics like carbon sequestration. Volume growth information, which is based on volume calculations, can be more than just a measure of investment potential; it can describe the cumulative effects of the environment on trees since the bole develops and persists over time.

There are many ways to calculate tree volume. These range from tables like those presented in Miscellaneous Publication 50 (U.S. Department of Agriculture Forest Service 1976) to stem profile functions of the form suggested by Bennett and others (1978), which are used in this program. The form of stem profile function chosen works well and several authors who will be mentioned below have used it for a variety of species of southern pines. However, using a stem profile function to calculate volume is mathematically intensive. PINEVOL is a Visual Basic® program that performs all of the necessary calculations to calculate volume by several log rules to any desired merchantability limits.

Model Design and Assumptions

PINEVOL is based on the taper function developed by Bennett and others (1978). This model has been applied to most of the major southern pine species. A list of these species and the authors who prepared the models is presented in table 1.

This taper model allows volume calculation for any portion of a tree simply by integrating the function over height for any given upper and lower height. Volumes can also be calculated using a piecewise method if the upper and lower diameters of each piece are known.

Bennett and others (1978) provided one set of parameters for inside bark taper and another for outside bark taper. In order to increase the accuracy of these taper functions, each parameter set was further subdivided into three crown ratio classes, resulting in six sets of parameters for taper (Dell and others 1979, Feduccia and others 1979). A function for converting outside bark diameter at breast height in inches to inside bark diameter at breast height in inches was also calculated for each species and crown ratio class.

Base Taper Function

Bennett and others (1978) derive the following taper function:

$$d = \begin{cases} D(h/4.5)^{b_0} & \text{if } h_s \leq h \leq 4.5 \text{ feet} \quad (1) \\ \begin{aligned} &D(H-h)/(H-4.5) \\ &+ b_1(H-h)(h-4.5)/H^2 \\ &+ b_2D(H-h)(h-4.5)/H^2 \\ &+ b_3D^2(H-h)(h-4.5)/H^2 \\ &+ b_4(H-h)(H-4.5)(2H-h-4.5)/H^3 \end{aligned} & \text{if } 4.5 \text{ feet} \leq h \leq H \end{cases}$$

where

b_1 = estimated regression parameters

d = predicted stem diameter (inches) at height h

D = diameter at breast height (inches)

h = height above groundline (feet)

H = total tree height (feet)

h_s = stump height above groundline (feet)

Table 1—Descriptions and limits of the models used for taper functions in PINEVOL. In many cases these limits were not shown by the original authors so the average of the remaining models was used for limits and these limits are shown in parentheses

Citation	Species	Location	D.b.h. range	Height range	Crown ratio range	Trees
			<i>inches</i>	<i>feet</i>	<i>percent</i>	<i>number</i>
Baldwin and Polmer 1981	Planted longleaf pine (<i>Pinus palustris</i> Mill.)	Central Louisiana and east Texas	1 – 21	12 – 90	(14 – 89)	113
Dell and others 1979	Planted slash pine (<i>P. elliottii</i> Engelm.)	West Gulf	(1 – 23)	(8 – 105)	(14 – 89)	3,784 ^a
Farrar 1987	Natural longleaf pine	East Gulf	1 – 23	5 – 105	(14 – 89)	214
Farrar and Murpy 1987	Natural shortleaf pine (<i>P. echinata</i> Mill.)	West Gulf	1 – 26	8 – 107	16 – 86	342
Farrar and Murphy 1988	Natural loblolly pine (<i>P. taeda</i> L.)	West Gulf	1 – 34	9 – 119	13 – 93	268
Feduccia and others 1979	Planted loblolly pine	West Gulf	(1 – 23)	(8 – 105)	(14 – 89)	100

^aThis represents the number of upper stem taper measurements since the number of trees was not given.

Cubic Volume Calculation

Integrating equation (1) with respect to height of the base and top of the piece provides one means to estimate piece volume (Bennett and others 1978). Bennett and others (1978) divided this integral to predict volumes for parts above and below D (if both parts are included, simply add the partial volumes together).

$$VOL = \frac{\pi 4.5^{-2b_0} D^2 (h_u^{2b_0+1} - h_L^{2b_0+1})}{576(2b_0 + 1)} \quad \text{if } h_s \leq h_L < h_u \leq 4.5 \quad (2a)$$

$$VOL = \frac{\pi}{576} [R_0^2 (h_u - h_L) + R_0 R_1 (h_u^2 - h_L^2) + \frac{1}{3} (R_1^2 + 2R_0 R_2) (h_u^3 - h_L^3) + \frac{1}{2} (R_0 R_3 + R_1 R_2) (h_u^4 - h_L^4) + \frac{1}{5} (R_2^2 + 2R_1 R_3) (h_u^5 - h_L^5) + \frac{1}{3} R_2 R_3 (h_u^6 - h_L^6) + \frac{1}{7} R_3^2 (h_u^7 - h_L^7)] \quad \text{if } 4.5 \leq h_L < h_u \leq H \quad (2b)$$

where

$$R_0 = \frac{DH}{H - 4.5} - \frac{4.5b_1 + 9b_4 - 4.5b_2 \cdot D - 4.5b_3 D^2}{H} + \frac{20.25b_4}{H^2}$$

$$R_1 = \frac{-D}{H - 4.5} + \frac{b_1 + 2b_4 + b_2 \cdot D + b_3 \cdot D^2}{H}$$

$$\frac{4.5b_1 + 9b_4 + 4.5b_2 D + 4.5b_3 \cdot D^2}{H^2} - \frac{20.25b_4}{H^3}$$

$$R_2 = \frac{-b_1 - 3b_4 - b_2 \cdot D - b_3 \cdot D^2}{H^2}$$

$$R_3 = \frac{b_4}{H^3}$$

and h_L and h_u are the lower and upper piece heights, respectively. The R_i variables are used just to make equation (2b) more tractable. Volume could also be obtained numerically by quadrature, but this method is not discussed here.

Board Foot Volume Calculation

Some forest products are not measured in ways that are simply geometrical. For these, the taper function can be used to find the diameter at various heights. In turn, this information can

be used to assemble product volumes as if one were physically scaling the tree. For instance, PINEVOL can determine tree volumes using Doyle, Scribner, and International ¼-inch rules. Doyle and Scribner are based on 16-foot logs with a trim allowance of 0.3 feet added for each 16-foot log. The International ¼-inch rule is based on 4-foot sections with the same trim allowance added every 16 feet.

For Doyle and Scribner rules, PINEVOL performs the following steps:

1. Sets the saw-log height utilized (HSAW) to the stump height and calculates the height of the tree (MERHT) to the specified minimum diameter for saw logs
2. Finds the minimum of the unused log (MERHT- HSAW) or a standard log (16 feet) and calls it the new piece
3. Sets the length of the new piece to be an even 2-foot interval equal to or lower than its current length
4. Checks whether the top of this piece with trim allowance added is still less than MERHT, and subtracts 2 feet if it isn't
5. Calculates the new HSAW as the sum of the previous HSAW plus the new piece length plus the trim allowance and finds the scaling diameter at the top of this piece
6. Calculates the volume of this piece using the appropriate volume equation [equation (3) or (4)] and adds it to the total volume

The actual volume equations used are from the "Forestry Handbook" (Wenger 1984):

$$\text{Doyle Volume} = (d_s - 4)^2 \cdot \frac{L}{16} \quad (3)$$

$$\text{Scribner Volume} = \frac{(0.79 d_s^2 - 2 d_s - 4) L}{16} \quad (4)$$

where

d_s = the scaling diameter (inches) of the piece

L = its length (feet)

7. Loops back to step 2 until there is not at least a 2-foot section remaining below MERHT

The process for calculating the volume by the International ¼-inch rule is slightly different; PINEVOL

1. Sets the saw-log height utilized (HSAW) to the stump height, calculates the height of the tree (MERHT) to the specified minimum diameter for saw logs, sets the number of pieces (NPIECE) to one, and sets the length of a piece (LPIECE) to 4 feet
2. Finds the new HSAW by either adding LPIECE and a trim allowance to the existing saw-log height if NPIECE is a

multiple of four (16-foot log) or the last possible piece on the tree or by just adding LPIECE if it is in the middle of the log—increments NPIECE by one

3. Calculates the scaling diameter at HSAW
4. Calculates the volume of this piece using the appropriate mathematical volume equation [equation (5)] and adds it to the total volume

$$\text{Int } \frac{1}{4}\text{-inch Volume} = \begin{aligned} &0.049762Ld_s^2 + 0.00622L^2d_s \\ &- 0.185476Ld_s + 0.000259L^3 \\ &- 0.011592L^2 + 0.042222L \end{aligned} \quad (5)$$
5. Increments NPIECE by one and sets LPIECE to 4 feet
6. Determines if HSAW plus LPIECE plus trim allowance will fit below MERHT and if not reduces LPIECE by 2 feet—repeats this until LPIECE is < 2 feet in length
7. If LPIECE is at least 2 feet in length loops back to step 2

Program Operation

System Requirements

PINEVOL is a Windows® program so some version of Microsoft Windows 95 or higher is necessary. At least 10 MB of hard disk space for installation of the program and help files will be required. When running, the program uses 7 MB of RAM. The minimum screen resolution for this program is 1024 X 768. Lower resolutions do not prevent the program from running, but several of the screens will not fit entirely on the monitor.

Installation

PINEVOL is a standard Windows® program complete with an installation package packed in a Zip™ file. This Zip™ file is available at <http://www.srs.fs.usda.gov/4111/techtrans.htm> or by request from the author. To perform the installation a user has to open the Zip™ file, double click on setup.exe, and follow the prompts. Administrative privileges are not required to install PINEVOL. On some systems, such as Windows 2000®, there might be a warning about the possible need for administrative privileges but they are not necessary since PINEVOL does not change your system settings in any significant way. PINEVOL can be removed from a system via the Add/Remove Programs icon in the Windows® Control Panel.

Usage

If installed with the installation program, PINEVOL can be selected and run from the Start menu. This will produce the title screen shown in figure 1.



Figure 1—The PINEVOL title screen that introduces the program.

The title screen remains for up to 5 seconds. Click on the box labeled PINEVOL and the Volume Parameters screen (fig. 2) will appear immediately.

This screen is used to specify the parameters that affect what trees and what parts of those trees will be included in volume. PINEVOL assumes that total volume is always from groundline to the tip of the crown. However, merchantable and saw-log volumes can have variable stump heights, minimum breast height diameters, or minimum inside or outside bark top diameters.

PINEVOL looks for stored volume parameters in the file VOLUME.PRM in the install folder of this program. If PINEVOL fails to locate VOLUME.PRM, it applies a set of changeable default values. To replace the existing VOLUME.PRM file or create a new one, check the box “Save for future runs” before continuing.

The next screen (fig. 3) presents the user with a choice of modes of operation. PINEVOL can operate in either batch or

interactive mode. The batch mode reads a data file for multiple stems and creates a new file containing volume estimates, whereas the interactive mode allows the user to input the parameters for individual trees.

Output

Whether the batch mode or the interactive mode is chosen, PINEVOL calculates the same information. Only the format differs. The first variable calculated is crown ratio. This is very important because the mathematical models used in this program rely on crown ratio to determine which taper parameters will be used. Next, PINEVOL shows which of the three crown ratio classes is actually used. Crown ratio class 1 is for crown ratios < 36 percent, crown ratio class 2 is for crown ratios from 36 to 50 percent, and crown ratio class 3 is for crown ratios that exceed 50 percent. Girard form class, or the percentage ratio of the inside bark diameter at the top of the first log to d.b.h. outside bark, is presented. Merchantable height is the height to the diameter specified for merchantable volume, and height to a saw-log top is the height to the diameter specified for sawtimber volume.

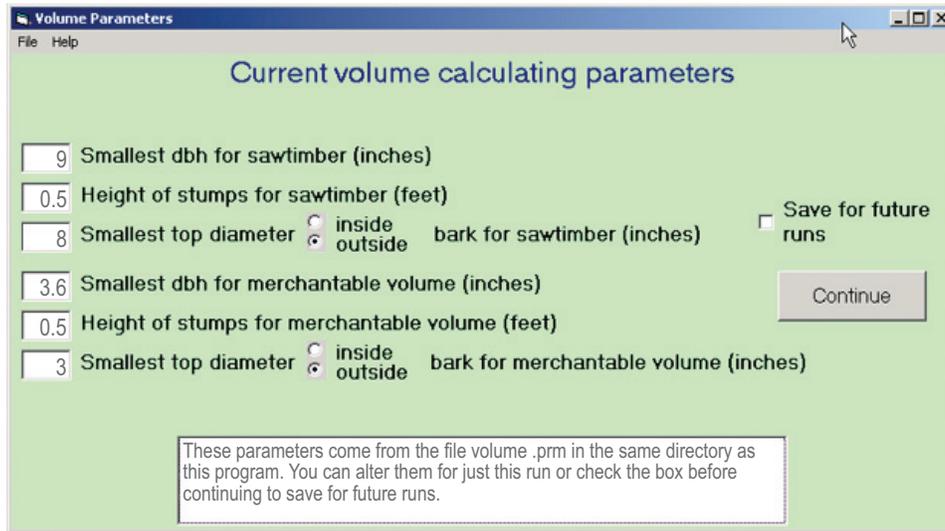


Figure 2—The Volume Parameters screen is used to customize the calculated volume standards and also provides a save option for later use.

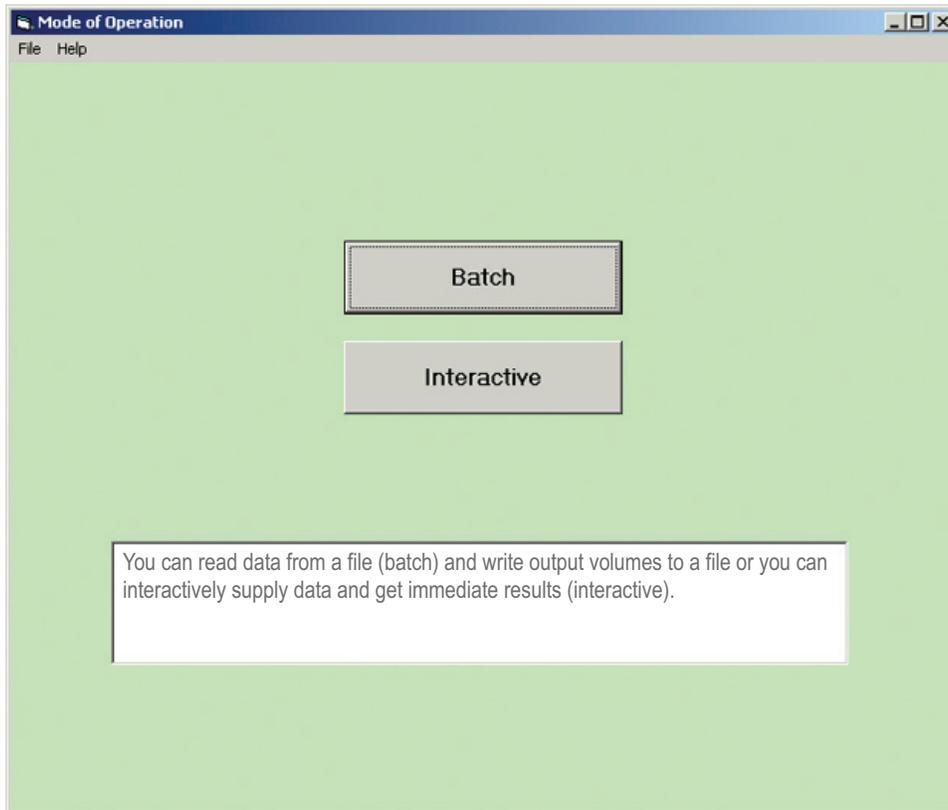


Figure 3—The Mode of Operation screen lets the user choose to process a file in batch mode or use the program as an interactive volume calculator.

When a tree with a given saw-log height is actually broken into logs with trim allowance, usually the full height to a saw-log top cannot be used. Saw-log height actually utilized is the part that can. Total cubic-foot volume inside bark and total cubic-foot volume outside bark are volumes from the base to the tip of the tree. Merchantable volume inside bark and merchantable volume outside bark are volumes in cubic feet from stump height to the height of the specified merchantable diameter. The stump height used depends on the size of the tree. The saw-log stump height is used for trees that are large enough to have saw-log volume, and merchantable stump height is used for smaller trees. Saw-log volume inside bark and saw-log volume outside bark are the volumes in cubic feet from the saw-log stump height to the saw-log height actually utilized. Note that one can calculate the pulpwood harvest by subtracting saw-log volume from the merchantable volume in cubic feet. Volume by the Doyle rule, volume by the Scribner rule, and volume by the International 1/4-inch rule are volumes in board feet by the most commonly used log rules. All of the volumes calculated are independent. This means that total tree volume includes merchantable tree volume. To calculate the unmerchantable portion of a tree, one can subtract merchantable volume from total volume.

Batch Mode Operation

Once batch mode is selected, the user is prompted to identify the data file (fig. 4). By default, only files with a .dat extension are shown. However, other specific extensions (such as .txt) can be used. PINEVOL input files must be ASCII text

files and must contain at least a tree identification, a species code, a stand origin indicator (0 = natural, 1 = planted), a d.b.h. in inches, a total height in feet, and a height to the base of live crown in feet. Several arrangements of these variables are possible in delimited files or any arrangement is possible in a fixed-column format file. There is an example in figure 5. Most application-specific files like Word®, Excel®, or WordPerfect® have invisible formatting characters embedded in them that this program cannot read. Your file can have headers or footers since the starting line and number of lines to process are selected at run time. Comments and data cannot be intermixed unless each block of data is processed in a separate run. Acceptable species codes and stand origin values are listed in table 2.

After an input file is selected, an output file must be identified (fig. 6). By default, only files with the extension .txt are listed, but all files can be shown. PINEVOL creates an ASCII text file with a header line and one line for each tree processed (fig. 7). In addition to presenting the calculated variables described above, each output tree line begins with tree identification information followed by the species code, d.b.h., height to the base of the live crown, and total height.

The next screen displays the full path of your input and output files and the first 100 lines of the input file (fig. 8). There is no limit to the number of trees that can be processed, but the file display is limited to 100 lines to save memory. To continue, select the format of your data using the combo box beneath the file display. Several delimited formats and fixed-column format are available.

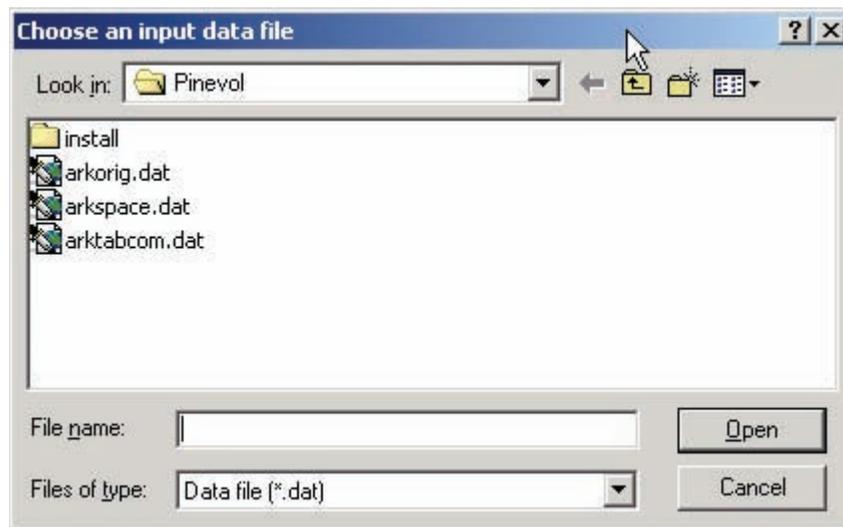


Figure 4—The program uses a standard Windows® common dialog box for the selection of a file to be processed. The default file extension is .dat.

```

1 131 1 12. 60 70
1 131 1 30. 35 70
1 131 1 12. 20 70
1 131 1 8. 40 50
1 131 1 8. 25 50
1 131 1 8. 10 50
1 131 1 4. 25 30
1 131 1 4. 15 30
1 131 1 4. 5 30
1 6 1 4. 15 30
1 110 1 4. 5 30
1 131 0 12. 60 70
1 131 0 a2. 35 70
1 131 0 12. 20 70
1 131 0 8. 40 50
1 131 0 8. 25 50
1 131 0 8. 10 50
1 131 0 0. 25 30
1 131 0 4. 15 30
1 131 0 4. 5 30
1 110 0 12. 60 70
1 110 0 12. 35 70
1 110 0 12. 20 70
1 110 0 8. 40 50
1 110 0 8. 25 50
1 110 0 8. 10 50
1 110 0 4. 25 30
1 110 0 24. 23 30
1 121 0 4. 15 30
1 121 0 4. 15 30
1 121 0 4. 15 30
1 121 0 4. 15 30
1 121 0 4. 15 30
1 6 0 4. 15 30
1 110 0 4. 5 30

```

Figure 5—An example of an input file in fixed-column format. This file, which has no header information, has a plot identifier, a species code, a planting indicator, a d.b.h., a height to base of live crown, and a total height. There are some intentional errors in this file so that their effects can be shown in the output and log files.

Table 2—Species codes, species names, and the taper models available in this program

Species code	Species name	Models available
110	Shortleaf pine (<i>Pinus echinata</i> Mill.)	0 = Natural (Farrar and Murphy 1987)
111	Slash pine (<i>P. elliotii</i> Engelm.)	1 = Planted (Dell and others 1979)
121	Longleaf pine (<i>P. palustris</i> Mill.)	0 = Natural (Farrar 1987) 1 = Planted (Baldwin and Polmer 1981)
131	Loblolly pine (<i>P. taeda</i> L.)	0 = Natural (Farrar and Murphy 1988) 1 = Planted (Feduccia and others 1979)

In delimited formats, the input variables must be separated by nonnumeric characters (spaces or commas are preferred for readability). All characters to the left of the required numeric data are considered tree identification information, and this is copied to the output file. The length of the tree identification information in the output file is determined by its apparent length in the first record processed.

If the fixed-column format is used, the input file columns that contain the required information will have to be specified. In

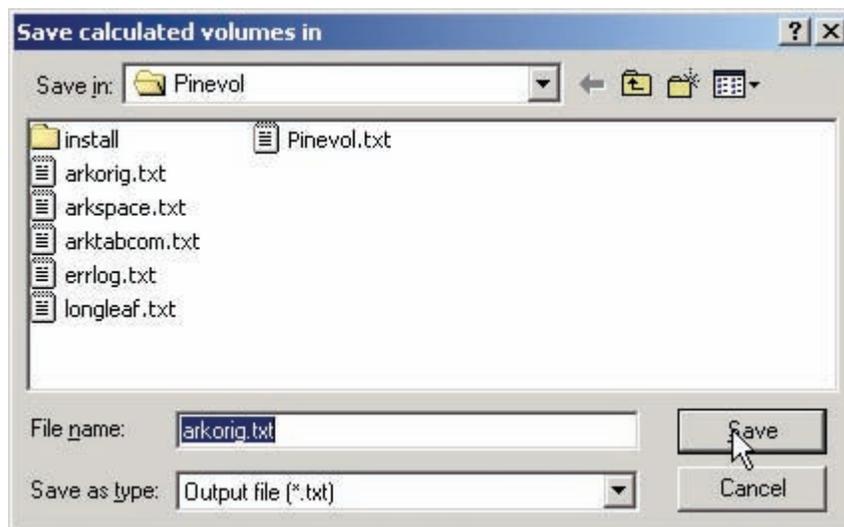


Figure 6—The program uses a standard Windows® common dialog box for the specification of a file to save results in. The default file extension is .txt.

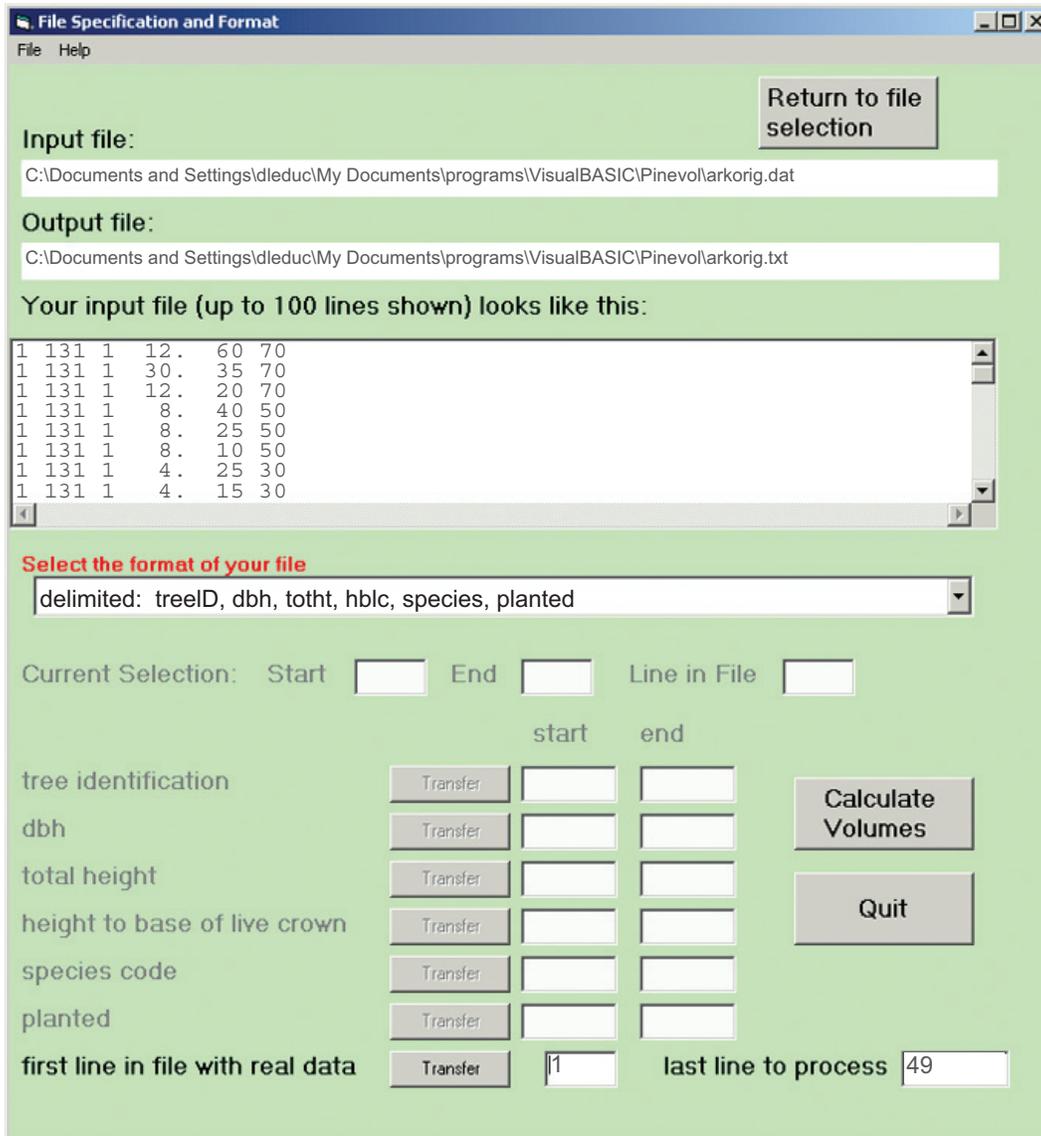


Figure 8—The File Specification and Format screen shows the names of the input and output files and some sample lines from the input file. It is used to define the format of the input data so that the proper columns of numbers can be used in calculations.

this format column numbers can be entered if they are known, but PINEVOL does have a tool to determine these column numbers. The procedure is best explained by a video in the help file. Basically, this tool allows the user to select variables in the input file preview, and the first and last columns as well as the line in the file are displayed immediately beneath the box. Transfer buttons are available to copy these values to the input boxes for each variable. The row in the file is always displayed but is primarily used to specify a starting row beneath any header information. For completeness, there is also a last row to process option. There is no transfer button for this function since, in most cases, this row

will not appear within the first 100 rows. The value defaults to the last line in the file, but can be changed by the user.

In fixed-column format, whatever columns might constitute tree and plot information can be selected, or even the entire observation can be selected. These data are simply copied to the output file and can include spaces and overlap the real numeric variables.

When all of the columns and rows have been filled in, a click of the calculate volumes button will start the calculation process. If a line of data cannot be interpreted as tree data an

```

ERROR: Invalid data on line 8
==> Species code invalid or nonexistent model combination specified.
==> species code: 6 planted indicator: 1 dbh: 4 height to base of live crown: 15 total height: 30

ERROR: Invalid data on line 9
==> Species code invalid or nonexistent model combination specified.
==> species code: 110 planted indicator: 1 dbh: 4 height to base of live crown: 5 total height: 30

ERROR: Invalid data on line 11
==> DBH is unreadable or equal to zero.
==> species code: 131 planted indicator: 0 dbh: 0 height to base of live crown: 35 total height: 70

ERROR: Invalid data on line 16
==> DBH is unreadable or equal to zero.
==> species code: 131 planted indicator: 0 dbh: 0 height to base of live crown: 25 total height: 30

ERROR: Invalid data on line 21
==> Height to the base of live crown cannot exceed or equal total height.
==> Total height is unreadable or equal to zero.
==> species code: 110 planted indicator: 0 dbh: 12 height to base of live crown: 20 total height: 0

ERROR: Invalid data on line 32
==> Species code invalid or nonexistent model combination specified.
==> species code: 6 planted indicator: 0 dbh: 4 height to base of live crown: 15 total height: 30

```

Figure 9—An example of PINEVOL.LOG showing the form of error messages. These messages correspond to the input file shown in figure 5.

error box will pop up and calculation will be stopped so that the input file can be fixed. If any individual variable cannot be read as a number, it is set to zero. If any of the numeric data would result in a failed calculation (for example, 0 for d.b.h., height to base of live crown, or total height or an invalid species code) that line is marked as an error, and all output volumes will be set to zero, but calculation continues with the next tree. An error message will be written into PINEVOL.LOG (fig. 9). If the d.b.h. or total height or height to base of live crown is outside of the range used to develop these taper functions, the user will be warned, but the calculation will proceed. The warnings will indicate which variable was out of range. A summary box will appear indicating the number of records processed. After PINEVOL completes its calculations, exit the program and use any text editor to review the results or stay in the program and pick a new file to process.

Interactive Mode Operation

If interactive mode is chosen, the screen shown in figure 10 will appear. In interactive mode species selection is presented as option buttons, and the d.b.h. (in inches), total height (in feet), and height to the base of the live crown (in feet) are entered manually in text boxes. After this data is entered, clicking on the calculate button will calculate volume. Changes to any of the input tree parameters after volume has been calculated produces a warning that the calculated numbers shown on the screen are no longer applicable to the current tree (fig. 11).

The interactive mode screen also has a button to change volume calculation parameters. This button returns the user

to the screen where stump height, minimum d.b.h., and minimum top diameter for merchantable and saw-log trees is specified. The results can be printed by clicking the “Print” button.

Troubleshooting

PINEVOL uses the standard Windows install routine. This can fail on some systems. If it does, the PINEVOL.CAB file can be unpacked with “EXTRACT /E PINEVOL.CAB” and PINEVOL.EXE can be run. Doing this will not set up the directory in the Program Files directory or add the program to your Start menu, but the program should run. But it is also possible that the .DLL files might have to be registered with Windows. The basic syntax for doing that is “REGSVR32 FILENAME.DLL” for each of the .DLL files in the .CAB file. Neither of these corrective actions should be necessary.

When PINEVOL is running, anticipated errors will generate warning or error messages. In batch mode the user is warned that there may be errors and each line of output is flagged for errors, but the actual error messages are contained in a file called PINEVOL.LOG located in the same directory as the output file. These messages indicate the line number of the input file on which the error occurred as well as some explanation of what caused the error. An example log file is shown in figure 9.

The equations used in these volume models were developed for a specific range of data. The user is allowed to specify trees that are not within the recommended ranges, but a warning message will be printed if this is done. Warnings in

Figure 10—The Interactive Data Entry screen requires the selection of a species and entry of a d.b.h., total height, and height to base of live crown for the tree of interest. Limits are shown for the selected species and all calculated volumes are shown on the lower portion of the screen.

the output file for batch mode are appended to the end of output lines and just indicate the tree parameter that is out of range. Examples of warnings and errors are shown in the example output file (fig. 7). The user can choose to ignore these messages or find a more suitable model for these special cases. In interactive mode the warnings are similar and the program will refuse to calculate results if attempting to do so would result in a mathematical error.

Conclusion

PINEVOL is a handy program for calculating the volume of southern pine trees. It has been used internally for a number of years, but has now been repackaged for the general public. Visual Basic® source is also available upon request.

Acknowledgments

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Interactive data entry

File Help

pine species: natural: loblolly longleaf shortleaf
 planted: loblolly longleaf slash

dbh (inches): (1 to 34) Specifications changed! Results shown may not be valid.

total height (feet): (9 to 119)

height to live crown (feet): (15.84 to 85.1) Calculate Change Parameters Print

Crown Ratio: 0.24 Crown Ratio Class: 1 Form Class: 85

Merchantable Height: 93.4 feet Sawlog Height: 82.3 feet Utilized Height: 82.0 feet

	Inside Bark	Outside Bark
Total Cubic-Foot Volume:	134.33 cuft	157.94 cuft
Merchantable Cubic-Foot Volume:	131.73 cuft	154.62 cuft
Sawtimber Cubic-Foot Volume:	129.96 cuft	152.43 cuft

Doyle Board-Foot Volume: 706.9 bdf

Scribner Board-Foot Volume: 798.4 bdf

International 1/4-inch Board-Foot Volume: 901.6 bdf

Quit

Figure 11—Once volume has been calculated and any tree specification has been changed the results of the previous calculation are changed to red and a warning is printed that these are no longer the correct results. The previous volume results are not cleared so that the user can observe volume changes when the Calculate button is clicked.

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Taper functions describe a model of the actual geometric shape of a tree. When this shape is assumed to be known, volume by any log rule and to any merchantability standard can be calculated. PINEVOL is a computer program for calculating the volume of the major southern pines using species-specific bole taper functions. It can use the Doyle, Scribner, or International 1/4-inch log rules or calculate solid wood volume inside or outside of bark. This document describes the methods used in volume calculation in PINEVOL and is a program user's guide.

Keywords: Loblolly pine, longleaf pine, shortleaf pine, slash pine, stem profile equations, taper functions.



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