Annual Report to the Department of Conservation and Recreation On the Activities of Friends of Mohawk Trail State Forest For 2007-2008

Prepared by

Robert T. Leverett, President, and

Professor Gary Beluzo, Science Advisor

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Introduction

The years 2007 and 2008 were times of relatively light activity for Friends of Mohawk Trail State Forest (FMTSF). Nonetheless, Friends has collected significant new information on forest, stand, and individual tree growth in Mohawk Trail State Forest (MTSF), Monroe State Forest (MSF), and on other DCR properties. The tables and lists of this report present both raw and summary data, to include data from non-DCR properties. Data from both classes of properties are compared, the purpose being to put the DCR data in a more relevant context. A few words on this point are in order.

Without meaningful comparisons, conclusions about important DCR properties would be less valuable to forest historians, foresters, naturalists, and ecologists. Our intention in presenting our analysis, findings, and conclusions in this report is to increase our understanding of the particular attributes and values of the DCR forests that we are studying.

We note that an indispensable partner of Friends throughout the 2007-2008 period has been the Eastern Native Tree Society (ENTS). The scientific expertise of ENTS has been continuously available to FMTSF. In fact, ENTS members have contributed most of the data, analysis, and conclusions. Of particular noteworthiness are the contributions of the authors Professor Gary Beluzo and Robert T. Leverett. Valuable contributions have also been made by Dr. Lee Frelich, Dr. Don Bragg, Dr. David Stahle, Dr. Tom Diggins, President of ENTS Will Blozan, ENTS mathematician John Eichholz, and others. ENTS Webmaster Ed Frank has also made major contributions to FMTSF through his publishing of study results on the ENTS website and his creation of web space for FMTSF. All the foregoing have been conceptual thinkers in terms of forest processes studied, measurement protocols, and actual field measurements.

We will now briefly discuss the type of data included in this report. A full understanding of the forests on DCR properties can only be achieved by approaching the subject from different perspectives and disciplines. The FMTSF perspective presented in this report is not available from other sources either internally or externally to DCR. Consequently, the type of data presented is unique and fills a gap.

Most forest-based data systems are concerned with timber production and wildlife habitat on the utilization side and old-growth, wetlands, and rare and endangered species on the protection side. Over the past decade here in Massachusetts, the Rare and Endangered Species Program, old-growth forest policy, and wetland statutes that afford protection for forested corridors adjacent to streams have protected areas of forest. Today the concept of forest reserves under Green Certification provides another vehicle for protecting forest sites from active management. The aforementioned four programs provide us with tools to insure special forest sites are exempted from cutting plans. However, gaps remain in our protection apparatus, especially where old growth, wetland, and/or rare and endangered species protections do not specifically apply. This is the case for individual trees and stands of trees that exhibit exceptional growth or structural characteristics, have a historical value, or are highly appealing from an aesthetics standpoint.

With respect to individual trees, there is a state champion tree program that follows the lead of the national champion tree program operated by American Forests. The state program maintains a list of "champion trees" considered to be the largest members of their species, and presumably champion trees have value as a consequence of their status. The champion tree program was originally conceived to get the general public to recognize and appreciate big trees as important for genetic potential during a period when big trees were rapidly disappearing across the landscape. In the champion tree program, trees are evaluated for championship status through a simple formula that adds tree girth in inches, height in feet, and one-fourth the average crown spread in feet to get a composite point total. The tree of a species that earns the highest point total is acclaimed the champion of the species and afforded administrative protection. The champion tree formula favors open-grown trees with large trunks and spreading crowns over the taller, straight-bole trees grown in a forest environment.

The champion tree program is useful, but does not provide insights into the genetic potential of a forested site The program is not designed to highlight special stands of trees or forested areas that exhibit exemplary characteristics, such as larger than average tree size, or great age, nor does the program recognize forest value for historic and/or cultural reasons. Consequently, the champion tree programs have little traction with groups who are otherwise invested in our forests such as foresters who understandably prefer straight-trunk and forest-grown shapes. From the standpoint of tree aficionados, the champion tree programs do not recognize outstanding trees based on the criterion of individual tree dimensions. For the most part, the champion tree programs are relegated to hobby status.

Individual trees in towns are sometimes preserved because of historical associations with prominent people, but not because of a single outstanding dimension such as height, girth, or crown spread. Protections of this type are strictly local. Consequently, we conclude that official recognition in Massachusetts for stands or groves of trees as valuable for historical documentation, exceptional beauty, size of their trees, genetic features, etc. and recognition of individual trees based on a specific dimension does not exist on state-owned lands. Data that might otherwise be collected to open the door to special administrative site and tree protections are, in so far as we are aware, not collected except by FMTSF and ENTS.

For the purposes of this report, we summarize by emphasizing that the data that FMTSF gathers on forested properties in Massachusetts and that ENTS gathers throughout the eastern United States help to fill the void described above. As a society, we are likely to do a better job of protecting particular trees and stands of trees when we understand where they fit into the broader scheme of forests and trees and to determine the hierarchy, more accurate measurement techniques are needed than those commonly in use today. It is primarily in this context that FMTSF is pleased to present the following data, analysis, and conclusions on the outstanding trees and forests sites on DCR properties. We include the methods used to study them. We make the methods available to DCR foresters and would be pleased to present a workshop on use of the techniques.

The report is organized around a series of independent topics. Given the heterogeneous nature of our research and our limited staff, this organization serves us best. Any questions concerning this report should be addressed to either Robert T. Leverett or Gary Beluzo who are solely responsible for the contents of the document.

Update on Rucker Analysis

The first topic of this report is an update on Rucker Analysis as defined and discussed in prior reports. As a brief review, Rucker Analysis has been developed by the Eastern Native Tree Society (ENTS) as a means of evaluating the productivity of a site to grow large and/or tall trees and to provide a glimpse at a point in time of the growth achieved at a site. There is historic value to maintaining the index for a site over a period of years. The historical trend, married with age data, allows us to analyze the interplay of growth capability with disturbance impact.

A Rucker Index focuses attention on the maximum girths and heights of the largest and tallest species on a site as of a point in time. Basically, there are four kinds of Rucker indices: girth, height, spread, and volume. Heretofore, the most widely used index has been the height index. To calculate a site height index, the tallest individual member of each of the ten tallest species is measured. The ten heights are then averaged. The average is called the RHI-10 (Rucker height index for 10 species) or RI for short when 10 species are used. A particular species can enter the index only once. If the index is based on a different number of species, e.g. 7 instead of 10, the notation is RHI-7. If we record the time interval to which the index applies, we may use notation such as RHI-10-2008. A similar notation is used for tree girths. The notation is RGI-10 or RG for short with the number of species variation and date addition as shown. RSI and RVI are applied to crown spread and trunk volume indices.

On the surface, the full utility of these indices may not be obvious. However, RHI can be used as a substitute for forestry's site index where multi-aged forests are involved and collection of tree age data is not feasible. In addition, Rucker indices provide us reminders of what forests and individual species are capable of achieving in different time periods. This can provide us with a balanced perspective on forest use where commercial pressures continually reduce forests to average younger ages.

Through the efforts of ENTS, Rucker indices have been developed for much of the eastern United States. However, the indices are not strictly comparable. The average ages of the trees on one site can be very different from another and the size of the sites varies greatly. However, general trends emerge. For a species with a wide range, as a general rule, the species gets larger and taller in southern climates than in northern ones. There are exceptions, but the rule holds in general. ENTS is developing guidelines to species maximums by region. The results will be presented in these reports as appropriate.

As we have reported in the past, in terms of tree height superlatives, Cook Forest State Park in PA, Zoar Valley in NY, MTSF in MA, and Fairmount Park in PA are the top four sites in the Northeast. The position of MTSF continues to be an intriguing one, especially since it is the most northerly of the sites. Table 1 below shows the RI for MTSF, updated as of November 2008.

Table 1
Rucker Height Index Report for MTSF

As of November 2008

Height	*Species*	*Location*	*Circumference*	*DOM-Last*
168.5	White pine	Trees of Peace	10.5	11/2/2008
150.3	White ash	Trout Brook	6.4	11/1/2008
134.4	Sugar maple	Trout Brook	5.0	10/23/2006
133.5	N. red oak	Todd Mtn	9.3	11/25/2004

131.8	Bitternut hickory	Indian Flats	4.3	4/24/2006
130.5	American beech	Clark Ridge-North	8.4	4/9/2006
130.3	Hemlock	Black Brook	11.1	11/26/2006
128.0	Red maple	Clark Ridge-Elders	6.6	4/15/2006
126.9	American basswood	Clark Ridge-North	5.5	4/26/2006
126.0	Bigtooth aspen	Clark Ridge-Shunpike	3.5	4/27/2006
136.0	**Rucker Index**			

The Rucker analysis that we have done to date shows that for any particular site, the RI moves up and down more quickly than we previously thought. Of course, trees grow, die, sustain crown damage, and recover. Entire species become susceptible to disease or are attacked by insects and decline rapidly. We also find new champions. However, MTSF and MSF have been intensively measured and we can generalize. Over the next decade, the RI for MTSF will likely move between 134 and 136 and will probably remain above 130 for two or three decades. The high diversity of tall tree species and the relative youth of large areas of the forest are the reasons. In particular, the white pines of MTSF are extremely healthy and will continue to grow at a rapid rate into middle maturity (125 to 175 years). Barring damage, many pines will move into the higher height brackets within the next two to three decades to insure the white pines contribution to MTSF's RHI.

It is not as clear that the white ash and sugar maple are fairing as well as the pines in MTSF. A longer period of observation is necessary to determine what is happening to them. However, it is our tentative conclusion that the present RI of 136 is near the maximum for MTSF and the ceiling for all New England properties of comparable area. The chances of a higher index north of MTSF are extremely minimal to nonexistent and we have yet to discover a site in southwestern Connecticut to rival Mohawk, although searching there has not been intensive. We mention southwestern Connecticut because that region has both the white pine and tuliptree as super canopy species along with American sycamore, white ash, eastern hemlock, and pignut hickory as other tall species. Average stand age can be low in Connecticut. Sites that would otherwise have tall trees are too young to reflect the full potential of the species for the latitude.

While an oscillating value can be expected for Mohawk's RHI , the RGI can be expected to remain stable for longer periods of time. Table #2 below shows the RGI for MTSF. The large sugar maple is probably a double. Single-trunk maples reach up to 11 feet in girth in MTSF. With more refinement and measurements, an RGI of between 11.5 and 11.9 is probable for MTSF.

Table 2

Rucker Girth Index Report for MTSF

As of November 2008

Circumference	*Species*	*Location*	*Height*	*DOM-Last*
18.4	Sugar maple	Todd Mtn	106.5	10/16/2004
14.8	Hemlock	Cold River A	105.8	6/16/2003
14.6	White pine	Trout Brook	148.3	6/8/2002
13.0	Black locust	Todd Mtn	84.8	2/22/2004
12.5	Red maple	Trout Brook	93.9	11/4/2000

12.3	N. red oak	Clark Ridge-North	117.5	5/30/2004
11.2	White ash	Clark Ridge-North	123.4	1/10/2000
10.2	Yellow birch	Trout Brook	90.4	4/10/2005
8.6	Black birch	Cold River E	80.5	4/11/1999
8.6	Black cherry	Cold River C	105.5	11/1/1998
12.4	**Rucker Index**			

Other indices that ENTS computes include the Rucker Crown Index (RCI) and the Rucker Volume Index (RVI). Crown and volume indices have not been actively pursued because of the labor-intensive nature of the measurements. We have pursued height to diameter ratios as another way of assessing site productivity. However, not enough data have been gathered at this point to be presented in the annual reports.

As a summary of Rucker analysis, Table #3 below shows RI values for States in the Northeast. RI values for states in the Southeast, as shown in prior reports, are excluded. Comparisons made with Massachusetts sites are intended for areas of similar climate and overall growing conditions.

Table #4 gives Rucker values for Massachusetts. The first part of the table lists important townships. The second part shows individual sites. With a RI of 136.0, as can be seen, MTSF continues to dominate individual sites in Massachusetts and ranks #3 in the entire Northeast. Finally, Table #5 gives RHI values for Pennsylvania sites.

Table 3
Rucker Heights for Northeastern States

State	No. Species	RHI Value	Sampling Status
PA	10	145.2	Heavy
MA	10	141.1	Heavy
NY	10	139.7	Moderate
NH	10	116.5	Moderate
CT	10	114.8	Light
VT	10	108.3	Light
ME			Minimal
NJ			Minimal

In Massachusetts, we have extensively searched for the high growth sites with trees that are sufficiently old to demonstrate species potential. The following table shows composite RI values for 12 townships including multiple sites followed by 13 individual sites.

Table 4
Rucker Heights for Massachusetts Sites

State	Township	No. Properties	No. Species	RHI Value	Sampling Status
MA	Charlemont	Multiple	10	135.2	Heavy
MA	Stockbridge	Multiple	10	129.0	Heavy
MA	Savoy	Multiple	10	125.9	Moderate
MA	Northampton	Multiple	10	120.3	Heavy
MA	Holyoke	Multiple	10	118.6	Heavy
MA	Florence	Multiple	10	117.1	Heavy
MA	Westfield	Multiple	10	115.8	Moderate
MA	Deerfield(South & Old)	Multiple	10	115.6	Moderate
MA	Greenfield	Multiple	10	114.8	Moderate
MA	Williamsburg	Multiple	10	112.1	Moderate
MA	Hatfield	Multiple	10	107.4	Moderate
State	**Site**	**No. Properties**	**No. Species**	**RHI Value**	**Sampling Status**
MA	MTSF	Single	10	136.0	Heavy
MA	Ice Glen	Single	10	128.2	Heavy
MA	MSF	Single	10	123.7	Heavy
MA	Robinson	Single	10	118.8	Heavy
MA	Mt Tom	Single	10	118.0	Heavy
MA	Mt Greylock	Single	10	116.0	Estimated
MA	Broadbrook	Single	10	115.6	Heavy
MA	Bullard Woods	Single	10	113.1	Heavy
MA	Bartholomew Cobble	Single	7	112.5	Moderate
MA	Petticoat Hill	Single	10	110.8	Heavy
MA	Smith College	Single	10	110.1	Heavy
MA	Bryant Homestead	Single	10	106.9	Heavy
MA	Look Park, Northhampton	Single	10	106.6	Heavy

The most productive comparison of sites outside Massachusetts can be made with those in Pennsylvania. The latitude of Pennsylvania sites overlaps those of Massachusetts. In general, the PA sites are a little south of those in Massachusetts. Growing conditions are on the whole, more favorable. The table below gives Pennsylvania sites that ENTS has documented.

Table 5
Rucker Heights for Pennsylvania Sites

Site	Rucker Index
Cook Forest State Park	137.15
Fairmont Park	132.27
McConnells Mill State Park	130.85
Clarion River	129.72
Wintergreen Gorge	127.53
Greendale Cemetary	127.23
Ricketts Glen State Park	126.29
Walnut Creek Gorge	123.66
Anders Run Natural Area	121.59
Ohiopyle State Park	120.36
Allegheny River: Buckaloons-Kibbe's Island	119.75
Little Elk Creek Gorge	119.45
Clear Creek State Park	118.30
Delaware Water Gap National Recreation Area	118.24
Heart's Content Natural Area	117.95
Coho Property	116.28
Sisters of St. Francis	115.15
Hemlocks Natural Area	114.75
Allegheny River Islands Wilderness Area-Hemlock Island	114.75
Sixmile Creek Gorge	114.58
Lake Erie Community Park	113.57
Raccoon Creek State Park	112.36
Cook Estate	111.70
Alan Seeger Natural Area	111.13
Tionesta Scenic & Research Natural Area	110.96
Scott Community Park	109.56
Keystone State Park	109.40
Parker Dam State Park	108.89
Gettysburg National Military Park	108.12
Latodami Nature Center	106.51
Asbury Woods	105.84
Allegheny River Islands Wilderness Area – Thompson Island	105.33
Detweiler Run Natural Area	104.65
Laurel Run Rd-Centre County	104.60
SGL 155-Erie County	103.04
Hemlock N.A.-Laurel Hill State Park	99.82
Glenwood Park	98.08
Shingletown Gap	97.47
Clarion River-Millstone	95.55
Bear Meadows Natural Area	93.72
Allegheny River Islands Wilderness Area – Courson Island	92.10
Erie Cemetery	91.88

Conneaut Marsh-SGL213	90.37
Frank residence, Reynoldsville, PA	88.82
Erie Wildlife Refuge, Cambridge Springs	87.08
Oil Creek State Park	83.03

Summary

The above site indices place Pennsylvania at the top of the list in the Northeast and suggest that within the latitude range of 39 to 42 degrees, the best Pennsylvania sites to have RIs of 115 or more. A few exceed 125 with a small subset at or above 130. Three Pennsylvania sites exceed 130, with Cook Forest at 137.15 – highest in the Northeast. Top sites in southern New York in the foothills of the Catskills and along the Hudson River achieve RIs of 120 to just below 130. The highest site in New York is Zoar Valley, a true anomaly at 137. Massachusetts boasts one site above 130, MTSF.

The difference in degree days between Pennsylvania and Massachusetts is likely correlated to the higher tree growth rates for Pennsylvania and this trend continues farther south in those regions with favorable soils and precipitation. How does Massachusetts stack up to the best tree growth in: (1) the entire East, (2) the Northeast, and (3) New England for a selection of species that grow in Massachusetts? This is a question that FMTSF and ENTS have been in the processing of answering for several years. The following table shows the results for 20 species of trees that grow in Massachusetts.

Table 6
Height Comparison: All Eastern US to Massachusetts

Species	Eastern Record	Where	Massachusetts Record	Where	Diff
White pine	188.80	GSMNP, NC	168.50	MTSF	20.30
Tulip Poplar	182.30	GSMNP, NC	139.70	Robinson SP	42.60
Eastern Hemlock	173.10	GSMNP, NC	138.40	Ice Glen, Laurel Hill	34.70
Black Locust	171.80	GSMNP, NC	118.20	Northampton	53.60
Pignut hickory	168.20	Sumter, NF, SC	128.50	Southwick, Private	39.70
White ash	167.10	GSMNP, NC	150.30	MTSF	16.80
Sycamore	162.20	GSMNP, NC	137.00	Easthampton	25.20
Bitternut Hickory	156.30	GSMNP, NC	131.80	MTSF	24.50
Red Spruce	155.30	GSMNP, NC	133.50	Mt Greylock	21.80
Eastern Cottonwood	153.60	Meeman Shelby, TN	129.00	Bartholomew'sCobble	24.60
Northern Red Oak	152.90	Whitewater Falls, SC	133.00	MTSF	19.90
Sugar Maple	151.00	GSMNP, NC	134.40	MTSF	16.60
Shagbark hickory	150.30	Savage Gulf, TN	135.30	Ice Glen, Laurel Hill	15.00
White Oak	147.10	GSMNP, NC	115.20	Bullard Woods	31.90
Black Cherry	147.00	GSMNP, NC	125.30	MTSF	21.70
American Elm	144.30	GSMNP, NC	120.00	MTSF	24.30
Red Pine	142.70	Hartwick Pines, MI	120.50	Mt Tom SR	22.20
American Beech	142.60	GSMNP, NC	130.50	MTSF	12.10
Red Maple	142.20	GSMNP, NC	128.00	MTSF	14.20
Bigtooth Aspen	126.00	MTSF	126.00	MTSF	0.00
Average					**24.09**

ENTS Advances in Tree Measurement Methodology for Field Operations

One of the primary missions of ENTS, with FMTSF being a recipient of the results, is to develop more efficient methods for accurately measuring the dimensions of trees to include height, girth, crown spread, limb length, trunk volume, and limb volume. Crown spread, limb length, and limb volume have little value to timber specialists. The same cannot be said for height, girth, and trunk volume. These last three measurements are of value to forestry.

The ENTS role in developing an accurate method of measuring tree height has been thoroughly explained in past annual reports. It has been the method that has led to the RHI data of above. A scientific paper is currently being coauthored by Dr. Lee Frelich of the University of Minnesota, Robert T. Leverett of FMTSF, Will Blozan of Appalachian Arborists, and Dr. Don Bragg of the U.S. Forest Service that quantifies the errors made when using a clinometer and tape to measure tree height as compared to ENTS-engineered methods that employ lasers and clinometers. The errors commonly made by timber professionals with the clinometer and tape measure method are not necessarily important to forestry field work where approximations may be sufficient, but in answering questions about how much carbon sequestering occurs as trees of different dimensions grow both radially and in height, measurement errors need to be minimized. Accurately answering questions about height gains of individual trees requires ENTS methods.

Beyond the ENTS focus on measuring single tree dimensions, extensive analysis has gone into developing methods for quickly determining trunk volumes for white pines based on form class, full height, and girth at root collar and breast height. This work is directly applicable in situations where total volume increases are wanted. Volumes are determined at two points in time by the above method and an average annual rate of absolute volume increase is then calculated. The latter figure can be converted to a board foot equivalent if desired. The challenge boils down to determining the appropriate form factor for a tree, the shape of its truck.

Trunk Measurements

Forestry texts typically show trunk shape beginning as a neiloid, progressing to a paraboloid, and then changing to a cone. In old trees, the top may once again become paraboloid in shape. Although these archetypal forms are mathematical abstractions, they are useful in trunk modeling and are routinely employed by ENTS. There are form or shape factors that govern the neiloid, paraboloid, and cone. The factors reflect the percentages of the cylindrical shape of the form. They are shown in the table below.

Table 7
Trunk Shape Factors

Shape	Factor
Neiloid	**0.25**
Paraboloid	**0.50**
Cone	**0.33**

In other words, the neiloid shape occupies 25% of the volume of a cylinder of the same base and height. The three shapes are canonical, but it is not always clear how they can be applied to a particular tree. Trunks change shape with increasing height, sometimes gradually, and sometime dramatically. Trees with abnormally large basal trunk flare will fall below the typical volume for the form. Trees with broken tops will have a form factor that is higher than is typical for the species because the rapidly taper of the cone shape versus the paraboloid will be lost. These variant forms are an indication of atypical development and the form factor or factors must be adjusted accordingly.

When the shape of the trunk clearly transitions from one of the standard forms to another, the changeover is called a point of inflection and its location above the base of the tree can be measured with clinometer and laser rangefinder. Instruments such as the RD1000 Relascope-Dendrometer and Macroscope 25/45 can be used to measure the cross-sectional width of the trunk at various points above the base. By choosing sections of the trunk that have a uniform taper and using frustums of the geometric solids identified above, the entire trunk can be modeled. This, with refinements, is the ENTS method. However, for the amateur tree measurer, the specialized instruments needed to measure cross-sectional width are fairly expensive and their use is labor intensive. Consequently, it would be very useful if we could develop form factors to apply that would get us between say 4 and 8% of the water displacement volume of the trunk for simple trunk shapes such as those characteristic of conifers. This brings us to a point.

Broad spreading hardwoods that branch low to the ground do not lend themselves to the use of trunk form factors. Modeling hardwoods of these forms requires much more trunk and limb dissection. However, conifers such as spruce and fir that have grown in competition with one another are ideally suited to using an overall trunk form factor. Hemlocks are also compliant. Pines are almost as amenable, and in particular, the white pine lends itself to the form factor.

In ENTS trunk volume formulas, the form factor is defined as *F*. The volume formula for the entire trunk takes on the simplified form as shown below. Let:

A = cross-sectional area at a predetermined height of the trunk above the base,
H = full height of tree from base to tip of the highest twig,
F = form factor for the trunk's shape,
V = equivalent water displacement volume of the trunk.

$$V = FAH$$

The cross-sectional area is often calculated as that of a circle and sometimes an ellipse. The actual shape will vary for different points along the trunk. Use of a circle tends to over-estimate the cross-sectional area by between 1% and 4% and occasionally more. The standard values of F are as shown in the previous table, but *F* can often be expressed as a broad average that includes neiloid, paraboloid, and conical sections. For example, a trunk that has 10% of its height as a neiloid, 50% as a paraboloid, and 40% as a cone yields a composite *F* value of 0.407. Interestingly, this value is close to what we have determined applies to many of the mature pines that we have completely modeled. We can apply an F = 0.42 for the trunks of trees that are between 80 and 180 years of age as an estimate of trunk volume. However, we also point out that this *F* value can be off by as much as +/- 0.05 for a significant number of trees that we have modeled. It cannot be blindly applied. In particular, if the trunk form is highly cylindrical or has a pronounced neiloid shape below 6 feet, then *F* needs to be adjusted. The table below shows the *F* form factor computed for 10 trees that were climbed by ENTS president Will Blozan. Will modeled the listed trees by taking periodic girth measurements and then applying the formula for the frustum of a cone to the individual sections. He made special adjustments to more accurately capture the basal volume.

Table 8
Derived F Form Factor

Trunk Class = Single, Stand Class = Forest-grown						
Pine	**Location**	**Diameter**	**Height**	**Volume**	**F**	**Age Class**
Coon Branch	Jocassee Gorges SP, SC	4.70	148.8	1,035.0	0.401	Old
Cornplanter	Cornplanter SP, PA	4.20	167.7	1,012.0	0.436	Old
Mill Creek	GSMNP, TN	4.37	148.8	941.0	0.422	Old
Mountain Mama	GSMNP, NC	3.98	174.9	931.0	0.428	Old
Zahner Pine	Nantahala NF, NC	4.39	162.0	1,127.0	0.459	Old
Jake Swamp	MTSF, MA	3.31	168.5	573.0	0.395	Mature
Tecumseh	MTSF, MA	3.79	163.0	779.0	0.424	Mature
Thoreau	MSF,MA	4.01	160.3	816.0	0.403	Mature
Grandfather	MSF,MA	4.49	143.3	967.0	0.427	Mature
Ice Glen	Stockbridge, MA	4.14	154.4	920.5	0.443	Old
Average					**0.424**	

Limb Measurements

Determining the length of limbs is an esoteric pursuit for tree measurers and ground-based determinations usually involve multiple measurements. Limb measurement is usually reserved to document truly extraordinary trees. FMTSF will be applying the techniques explained below in 2009 for a few trees in MTSF, MSF, and on other DCR properties, but principally for trees on non-DCR properties, such as the famous Sunderland and Pinchot sycamores.

There are several viable measurement techniques that can provide us with useful information about limb extension. The following definitions all relate to limb length.

L_h = Horizontal length (horizontal distance from start to end of limb) using 2 measurement points,

L_s = Straight line distance from start to end of limb (slope distance) using 2 measurement points,

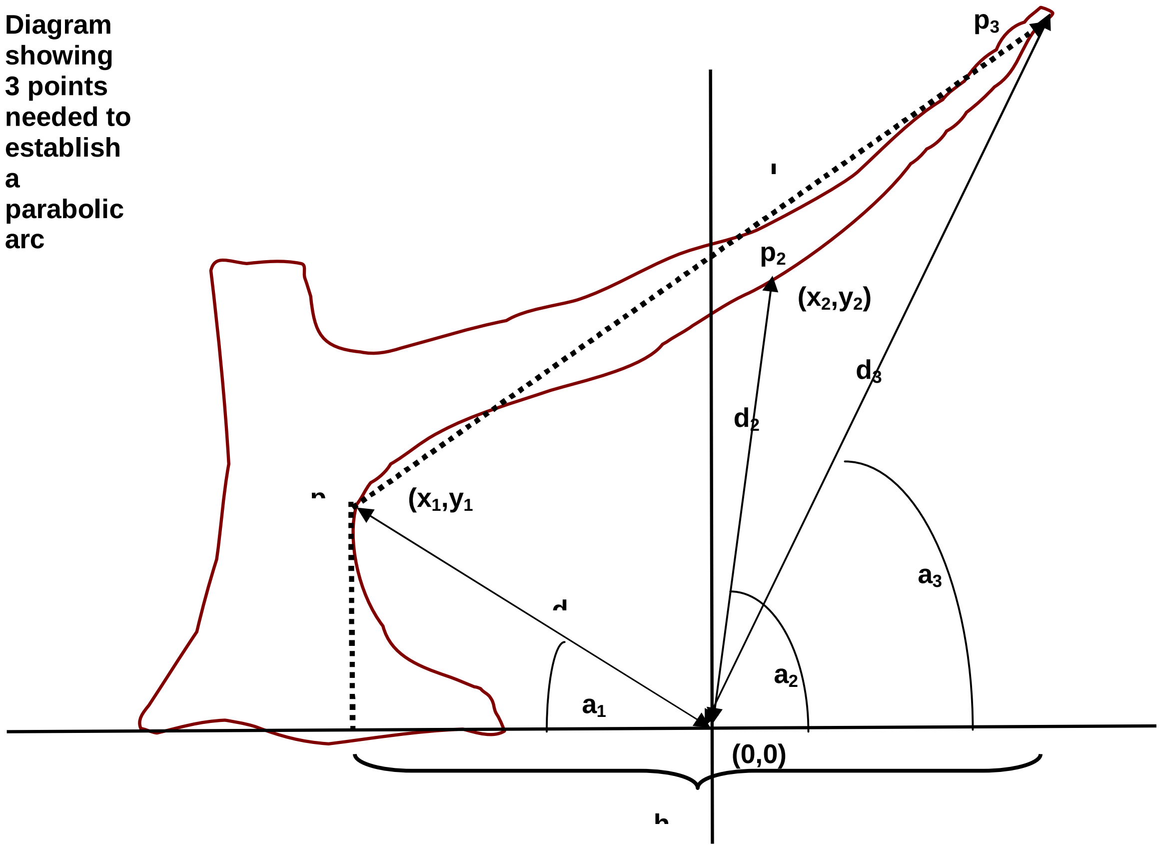
L_p = Parabolic arc length of limb using 3 measurement points,

L_r = Length based on a bivariate curvilinear regression model using multiple measurement points,

L_d = Length based on division of the limb into segments with each segment measured using one of the previous methods.

For long limbs with changing curvature, L_d will almost always be required if acceptable accuracy is to be achieved. The L_r method holds promise provided a regression program is used that allows for both bivariate linear and nonlinear regression. A good statistical package that provides this capability is Minitab, which supports second and third degree equations. However, regression models for parabolas and exponential curve forms have been developed by ENTS in Excel spreadsheet format for the benefit of measurers who don't use statistical software. Of particular interest is the parabolic curve. A spreadsheet application of this method has been developed by ENTS. The following diagram shows the field measurements and calculations that are needed.

Diagram 1
Establishing a Parabolic Arc



l_1=slope distance between p_1 and p_3
h_1=horizontal offset distance between p_1 and p_3

Assuming p_1, p_2, and p_3 are in the same vertical plane.

$$x_1 = d_1 \cos(a_1) \qquad y_1 = d_1 \sin(a_1)$$
$$x_2 = d_2 \cos(a2) \qquad y_2 = d_2 \sin(a_2)$$
$$x_3 = d_3 \cos(a_3) \qquad y_3 = d_3 \sin(a_3)$$

The coordinates of the 3 points are used to determine the equation of a parabola of the general form:

$$y = ax^2 + bx + c$$

The arc length between points P_1 and P_2 is given by the definite integral:

$$s = \int_{x_1}^{x_3} \sqrt{(2ax+b)^2 + 1}\,dx$$

The derivation of the coefficients a, b, and c and the evaluation of the definite integral are included as an appendix and are included to illustrate the extent of the development of methods and protocols for limb length determination employing ground-based measurements.

Establishing the Base of a Tree

Foresters typically measure tree diameter 4.5 feet above the highest point of contact of trunk with the ground. American Forests attempts to establish the midpoint of the slope for trees growing on sloping ground and measure the diameter at 4.5 feet above that point. The former method often cheats the tree and the latter is an improvement, but located the midpoint can be subjective. ENTS has established a method for marking the midpoint of the slope. A ribbon or marker (thumb tack) is put around the trunk at 4.5 feet above the base on the high side. On the downhill side, the point on the trunk 4.5 feet above the downhill side is located and marked. Finally, the point midway between the uphill and downhill 4.5-foot lines is located and a ribbon placed that this height. The ribbon represents the 4.5-foot height line used for diameter (girth) purposes.

In establishing the downhill spot, the lowest spot of the trunk is located. It is the lowest point for which the trunk's vertical wood touches the ground.

Tree Dimension Index

The method used by American Forests to crown a tree champion uses the following formula.

Let:

G = girth in inches at 4.5 feet above the base
H = height in feet
S = average crown spread in feet
P = points

$$P = H + G + S/4$$

Another method for identifying the champion of a species uses the percentage that a candidate tree's dimension is of the maximum dimension for the species for the geographical area under consideration. The following formula expresses the TDI concept

Let:

H_t = height of the tree
H_m = maximum height for the species
G_t = girth for the tree at 4.5 feet
G_M = maximum girth for the species
S_t = average crown spread for the tree
S_m = maximum spread for the species
TDI = total points for the tree

$$TDI = \frac{H_t}{H_m}100 + \frac{G_t}{G_m}100 + \frac{S_t}{S_m}100$$

The TDI is preferred by ENTS although we also use the American Forests system. The reason for preferring the TDI method is that it does not unfairly weight girth over height or crown spread.

Distinguishing Single Trees from Fused Pairs

Separate trees that have grown together are often confused by measurers as being a single tree and measured as one for the state and national champion tree programs. For species like white pine and hemlock that are non-coppicing, ENTS uses the method of pith tracing to establish whether a double-trunked tree form is in fact a single tree or two trees that have grown together. If straight lines following the piths of each trunk cross above ground, the form is considered to be a single tree with two trunks. If the pith lines projected to the point of intersection cross beneath ground level, the form is considered to be separate trees that have grown together.

A number of past and present champion trees listed in the National Register appear to be two or more trees grown together. The practice by tree measurers of submitting such trees to American Forests has led to the need to clean up the register. From time to time American Forests attempts to purge the doubles, but they creep back in, making the Register something of a big tree popularity contest. The Register's value for documenting the maximum sizes of different species has been compromised by the inclusion of doubles and triples. For most doubles, in time, the bark grows over the fusion area and the composite form appears to be a single tree at first glance. Upon close inspection, seems can usually be seen on one side of the form, but there are tree shapes with low branching can cause confusion even for experts. Nevertheless, treating a fusion as a single tree greatly distorts our understanding of the dimensions that can be reached by a species.

Closely associated with fused trees are single trees that develop multiple trunks through sprouting from the root collar after damage or cutting. Species lie silver maple commonly stump sprout in wetland areas. In terms of tracking big trees, separate categories are needed to handle single versus multiple trunk specimens.

White Pine Profiles

Introduction

The eastern white pine (*Pinus strobus*) is the tree icon of New England. It is our only native five-needle pine and has many current and historical uses that keep it in our consciousness. In historical times, and again today, the white pine is a valuable timber source. The white pine's range is widespread, from southern Canada to Georgia and westward to Iowa. Its economic importance was second to none during the colonial period. However, this noble species represents far more than a convenient source of timber. The eastern white pine is the sacred tree of peace of the Iroquois and Algonquin speaking Indian nations. Its inner bark served as a food source, and it is an important wildlife tree. Most notable is its physical appearance. As a young tree, it is cluttered with lower limbs and unattractive, but loses the limbs in advanced age to become stately, outgrowing all other eastern species with the exception of the tuliptree in some locales. However, since the appearance of Europeans on the North American continent, the white pine has suffered from attacks by the white pine weevil and white pine blister rust. Weevil damaged trees can be contorted and valueless as timber.

As our tallest eastern species of tree, the white pine is especially important to ENTS, which measures and tracks its growth, and documents significant pines and stands throughout its native range. It is incontestable that the white pine reaches loftier heights than any other eastern species and many anecdotal accounts exist of trees reaching heights of over 200 feet in the 1600s and 1700s. Most of the older reports are of doubtful authenticity. In colonial reports, exaggerations were likely mixed with nonstandard values for the inch and the foot, leading to accounts of trees reaching heights of 264 feet in unlikely locations like Lancaster, New Hampshire. A mission of ENTS is to determine the maximum limits of growth for the species and where it achieves those limits, range-wide and regionally.

To track white pine growth, five measurements are recorded by ENTS: trunk volume, height, girth, average crown spread, and maximum limb length. We will deal with three of these measurements in this section of the report: height, girth, and trunk volume.

Volume Considerations

Over the past several years, much of the FMTSF-ENTS research has concentrated on modeling white pines for trunk volume and calculating annual rates of volume increase. Trees have been climbed and tape-drop-measured to establish accurate height baselines and to calculate girths at set intervals of trunk length. In climbs of several prominent white pines in MTSF and MSF, girth measurements have been taken at intervals of trunk length according to one of two protocols:

1. Set intervals of 1 meters or yard,
2. Variable distances to match points of inflection along the trunk.

Either method allows us to model trunk volume to within 2 to 5 percent of the water displacement volume. We emphasize that to obtain our data, tree climbs are often made. These climbs never use spikes. They are always non-destructive. Only through actual climbs can we develop tree profile data to the level of accuracy that we seek. All climbs are performed by or under the supervision of master climber Will Blozan, President of ENTS. The following table lists the specific tree climbs that Will Blozan has made in Massachusetts. The table includes two species, white pine and eastern hemlock.

Table 9
Tree Climbs

Will Blozan's Massachusetts Tree Climbs Nov 1998 - Nov 2008						
Tree	**Date**	**Property**	**Stand**	**Height at Measurement**	**Current Height**	**Avg Annual Growth**
Jake Swamp	Nov-98	MTSF	Trees of Peace	158.6	168.5	0.99
Saheda	Nov-98	MTSF	Elders	158.3	164.1	0.58
Jake Swamp	Oct-01	MTSF	Trees of Peace	160.9	168.5	1.09
Joe Norton	Oct-01	MTSF	Trees of Peace	159.6	165.5	0.84
Tecumseh	Oct-03	MTSF	Elders	160.1	163	0.58
Thoreau	Oct-04	MSF	Dunbar Brook	160.3	160.3	
Metacomet	Oct-05	MTSF	Pocumtuck Pines	146.6	147.5	0.30
Ice Glen	Oct-06	Laurel Hill Assoc.	Ice Glen	154.4	154.4	
Grandfather	Oct-07	MSF	Dunbar Brook	143.3	143.3	
Dunbar Hemlock	Oct-07	MSF	Dunbar Brook	115.5	115.5	
Tunkashala	Oct-07	Sandisfield SF		99.2	99.2	
Saheda	Oct-07	MTSF	Elders	163.6	164.1	0.50
Jake Swamp	Nov-08	MTSF	Trees of Peace	168.5	168.5	
Tecumseh	Nov-08	MTSF	Elders	163.0	163	

Noteworthy in the above table is the calculation of annual height growth. If a tree has not been re-measured since the last climb, annual growth is not calculated. Four trees have been climbed more than once. The Jake Swamp Tree has been climbed 3 times over a 10-year period and our measurements show that during this time, the Jake Swamp Tree overall has averaged 0.99 feet of height per year. The average incorporates some re-growth from crown breakage, so the total growth probably averages between 1.2 and 1.4 feet annually. The Jake Swamp pine is around 150 years in age.

The main reason for our concentrated focus on the Jake Swamp and other pines in MTSF and MSF is to obtain a better understanding of volume growth in an exceptional stand of mature white pines. The Indian Pines of MTSF, as we call them, have provided us with our most significant data. In past reports, we have cited these pines as having special significance for several reasons. We list the reasons again below. The MTSF pines:

1. Are the tallest accurately measured trees in New England,
2. Exhibit sustained high growth rates for mature pines,
3. Possess excellent form with most trees being free of weevil damage,
4. Provide us with a record of what stand-grown white pines are capable of achieving in girth, height, and total volume for an age span of 60 to 180 years,
5. Provide us with picture of how self-thinning occurs over a time period of 120 years.

The table below presents an analysis of the annual growth of 11significant white pines. The trees with Vol-2 shown in red have been climbed.

Table 10
White Pine Volume Growth Analysis

White Pine Annual Growth Analysis for Listed Trees														
Tree Name	**Loc**	**F Factor**	**Girth**	**Hgt**	**Yr**	**Area**	**Vol-1**	**Girth**	**Hgt**	**Yr**	**Area**	**Vol-2**	**Diff**	**Ann Rate**
Grandfather	MSF	0.427	13.6	141	2001	14.719	886.2	14.1	143.3	2007	15.821	967.00	80.8	13.5
Thoreau	MSF	0.412	12.2	156.2	2001	11.844	762.2	12.6	160.3	2008	12.634	864.75	103	14.6
King Trout	MTSF	0.424	11.6	145.4	2001	10.708	660.1	11.9	148.6	2008	11.269	715.04	54.9	13.7
Jake Swamp	MTSF	0.395	9.5	155	1992	7.1819	439.7	10.4	168.5	2008	8.6071	573.00	133	8.3
Tecumseh	MTSF	0.424	11.3	160.1	2003	10.161	689.8	11.9	163	2008	11.269	779.00	89.2	17.8
Saheda	MTSF	0.382	11	158.3	1998	9.6289	582.3	11.8	163.6	2007	11.08	695.00	113	12.5
Ice Glen	Ice Glen	0.44	12.9	152.9	2001	13.242	890.9	13	155.5	2006	13.449	920.00	29.1	5.8
Jani Tree	MTSF	0.34	10.4	144.8	2001	8.6071	423.7	11	152	2008	9.6289	502.00	78.3	11.2
Picnic	MTSF	0.4	9.1	140.6	2002	6.5898	370.6	9.4	143.5	2008	7.0315	430.85	60.2	10.0
Joe Norton	MTSF	0.34	8.9	155.5	1992	6.3033	333.3	9.6	165.5	2008	7.3339	518.27	185	11.6
Mast Pine	MTSF	0.424	8.3	150.2	2001	5.4821	349.1	9	155.9	2008	6.4458	429.09	80	11.4
Average														11.9

The average annual volume increase of 11.9 cubic feet is extraordinary for even the healthiest of the white pines in MTSF that are in the 90 to 180-year age class. The lone tree in the above table that is not in MTSF or MSF is the Ice Glen Pine in Stockbridge, Massachusetts, which is around 300 years old or possibly older based on dating of nearby pines. The Ice Glen pine shows a decline in annual volume increase to approximately half of that for the trees in the 90 to 180-year age class.

The above volumes apply only to the trunk. Limb volume increase likely adds 0.5 to 1.00 additional cubic feet to the 11.9 average for a total average annual increase of 12.4 to 12.9 cubic feet for the listed pines. When the total volumes of these trees are averaged over their life spans, the average annual increase should be on the order of 4 cubic feet per year. Are the modeled pines actually adding volume at three times that overall rate at their present ages? This is a question that will receive concentrated attention in the next several years. To begin, we need to examine volume increases of some younger pines.

As a comparison of the volume change in older, larger pines as compared to younger trees, the following table shows growth rates and volume increases for some fast growing pines on Broad Brook in Florence, MA. The Broad Brook pines form a control group for monitoring. They all have good form and are located on a favorable site to create a valid comparison to the Mohawk pines. The following table lists successive annual measurements for 6 trees.

Table 11
White Pine Volume Growth Analysis-Continued

Volume Increases for Young Pines H = Height, G = Girth, F = Form Factor, Vol = Volume, Rad = Radius														
Tree	**F**	**G-1**	**H-1**	**Area-1**	**Vol-1**	**G-2**	**H-2**	**Area-2**	**Vol-2**	**Diff-2**	**Rad-1**	**Rad-2**	**Annual Growth-in**	**Yrs/in**
BB1	0.36	6.80	132.00	3.68	174.86	6.95	133.00	3.84	184.04	9.18	1.08	1.11	0.29	3.49
BB2	0.36	6.00	115.00	2.86	118.60	6.20	116.50	3.06	128.29	9.69	0.95	0.99	0.38	2.62
BB3	0.36	5.00	100.00	1.99	71.62	5.20	102.00	2.15	79.01	7.39	0.80	0.83	0.38	2.62
BB4	0.36	3.50	85.00	0.97	29.83	3.80	87.00	1.15	35.99	6.16	0.56	0.60	0.57	1.75
BB5	0.36	3.00	80.00	0.72	20.63	3.30	83.00	0.87	25.89	5.27	0.48	0.53	0.57	1.75
BB6	0.36	2.00	70.00	0.32	8.02	2.30	72.00	0.42	10.91	2.89	0.32	0.37	0.57	1.75
Avgs										**6.76**				

Annual radial growth varies between 0.29 and 0.57 inches for the 6 trees. Height growth varies between 1 and 3 feet. The smaller trees grow at a higher relative rate, but their actual volume increase is less than the larger trees. The average annual volume increase is 6.76 cubic feet, a high, but believable figure. In the case of the 180-year old Tecumseh Pine in MTSF, the calculations show an average annual volume increase of 17.8 cubic feet. This is an improbable figure, but if it holds, the interpretation is that it requires 2.76 of the smaller Broad Brook Pines to equal the Tecumseh Tree's annual volume increase. In actuality, most of the pines in the Broad Brook area are not adding three feet of height per growing season, but closer to 2 feet.

The volume growth of the large Mohawk pines listed above is unusual, if not extraordinary. Logically, a Mohawk pine growing for 150 years can be expected to achieve a trunk volume of between 500 and 600 cubic feet. This represents an annual average of 4 cubic feet of add-on per year. The expected volume increase of a pine in the 150-year age class and in the size and height class of the Mohawk pines is investigated more completely in Appendix II.

At this point, our conclusion is that the larger Mohawk pines are sequestering carbon at a very high rate although the percentage change in the radial growths, to be expected, is low. Focusing on radial growth may obscure the actual volume increases of the larger, older trees and their role in carbon sequestration.

Height Considerations

Most people gauge bigness in trees principally through trunk diameter. Eastern cottonwoods, sycamores, silver maples, American elms, northern red oaks, white oaks, and sugar maples commonly reach greater trunk diameters than do white pines in southern New England. Other species such as white ash also can achieve greater diameters than white pines. As an example, within the Connecticut River corridor, ENTS has measured 5 American sycamores to over 19 feet in girth. ENTS has measured over 25 hardwoods to girths of 15 feet or more, and there remain many more to document. The number can be expected to be at least double what has already been measured.

By contrast, only one white pine has been measured to a girth of 15 feet or more in the Connecticut River corridor. Consequently, it is not large girth that separates the white pine from other species, but great height. In the stature department, white pines dominate. As a result, ENTS has concentrated on measuring and tracking the stature of this species throughout its range. The central questions about white pine are: how tall can the species grow and at what rate? When do pines on good growing sites experience diminished growth? Do Massachusetts and DCR properties have pines of significance?

Use of the Macroscope 25/45 shows the average annual height increase to vary from 0.75 to 1.5 feet among the MTSF pines. The upper limit of height growth for the Mohawk pines is unknown, but if the Cook Forest Pines in Pennsylvania provide good examples, the Mohawk Pines have a practical upper limit of between 170 and 175 feet, with the possibility of one or two pines reaching between 175 and 180 feet. This height range equals what is typically considered to be the upper limit of the species with a few statistical outliers recognized in the above 200-foot category.

How commonly do white pines meet different height thresholds? The following outline looks at pines in the 100 feet and over class.

1. White pines in Massachusetts over 75 years old growing individually or in stands that exceed 100 feet in height are very common. They occur in yards, along roadways, graveyards, and in city parks, as well as in forested stands. Authors of tree identification guides that place the typical height of mature white pines in the 75 to 100-foot class do not know the species.

2. White pines over 100 years old growing in stands on good sites often exceed 120 feet in height in western Massachusetts and on occasion in eastern Massachusetts. Pines in this height class do occur as isolated trees, but more commonly occur in stands where competition is strong.

3. Stands with white pines over 130 feet are far less common across the Massachusetts landscape. Virtually all occur from the longitude of Petersham, Massachusetts and westward. In many respects, the 130-foot height threshold distinguishes tall white pines throughout New England. Stands with pines over 130 in Vermont are rare. As of this report, none have been found in Rhode Island. Massachusetts and New Hampshire have the most.

4. The number of stands in Massachusetts with white pines 140 feet tall and over is extremely small. To date, 11 sites have been documented with one or more pines reaching the 140-foot threshold. There are likely a few that have not been documented, but the number state-wide likely does not exceed 20. Most of these sites have from 1 to 4 pines that reach 140 feet. Of the 11 documented stands, two pines representing two of the 11 sites are in the Connecticut River Valley region. Two pines representing a third site have been measured in the Quabbin Reservoir. The remaining sites with pines in the 140-foot class are in the Berkshire region.

5. Stands with white pines reaching to 150 feet are extremely rare in Massachusetts. To date, only 4 sites have been confirmed in Massachusetts with pines meeting the 150-foot height threshold: MTSF, MSF, the Bryant Homestead in Cummington, and Ice Glen in Stockbridge. A couple of private sites have trees approaching 145 feet, but none over 150.

6. Finally, stands with pines reaching to 160 feet or more number only 2 in Massachusetts and 3 in all New England. One of these two Massachusetts sites, Monroe State Forest, has a single pine that reaches to 160 feet. The other site, Mohawk Trail State Forest, has 8 white pines reaching to 160 feet or more. The total for Massachusetts is 9 trees. New Hampshire has 6.

There are no other 160-footers in New England. Prior to July 1989, the Cathedral Pines in Cornwall, Connecticut had several pines that had reached the 160-foot threshold.

Girth Considerations

Throughout southern New England, mature white pines growing in stands commonly reach girths between 7 and 10 feet. It is at this point unclear what the expected diameter distribution of the species is over the major part of its range. It is clear, though, that large pines on the order of 12 feet in girth occur with low frequency throughout the natural range of the species. Although the 12-foot threshold is arbitrary, ENTS considers white pines in this girth class to be statistically significant enough to track as a sub-population of the total. White pines exceeding 12 to 13 feet in girth generally reflect time growing with limited competition from nearby trees. Most of the pines in the 12-foot and above girth class are partially to completely open grown, and it is difficult to predict where they will occur. The largest white pine we have so far found, as a single trunk tree, is 16 feet in girth and grows in the township of Sheffield, MA. Several pines between 15 and 16 feet have also been located. All are open grown specimens.

For Massachusetts, and consequently DCR properties, our conclusion is that the probability of a stand of white pines in the 100-200 year age range supporting one or more pines the 12-foot circumference class is relatively small. MTSF and MSF are the only DCR properties that we have found with forest-grown pines in this size class. Savoy Mountain State Forest had a single pine in this class, but it has fallen.

Based on the scarcity of forest-grown white pines in the 12-foot girth class, FMTSF-ENTS has begun a concentrated search for pines in Massachusetts that reach 12 feet or more in girth. Each tree is measured and cataloged. In time we will be able to assign probabilities to the occurrence of trees in the 12-foot girth class and show where they are most likely to occur.

We are also tracking smaller size pines, but being more numerous, they are not a scarce resource. The contribution of each size class will help us answer a set of questions about the role of individual trees and stands of trees in sequestering carbon. The prevailing belief was that larger, older trees serve little purpose in sequestration and that young fast growing pines do a much better job. There is forestry data that likely suggests that the slow down of diameter growth is correlated to a commensurate slow down in volume growth, but the association is not straightforward. Diameter represents linear growth and volume is growth within a three dimensional context. Slowdown in radial growth rates can occur without slowdown in corresponding cross-sectional area or volume growth. The way this happens is that the rate of radial growth decrease itself slows or ceases while height growth continues unabated.

Significant White Pines and Stands on DCR Properties

Use of height and girth thresholds misses many trees that do not reach one of the individual thresholds, but are nonetheless impressive in physical appearance and in the combination of their dimensions. The following list is of significant white pine stands and individual trees on DCR properties that have been documented to date. This list will be expanded as the search goes on. An individual pine is considered significant if it meets any of the following criteria:

- Reaches a height of 150 feet or more
- Reaches a girth of 12 feet or more
- Earns 1800 ENTS points or more

ENTS points are calculated for a tree by multiplying height (H) by girth (G) squared and dividing by 10. In a sense, ENTS points are a surrogate for trunk volume. That is,

$$P = \frac{HG^2}{10}$$

The frequency of occurrence of pines on DCR properties that meet the above criteria as measured by ENTS is shown in the following table. Properties are also included that have been searched, but with no pines having been found that meet one or more of the significant criterions.

Table 12
DCR Properties v.s. the White Pine Criteria

DCR Property	Township	No. Pines
Mohawk Trail SF	Charlemont	86
Monroe SF	Monroe	5
Mt Tom SR	Holyoke	3
Quabbin Reservoir	Belchertown	2
Windsor SF	Windsor	2
Savoy Mt SF	Savoy	1
Snow Basin Property	Cummington	1
Bash Bish Falls SP	Mt Washington	0
Beartown SF	Monterey	0
Chester-Blandford SF	Chester	0
Clarksburg SP	Clarksburg	0
Conn River Greenway SP	Northampton	0
Halibut Point SP	Rockport	0
Hampton Ponds SP	Westfield	0
Mt Everett SR	Mt Washington	0
Mt Greylock SR	Adams	0
Mt Sugar Loaf SR	S. Deerfield	0
Mt Washington SF	Washington	0
Natural Bridge SP	Clarksburg	0
Purgatory Chasm SR	Sutton	0
Robinson SP	Agawam	0
Skinner SP	South Hadley	0
Wachusett Mt SR	Princeton	0
Waconah Falls SP	Dalton	0
Total		**98**

Properties that will be searched in the coming months include D.A.R. SF, Pittsfield SF, Erving SF, and Wendell SF. While there may be a few surprising discoveries yet to be made on DCR properties, the overall dominance of one property, MTSF, is remarkable.

As a final topic on tall white pines, the tallest tree in the eastern United States is the "Boogerman Pine" in the Great Smoky Mountains N.P. The Boogerman Pine is 188.8 feet tall as of the last measurement. The tree is over 350 years old, has suffered one major crown break, has recovered and is growing annually at the rate of around 5 or 6 inches per year. The tallest tree in the Northeast is the Longfellow Pine in Cook Forest State Park, Pennsylvania. The tree is over 300 years old. Its current height is 183.6 feet. The tallest tree in New England is the Jake Swamp Pine in MTSF. It is approximately 150 years old. It is growing at about one foot per year and is currently 168.5 feet tall. All these trees have been climbed and tape-drop-measured by Will Blozan, President of ENTS.

At the risk of over-emphasizing the importance of the above information, we note that in states like Wisconsin, Michigan, and Minnesota in the upper-Midwest, and Pennsylvania in the Northeast, stands of great white pines and individual trees receive more recognition. Hartwick Pines SP in Michigan spotlights its large old-growth white pines. The largest pine in Hartwick was named the Monarch pine and at the time of its death was 12.3 feet in circumference and 151 feet tall. Today, there are at most 2 white pines in Hartwick that reach 150 feet tall and none reaching 12 feet in girth.

Massachusetts has white pines that Bay State citizens can be proud of, especially recognizing the importance of the species to Massachusetts in colonial times. We encourage DCR to take a position of leadership in recognizing these special pines by awarding them administrative recognition and where appropriate, protection. The number of pines in stands and as isolated trees that meet one of the previously listed criteria is miniscule relative to the abundance of the resource. Awarding special status to the few does not impact the availability of the resource for active management

As a final comment, barring damage from weather, insects, fungal attacks, etc., in a couple of years the Jake Swamp tree will surpass 170 feet in height and other Mohawk pines will join the collection of 160-footers. The number of 150-footers will eventually surpass 100 and rival Cook Forest's old-growth pines. It is entirely possible that the Mohawk pines will surpass Cook's Pines as the latter succumb to age. Regardless of whether or not MTSF surpasses Cook Forest, Mohawk will continue its dominance of all stands of white pine in New England. It is time for us to officially recognize the unique status of Mohawk's pines. We believe this should be done administratively within DCR. We do not believe that publicity should be devoted to the pines to increase public visitation. However, it is time that New England's most charismatic stand of white pines is properly acknowledged as a valued historic, cultural, scientific, and aesthetic resource. Other Northeastern and Midwestern states with great stands of white pines have given their pines special official recognition. Examples include Hartwick Pines in Michigan, Fisher Scott and Cambridge Pines in Vermont, Cook Forest and Hearts Content in Pennsylvania, the Tamworth, Bradford, and College Pines in New Hampshire, the Ordway and Bowdoin College Pines in Maine, and the Gold Pines and formerly the Cathedral Pines in Connecticut.

Ecological Considerations

The annual volume increase of larger, older white pines shows them to be good vehicles to sequester carbon, at least at the present time. This conclusion appears at odds with what many have heretofore believed. Timber professionals commonly employ the rate of annual growth increase of the trees in a stand to set the point of economic maturity, as opposed to absolute changes in volume. Young trees have the highest annual rates of diameter increase and that rate of increase is tied to the concept of return on investment. However, this economic view does not tell the ecological story of the pines. The absolute increase in volume is the correct measure of carbon sequestration. White pines in relatively good condition can sequester carbon for up to 250 years and for individual trees, far longer. As a general rule of thumb, a maximum effective age may be on the order of 200 years. If true, this conclusion needs to be taken into consideration on public lands where carbon sequestration is a consideration and active timber management is not the priority.

At this point, it is unclear if any additional ecological advantages are offered by old white pine forests beyond what is currently known by researchers in Minnesota. Research of FMTSF will increasingly turn toward more subtle questions with respect to the role of maturing white pine forests. Do they provide specialized habitat for species of animals. For example, older white pines that thrust upward through a canopy of hardwoods have often been used by raptors, especially bald eagles. Mother bears often use old white pines as temporary den sites because the strong, rough bark is useful for climbing and in the spring bears can climb in the canopy and stay cool. Bears tend to overheat when their fur is exposed to direct sunlight as is the case in spring in leafless hardwoods.

On November 1, 2008, several ENTS representatives including Dr. Lee Frelich visited the upper reaches of Trout Brook in MTSF. The destination was an unusually productive site that features two of the champion trees in MTSF. A white ash on the site reaches the improbable height of 150.1 feet and a close-by sugar maple reaches 134.4 feet. These are relatively young trees and their extraordinary growth rates reflect some combination of environmental factors that we have yet to quantify. What ecological value do these high growth sites have? This is a question in need of an answer. In the year 2009, FMTSF will turn to this question as a special research project.

One of the most important missions of FMTSF is to understand the ecological processes and niches represented in a property. To this end, our work in not only MTSF and MSF, but Robinson State Park and Mount Tom State Reservation during the period of this report has been especially important. As a final topic, one fact of significance to resource managers is the age distribution of forests on these properties and in general on other DCR properties. The current trend is to speak of Massachusetts forests as even-aged, developing from a common time period. While there are sizable areas of common-aged forests, to describe the landscape as one of even ages stretches the actual composition of these forests. Properties like MTSF exhibit broad age classes. For example, the hardwoods on the Todd Mountain-Clark Ridge complex span ages from seedlings to trees over 400 years old. Sections of the ridge have a fire history from one of several events. Ages of northern red and white oaks can often be placed in one of 4 age classes: under 60 - 80 years, 120-140, 170-190, and over 200. Those over 200 can be close to 200 or over 250. Areas of the bowl on Todd have trees commonly over 200 years, and in the case of a black birch, 332 years, the 6th oldest black birch dated anywhere. As seen from a distance, an inexperienced timber eye might think the entire ridge complex to be mature, even-aged forest. That could not be further from the case. The white pine stands of MTSF fall into one of several distinct age classes. Within relatively small stands, pines are fairly even-aged, but wide age variation exists across the stands.

In 2009, we will investigate the age classes of forests on several important DCR properties more thoroughly to develop a better understanding of the age groupings that exist there.

Tsuga Search Results

FMTSF acts as the funding arm of the Eastern Native Tree Society and recently served in that capacity in a joint effort between Great Smoky Mountains National Park and ENTS to climb, measure, treat, and document the largest and oldest eastern hemlocks growing in the Park. The program, entitled the *Tsuga Search Project* concentrated on finding and studying eastern hemlocks of great size as a vanishing treasure due to the hemlock woolly adelgid. The program concentrated on Great Smoky Mountains National Park, but for documentation and comparison purposes, the program was extended to other areas of the Southeast and to a number of prominent hemlock sites in the Northeastern U.S. Cook Forest State Park and Tionesta Scenic Area and Hearts Content in the Allegheny National Park in Pennsylvania were visited along with three sites in Massachusetts: Sandisfield State Forest, Monroe State Forest, and Mount Tom State Reservation. Information on Tsuga Search is available on the ENTS website at www.nativetreesociety.org. Click on the button entitled Tsuga Search.

As a result of Tsuga Search, what have we learned? One fact is that the older, larger trees are especially susceptible to adelgid attack. Treatments have to be intense to work. This suggests the need for a pre-emptive management plan for areas and trees in Massachusetts. The large, old hemlocks above Dunbar Brook in Monroe State Forest are examples.

What else have we learned? From the hemlock volume modeling performed at the various study sites and from work previously accomplished, we know that a sizable number of the eastern hemlocks in the Great Smoky Mountains reach trunk volumes of between 1,000 and 1,300 cubic feet, with a few trees exceeding this range and one tree reaching 1,600 cubic feet. By contrast, hemlocks in the Northeast can reach volumes of up to 800 cubic feet. The largest in Massachusetts are on the order of 750 cubic feet. Pennsylvania has several over 800 cubic feet. To the north of Massachusetts, 600 cubic feet is likely to be the largest encountered in a forest setting. Five hundred cubic feet likely represents the maximum for central New Hampshire and Vermont.

Trunk modeling of over 40 trees in Tsuga Search confirms that eastern hemlocks with girths of between 13.5 and 14.0 feet and heights of at least 150 feet are at the threshold of 1,000 cubic feet of trunk volume. The Tsuga Search Project results show conclusively that the largest hemlocks are growing in the southern Appalachians and most of them within the boundaries of Great Smoky Mountains National Park. In decades past, West Virginia may have had hemlocks in this size range, but the Smoky Mountains trees confirm that the *Tsuga canadensis* is the largest evergreen conifer growing naturally in the eastern United States. This conclusion is relatively recent and cannot be reached from data maintained by traditional sources of tree dimension information.

It is interesting that in the southern Appalachians, eastern hemlocks achieve significantly greater trunk volumes than the largest white pines. The volume advantage of the hemlock is on the order of between 30% and 50%. The reverse is true in the Northeast where white pines achieve larger trunk volumes. However, the white pines of today seldom reach trunk volumes of 1,000 cubic feet anywhere within the natural range of the species. So far, only four white pines have been modeled to 1,000 cubic feet, three of which are in the southern Appalachians and the fourth in Pennsylvania. By contrast, the loblolly pine can reach volumes over 1,000 cubic feet with 1,380 representing the upper limit found to date. Interestingly, all the loblollies modeled by ENTS to volumes over 1,000 cubic feet grow in Congaree NP, South Carolina. ENTS will be receiving a three year special research permit to measure and document this greatest of United States eastern swamp forests.

In terms of the large hemlocks in Masachusetts, three immense trees have been modeled in Massachusetts: the Tunkashala Tree in Sandisfield State Forest, the Dunbar Brook hemlock in Monroe State Forest, and the Mount Tom hemlock on Mount Tom State Reservation. The following table shows the modeling results of the Dunbar Brook hemlock from an October 2007 modeling.

Table 13
Hemlock Modeling

Dunbar Brook						
Hemlock			**4242197:7258161**			
10/22/2007						
Climbed by Will Blozan			**Total volume=**		**758**	**ft3**
Diameter	**Girth (ft)**	**Radius (ft)**	**Height (ft)**	**Section Vol**	**Cumulative Vol**	
0.00	0.00	0.00	115.50	10.42	10.42	
20.60	5.39	0.86	102.00	13.70	24.12	
25.55	6.69	1.06	97.30	16.57	40.69	
27.00	7.07	1.13	92.90	7.17	47.86	
28.60	7.49	1.19	91.20	35.86	83.72	
31.00	8.12	1.29	83.80	48.66	132.37	
33.40	8.74	1.39	75.20	48.00	180.37	
35.10	9.19	1.46	67.70	64.72	245.09	
36.72	9.61	1.53	58.50	80.80	325.88	
37.35	9.78	1.56	47.70	63.15	389.03	
37.80	9.90	1.58	39.50	54.42	443.44	
39.95	10.46	1.66	32.90	66.30	509.75	
38.50	10.08	1.60	25.00	66.87	576.62	
38.37	10.05	1.60	16.70	53.54	630.16	
39.95	10.46	1.66	10.30	31.85	662.01	
42.92	11.24	1.79	6.90	18.18	680.19	
45.63	11.95	1.90	5.20	8.32	688.51	
47.74	12.50	1.99	4.50	28.62	717.13	
54.62	14.30	2.28	2.50	40.68	757.81	
54.62	14.30	2.28	0.00			

Final Topics and Summary Comments

Introduction

This annual report to DCR is submitted in compliance with the agreement of understanding between the Department and FMTSF in fulfillment of the understanding included in the special use permit. Beyond the simple presentation of our research findings in compliance with the understanding, we believe that the data we are presenting continues to fill what would otherwise be a void in the statistical picture and understanding of the forests on DCR properties possessed by academics, governmental officials, environmental organizations, and the public at large – especially in terms of what different species of trees can and have achieved in terms of maximum dimensions and growth rates over various spans of time.

Special Status for MTSF

As with prior submissions, this report highlights the unique role of one property, MTSF. As a friends group for Mohawk, it is expected that we would advocate for the property and our highlighting of Mohawk will continue in future reports as new information becomes available. However, on what we believe to be a strictly objective basis, we have made a compelling case for this exemplary property to receive a special administrative designation. More specifically, it is the position of FMTSF and ENTS that special state recognition should be given to MTSF in view of its unique historical, scientific, ecological, cultural, and aesthetic value to the citizens of the Commonwealth. Descriptions of MTSF on the DCR website and in DCR brochures fail to acknowledge the unique features of this forest icon of Massachusetts and as a consequence visitors often visit the property without understanding its status.

Of particular scientific interest are the data and measurements of volume increases in the white pines and how the increases contribute to carbon sequestration. This will be a continuing research project for 2009 in keeping with our original commitment to do research on white pine growth.

The conclusions we have reached with respect to sequestration of the Mohawk Pines suggests that a number of the bigger trees have gained volume at the rate of nearly 12 cubic feet per year over the last decade. If this is true, it is a significant finding. We say, if it is true, because other calculations suggest that the average volume increase should be on the order of 4.0 cubic feet annually with a maximum in any one year of between 7 and 8 cubes for a tree in the size range of the Jake Swamp pine.

System for Evaluating Protected Properties

A subject of great importance to investigate in 2009 is the value system or systems that we employ in managing our state forests. Because of the kinds of data that we collect, FMTSF often has a perspective that differs considerably from the extremes of total forest protection versus constant harvesting, be it for timber, wildlife, or purported biodiversity. There are DCR properties that deserve special protection because they incorporate historic and/or cultural values or are important as part of a scenic resource that advertises Massachusetts to visitors. There are plenty of areas that are well suited for active management, albeit always carefully implemented. The division of 20% in forest reserves versus 80% in some form of active management can be debated as to whether more forest should be in reserves and other specially protected areas, but there should certainly not be less.

The principles of Green Certification need to be revisited to see how well they apply to DCR properties when areas with high historic, cultural, scientific, or aesthetic significance need to take precedence. Green Certification seems to adequately address the need to set aside areas with high conservation value, exempting those areas from logging. Through the concept of high conservation value, ecological and special habitat values are being addressed. However, there are properties that do not seem to fit into the active management versus forest reserves concept that is currently in effect.

DCR locations within the Connecticut River Valley region that are surrounded by a population that is essentially urban or suburban are examples of properties that have fallen through the crack. Each of these Valley properties needs to be carefully examined from the standpoint of what the principal stakeholders see as the primary purposes of these properties. Who visits the forests in these properties and for what purposes? FMTSF will be available to DCR to help sort through the relevant considerations and arguments by bringing in outside experts.

Survey of Tuliptrees

In 2009, we also hope to complete our survey of the tuliptree (*Liriodendron tulipifera*) in Massachusetts, and in particular, on properties of DCR. It has been through the efforts of study leader Professor Gary Beluzo that we not only have a better understanding of the distribution of the tuliptree in southern New England, but also more importantly to us, its regional growth patterns. We also plan to spend considerable time in 2009 examining the distribution and growth patterns of the species in Connecticut, Rhode Island, New York, and Pennsylvania. The picture we hope to develop will highlight areas of maximum tuliptree development in Massachusetts as a subject of special interest. The plan is to identify the range of tree development in Massachusetts from yards to forests and to specify conditions for the tuliptree's maximum development in each habitat. This will help us better assess the development of the species on DCR properties and identify exceptional sites.

As a fact of interest, at present the tuliptree champion in the Northeast is in Longwood Gardens, PA. Its dimensions are: height 163.3 feet and girth 11.7 feet. It was measured by Scott Wade, champion tree coordinator for Pennsylvania and member of ENTS. By comparison, the tallest tuliptree in New York measured to date is in Zoar Valley and is slightly over 156 feet tall. We anticipate confirming tuliptrees in southern Connecticut between 140 and 150 feet. By contrast, the Massachusetts champion tuliptree is the specimen in Robinson State Park at 139.7 feet. Growth for the species definitely falls off markedly in Massachusetts.

Advances in Field Measurement

Through ENTS, FMTSF continues to engineer field techniques to better measure and model trees, with special emphasis on volume. Computer methods will almost certainly overtake the field methods, but field checking, i.e. ground-truthing, will become critically important. The field measurement methods that ENTS is developing may become instrumental in verifying computer models. Because of the importance of the field techniques, this report submission has devoted space to describing methods for measuring limb length using ground-based measurements. Use of common curve fitting techniques as discussed in this report will be a subject of focus in 2009. Linear, parabolic, cubic, and exponential models will become the tools of choice and they will be implemented primarily through Excel workbooks. Developing the ground measurement implementation protocols will be the operative challenge.

Old Growth Documentation

We plan to return to old growth study and documentation in 2009. Identification of the features accompanying small pockets of old growth will be a principal focus. How survivable are the small areas of old growth? Age distributions within the remnants will be more of a focus than the mere identification of old growth sites and listing of characteristics.

Forest Conference - 2009

During Oct 22-24, 2009, Holyoke Community College, ENTS, FMTSF, Massachusetts Audubon Society, Harvard Forest, and other organizations will hold a joint event that represents the 6th conference in the Forest Summit Lecture Series, the 9th in the Ancient Eastern Forest Conference Series, and the annual ENTS rendezvous. The combined event will address:

1. Definitions of forest health,
2. Old growth forest ecology,
3. Outstanding forest sites in Massachusetts and the Eastern United States,
4. Threats to our forests,
5. FMTSF & ENTS achievements

Of special significance will be a planned discussion on forest health and threats to our forests. Forest health is at best a nebulous concept - one that is bandied about by forest stakeholders, often with no clear comprehension of the difference between ecological and economic considerations. As stands of timber mature on public lands, pressure builds to derive economic benefits from that timber. Advocates for increased timber harvesting vie with forest preservationists. The public is often left in the dark. The conference will explore the concept of forest health from the viewpoint of stakeholders and what science tells us about the viability of forests of different development histories.

As with past events, this conference will bring together experts from academia, the government, environmental organizations, professional forestry, and independent researchers. Details of the event will be posted on the Holyoke Community College website. The conference is being offered by Holyoke Community College as a public service free of charge to the public. Principle conference planners are Gary Beluzo and Robert T. Leverett. A tentative list of speakers include the following:

1. Dr. David Stahle, Director of the Tree-ring Laboratory, University of Arkansa
2. Dr. Lee Frelich, Director of the Center For Hardwood Ecology, University of Minnesota
3. Dr. David Foster, Harvard Forest
4. Dr. Donald Bragg, Research scientist, U.S.D.A. Forest Service
5. Dr. Rick Van de Poll, independent forest consultant
6. Professor Gary Beluzo, Professor of Environmental Science, Holyoke Community College
7. Will Blozan, President, Eastern Native Tree Society
8. Dale Luthringer, Naturalist and Educational Director, Cook Forest State Park, Pennsylvania
9. Robert T. Leverett, Executive Director, Eastern Native Tree Society
10. Ed Frank, Geologist and Webmaster, Eastern Native Tree Society
11. Ehrhard Frost, Consulting Forester and Representative of the Forest Stewards Guild

Appendix I

Spreadsheet Format for Calculating Limb Length Using a Parabolic or Cubic Arc

The following Excel spreadsheet extract shows how Simpson's Rule is applied to compute the arc length of a parabola fit to 3 measured points. An alternative method uses bivariate nonlinear regression analysis, which allows multiple points to be derived along the arc of the limb. In the example, 8 iterations are shown. The spreadsheet actually accommodates 801 iterations. For a limb with a horizontal extension of 80 feet, this allows for each subdivision to be 0.1 feet. The error in the length calculation is <= 0.17%.

Fit a parabola to 3 points
and compute arc length for the parabola

$$y = ax^2 + bx + c$$

<--- The equation for a parabola

$$b = \frac{s_2 s_3 - s_0 s_5}{s_2 s_4 - s_1 s_5} \qquad a = \frac{s_3 - bs_4}{s_5} \qquad c = y_1 - ax_1^2 - bx_1 \qquad s = \int_{x_1}^{x_3} \sqrt{(2ax+b)^2 + 1}\,dx$$

<-- arc length

x_1	y_1	x_2	y_2	x_3	y_3			
-25	10	0	30	50	60			
$s_0=y_2-y_1$	$s_1=x_2-x_1$	$s_2=x_2^2-x_1^2$	$s_3=y_3-y_1$	$s_4=x_3-x_1$	$s_5=x_3^2-x_1^2$	b	a	c
20	25	-625	50	75	1875	0.7333	-0.0027	30.0000

<---- See diagram for (x_1,y_1), (x_2,y_2), (x_3,y_3)
<---- Enter x,y values in green boxes

Simpson's Rule applied to the parabola

x_1	x_3	$s_4=x_3-x_1$	n	$h=s_4/n$	s	
-25	50	75	801	0.093633	**90.33**	**<--- arc length**

No.	x	y	f	s
1	-25	1.323295549	1	1.323296
2	-24.9064	1.322968547	4	5.291874
3	-24.8127	1.322641652	2	2.645283
4	-24.7191	1.322314865	4	5.289259
5	-24.6255	1.321988185	2	2.643976
6	-24.5318	1.321661614	4	5.286646
7	-24.4382	1.321335151	2	2.64267
8	-24.3446	1.321008795	4	5.284035

NOTES:

1. $y = \sqrt{(2ax+b)^2 + 1}$ $\quad s = fy$
2. $L = \sum(s)$
3. **Arc length approximates limb length**
4. **Subdivisions of 801, sufficient for a limb up to 80 feet in length**
5. $b = \frac{\left[(x_2^2 - x_1^2)(y_3 - y_1) - (y_2 - y_1)(x_3^2 - x_1^2)\right]}{\left[(x_2^2 - x_1^2)(x_3 - x_1) - (x_2 - x_1)(x_3^2 - x_1^2)\right]}$

6 $$a = \frac{(y_3 - y_1) - b(x_3 - x_1)}{x_3^{\,2} - x_1^{\,2}}$$

7 $$c = y_1 - ax_1^{\,2} - bx_1$$

In applying polynomials to determine limb length, beyond the quadratic equation, the cubic equation has many possibilities primarily because the cubic curve form changes from concave to convex and vice versa. The S-curve shape of the cubic model, follows the architecture of many limbs.

The following equations reflect the fitting of a third degree polynomial to 4 points. The definite integral needed for calculating arc length is also given.

For notation simplicity, we define the following terms.

$$s_0 = y_2 - y_1,\ s_1 = x_2^{\,3} - x_1^{\,3},\ s_2 = x_2^{\,2} - x_1^{\,2},\ s_3 = x_2 - x_1$$

$$s = y_3 - y_1,\ s_5 = x_3^{\,3} - x_1^{\,3},\ s_6 = x_3^{\,2} - x_1^{\,2},\ s_7 = x_3 - x_1$$

$$s_8 = y_3 - y_2,\ s_9 = x_3^{\,3} - x_2^{\,3},\ s_{10} = x_3^{\,2} - x_2^{\,2},\ s_{11} = x_3 - x_2$$

$$a = \frac{s_0 s_{11} - s_8 s_3}{\left[(s_1 s_{11} - s_9 s_3) + (s_2 s_{11} - s_{10} s_3)\left(\frac{s_0 s_7 - s_4 s_3 - s_1 s_7 + s_5 s_3}{s_2 s_7 - s_6 s_3}\right)\right]}$$

$$b = \frac{s_0 s_7 - s_4 s_3 - (s_1 s_7 - s_5 s_3)a}{s_2 s_7 - s_6 s3}$$

$$c = \frac{s_0 - s_1 a - s_2 b}{s_3}$$

Finally, based on the values of a, b, and c, the arc length s is derived as:

$$s = \int \sqrt{(3ax^2 + 2bx + c)^2 + 1}\,dx$$

The next spreadsheet shows the regression process applied to more than 3 points. The objective is to fit a parabola to the data. The regression process is required where additional measurements can be obtained. In general, the more measurements we take, the better we are able to accurately capture the curve of the limb.

Fit parabola to set of up to 10 points

$$y = ax^2 + bx + c$$

k_2	k_1	k_3	k_4	k_5	k_6	k_7	
Number of points:	6						
X_i	Y_i	X_iY_i	X_i^2	$X_i^2Y_i$	X_i^3	X_i^4	y_{est}
0	0	0	0	0	0	0	4.78
10	25	250	100	2500	1000	10000	17.49
30	35	1050	900	31500	27000	810000	35.12
40	37	1480	1600	59200	64000	2560000	40.06
50	40	2000	2500	100000	125000	6250000	42.40
60	45	2700	3600	162000	216000	12960000	
		0	0	0	0	0	
		0	0	0	0	0	
		0	0	0	0	0	
		0	0	0	0	0	
190	182	7480	8700	355200	433000	22590000	
$\sum x_i$	$\sum y_i$	$\sum x_i y_i$	$\sum x_i^2$	$\sum x_i^2 y_i$	$\sum x_i^3$	$\sum x_i^4$	

a	-0	Regression coefficients
b	1.4	
c	4.78	

Simpson's Rule for Evaluating Definite Integral	
s	74.37
a	-0.013
b	1.40000
c	4.78095

Note:
s = arc length above

x_1	x_3	x_3-x_1	n	h=(x_3-x_1)/n
0	60.000	60.000	801	0.0749

No.	x	y	f	s
1	0.000	1.720	1	1.7205
2	0.075	1.719	4	6.8755
3	0.150	1.717	2	3.4346
4	0.225	1.716	4	6.8629
5	0.300	1.714	2	3.4283
6	0.375	1.713	4	6.8503
7	0.449	1.711	2	3.4220
8	0.524	1.709	4	6.8377
9	0.599	1.708	2	3.4157
10	0.674	1.706	4	6.8251
11	0.749	1.705	2	3.4094
12	0.824	1.703	4	6.8126
13	0.899	1.702	2	3.4031
14	0.974	1.700	4	6.8000
15	1.049	1.698	2	3.3969
16	1.124	1.697	4	6.7875
17	1.199	1.695	2	3.3906
18	1.273	1.694	4	6.7749
19	1.348	1.692	2	3.3843
20	1.423	1.691	4	6.7624
21	1.498	1.689	2	3.3781
22	1.573	1.687	4	6.7499
23	1.648	1.686	2	3.3718
24	1.723	1.684	4	6.7374

Equations for computing a,b,c using the least squares method.

$$a = \frac{\left[\left(\sum x\right)^2 - n\sum x^2\right]\left[\sum xy\sum x^2 - \sum x\sum yx^2\right] - \left[\left(\sum x^2\right)^2 - \sum x\sum x^3\right]\left[\sum y\sum x - n\sum xy\right]}{\left[\sum x^2\sum x^3 - \sum x\sum x^4\right]\left[\left(\sum x\right)^2 - n\sum x^2\right] - \left[\sum x\sum x^2 - n\sum x^3\right]\left[\left(\sum x^2\right)^2 - \sum x\sum x^3\right]}$$

$$b = \frac{\left[\sum xy\sum x^2 - \sum x\sum yx^2\right] - a\left[\sum x^2\sum x^3 - \sum x\sum x^4\right]}{\left[\left(\sum x^2\right)^2 - \sum x\sum x^3\right]}$$

$$c = \frac{\sum y - a\sum x^2 - b\sum x}{n}$$

$$s = \int_{x_1}^{x_3} \sqrt{(2ax+b)^2 + 1}\,dx$$

After the regression process is completed, the a, b, and c coefficients are substituted in the definite integral for s to calculate the arc (limb) length. The application of Simpson's Rule above shows 24 iterations. The full evaluation uses 801. ENTS has also developed the above process for the cubic and exponential models.

Appendix II
White Pine Volume Increase Analysis

The unusually high volume increases, measured by ENTS for the large white pines in MTSF point to the need for further study and analysis. Standard forestry volume tables and assumptions about annual growth from the U.S. Forest Service's annual growth analysis cannot be meaningfully applied to the Mohawk pines. This is not a criticism of the above sources, just a recognition of reality. Consequently, ENTS and FMTSF are starting to develop descriptive/predictive models to address the components of growth for the pines. The models will factor in growth trends based on the data we have been collecting. We are at in the infancy of this project. The descriptive volume model in this appendix is meant only as illustrative of the path we are taking.

In our simple model, we generate annual volume increases for a hypothetical pine for a period of 150 years. We use a random number generator to produce the annual height increases. The generator is meant to factor in the vagaries of climate. In the simple model, we generate the trunk form factor by applying a constant increase in its value over the 150-year time spread, starting at 0.333 and ending at 0.37. The annual radial increases are changed at increments of 10 years. More sophisticated radial growth model are being developed, but the one included in the example points to a credible pattern of development, i.e. one that would not surprise us.

Interestingly, using the assumptions and values we show in the spreadsheet extract, the model leads to an overall volume close to what we have actually measured for the Jake Swamp tree. However, the model shows a slowdown in the annual volume increase beyond the 130 year point. This corresponds with the range of tree ages that we previously believed represented the maximum for annual volume increase, but as we explain in the main body of this report, the Jake Swamp tree has grown more rapidly in volume than our simple model predicts. The rapid annual growth may reflect climate change. We do not know.

We are working on more sophisticated predictive models that randomize height and radial changes within time segments that more closely match the trends we observe. The random generators for both height and radial growth take the form shown below.

Let: n = minimum change in attribute for year
m = maximum change in attribute for year
R = random number between 0 and 1 exclusive
A = amount of change in attribute (vertical or radial growth)

$$A = n + (m - n)R$$

Employing the above generation method, simulations were run to compute annual height, radial, and volume gains over 150 years for pines in the size class of those growing near the Jake Swamp tree. The model shows annual volume changes of up to 7.0 cubic feet per season, with an average of around 4.0. The form factor retains the linear trend.

The most useful models we could build should reflect the general slowing of annual radial ring widths over the life span of the tree in accordance with what we are able to determine from core sampling. We will eventually incorporate growth spurts and slow growth periods, again in accordance with what we see in the actual growth data we gather. Additional growth models for the pines will be presented in next year's report. As an example the following graph depicts height growth over a 150-year period using assumptions about maximum annual height growth. A similar graph and associated equation can be produced for an assumed minimum annual growth scenario. Then a simulated annual growth is produced by choosing a random value between minimum and maximum height growth curves for the chosen year. A similar approach can be used for radial growth to achieve a simulation of growth over the life span of the tree. The equation of the plot is:

$$H = 0.0000028C^3 - 0.0008216C^2 - 0.0629753C + 0.827625$$

In the above equation, H=annual height growth and C=year number. The plot was produced with Minitab software. The R^2 value is 75.8.

Graph1
Illustrative Height Growth Plot

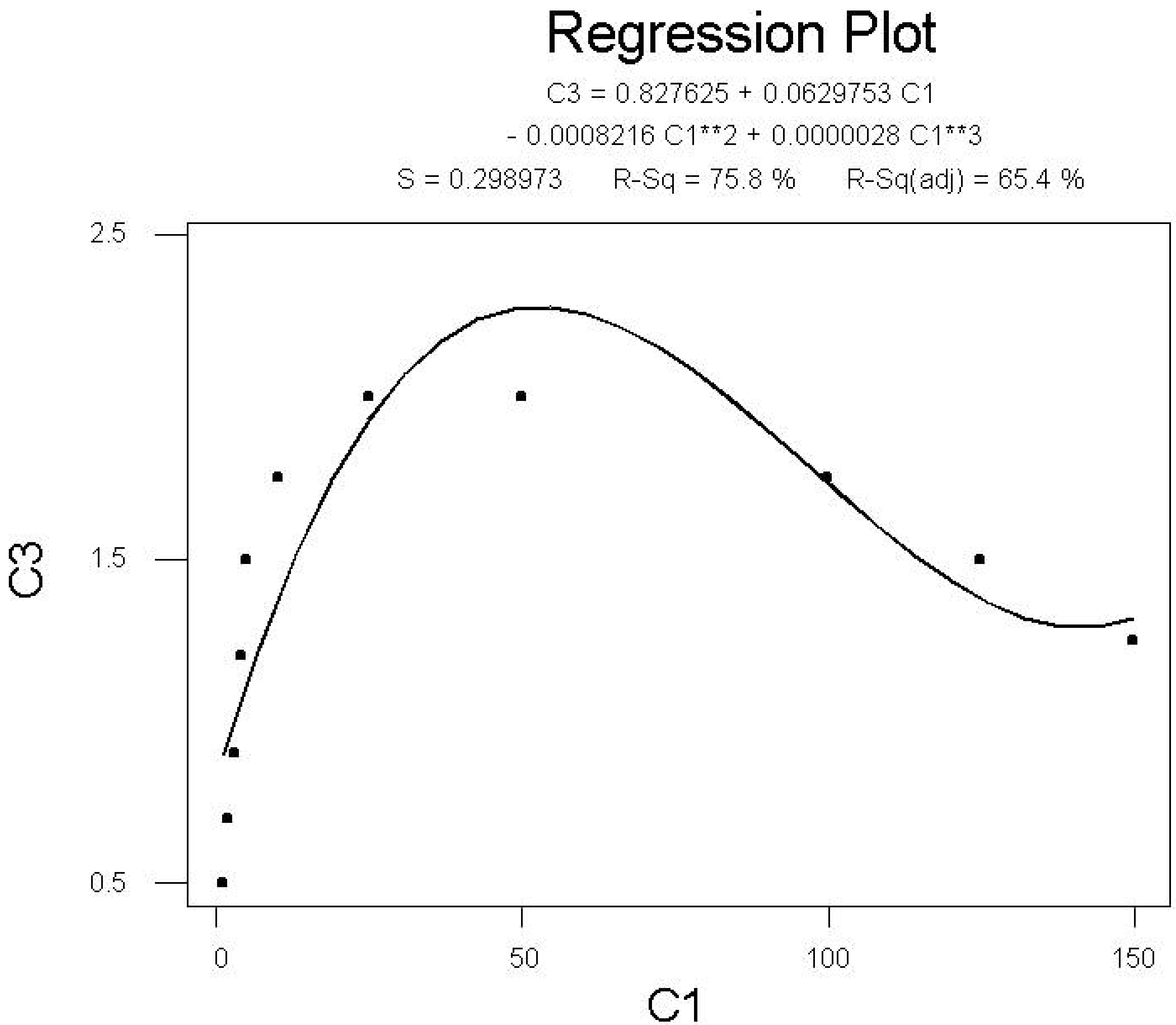


Table 14
Illustrative Volume Model

Hypothetical Volume Generator for Jake Swamp Type Pine

Yr	Hgt	Hgt-Incr	Radius-ft	Radius-Incr	Factor	Vol-ft^3	Vol Diff
1	1.00		0.0104		0.3330	0.000	
2	1.50	0.75	0.0167	0.0119	0.3332	0.000	0.000
3	3.00	1.50	0.0286	0.0119	0.3335	0.003	0.002
4	4.50	1.50	0.0452	0.0167	0.3337	0.010	0.007
5	6.50	2.00	0.0619	0.0167	0.3340	0.026	0.016
6	8.50	2.00	0.0786	0.0167	0.3342	0.055	0.029
7	10.00	1.50	0.0952	0.0167	0.3345	0.095	0.040
8	11.50	1.50	0.1119	0.0167	0.3347	0.151	0.056
9	13.00	1.50	0.1286	0.0167	0.3350	0.226	0.075
10	14.50	1.50	0.1452	0.0167	0.3352	0.322	0.096
11	16.15	1.65	0.1619	0.0167	0.3355	0.446	0.124
12	18.49	2.34	0.1786	0.0167	0.3357	0.622	0.176
13	20.79	2.30	0.1971	0.0185	0.3360	0.852	0.230
14	22.79	2.01	0.2156	0.0185	0.3362	1.119	0.267
15	24.59	1.80	0.2341	0.0185	0.3365	1.425	0.306
16	26.18	1.59	0.2526	0.0185	0.3367	1.768	0.343
17	28.30	2.12	0.2712	0.0185	0.3369	2.203	0.435
18	30.52	2.21	0.2920	0.0208	0.3372	2.756	0.553
19	32.25	1.73	0.3128	0.0208	0.3374	3.345	0.589
20	34.06	1.81	0.3337	0.0208	0.3377	4.022	0.677
21	35.66	1.60	0.3522	0.0185	0.3379	4.695	0.673
22	37.39	1.74	0.3707	0.0185	0.3382	5.459	0.764
23	38.83	1.44	0.3892	0.0185	0.3384	6.254	0.795
24	40.23	1.40	0.4077	0.0185	0.3387	7.116	0.862
25	42.39	2.17	0.4263	0.0185	0.3389	8.201	1.086
26	44.64	2.24	0.4448	0.0185	0.3392	9.409	1.207
27	46.00	1.37	0.4633	0.0185	0.3394	10.528	1.120
28	47.42	1.42	0.4818	0.0185	0.3397	11.747	1.219
29	49.10	1.67	0.5003	0.0185	0.3399	13.124	1.377
30	51.22	2.12	0.5188	0.0185	0.3402	14.735	1.611
31	52.80	1.58	0.5364	0.0175	0.3404	16.247	1.512
32	54.58	1.77	0.5539	0.0175	0.3406	17.923	1.675
33	55.80	1.22	0.5715	0.0175	0.3409	19.518	1.595
34	57.65	1.84	0.5890	0.0175	0.3411	21.435	1.917
35	59.69	2.05	0.6066	0.0175	0.3414	23.555	2.120
36	61.09	1.40	0.6241	0.0175	0.3416	25.540	1.985
37	62.57	1.48	0.6417	0.0175	0.3419	27.669	2.130
38	64.37	1.80	0.6592	0.0175	0.3421	30.066	2.396

0.000247 **<== Factor change Rate**

$$r = \frac{(e-b)}{p}$$

r= rate of form factor change
e = end value = 0.37
b = beginning value = 0.333
p = time period in years

Avg annual vol change for decade (years 1–10): **0.036 ft^3**

Avg annual vol change for decade (years 11–20): **0.370 ft^3**

Avg annual vol change for decade (years 21–30): **1.071 ft^3**

39	65.86	1.49	0.6767	0.0175	0.3424	32.444	2.378	**Avg annual vol change for decade**
40	67.93	2.07	0.6943	0.0175	0.3426	35.246	2.802	**2.051 ft^3**
41	69.40	1.47	0.7110	0.0167	0.3429	37.783	2.537	
42	70.62	1.22	0.7276	0.0167	0.3431	40.301	2.518	
43	71.86	1.24	0.7443	0.0167	0.3434	42.939	2.638	
44	73.27	1.41	0.7610	0.0167	0.3436	45.798	2.859	
45	75.15	1.88	0.7776	0.0167	0.3439	49.091	3.293	
46	76.60	1.45	0.7943	0.0167	0.3441	52.245	3.154	
47	78.57	1.97	0.8110	0.0167	0.3443	55.901	3.656	
48	80.20	1.63	0.8276	0.0167	0.3446	59.470	3.569	
49	81.40	1.20	0.8443	0.0167	0.3448	62.862	3.392	**Avg annual vol change for decade**
50	82.74	1.33	0.8610	0.0167	0.3451	66.487	3.625	**3.124 ft^3**
51	84.55	1.81	0.8776	0.0167	0.3453	70.649	4.163	
52	86.14	1.59	0.8943	0.0167	0.3456	74.791	4.142	
53	87.74	1.61	0.9110	0.0167	0.3458	79.108	4.317	
54	89.53	1.79	0.9276	0.0167	0.3461	83.763	4.654	
55	91.19	1.66	0.9443	0.0167	0.3463	88.468	4.706	
56	92.87	1.68	0.9610	0.0167	0.3466	93.374	4.906	
57	94.21	1.34	0.9776	0.0167	0.3468	98.107	4.733	
58	95.49	1.28	0.9943	0.0167	0.3471	102.929	4.822	
59	96.66	1.17	1.0110	0.0167	0.3473	107.783	4.854	**Avg annual vol change for decade**
60	98.47	1.81	1.0276	0.0167	0.3476	113.536	5.752	**4.705 ft^3**
61	100.03	1.56	1.0443	0.0167	0.3478	119.194	5.659	
62	101.72	1.69	1.0610	0.0167	0.3480	125.200	6.005	
63	102.56	0.83	1.0776	0.0167	0.3483	130.314	5.114	
64	103.32	0.76	1.0943	0.0167	0.3485	135.473	5.160	
65	104.08	0.76	1.1110	0.0167	0.3488	140.756	5.283	
66	105.57	1.49	1.1276	0.0167	0.3490	147.195	6.438	
67	106.42	0.85	1.1443	0.0167	0.3493	152.900	5.706	
68	107.45	1.03	1.1610	0.0167	0.3495	159.024	6.124	
69	108.85	1.40	1.1776	0.0167	0.3498	165.869	6.845	**Avg annual vol change for decade**
70	110.34	1.49	1.1943	0.0167	0.3500	173.059	7.190	**5.952 ft^3**
71	111.25	0.91	1.2047	0.0104	0.3503	177.662	4.604	
72	112.23	0.98	1.2151	0.0104	0.3505	182.471	4.808	
73	113.27	1.04	1.2255	0.0104	0.3508	187.466	4.995	
74	113.94	0.68	1.2360	0.0104	0.3510	191.940	4.474	
75	114.66	0.71	1.2464	0.0104	0.3513	196.551	4.611	
76	115.58	0.92	1.2568	0.0104	0.3515	201.595	5.044	
77	116.83	1.25	1.2672	0.0104	0.3517	207.312	5.717	
78	117.91	1.09	1.2776	0.0104	0.3520	212.841	5.530	
79	119.50	1.59	1.2880	0.0104	0.3522	219.390	6.549	**Avg annual vol change for decade**
80	120.83	1.33	1.2985	0.0104	0.3525	225.586	6.196	**5.253 ft^3**
81	121.61	0.78	1.3068	0.0083	0.3527	230.132	4.546	
82	123.05	1.44	1.3151	0.0083	0.3530	235.997	5.865	
83	124.52	1.47	1.3235	0.0083	0.3532	242.016	6.019	
84	125.93	1.42	1.3318	0.0083	0.3535	248.033	6.018	
85	126.58	0.65	1.3401	0.0083	0.3537	252.610	4.577	
86	127.92	1.35	1.3485	0.0083	0.3540	258.660	6.050	
87	129.46	1.54	1.3568	0.0083	0.3542	265.203	6.542	
88	130.24	0.78	1.3651	0.0083	0.3545	270.269	5.066	
89	130.89	0.66	1.3735	0.0083	0.3547	275.150	4.881	**Avg annual vol change for decade**

90	132.07	1.18	1.3818	0.0083	0.3550	281.199	6.049	**5.561 ft^3**
91	132.92	0.85	1.3901	0.0083	0.3552	286.638	5.440	
92	133.53	0.60	1.3985	0.0083	0.3554	291.599	4.960	
93	134.27	0.74	1.4068	0.0083	0.3557	296.926	5.327	
94	134.60	0.33	1.4151	0.0083	0.3559	301.402	4.477	
95	135.37	0.77	1.4235	0.0083	0.3562	306.929	5.527	
96	136.42	1.05	1.4318	0.0083	0.3564	313.156	6.227	
97	137.17	0.75	1.4401	0.0083	0.3567	318.766	5.611	
98	137.85	0.69	1.4485	0.0083	0.3569	324.301	5.535	
99	138.46	0.60	1.4568	0.0083	0.3572	329.711	5.409	**Avg annual vol change for decade**
100	139.42	0.97	1.4651	0.0083	0.3574	336.054	6.343	**5.485 ft^3**
101	140.20	0.77	1.4721	0.0069	0.3577	341.368	5.314	
102	141.04	0.85	1.4790	0.0069	0.3579	346.915	5.547	
103	141.98	0.94	1.4860	0.0069	0.3582	352.750	5.835	
104	143.07	1.09	1.4929	0.0069	0.3584	359.023	6.273	
105	143.99	0.93	1.4998	0.0069	0.3587	364.968	5.945	
106	144.82	0.83	1.5068	0.0069	0.3589	370.739	5.770	
107	145.86	1.03	1.5137	0.0069	0.3591	377.096	6.357	
108	146.10	0.24	1.5207	0.0069	0.3594	381.443	4.348	
109	146.56	0.46	1.5276	0.0069	0.3596	386.421	4.978	**Avg annual vol change for decade**
110	147.31	0.75	1.5346	0.0069	0.3599	392.208	5.787	**5.615 ft^3**
111	148.21	0.90	1.5415	0.0069	0.3601	398.462	6.254	
112	148.74	0.53	1.5485	0.0069	0.3604	403.780	5.318	
113	149.30	0.56	1.5554	0.0069	0.3606	409.214	5.434	
114	149.73	0.43	1.5623	0.0069	0.3609	414.343	5.129	
115	150.44	0.71	1.5693	0.0069	0.3611	420.302	5.959	
116	151.23	0.79	1.5762	0.0069	0.3614	426.543	6.240	
117	151.70	0.47	1.5832	0.0069	0.3616	431.952	5.409	
118	151.98	0.29	1.5901	0.0069	0.3619	436.869	4.917	
119	152.85	0.86	1.5971	0.0069	0.3621	443.503	6.634	**Avg annual vol change for decade**
120	153.26	0.41	1.6040	0.0069	0.3624	448.888	5.385	**5.668 ft^3**
121	153.62	0.35	1.6104	0.0064	0.3626	453.830	4.942	
122	153.86	0.24	1.6168	0.0064	0.3628	458.490	4.660	
123	154.36	0.50	1.6232	0.0064	0.3631	463.956	5.466	
124	154.61	0.24	1.6297	0.0064	0.3633	468.682	4.726	
125	155.35	0.74	1.6361	0.0064	0.3636	474.969	6.287	
126	156.09	0.74	1.6425	0.0064	0.3638	481.312	6.343	
127	156.68	0.59	1.6489	0.0064	0.3641	487.247	5.935	
128	157.63	0.94	1.6553	0.0064	0.3643	494.332	7.085	
129	157.97	0.34	1.6617	0.0064	0.3646	499.582	5.250	**Avg annual vol change for decade**
130	158.49	0.52	1.6681	0.0064	0.3648	505.438	5.856	**5.655 ft^3**
131	159.17	0.69	1.6733	0.0052	0.3651	511.147	5.709	
132	159.91	0.74	1.6785	0.0052	0.3653	517.084	5.937	
133	160.28	0.36	1.6837	0.0052	0.3656	521.832	4.748	
134	160.36	0.08	1.6889	0.0052	0.3658	525.682	3.850	
135	160.53	0.17	1.6942	0.0052	0.3661	529.843	4.161	
136	161.20	0.68	1.6994	0.0052	0.3663	535.719	5.876	
137	161.71	0.51	1.7046	0.0052	0.3665	541.062	5.343	
138	162.56	0.85	1.7098	0.0052	0.3668	547.613	6.551	
139	163.18	0.61	1.7150	0.0052	0.3670	553.410	5.797	**Avg annual vol change for decade**
140	164.12	0.95	1.7202	0.0052	0.3673	560.383	6.973	**5.494 ft^3**

141	164.15	0.03	1.7244	0.0042	0.3675	563.565	3.182	
142	164.33	0.18	1.7285	0.0042	0.3678	567.278	3.713	
143	164.41	0.08	1.7327	0.0042	0.3680	570.685	3.407	
144	165.23	0.82	1.7369	0.0042	0.3683	576.680	5.996	
145	166.15	0.93	1.7410	0.0042	0.3685	583.087	6.407	
146	166.15	0.00	1.7452	0.0042	0.3688	586.274	3.187	
147	166.20	0.04	1.7494	0.0042	0.3690	589.620	3.345	
148	167.02	0.82	1.7535	0.0042	0.3693	595.752	6.133	
149	167.28	0.26	1.7577	0.0042	0.3695	599.934	4.182	**Avg annual vol change for decade**
150	167.94	0.66	1.7619	0.0042	0.3698	605.553	5.619	**4.517 ft^3**

Jake Swamp Actual Dimensions:			**Random Number Generation for Annual Height Growth**	
Height	**168.50**	**ft**	$$n = \frac{(Int(R)10^4)}{10^4} + b$$	**R=Random # from generator**
Girth	**10.40**	**ft**		**b= base value**
Volume	**573.00**	**ft^3**		

In an advanced version of the above spreadsheet process, currently being developed, we will track minimum, maximum, and average volume changes for time intervals, such as 25 years. The advanced version will be submitted later as an addendum to this report. It will be parameter driven so that assumptions for annual height and radial growth and for the change in trunk shape can be conveniently entered into a table. As we gain experience with this model, we will build in tree age as a variable.