Mission Statement:

The Native Tree Society (NTS) is a cyberspace interest group devoted to the documentation and celebration of trees and forests of the eastern North America and around the world, through art, poetry, music, mythology, science, medicine, wood crafts, and collecting research data for a variety of purposes. This is a discussion forum for people who view trees and forests not just as a crop to be harvested, but also as something of value in their own right. Membership in the Native Tree Society and its regional chapters is free and open to anyone with an interest in trees living anywhere in the world.

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COVER: Yellow Birch by Robert T. Leverett.

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I want to remind the readers of this magazine that the articles presented here are only a part, usually just the beginning, of the discussions being held on our BBS at [http://www.ents-bbs.org](http://www.ents-bbs.org). The full discussion can be read by clicking on the link embedded in the title of each individual article. - Edward Frank

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Those interested in reproducing materials (articles or photographs) from the eNTS: the Magazine of the Native Tree Society should contact the Editor-in-Chief and/or the associated author/photographer directly for permission.
Matt, Thanks very much for reintroducing the thread. Thanks to you and our other new members, NTS has never been better. Nothing like fresh blood with fresh perspectives and an infusion of energy and passion. I especially liked your mentioned the enjoyment that comes from carving out a new niche. When one of us introduces a new place and takes ownership, revisiting it many times, it becomes alive in a way that I think we all come to appreciate.

Tomorrow, Monica and I are taking a couple of friends on a walk up the small stream flowing behind our house. They are in for a treat. But it was back in 2010 when I really began to worry that the Broad Brook woods were vulnerable to exploitation. Smith Vocational School owns a large chunk of the stream corridor and their goal is to train loggers. They've already reduced a sizable area to young, nondescript woodlands. Here is a look at what we're trying to get them to leave alone.

So your reference to what I think of as our personal missions is most timely.

Robert T. Leverett
Re: Broad Brook MA

by dbh guru » Mon Apr 01, 2013 1:29 pm

Joe Zorzin wrote: or, to use forestry doublespeak, those overmature, desert like forests have been regenerated to lovely, rare and endangered, baby forests- habitat for vast herds of early succession species, like bunnies.

Joe, So long as there's a dollar to be made by cutting trees as soon as they'll pay their way out of the forest, that will be the paradigm within the timber industry as a whole. We're thankful that there are those of you who advocate long term management and recognize the need for some of our forests to be unmanaged and unexploited. May the force be with you.

Here are two more Broad Brook images. Both taken about an hour ago. The first is the huge double pine. Ed Ritz and Susan Murphy pose along with Monica.

The next is an image with the same three with a 108-foot black birch, which we've named Schubirch. It is one of only two that I've measured in the Valley to that height.

Robert T. Leverett
Re: Fused redwoods
by Mark Collins » Mon Apr 01, 2013 8:12 pm

I came across this excellent example of a fused redwood over the weekend. Many fused redwoods seem to have one smaller tree attached to the side like this one pictured. To walk around to the backside of this incredible tree and see the giant fire cave was breathtaking. This fused redwood had a cbh of 58 feet, 6 in.
Re: Max Height List - Tree of the Week: Pinus strobus

Here's the information I've gathered.

Will - Do you know the last date the Boogerman Pine was measured and also the method of height measurement?

Country: USA
State or Province: North Carolina
Property Owner: National Park Service
Site Name: Great Smoky Mountains National Park
Species (Scientific): Pinus strobus
Species (Common): Eastern White Pine
Tree Name: Boogerman Pine
NTS Measurer: Will Blozan
Date of Measurement: Height (ft): 188.9
Method of Height Measurement:
Notes: Measured at 207 ft tall by Will Blozan and Robert Leverett, prior to losing its top in Oct 1995

Thanks,
Matt

Re: Max Height List - Tree of the Week: Pinus strobus

Very cool, what an interesting story that tree has to tell and so cool that you're telling it. I'll list you and Brian Beduhn as measuring it in 2011. If you happen to find the specific date, then that would be pretty cool too.

I'll definitely keep the “Tree of the Week” idea going. If/when taller specimens are found, this format will lend itself to being easily updated and kept current.

So maybe Frangula (Rhamnus) carolinianna can be the “Tree of the Week” next week? Why not!

- Matt

Re: Max Height List - Tree of the Week: Pinus strobus

The last measurement was taken by myself and Brian Beduhn sometime in 2011. If you want a specific date I can look it up later. We used NTS methods (Nikon 440 and clino) with a pole at the base. BTW- the initial 207' measurement was derived from a taped based line with cross-triangulation. First measure after breakage was via a climb and tape drop (186.1').

Good idea- let's see if it catches on. Let's not forget the little ones as well... I measured a 35' Frangula (Rhamnus) carolinianna last week which shatters the records!

Will

What should I look for in Marshall Forest, Rome, Georgia?

My daughter has decided to go to Shorter University in Rome, Georgia next year. It wouldn't be my choice, if I was going to college, but it's her life.

Soon, we are going to visit the campus. This gives me the opportunity to check out Marshall Forest, a Nature Conservancy preserve that is right around the corner from the campus.

Supposedly, Marshall Forest is the only virgin forest within any city limits in the United States. I think it encompasses about 600 acres, half of which have
reportedly never been logged.

Anybody ever been there? What should I look for?

Re: What should I look for in Marshall Forest, Rome, Georgia  
by Jess Riddle » Tue Apr 02, 2013 11:36 am

Hi Mark,

The area around Rome is botanically fascinating. Marshall Forest is certainly a good first stop in the area. I’m not completely convinced the site was never logged, but dendrochronologists have found a few trees dating back to the 1700’s at the site. The Trail for the Blind and the trail to the ridgetop, I believe the only two trails in the preserve, give a good overview of the site, and pass through forest that is unusually old for the region. Aside from the generally old forest, the botanical highlights of the area are the scattered montane longleaf pines. On the upper slopes, you can also see the uncommon shrub Georgia holly (Ilex longipes), and the thick coating of resurrection fern makes the old pecan plantation visually interesting.

Berry College’s campus, the largest in the country, is also worth a visit. There is a population of montane longleaf pine on the college owned Lavender Mountain. I believe the college also has one of only two stands of nutmeg hickory in the state. Nutmeg hickory is rare throughout its range, and was first discovered in Georgia only a few years ago. That stand is along a highway near the campus.

The other rare tree in the area is blue ash. It grows at The Nature Conservancy’s Blacks Bluff Preserve, one of only a handful of sites in Georgia for the essentially Midwestern species. Blacks Bluff Preserve also hosts a few other rare species.

Even without leaving town, you can see some impressive trees around Rome. There’s a 17’+ pecan by one of the rivers, and there’s an ~18’ cherrybark oak growing on a hilltop along Shorter Avenue.

If you’re not into just trees, the real botanical highlights of the area are the “Floyd Prairies”. Shrink-swell clays allow prairies to thrive on a few sites in the normally forested region. They host numerous rare or disjunct species, including whorled sunflower (Helianthus verticillatus). Whorled sunflower was last seen in the 1800’s until Richard Ware, a Rome botanist, rediscovered them.

You should contact the Georgia Botanical Society for more information on sites in the area. They often have field trips in the area, and Richard Ware, Georgia’s tree expert, is active with the group.

Hope this helps,

Jess

Re: Greensboro-The Grande/Bluffs Neighborhoods  
by bbeduhn » Wed Apr 03, 2013 3:20 pm

Some new finds:

- red hickory 100.1’ 115.3’ 112.8’
- mockernut hickory 109.5’
- black gum 97.4’
- white ash 107.8’
- red oak 113.5’ 114.4’
- white oak 111.6’

Not bad for a neighborhood

Brian Beduhn
Re: Metasequoia Glyptostroboides
(Dawn Redwood)
by bbeduhn » Wed Apr 03, 2013 4:59 pm

They just keep coming: All North Carolina sites

Henderson County
Flatrock playhouse 63.3'
East Henderson High 65.7'
176/I-26 76.9'

Transylvania County
Brevard Prebort st. 93.9'
Brevard Caldwell/Carver 95.9'
Pisgah Forest by Taco bell 113.8'

Buncombe County
280 by dollar store ~80.0'
Ray Hill Rd. 96.2'
280 Boyleston Hwy 80.7'

Guilford County
Greensboro Frsh Mrkt. 58.6’ 63.5’ 63.4’ 53.1’

Taxodium Distichum Asheville Maplewood
96.7’ 96.6’ 92.0’ 91.6’ 88.9’ 105.1’

This is the first instance I’ve seen with knees in a residential area. Thanks to Will for spotting these. The 105.1’ ranks 2nd in the city and I believe 6th in the county.

Brian Beduhn

Re: Chattooga River, SC
by bbeduhn » Wed Apr 03, 2013 4:03 pm

I concentrated on the East Fork of the Chattooga this time but also did a little bit on the main river as well. I couldn't find any hemlocks that came close to fitting the dimensions of the East Fork Spire. The skeletons were in the 130’ range.

It took a while to find the first pitch pine, about a mile or so, but then they were everywhere. White pines are growing steadily. Most seem to be second growth after leaving walhalla Fish hatchery. Sourwoods were again impressive.

Pinus strobus
white pine
140.1’ 142.5’ 142.7’ 143.0’
143.8’
147.7’ 148.2’ 149.0’ 149.1’
150.8’
151.8’ 153.1’ 156.3’ 156.9’
159.7’
165.6’ 166.9’ 171.4’

Pinus rigida
pitch pine
110.2’ 110.3’ 114.4’ 115.1’
115.2’
116.2’ 116.2’ 117.8’ 119.1’
119.5’
121.2’ 122.2’ 124.5’ 125.4’
126.5’
128.8’ 130.5’

Oxydendron arboreum
sourwood
72.5’ 73.2’ 76.1’ 77.1’
82.0’ 82.5’
82.5’ 83.1’ 85.1’ 86.0’
87.5’ 89.0’
90.1’ 95.3’ 95.3’

Tsuga canadensis
hemlock

Liriodendron tulipfera
tuliptree
129.5’ 133.9’ 134.5’

Betula lenta
black birch
90.2’ 103.5’

Halesia carolina
Mountain silverbell (hershey tree)
alluvial flats of the Chattooga. There are some flats up above the river as well but they've been logged and the hardwoods just don't seem to take over the way the pines do. There are several pockets of healthy second growth hemlocks, likely more in the 120's but the old growth hemlocks are all dead.

I'll have several pics to add.
Brian

Re: Chattooga River, SC
by bbeduhn » Wed Apr 03, 2013 4:19 pm

Some summary numbers so far:

- white pine 150' club: 150.8' 151.8' 152.8' 153.1'
- pitch pine 120' club: 120.0' 120.8' 121.2' 122.2'
- sourwood 90' club: 90.1' 90.1' 91.0' 94.1'

The prime section south of Burrells Ford is next on the agenda for Chattooga.

Need help with Ulmus ID
by Will Blozan » Tue Apr 02, 2013 8:08 pm

NTS,

I have been working on a site here in Western North Carolina that is really puzzling... It is on the SW slope of a 3,000 foot (915 m) peak but dominated by the weirdest mix of species. The most common tree is an elm (*Ulmus*) that perplexes me. It is likely an exotic and it occupies large areas of forest here and on several sites in the city of Asheville. Other species on the site we are working on include sugarberry (*Celtis*), black walnut (*Juglans*), and persimmon (*Diospyros*). It is more of a floodplain mix than a mountain mix!

Any help with ID would be great as keys are not very helpful yet. I am hoping a EuroNTS may recognize it right away or a local NTS may as well. The elms are quite vigorous and dominant where I have seen them.

Elm 1.JPG
Crown reduction for long-range vista

And this is the vista work we were doing...
Re: Guilford Courthouse-Greensboro, NC
by bbeduhn » Wed Apr 03, 2013 3:26 pm

[Guilford Courthouse is a Revolutionary War site. There's a chance this tree is from that era, but I'd guess it's a little younger. It's right on the side of the oldest road at the site, about a quarter mile from the presumed site of the original courthouse. A seven footer is what I'd consider a large shortleaf as well.]

I finally got back to the big shortleaf. It's a little smaller in girth than I thought but I got a slightly taller reading as well.

Intro Bill Brighoff
by brighhoff » Thu Apr 04, 2013 12:41 pm

Retired science teacher; hobbies: hiking, reading, practicing law; member Master Naturalist, Wild Ones, St Louis Mineral & Gem Society; volunteer work includes glade clearing, working at Forest Releaf, and planning rock hunting field trips.

Bill Brighoff
Wikipedia Articles
by edfrank » Wed Apr 03, 2013 11:53 pm

NTS,

I have published five articles on Tree Measurement to Wikipedia. Now my job is to fix problems with the articles and to keep idiots from screwing them up.

http://en.wikipedia.org/wiki/Tree_Measurement
http://en.wikipedia.org/wiki/Tree_girth_measurement
http://en.wikipedia.org/wiki/Tree_height_measurement
http://en.wikipedia.org/wiki/Tree_crown_measurement
http://en.wikipedia.org/wiki/Tree_volume_measurement

I will fix the reference's and add the images from the Wikipedia articles tomorrow. If anyone wants to help answer the comments or revise the articles based upon reviewer's comments, your help would be appreciated.

Edward Frank

Tree measurement

http://en.wikipedia.org/wiki/Tree_Measurement

From Wikipedia, the free encyclopedia

(Redirected from Tree Measurement)

Jump to: navigation, search

Trees have a wide variety of sizes and shapes and growth habits. Specimens may grow as individual trunks, multitrunk masses, coppices, clonal colonies, or even more exotic tree complexes. Most champion tree programs focus finding and measuring the largest single-trunk example of each species. There are three basic parameters commonly measured to characterize the size of a single trunk tree: height, girth, and crown spread. A detailed guideline to these basic measurements is provided in The Tree Measuring Guidelines of the Eastern Native Tree Society by Will Blozan.[1][2]

Summaries of how to measure trees are also presented by various groups involved in documenting big trees around the world. These include among others: a) American Forests Tree Measuring Guidelines;[3] b) National Register of Big Trees - Australia's Champion Trees: Tree Measurement, Champions and Verification;[4] c) Tree Register: A unique record of Notable and Ancient Trees in Britain and Ireland - How to measure trees for inclusion in the Tree Register;[5] and d) NZ Notable Trees Trust.[6] Other parameters also measured include trunk and branch volume, canopy structure, canopy volume, and overall tree shape. Overviews of some of these more advanced measurements are discussed in Blozan above and in “Tsuga Search Measurement Protocols” by Will Blozan and Jess Riddle, September 2006,[7] and tree trunk modeling by Robert Leverett[8] and Leverett and others.[9] The appropriate measurement protocols for multitrunk trees and other more exotic forms are less well-defined, but some general guidelines are presented below.

Contents

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• 2 Girth
• 3 Crown Spread
• 4 Tree Volume & Canopy Mapping
• 5 Trees with Unusual Forms
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• 8 Big Tree Formulas
• 9 Location
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Tree Height

Tree height is the vertical distance between the base of the tree and the highest sprig at the top of the tree. The base of the tree is measured for both height and girth as being the elevation at which the pith of the tree intersects the ground surface beneath, or “where the acorn sprouted.” On a slope this is considered as halfway between the ground level at the upper and lower sides of the tree. Tree height can be measured in a number of ways with varying degrees of accuracy. There are direct measurements. Shorter trees can be measured using a long pole extended vertically to the top of the tree. Larger trees can be climbed and a tape measurement made from the highest point of the climb to the base of the tree. The distance to the top of the tree can be measured from that point, if needed, using a pole.

Tree heights can also be measured remotely from the ground. The most basic remote height methodologies are all variations of the stick measurement. The height is calculated using the principle of similar triangles. A short stick is held out pointing vertically at arm’s length by its base pointing vertically. The surveyor moves in and out toward a tree until the base of the stick above the lower hand aligns with the base of the tree and the top of the stick aligns with the top of the tree. The distance from the lower hand to the eye is measured, the distance from the eye to the base of the tree is measured with a tape. The ratio of distance from the eye to the hand is to the distance from eye to the base of the tree, as is equal to the ratio of the length of the stick to the height of the tree provided that the top of the tree is positioned vertically over the base.

(distance from eye to base of tree/distance from eye to base of stick) x length of stick = tree height

A second method uses a clinometer and a tape and is commonly employed in the forestry industry. This process applies the trigonometric tangent function. In this process the horizontal distance is measured to the trunk of a tree from a sighting position. The angle to the top of the tree is measured with the clinometer.

horizontal distance at eye level to the tree trunk x tangent Θ = height above eye level

If the tree extends below eye level the same process is used to determine the length below eye level and that is added to height above eye level to determine total tree height. Different clinometers have different reading scales, but all apply the same function. Calculations are as above if it reads in degrees. If it has a percentage scale, then the percentage is multiplied by the distance to the tree to determine a height or extension above and below eye level. Others have a 66′ scale where if used at a distance of 66 feet from the tree the height above or below eye level can be directly read from the scale. Errors frequently accompany this type of measuring. The process assumes that the top of the tree is directly over the base of the tree. The tree top may be offset significantly from a point directly over the base (or level point on the trunk). Typical errors from this effect are often on the order of 10 to 20 feet. A bigger problem is misidentifying a forward leaning branch for the actual top of the tree. Errors associated with this mistake may yield measurements that are off many tens of feet and some errors of over forty feet and more have made it onto various champion tree lists, and in at least two cases, the errors have exceeded 60 feet.

A third remote method is called the sine-height method or ENTS method. It requires the use of a laser rangefinder and clinometer. In this method the distance to the top of a tree is directly measured by the surveyor using the laser rangefinder. The angle to the top is measured with the clinometer. The height of the tree top above eye level: [height = sine Θ of angle x distance to the top] the same process is used to measure the extension of the base of the tree below or even above eye level. Since the measurement is
along the hypotenuse of the right triangle and both the top and bottom triangles are independent, it doesn’t matter if the tree top is offset from the base as this does not affect the calculation. In addition the top branches of the tree can be scanned with the laser rangefinder to find which top is actually the tallest and the major error of misidentifying the top can be avoided. If the true top of the tree is misidentified the height measurement for the tree will simply be short by some amount, and will not be exaggerated. The height will be correct for the target being measured.

With calibration, multiple shots, and a technique to deal with scales that read only to the nearest yard or meter, tree heights can typically be measured to within one foot using this methodology. Other measurement techniques include surveying with a transit and a total station, extended baseline method, the parallax method, and the three verticals method.

**Girth**

Girth is a measurement of the distance around the trunk of a tree measured perpendicular to the axis of the trunk. Use of girth to arrive at an equivalent diameter is an older forestry measurement that is still used. In the United States girth is measured at a height of 4.5 feet above ground level. Elsewhere in the world it is measured at a height of 1.3 meters, 1.4 meters, or 1.5 meters.

Tree girth measurement is commonly performed by wrapping a tape around the trunk at the correct height. Tree girth may also be measured remotely using a monocular w/reticle, through photographic interpretation, or by some electronic surveying instruments. In these remote methods a diameter perpendicular to the surveyor is what is actually being measured and that is converted to girth by multiplying that number by pi. Many trees flare outward at their base. The standard height up the trunk for determining girth is easily measurable and in most trees it is above the majority of the basal flare and gives a fair approximation of the size of the trunk. For the largest trees, or those with a broad basal flare far up the trunk, it would be appropriate to also measure a second girth above the flare and to note this height.

If there are significant low branches that emerge below this height, ignoring any minor epicormic sprouts and dead branches, then the girth should be measured at the narrowest point below the lowest branch and that height noted. If there is a burl or protuberance at the measurement height, then the girth should be measured immediately above the protuberance or at the narrowest point of the trunk below the protuberance and that height noted.

If the tree is growing on sloping ground the base of the tree should be considered to be where the center or pith of the tree intersects the supporting surface below, typically at mid-slope along the side of the tree. If the tree is large and this measurement would place one portion of the girth loop below ground level, then the measurement should be made at 4.5 feet above ground level at the high side of the slope.

It should always be noted whether or not the tree being measured is single or multitrunk. A single trunk tree is one which would only have a single pith at ground level. If the tree would have more than one pith at ground level, it should be listed as a multitrunk tree and the number of trunks included in the girth measurement noted. If the flare at the base
of the tree extends above this default girth height, then ideally a second girth measurement should be collected where possible above the basal flare and this height noted.

**Crown Spread**

Crown spread is a measure of the footprint or plan area of the crown of the tree expressed as a diameter. The most basic crown spread measurement is the average length of two lines across the crown area. The first measurement is made along the longest axis of the crown from one edge to the opposite edge. A second measurement is taken perpendicular to the first line through the central mass of the crown. The two values are averaged to calculate crown spread. A second method is to take a series of four or more spokes running from the side of the center of the trunk to the edge of the crown. The more spokes measured the better the crown size is represented. The crown spread is the twice the average of all of the spokes. For trees in open areas, crown spreads can also be measured where high enough resolution photos are available using Google Earth. There are length measurements tools built into the program that will allow multiple diameters across the crown to be measured or averaged. Alternatively there are add-on software packages available that can allow an area to be outlined on the Google Earth image and the area enclosed calculated. This can then be converted to crown spread. Leverett has also provided four options for measuring the crown area through compass and clinometer surveys around the outer edge of the crown or through a combination of measurements from the edge of the crown and to the trunk, and those around the crown perimeter. Maximum crown spread and maximum limb length measurements can also be measured if needed.

Tree crown spread measurement

Crown Volumes can be measured as an extension of the basic crown spread measurement. One method is to map a network of points on the outer surface of the crown from various positions around the tree and plotted by map position and height. The crown itself can be subdivided into smaller segments and the volume of each segment calculated individually. For example, the crown could be subdivided into a series of disk-like slices by elevation, the volume of each disk calculated, and the total of all the disks are added together to determine crown volume. Frank developed a simpler method that requires measuring average crown spread, height of the crown from base to top, and matching the crown profile to best fit of a family of crown profile shapes. The method calculates the volume enclosed by rotating the selected profile around the axis of the tree given the measured crown length and average crown spread.

**Tree Volume & Canopy Mapping**

Tree volume measurements may include just the volume of the trunk, or may also include the volume of branches. Volume measurements can be achieved via ground based or aerial methods. Ground based measurements are obtained by the use of a monocular w/reticle, laser rangefinder, and a clinometer. Aerial measurements are direct tape measures obtained by a climber in the tree. A
monocular w/reticle is a small telescope with an internal scale visible through the glass. The monocular is mounted on a tripod and the trunk of the tree is sighted through the lens. The width of the trunk is measured as so many units of the reticle scale. The height and distance of the target point is measured using the laser rangefinder and clinometer. With the distance known, the diameter of the tree measured expressed as units of the reticle scale, and an optical scaling factor for the monocular w/reticle, provided by the manufacturer and calibrated by the user, the diameter of the tree at that point can be calculated:

Diameter = (Reticle scale) \times (distance to target) \div (optical factor)

A series of tree diameters up the trunk of the tree are systematically measured using this procedure from the base of the tree to the top and their height is noted. Some photographic methods are being developed to allow calculation of diameters of trunk and limb segments in photographs that contain a scale of known size and where distance to the target is known. [26][27][28]

Tree climbers can physically measure the circumference of the tree using a tape. The climber will ascend into the tree until he reaches the highest safe climbing point. Once this point is reached a tape is pulled up along the side of the trunk via a drop rope. The upper end of the tape is lightly tacked at this point and allowed to hang freely down the trunk. The distance from the highest climb point and the top of the tree is measured using a pole that extends from the tree top to the anchor point of the tape. This height is noted and the diameter of the tree is measured at that point. The climber then rappels down the tree measuring the trunk circumference by tape wrap at different heights with the height of each measurement referenced to the fixed tape running down the trunk. Whether using the aerial or ground based methods, the diameter or girth measurements do not need to be evenly spaced along the trunk of the tree, but a sufficient number of measurements need to be taken to adequately represent the changes in diameter of the trunk.

To calculate trunk volume, the tree is subdivided into a series of segments with the successive diameters being the bottom and top of each segment and its length equal to the difference in height between the lower and upper diameter. Cumulative trunk volume is calculated by adding the volume of the measured segments of the tree together. The volume of each segment is calculated as the volume of a frustum of a cone where:

Volume = \frac{h(\pi/3)(r_1^2 + r_2^2 + r_1r_2)}{2}

Frustum of a cone

A similar, but more complex formula can be used where the trunk is significantly more elliptical in shape where the lengths of the major and minor axis of the ellipse are measured at the top and bottom of each segment. [31][7]

In areas where the trunk bifurcates the trunk will not have a circular or simple elliptical diameter. Blozan as part of the Tsuga Search Project [24] created a wooden frame that would fit around the odd shaped section and measured the position of the surface of the trunk with respect to the frame. These points were plotted on a graph and the cross-sectional area of the irregular trunk shape was calculated. This area was, in turn, converted to an equivalent circular area for use in the volume formula.

Many trees flare outward significantly at the base and this basal wedge has a complex surface of bumps and hollows. This becomes an even more complex volume in trees growing on a slope. Approximations of the volume of this basal segment using best estimates of the effective diameters exhibited may be used in many cases. In other cases footprint mapping is an option. In footprint mapping a level, rectangular reference frame is placed around the base of the tree.
to create a horizontal plane. The position of the multiple points on the trunk surface is measured with respect to the frame and plotted. This process is repeated at different heights creating a series of virtual slices at different heights. The volume of each individual slice is then calculated and all are added together to determine the volume of the basal wedge. Taylor [29,30] has been developing a cloud mapping process using optical parallax scanning technology whereby thousands of measurements are made around the trunk of a tree. These can be used to recreate a three-dimensional model of the trunk and volume data is among the values that can be calculated.

Canopy mapping is the process whereby the positions and size of the branches within the canopy are mapped in three-dimensional space. It is a labor intensive process that is usually reserved for only the most significant specimens. This is usually done from a set position or a series of positions within the tree. Sketches and photographs are used to facilitate the process. Trees are climbed and the overall architecture is mapped including the location of the main stem and all reiterated trunks, in addition to all branches that originate from trunks. The position of every branch point in the canopy down to a certain size and also the positions of various reiterations, breaks, kinks, or any other eccentricities in the tree are also mapped. Each mapped trunk and branch is measured for basal diameter, length, and azimuth.

Trees with Unusual Forms

Not all trees have a single trunk, and others pose additional measurement problems because of their size or configuration. The odd forms include those forms that grew because of unusual circumstances that affected the tree, or those trees that simply have an unusual growth form not seen in most other tree species. Frank [34] proposed a classification system for various tree forms: 1) Single Trunk Trees; 2) Multitrunk Trees; 3) Clonal Coppices; 4) Clonal Colonies; 5) Conjoined and Hugging Trees; 6) Fallen Trees; 7) Tree complexes, and 8) Banyan-like trees; 9) Trees with Large Aerial Root Systems; and 10) Epiphytic Trees. This initial framework has continued to evolve in discussions within the NTS, but provides an initial beginning and suggestions on how to approach measuring these various tree growth forms.

Since most of these trees are unique or unusual in their form and not amenable to easy measurement, the recommended approach [15] is to write a detailed narrative description of the tree with what measurements that can be taken to amplify and better illuminate the descriptions. These trees should be documented even if the results are in the form of a written narrative rather than a collection of numerical measurements.

There are some parameters that should be consistently measured whenever possible, height is one example. The cross-sectional areas occupied by the trunks and the crown are also parameters that are generally measurable. Other measurements could be taken where they seem to add to the narrative description of that particular tree. GPS locations should be taken whenever possible. Absent a GPS instrument, the locations should be pulled from Google Maps, or topographic maps. Beyond these basics, values like number of trunks larger than a prescribed value, the maximum girth of the largest trunk, and whatever seems appropriate for that particular tree grouping should be recorded.

Photographs of these unusual trees are important as they can immensely improve the understanding of what is being described, and help others to visualize the tree. A process or system is needed whereby the photos of a particular tree can be associated with the description of the tree in the researcher’s notes. The goal of the narrative and measurements is to document the tree or tree grouping.

Single trunk trees can also pose measurement problems. Consider trees with very large girths, such as some of the sequoias growing the western United States. If they are growing on even a gentle slope, if girth is measured at 4.5 feet about the where the pith of the tree emerges from the ground, the upside of the tape could easily be below ground level. In this case a better option would be to measure the standard girth measurement at 4.5 feet above ground level on the high side of the tree and note this in the measurement description. If measuring a mountaintop forest of
stunted trees only six feet tall, a girth measurement made at 4.5 feet would be meaningless. In the case of these stunted trees a girth taken at 1 foot above the base might be more appropriate. Girth measurements should be taken at the standard heights whenever possible. Where this measurement is not meaningful, an additional girth measurement should be taken at a more appropriate position and that height noted.

Double trunked Cherry Tree

Multitrunk trees are the most common form after single trunk trees. Often these represent separate trunks growing from a single root mass. This occurs frequently in some species when the initial trunk has been damaged or broken and in its place two or more new shoots grow from the original root mass. These are genetically the same, but as their growth form is different they should be considered as a different measurement category than single trunk trees. These multiple trunks commonly will grow together to form a large combined mass at the base and split into individual trunk at greater heights. If they have grown together at breast height then a measurement of their combined girth should be made at that height the number of trunks incorporated into the girth measurement listed. If the tree splays outward dramatically at breast height, then the girth should be measured at the narrowest point between breast height and the ground and that height noted. Other girth measurements guidelines outlined for single trunk trees, such as low branches and burls, apply to multitrunk girths as well. The height of the tallest trunk in the multitrunk specimen would then be the height of the multitrunk specimen and the combined crown spread of all the individual trunks the multitrunk specimen collectively would be the multitrunk crown spread. If one of the individual trunks is significantly larger than all the others, it can be treated as if it were a single trunk tree. Its girth is measured where it emerges from the combined mass, and the height and crown spread of that particular trunk is measured individually.

Clonal colonies, such as the Pando aspen, may occupy many acres. The area occupied by the colony should be measured as well as the size of the largest individual trunk present.

Banyan-like trees similarly consist of multiple trunks spread across a large area. In many of these specimens the interior trunks are not easily accessible. An approach to their measurement would be to measure the area occupied by the many trunks, the area occupied by the crown of the tree, the height of the tree, and any other measurements the investigator deems appropriate. These measurements would then be supplemented by a narrative description and photographs. The goal in all of these cases of trees with unusual forms is to document their characteristics.

Tree Shape

Different tree species tend to have different shapes and tree shapes also vary within a single tree species. As a general observation trees growing in an open setting tend to be shorter and have broader crowns, while those growing in a forested setting tend to be taller and have narrower crowns. In forested areas trees grow taller and put more energy into height growth as they compete with other trees for the available light. Often the tallest examples of many species are found where they are a secondary species on a site and competing for light with other taller tree species. The tall bay laurel (Umbellularia californica) at 169.4 feet discovered by Zane Moore in Henry Cowell Redwoods State Park is an example of an exceptionally tall understory tree growing among other taller species.

Ternary Tree Shape Plots. A methodology for plotting different tree shapes graphically was developed by Frank using ternary plot diagrams.
Ternary plots can be used to graphically display any set of data that includes three terms which total to some constant. Generally this constant is 1 or 100%. This is ideal for plotting the three most commonly measured tree dimensions. The first step in the analysis is to determine what an average shape for trees is in general. These three basic parameters can be expressed as a ratio of height to girth to average crown spread. Some trees are tall and narrow, while others are low and broadly spreading. The data used to determine the average tree shape is derived from a tabulation of the largest trees of each of 192 different species in the NTS 2009 dataset. The average girth, height, and crown spread values were calculated for the measurements included in the listing. For the dataset the average height was 87.6 feet, the average girth was 100.1 inches, and the average spread was 54.9 feet. It is not critical that these values be exact for analysis purposes. The next step is to standardize each measured parameter. The quantity measured for a particular tree is divided by the standard value as determined above. The next step is to normalize the data set so that the sum of the three parameters expressed as a percentage will equal one. This enables the shapes of different trees of different sizes to be compared. The final step is to plot these results as a ternary graph to better compare the results. As an example, the measurement data for 140 live oaks measured as part of the NTS Live Oak Project were graphically plotted using this process.

The cluster representing the live oak data falls on the extreme edge of the general pattern of tree shapes. The height proportion exhibits a maximum of 17.23% of the shape value and a minimum of 6.55%, the girth (minimum of 19 feet in the data set) exhibits a maximum of 58.25% and a minimum of 40.25%, and Average Crown Spread maximum of 49.08% and a minimum of 30.92%. These points represent the measurements of the largest specimens of live oak measured in the field and typically represent open grown specimens, but the tightness of the shape cluster is still remarkable. It is even more interesting to note that while the data set contains both multiple trunk trees and single trunk trees, both plot within the same tight cluster.

**Dendrochronology**

Dendrochronology is the science of dating and study of annual rings in trees. A tree in temperate and colder climates typically will grow one new ring every year, therefore the age of the tree can theoretically be determined by counting the number of rings present. The problem lies in the fact that some years, particularly in years of drought, a tree will not grow an annual ring. In other years where the growing season is interrupted a tree may grow a second false ring. The trees rings are commonly measured by taking a series of core samples. A borer is used to extract a pencil-size diameter or smaller core from a living tree or from a log. For downed and dead trees a disk section or “tree cookie” may also be taken, these are polished, the rings identified, and the number of rings and the distance between each are recorded. By comparing rings from multiple trees, through cross-dating, a dendrochronologists can determine if rings are missing or if false rings are present. Through this process the tree ring record can be used to investigate past climatic conditions. Tropical trees often lack annual rings and ages for these trees can be measured using radiocarbon dating of wood samples from the trees.

There are two major listings of the maximum ages of trees. The OldList is a database of ancient trees maintained by Rocky Mountain Tree-Ring research. Its purpose is to identify maximum ages that different species in different localities can attain such that exceptionally old age individuals may be
recognized. In addition to the original OldList, Neil Pederson at the Tree Ring Laboratory of Lamont-Doherty Earth Observatory and Columbia University has created an eastern OLDLIST focused on old trees in the eastern North America. In addition to these sources of tree ring data there is the ITRDB. The International Tree-Ring Data Bank is maintained by the NOAA Paleoclimatology Program and World Data Center for Paleoclimatology. The Data Bank includes raw ring width or wood density measurements, and site chronologies. Reconstructed climate parameters, including North American Drought, are also available for some areas. Over 2000 sites on six continents are included.

The oldest known tree is a bristlecone pine (Pinus longaeva) growing in the White Mountains of eastern California. The tree was cored by Edmund Schulman in the late 1950s, but was never dated. Recently Tom Harlan completed the dating of the old core sample. The tree is still alive and is 5062 years old as of the 2012 growing season. Older ages are given for sprouts growing from roots or clonal colonies, but these values are not from an individual stem that has persisted for that duration. Whether these are considered to be older trees or not is dependent on the definition used to define what is a tree.

In spite of the extensive amounts of work done by dendrochronologists in investigating trees, the maximum ages attainable by most common species is not clear. Dendrochronologists typically focus on trees that are known to have a long life span when investigating a site. This is because their goal is paleoclimatic reconstruction or archaeological investigation and longer lived trees provide longer data record. Most species believed to be shorter lived have not been systematically investigated and cross dated. The Native Tree Society is compiling basic ring counts for many of these species in order to better understand the age structure of the forests they are investigating, with the recognition that ring counts ages may be off due to missing or false rings.

**Big Tree Formulas**

American Forest Formula. American Forests has developed a formula for calculation tree points for determining champion trees for each species. Three measurements: Trunk Circumference (inches), Height (feet), and Average Crown Spread (feet). Trees of the same species are compared using the following calculation:

\[
\text{Trunk Circumference (inches) + Height (feet) + } \frac{1}{4} \text{ Average Crown Spread (feet)} = \text{Total Points.}
\]

The American Forests National Big Tree Program is the largest in the world with coordinators in all fifty states and the District of Columbia and is used as a model for several Big Tree programs around the world. American Forests describe it as a conservation movement to locate, appreciate and protect the biggest tree species in the United States with more than 780 champions crowned each year, with 200 more species without a crowned champion in 2012, and documented in their biannual publication — the National Register of Big Trees. The program has been operating since 1940.

For example, the Australian National Register of Big Trees uses the American Forests formula. The individual measurements are listed using both Imperial and metric values. Trees must be single-stemmed at 1.4m above ground where circumference is measured. They write that making the Australian tree Points directly comparable to the U.S.A. is important because Australians can view the American Forests Register of Big Trees and gain immediate, and much enjoyment, in comparing their Champions with ours, and vice versa for North American tree enthusiasts viewing our NRBT.

Tree Dimension Index. The Native Tree Society, in addition to the American Forests formula, uses an alternative approach to compare relative sizes of trees, both within the same species and against others. The Tree Dimension Index (TDI) is highly adaptable and can be tailored to reflect the attributes of an individual tree and how they compare relative to the largest known specimen. The premise is that the specific dimensions of the tree are given a value (percentage) that reflects its relative rank against the maximum known for the same dimension for the species. For example, the tallest known eastern hemlock would get a value of 100 for height since it represents 100% of the maximum value known for the species. A shorter tree that was 75% of
the maximum known height would get a value of 75 for its height. Likewise, the values of diameter and volume would be determined by the relative value when ranked against the known maxima. With three ranked attributes the maximum TDI value would theoretically be 300. However, this would represent one tree exhibiting all three maxima- an unlikely possibility. However, the apparent size of a tree can be realized by ranking the cumulative values against the theoretical maximum. A tree scaling close to 300 would suggest that it was nearly the largest specimen theoretically possible based on currently known maxima. A two-value TDI using height and girth was presented for 259 white pines (Pinus strobus) by Friends of Mohawk Trail State Forest to MA DCNR in 2006. The TDI values in the dataset ranged from 172.1 to 125.2 out of a possible maximum of 200.

Location

As with any other scientific investigation it is critical to establish the location of the trees being investigated. Without that information, the location of tree may be lost and other investigators will not be able to relocate the tree in the future. There is also the possibility that the same tree might be misidentified and re-measured as a different tree. GPS locations should be taken for every tree measured. GPS in most cases is accurate enough to distinguish the location of a specific tree. The actual accuracy users attain depends on a number of factors, including atmospheric effects and receiver quality. Real-world data collected by the FAA show that some high-quality GPS SPS receivers currently provide better than 3 meter horizontal accuracy. If GPs is not available then the approximate latitude and longitude data should be topographic maps, or air photo sources such as Bing Maps, Google Earth, or similar services.

Tree Databases

Several of the larger tree groups maintain interactive databases of tree information. Different types of information are available on different databases and there are different requirements for data entry. American Forests provides a searchable database of their Champion trees and in 2012 included data on 780 tree species. Most of the individual state big programs are administrated through the American Forest Big Tree Programs. The Native Tree Society has its own database Trees Database with the requirement that the trees entered meet their height measurement standards. There also are databases maintained by Australia’s National Register of Big Trees, Notable trees of New Zealand, Monumental Trees (primarily focused on Europe but including trees from elsewhere in the world), and The Tree Register - A unique record of Notable and Ancient Trees in Britain and Ireland.

There are many other sites maintained by groups and individuals that include tabulations of big trees of a specific area, of a particular species, or simply the largest individuals. Some of these include Landmark Trees, Native Tree Society, baumzaehlen, Old Trees in The Netherlands and Western Europe, the big eucalypts of Tasmania and Victoria, and the Old Growth Forest Network.

In all cases, the data collected needs to be organized into a useful searchable format that can be used. The Native Tree Society provides a free downloadable excel spreadsheet that can be used for organizing tree datasets. The spreadsheet can be modified for the needs of the user.

Rucker Indexes

Rucker Index is a family of indexes that are used to compare tree population between different tree sites. It is not species dependent and can be applied to sites of different sizes. The basic Rucker Index is a measure of overall tree height. The Rucker Height Index 10 or RI10 is the numerical average of the height in feet of the tallest individual of each of the ten tallest species on a site. A particular species enters the index only once. The index provides a numerical evaluation of both maximum height and diversity of the dominant species. High index values are the result of many factors, including climate, topography, soils, and a lack of disturbance. While the most extensive sites benefit from a greater variety of habitat and more individual trees, some exceptional sites are quite small. The Rucker Height Index is essentially a foreshortened version of a complete profile of all the species found on a particular site.
Variations of the Rucker Index can also be calculated. If the site has a high diversity of species a R120 can be calculated using twenty species. For sites with limited data or low species diversity, a R15 with only five species can be calculated. A Rucker Girth Index or RGI10 can also be calculated using the girth of the largest girth individual in each of the ten fattest species on a site.

The Rucker Height Index or Rucker Index has a numerous merits that make it a useful measurement when comparing various tall tree sites: 1) The formula is straightforward, unambiguous, and easy to apply; 2) The index can be applied to forests in any area with any make-up of trees; 3) The index requires a fairly diverse mix of trees in order to generate a high index value; and 4) To get a sufficient diversity of trees of great height requires at least a modest size or larger plot of forest and a reasonably thorough examination to generate a high RI value.

In January 2012 the calculated Rucker Index for the World was: 312.39 feet. The Rucker Index for the west coast of North America, and also all of North America is 297. The R110 for Great Smoky Mountains National Park is 169.24, the tallest site in eastern United States. For the northeastern United States the R110 is 152.6, and for the southeast, excluding GSMNP the R110 is 166.9.

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This article outlines the basic procedures for measuring trees for scientific and champion tree purposes. It does not cover timber assessment for production purposes, which is focused on marketable wood volumes rather than overall tree size.

Tree height is the vertical distance between the base of the tree and the tip of the highest branch on the tree, and is difficult to measure accurately. It is not the same as the length of the trunk. If a tree is leaning, the trunk length may be greater than the height of the tree. The base of the tree is where the projection of the pith (center) of the tree intersects the existing supporting surface upon which the tree is growing or where the acorn sprouted.[1][2] If the tree is growing on the side of a cliff, the base of the tree is at the point where the pith would intersect the cliff side. Roots extending down from that point would not add to the height of the tree. On a slope this base point is considered as halfway between the ground level at the upper and lower sides of the tree. Tree height can be measured in a number of ways with varying degrees of accuracy.

Tree height is one of the parameters commonly measured as part of various champion tree programs and documentation efforts. American Forests, for example, uses a formula to calculate Big Tree Points as part of their Big Tree Program[3] that awards a tree 1 point for each foot of height, 1 point for each inch of girth,[4] and ¼ point for each foot of crown spread.[4] The tree whose point total is the highest for that species is crowned as the champion in their registry. The other parameter commonly measured, in addition to the species and location information, is wood volume.[4] A general outline of tree measurements is provided in the article Tree Measurement with more detailed instructions in taking these basic measurements is provided in “The Tree Measuring Guidelines of the Eastern Native Tree Society” by Will Blozan.[7][8]

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Maximum Heights

The tallest tree in the world is a coast redwood (Sequoia sempervirens) growing in Northern California that has been named Hyperion. In September 2012, it was measured at 379.65 ft (115.72m) tall.[9] There are 7 other coastal redwoods known to be over 370 feet (112 meters) in height, and 222 specimens over 350 feet.[10] There are only five species known to grow over 300 feet in height worldwide.[11]

There are historical accounts of extremely tall and large trees. In the northeastern United States, for example, there are frequent stories published in newspapers and magazines dating from the 1800’s telling of extremely tall white pines (Pinus strobus).[12] One extraordinary account in the Weekly Transcript, North Adams, Mass., Thursday, July 12, 1849 reads: “A Large Tree. --- Mr. D. E. Hawks, of Charlemont, cut a Pine tree a short time since, of the following dimensions. It was 7 feet through 10 feet from the stump, and ½ point for each foot of crown spread.[4] The tree whose point total is the highest for that species is crowned as the champion in their registry. The other parameter commonly measured, in addition to the species and location information, is wood volume.[4] A general outline of tree measurements is provided in the article Tree Measurement with more detailed instructions in taking these basic measurements is provided in “The Tree Measuring Guidelines of the Eastern Native Tree Society” by Will Blozan.[7][8]
Leverett and Will Blozan measured the Boogerman Pine, a white pine in Great Smokey Mountains National Park, at a height of 207 feet in 1995 using ground based cross triangulation methods. This the highest accurate measurement obtained for any tree in the eastern United States within modern times. The top of the tree was lost in Hurricane Opal in 1995 and it currently stands at just under 190 feet in height. It is possible that some white pines in the past reached heights of well over 200 feet given the much larger area of primary forest prior to the timber boom in the 1800’s, however, based on what grows today, it is highly unlikely they ever reached the heights in some of these historical accounts. These reported heights are likely just a mixture of personal and commercial bravado by the lumbermen of the time.

**Approximate Tree Heights**

Of the various methods of approximating tree heights, the best options, requiring only a minimal amount of equipment, are the stick method and the tape and clinometer (tangent) method. To get accurate measurements with either method, care must be taken. First try to view the tree from several different angles to see where the actual top of the tree is located. Use that point for the measurements. This will eliminate the greatest potential for error.

**Stick Method**

The stick method requires a measuring tape and a stick or ruler and uses the principle of similar triangles to estimate tree heights. There are three primary variations of the stick method.

A) Stick-rotation method or pencil method for trees on level ground and with top vertically over the base: 1) grasp the end of a stick and hold it at arm’s length with the free end pointed straight up; 2) move back and forth toward or away from the tree to be measured until the base of the tree aligns visually with the top of the hand at the base of the stick and the top of the tree is aligned with the top of the stick; 3) without moving the arm up or down rotate the stick until it is parallel to the ground. The base of the stick should still be aligned with the base of the tree. 4) If you have an assistant, have them walk away from the base of the tree at a right angle to your position until they reach the spot on the ground that aligns with the top of the stick. If alone pick a distinctive point on the ground to mark this point. The distance from the base of the tree to this point is equal to the height of the tree. Again, this method assumes that the top of the tree is vertically over the base.

B) Standard stick method: 1) Find a straight stick or ruler; 2) Hold the stick vertically at arm’s length, making sure that the length of the stick above your hand equals the distance from your hand to your eye. 3) Walk backward away from the tree. Stop when the stick above your hand exactly masks the tree. 4) Measure the straight-line distance from your eye to the base of the tree. Record that measurement as the tree’s height to the closest foot. As with A, if the top is not vertically over the base, this method will generate an error.

C) Advanced stick method uses the same procedure outlined above with the addition of a few measurements and some basic multiplication. This method does not require that the length of the measuring stick be the same as the distance from your bottom hand to your eye, so it can be used in more varied settings to get a height measurement: 1) holding the stick as outlined above, align both the base of the tree with the top of your hand holding the stick and the top of the tree with the top of the stick. You can do this by moving toward or away from the tree, adjusting the stick length, and by moving your arm up and down; 2) once aligned, measure the distance from the top of your hand grasping the base of the stick to your eye; 3) measure the distance from the top of your hand to the top of the stick; 4) measure the distance from your eye to the base of the tree. So long as the yardstick is held straight up and down and the top of the tree is vertically over the base, the various measurements are still proportional and then you can calculate the height of the tree using a simple formula:

\[ \text{tree height} = \frac{(\text{length of stick} \times \text{distance to the tree})}{\text{(distance to eye)}} \]

Using this formula the height of the tree can be calculated no matter what angle you are holding your arm, and no matter what the length of the yardstick that extends above your hand. This has a big
advantage if you are measuring a tree on uneven ground or if you can only measure the tree from a single angle. One problem that also often occurs is in order to see the top of the tree; the surveyor must be farther away from the tree than possible using a yardstick length of 23-25 inches (average arm to eye length). Using the simple formula above a smaller length of stick can be used allowing the surveyor to actually see the top of the tree. As with A. and B. above, this method assumes that the top of the tree is vertically over the base. If this assumption is violated, the triangles will not be similar and the ratio and proportion relationship of the sides of similar triangles will not apply.

**Clinometer and Tape Method**

Clinometer and Tape Method or the Tangent Method, is commonly used in the forestry industry to measure log length. A clinometer is a hand held device used for measuring angles of slope. The user can sight to the top of a tree using the clinometer and read the angle to the top using a scale in the instrument. Some are calibrated so when read at a distance of 66 feet from the tree, the height to the top of the tree above eye level can be directly read on the scale, or if at 132 feet the estimated height is exactly twice the reading on the scale. There are different scales found in different models of the clinometer. A better option for tree height measurement is a scale that reads the angle in degrees. Instruments with a degree scale can be used to measure the tree height when sighting at any distance. The angle from the eye to the top of the tree is measured using the clinometer. The horizontal distance to the tree at eye level is measured using a tape. The height above eye level calculation is calculated by using the tangent function:

\[
\text{horizontal distance at eye level to the tree} \times \text{tangent } \Theta = \text{height above eye level}
\]

The same process is used to measure the height of the base of the tree above or below eye level. If the base of the tree is below eye level, then the height of the tree below eye level is added to the height above eye level. If the base of the tree is above eye level, then the height of the base of the tree above eye level is subtracted from the height of the treetop above eye level. It may be difficult to directly measure the horizontal distance at eye level if that distance is high off the ground or if the base of the tree is above eye level. In these cases the distance to the base of the tree can be measured using the tape along the slope from eye level to the base of the tree and noting the slope angle \( \Theta \). In this case the height of the base of the tree above or below eye level is equal to the (\( \sin \Theta \times \text{slope distance} \)) and the horizontal distance to the tree is (\( \cos \Theta \times \text{slope distance} \)).

Errors Associated with the Stick Method and the Clinometer and Tape Method: Aside from the obvious errors associated with bad measurements of distances or misreading the angles with the clinometer, there are several less apparent sources of error that can compromise the accuracy of the tree height calculations. With the stick method if the stick is not held vertically, the similar triangle will be malformed. This potential error can be offset by fastening a string with a small, suspended weight to the top of the stick so that the stick can be aligned with the weighted string to assure it is being held vertically. A more pernicious error occurs in both methods where 1) the treetop is offset from the base of the tree, or 2) where the top of the tree has been misidentified. Except for young, plantation-grown conifers, the top of the tree is rarely directly over the base; therefore a right triangle used as the basis for the height calculation isn’t truly being formed. An analysis of data collected by the Native Tree Society (NTS), of over 1800 mature trees found, on average, the top of the tree was offset from the base of the tree by a distance of 8.3 feet, and therefore was offset from the base of the tree by around 13 feet. Conifers tended to have offsets less than that average and large, broad canopied hardwoods tended to have higher offsets. The top of the tree therefore has a different baseline length than the bottom of the tree resulting in height errors:

\[
\text{(top to bottom offset distance} \times \text{tan } \Theta) = \text{height error}
\]

The error almost always incorrectly adds to the height of the tree. For example, if measuring a tree at an angle of 64 degrees, given an average offset of 8.3 feet in the direction of the measurer, the height of the tree would be overestimated by 17 feet. This type of error will be present in all of the readings using the tangent method, except in the cases where the highest
point of the tree actually is located directly above the base of the tree, and except in this unusual case, the result is not repeatable as a different height reading would be obtained depending on the direction and position from which the measurement was taken.

When the top of the tree is misidentified and a forward leaning branch is mistaken for the treetop, the height measurement errors are even larger because of the bigger error in the measurement baseline. It is extremely difficult to identify the actual top branch from the ground. Even experienced people will often choose the wrong sprig among the several that might be the actual treetop. Walking around the tree and viewing it from different angles will often help the observer to distinguish the actual top from other branches, but this is not always practical or possible to do. Major height errors have made it onto big tree lists even after some degree of vetting, and are often wrongly repeated as valid heights for many tree species. A listing compiled by the NTS\textsuperscript{[19]} shows the magnitude of some of these errors: water hickory listed as 148 feet, actually 128 feet; pignut hickory listed at 190 feet, actually 123 feet; red oak listed as 175 feet, actually 136 feet; red maple listed at 179 feet, actually 119 feet, and these are only a few of the examples listed. These errors are not amenable to correction through statistical analysis as they are unidirectional and random in magnitude. A review of historical accounts of large trees and comparisons with measurements of examples still living\textsuperscript{[20]} found many additional examples of large tree height errors in published accounts.

Sine Height or ENTS Method

Many of the limitations and errors associated with the stick method and the tangent method can be overcome by using a laser rangefinder in conjunction with a clinometer, or a hypsometer, which incorporates both devices into a single unit.\textsuperscript{[21]} A laser rangefinder is a device, which uses a laser beam to determine the distance to an object. The laser rangefinder sends a laser pulse in a narrow beam toward the object and measures the time taken by the pulse to be reflected off the target and returned to the sender. Different instruments have different degrees of accuracy and precision.\textsuperscript{[22]}

The development of laser rangefinders was a significant breakthrough in a person’s ability to quickly and accurately measure tree heights. Soon after the introduction of laser rangefinders, their utility in measuring trees and use of the sine based height calculations was recognized and adopted independently by a number of big tree hunters.\textsuperscript{[23]}\textsuperscript{[24]} Robert Van Pelt\textsuperscript{[25]} began using a Criterion 400 laser circa 1994 in the Pacific northwest of North American. The instrument had a preprogrammed tree height routine based upon the tangent method, but he used the alternate Vertical Distance (VD) mode, essentially the sine method with no frills to measure tree heights. Michael Taylor\textsuperscript{[26]} began using an optical rangefinder and Suunto clinometer circa 1993-94 using the sine method. About a year later he purchased a Bushnell Lytespeed 400 laser rangefinder and began using it in tree measurements. Robert T. Leverett\textsuperscript{[27]} began using laser rangefinders in the eastern United States in 1996. He and Will Blozan\textsuperscript{[28]} had previously been using cross-triangulation methods to measure tree heights prior to adopting the laser rangefinder techniques. The first publication describing the process was in the book “Stalking the Forest Monarchs - A Guide to Measuring Champion Trees,” published by Will Blozan, Jack Sobon, and Robert Leverett in early 1997.\textsuperscript{[29]}\textsuperscript{[30]} The technique was soon adopted by other big tree surveyors in other areas of the world. Brett Mifsud (2002) writes: New techniques for measuring tall trees were used in this study. Initially, a Bushnell ‘500 Yardage Pro’ laser rangefinder was used in conjunction with a Suunto clinometer to estimate tree heights in all regions. The previously-used ‘simple tan’ method of measuring tall trees was discarded in favor of the ‘sine’ method.\textsuperscript{[31]} Currently this method is being used by tree researchers and surveys in Asia, Africa, Europe, and South America.

Using the rangefinder and clinometer, only four numbers are needed to complete the tree height calculation, and no tape is necessary, nor is direct contact with the tree.\textsuperscript{[32]}\textsuperscript{[33]} The readings are 1) the distance to the top of the tree measured using the laser rangefinder, 2) the angle to the top of the tree measured with the clinometer, 3) the distance to the base of the tree measured with the laser rangefinder, and 4) the angle to the base of the tree measured with the clinometer. The calculations involve some basic
trigonometry but these calculations can easily be done on any inexpensive scientific calculator.

Sine height measurement

Situations where the top of the tree being measured is above eye level and the base of the tree being measured is below eye level is the most common situation encountered in the field. The other two cases are those where both the top of the tree and the base of the tree are above eye level, and where both the top of the tree and base of the tree are located below eye level. In the first situation, if \( D_1 \) is the distance to the top of the tree as measured with a laser rangefinder, and \( a \) is the angle to the top of the tree measured with a clinometer, then this forms the hypotenuse of a right triangle with the base of the triangle at eye level. The height of the tree above eye level is \( h_1 = \sin(a) \times D_1 \). The same process is used to measure the height or extension of the base of the tree above or below eye level where \( D_1 \) is the distance to the base of the tree and \( b \) is the angle to the base of the tree. Therefore the vertical distance to the base of the tree above or below eye level is \( h_2 = \sin(b) \times D_2 \). Common sense should prevail when adding \( h_1 \) and \( h_2 \). If the base of the tree is below eye level the distance it extends below eye level is added to the height of the tree above eye level to calculate the total height of the tree. If the base of the tree is above level then this height is subtracted from the height to the top of the tree. Mathematically since the sine of a negative angle is negative, we always get the following formula:

\[
\text{height} = \sin(a) \times (D_1) - \sin(b) \times (D_2)
\]

There are some errors associated with the sine top/sine bottom method. First the resolution of the laser rangefinder may range from an inch or less to half a yard or more dependent on the model being used. By checking the characteristics of the laser through a calibration procedure and taking measurements at only the click-over points where the numbers change from one value to the next highest much greater precision can be obtained from the instrument.\(^{[2]}\) A hand held clinometer can only be read to an accuracy of about ¼ of a degree, leading to another source of error. However by taking multiple shots to the top from different positions and by shooting at the click-over points, accurate heights can be obtained from the ground to within less than a foot of the tree’s actual height. In addition, multiple measurements allow erroneous values where the clinometer was misread to be identified and eliminated from the measurement set. Problems may also occur where the base of the tree is obscured by brush, in these situations a combination of the tangent method and sine methods may be used. If the base of the tree is not far below eye level, the horizontal distance to the tree trunk can be measured with the laser rangefinder, and the angle to the base measured with the clinometer. The vertical offset from the base of the tree to horizontal can be determined using the tangent method for the lower triangle, where \( H_2 = \tan(A_2) \times D_2 \). In these cases where the tree is fairly vertical and the vertical distance from the base of the tree to eye level is small, any errors from using the tangent method for the base are minimal.

There are considerable advantages to using this method over the basic clinometer and tape tangent method. Using this methodology, it no longer matters if the top of the tree is offset from the base of the tree, eliminating one major source of error present in the tangent method. A second benefit of the laser rangefinder technology is that the laser can be used to scan the upper portions of the tree to find which top is actually the true top of the tree. As a general rule, if there are several readings from different tops of the tree at or near the same inclination, the one that is the farthest in distance represents the tallest top of the group. This ability to scan for the highest point helps eliminate the second major source of error caused by misidentifying a forward leaning branch or the wrong top. Additionally, aside from gross errors resulting from misreading the instrument, the results will not overstate the height of the tree. The height can still be under-measured if the true top of the tree is not correctly identified. The sine top/sine bottom method allows the height of trees to be measured that are...
entirely above or below the eye level of the surveyor as well as on level ground. A tree can also be measured in segments where the top and bottom of the tree are not both visible from a single location. A single height measurement takes only a matter of a few minutes using separate laser rangefinder and clinometer or less when using instruments with a built in electronic clinometer. The measurements made using these techniques, through averaging multiple shots, are typically within a foot or less of climber deployed tape measurements.

Some laser hypsometers have a built in height measurement function. Before using this function the user should read the instructions on how it works. In some implementations it calculates tree heights using the flawed tangent method, while in others it allows you to use the better sine top/sine bottom method. The sine top /sine bottom method may be called the vertical distance function or a two point method. For example the Nikon Forestry 550 implements the sine top/sine bottom method only, while the successor the Forestry Pro has both a two-point measurement and a three-point measurement function. The three-point measurement function uses the tangent method, while the two point method uses the sine top/sine bottom method. The top and bottom triangles are automatically measured using the two point function and added together, giving an accurate height measurement.

A more detailed discussion of the laser rangefinder/clinometer sine method can be found in Blozan [7][8] and Frank [12] in discussions on the Native Tree Society website and BBS.[29][30]

Reviews of the sine method have been published by U. S. Forest researcher Dr. Don Bragg. He writes: When heights were measured properly and under favorable circumstances, the results obtained by the tangent and sine methods differed only by about 2 percent. Under more challenging conditions, however, errors ranged from 8 to 42 percent. These examples also highlight a number of distinct advantages of using the sine method, especially when exact tree height is required. Under typical circumstances, the sine method is the most reliable means currently available to determine standing tree height, largely because it is relatively insensitive to some of the underlying assumptions of the tangent method. Unfortunately, only recently has technology permitted the use of the sine method, whereas the tangent method has been ingrained into procedures and instrumentation for many decades.

Direct Height Measurement

Tree heights can be directly measured using a pole for shorter trees, or by climbing a larger tree and measuring the height via a long measuring tape. Pole measurements work well for small trees eliminating the need for trigonometry involving multiple triangles, and for trees shorter than the minimal range for laser rangefinders. Colby Rucker writes: For the smallest trees, a carpenter’s six-foot folding ruler works well. Above the ruler’s reach, a pole is needed. An aluminum painter’s pole telescopes to nearly twelve feet, and works quite nicely. It can be adjusted to the height of a small tree, and the pole measured with a steel tape hooked to one end. It can be raised to the top of a slightly taller tree, and the distance to the ground measured with the carpenters’ rule. For additional reach, two aluminum extensions can be made that fit inside one another, and both fit inside the pole. I used a sturdy aluminum ski pole for the top piece. That extends the pole to about twenty feet, which is convenient for most work. Occasionally, additional height is needed and additional lengths can be added, but the pole becomes unwieldy at these greater heights. Standard ten foot sections of PVC pipe can be used for the poles, but they tend to become floppier with increasing length.

Tree heights can also be directly measured by a tree climber. The climber accesses the top of the tree finding a position as near to the top as can be safely reached. Once safely anchored from that position the climber finds a clear path and drops a weighted line to the ground. A tape is fastened to the end of the drop line and pulled up to the top following the path of the weighted line. The bottom reference point is the mid-slope position of the trunk at ground level. The total height of the tree to the climber’s position is read directly from the tape. Fiberglass tapes are generally used for these measurements because of their light weight, negligible stretch, and because they do not need to be calibrated for use at different
temperatures. If the tape is to be used later as a fixed reference for later trunk volume measurements the top is fastened in place using several thumbtacks. This holds the tape in position during the volume measurements, but it still can be pulled free from below when finished.

**Tree Top Measurement**

A pole is generally used to measure the remaining height of the tree. The climber pulls up an extendable pole and uses it to reach to the top of the tree from the point at the upper end of the tape. If not vertical, the slope of the leaning pole is measured and the length of the pole is measured. The vertical distance added by the pole to the tape length is \( \sin(\Theta) \times \text{pole length} \).

**Additional Height measurement techniques**

There are several additional methods that can be used to measure tree heights from a distance that can produce reasonably accurate results. These include traditional surveying methods using a theodolite, cross-triangulation, the extended baseline method, the parallax method, and the triangle method.

Standard Surveying techniques may be used to measure tree heights. A theodolite with an electronic distance measurement (EDM) function or Total Station can provide accurate heights because a specific point on the tree crown could be consistently chosen and "shot" through a high magnification lens with cross hairs mounted on a tripod which further steadied the device. The drawbacks are the prohibitive cost of the instrument for average users and the need for a well cut corridor for horizontal distance measurement, and the general lack of easy portability.

Cross-triangulation methods can be used. The top of the tree is sighted from one position and the line along the ground from the viewer toward the top of the tree is marked. The top of the tree is then located from a second viewing position, ideally about 90 degrees around the tree from the first location, and the line along the ground toward the top of the tree is again marked. The intersection of these two lines should be position on the ground directly underneath the top of the tree. Once this position is known the height of the treetop above this point can be measured using the tangent method without the need for a laser rangefinder. Then the relative height of this point to the base of the tree can be measured, and the total height of the tree determined. A two-person team will make this process easier. The drawbacks of this method include among others: 1) difficulty in correctly identifying the actual top of the tree from the ground, 2) being able to locate the same top from both positions, and 3) it is a very time consuming process.

External Baseline Method developed by Robert T. Leverett is based upon the idea that there will be difference in the angle to the top of an object if it is viewed from two different distances along a common baseline. The height of the tree above a level baseline can be determined by measuring the angle to the top of the tree from two different positions, one farther than the other along the same baseline and horizontal plane, if the distance between these two measuring points is known.

**Extended baseline tree height measurement**

By accurately measuring the differences between the angles and the distance to the object from the closer position, the height of the object can be calculated. A
very accurate angle measurement is required by the process. To use the method for both top and base, requires eight measurements and the use of three separate formulae. The set of formulae is applied once for the top of the tree and once for the bottom. If the baseline cannot be level, a more complex calculation must be made that takes into account the slope of the baseline. An Excel spreadsheet has been developed that automates the calculations and is available on the ENTS BBS/website. It covers the common tangent-based methods and includes error analysis. There are a series of variations for other scenarios where the observation points are not at the same elevation, or not along the same baseline.

Parallax Method 3-D [40][41] is a survey technique for measuring the tree height indirectly by Michael Taylor. The Parallax Method involves finding two different views to the tree’s top, the ground level differential and horizontal sweep angles between the top and the two views. These values can be used in an algebraic equation to determine the height of the tree’s top above the stations can be calculated. No direct measurement to the tree's trunk or top is taken in the parallax Method.

Three Verticals method (formerly the Triangle method) is a modification of the simpler parallax method.[42] It is possible to measure the height of a tree indirectly without taking any horizontal sweep angles, which can be difficult to obtain accurately in the field. With this method, find three open views in any space to the treetop. These points ideally should be within view of each other to avoid indirect surveys. Once the surveyor has taken the three vertical angles to the tree’s top, the slope distances and angles between the three viewing stations is taken. The height of the treetop can then be derived using a series of equations, which require an iterative numerical solution and the use of a computer. The Triangle Technique, equations, measurement diagrams, and derivations were developed by Michael Taylor and are available on his website. The software program for the calculations is written in basic and can also be downloaded from his website.[43]

**LiDAR**

LiDAR, an acronym for Light Detection and Ranging,[44] is an optical remote sensing technology that can measure distance to objects. LiDAR data is publicly available for many areas [45] and these data sets can be used to display tree heights present on any of these locations. Heights are determined by measuring the distance to the ground from the air, the distance to the tops of the trees, and displaying the difference between the two values. A USGS report [46] compared ground based measurements made using a total station at two different sites, one dominated by Douglas-fir (Pseudotsuga menziesii) and another dominated by ponderosa pine (Pinus ponderosa) with results obtained from LiDAR data. They found height measurements obtained from narrow-beam (0.33 m), high-density (6 points/m2) LiDAR were more accurate (mean error i: SD = -0.73 + 0.43 m) than those obtained from wide-beam (0.8 m) LiDAR (-1.12 0.56 m). LiDAR-derived height measurements were more accurate for ponderosa pine (-0.43 i: 0.13 m) than for Douglas-fir (-1.05 i: 0.41 m) at the narrow beam setting. Tree heights acquired using conventional field techniques (-0.27 to 0.27 m) were more accurate than those obtained using LiDAR (-0.73 i: 0.43 m for narrow beam setting).

Kelly et. al.[47] found that LiDAR at a 20-ft (6.1-m) cell size for the target area in North Carolina did not have enough detail to measure individual trees, but was sufficient for identifying the best growing sites with mature forest and most tall trees. They found that highly reflective surfaces, such as water and roofs of houses sometimes erroneously appeared as tall trees in the data maps and recommends that use of LiDAR be coordinated with topographic maps to identify these potential false returns. Underestimations of the true tree heights of individual trees were found for some of the tall tree locations located on the LiDAR maps and was attributed to the failure of the LiDAR at that resolution does not seem to detect all twigs in a forest canopy. They write: In addition to using LiDAR to locate tall trees, there is great promise for using LiDAR to locate old-growth forests. When comparing known old-growth sites to second-growth in LiDAR, old-growth has a much more textured canopy because of the frequent and often times remarkably
evenly spaced tree fall gaps. Finding equations that can predict old-growth forests of various types using LiDAR and other data sources is an important area of scientific inquiry that could further conservation of old-growth forest.

Maps of global canopy heights have been developed using LiDAR by Michael Lefsky in 2010 [48] and updated a year later by a team led by Marc Simard of NASA’s Jet Propulsion Laboratory. [49] A smaller version of the map can be found on NASA’s Earth Observatory website. [50]

LiDAR has frequently been used by members of the NTS to search for tall tree sites and to locate areas within a site with the greatest potential for tall tree finds. They have found LiDAR to be a useful tool for scouting locations prior to visits, but the values need to be ground truthed for accuracy. Michael Taylor writes: “In the flat areas like Humboldt Redwoods State Park the LiDAR was usually within 3 feet accuracy and tended to be on the conservative side. For steep hill areas the LiDAR often over-estimated by 20 feet more due to the fact that redwoods tend to lean down-hill in notch canyons as they seek the open areas for more light. If the tree grows near a ravine this over-estimation from LiDAR was more the norm than the exception. Perhaps only 50% of the LiDAR hit list trees from Redwood National Park were actually trees over 350 feet. From Humboldt Redwoods State Park nearly 100% of the LiDAR returns that came back as being over 350 feet were actually trees over 350 feet when confirmed from the ground or climber deployed tape. It depends on the terrain and how well the ground/trunk interface was captured. For steep and dense canopies the ground determination is a great challenge. [51]” An overview of using LiDAR for tree measurement was written by Paul Jost on the NTS website. [52] Data for much of the United States can be downloaded from the USGS or from various state agencies. Several different data viewers are available. Isenburg and Sewchuk have developed software for Visualizing LiDAR in Google Earth. [53] Another viewer is called Fusion, a LiDAR viewing and analysis software tool developed by the Silviculture and Forest Models Team, Research Branch of the US Forest Service. Steve Galehouse provides a step by step guide to using the Fusion software to supplement the instructions on the Fusion website itself.

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Tree girth measurement
http://en.wikipedia.org/wiki/Tree_girth_measurement

From Wikipedia, the free encyclopedia

Tree girth measurement is one of the most ancient, quickest, and simplest, of foresters’ measures of size and records of growth of living and standing trees. The methods and equipment have been standardized differently in different countries. A popular use of this measurement is to compare outstanding individual trees from different locations or of different species.

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Tree girth measurements

Girth is a measurement of the distance around the trunk of a tree measured perpendicular to the axis of the trunk. In the United States it is measured at breast height, or at 4.5 feet above ground level.[1][2][3] Elsewhere in the world it is measured at a height of 1.3 meters,[4] 1.4 meters,[5][6] or 1.5 meters.[7] The base of the tree is measured for both height and girth as being the elevation at which the pith of the tree intersects the ground surface beneath, or where the acorn sprouted.[8] On a slope this is considered as halfway between the ground level at the upper and lower sides of the tree. This “breast height” value is a measurement grandfathered from decades of forestry applications. It was developed because of the simplicity and ease of measurement. There is no one
ideal height at which to measure girth. Tree trunks flare outward at their base. In some trees this flare or buttressing extends only a short distance up the trunk, while in others it may extend thirty feet or more up the tree, but the measurement is still taken at this default height for consistency. If the flare at the base of the tree extends above this default girth height, then ideally a second girth measurement should be collected where possible above the basal flare and this height noted.

Tree girth is one of the parameters commonly measured as part of various champion tree programs and documentation efforts. American Forests, for example, uses a formula to calculate Big Tree Points as part of their Big Tree Program[4] that awards a tree 1 point for each foot of height,[8] 1 point for each inch of girth, and ¼ point for each foot of average crown spread.[9] The tree whose point total is the highest for that species is crowned as the champion in their registry. The other parameter commonly measured, in addition to the species and location information, is wood volume.[10] A general outline of tree measurements is provided in the article Tree Measurement Overview[11] with more detailed instructions in taking these basic measurements is provided in “The Tree Measuring Guidelines of the Eastern Native Tree Society” by Will Blozan.[12]

Maximum girth records

The tree with the largest girth was the Glencoe Baobab (Adansonia digitata) in South Africa with a diameter near ground level of 52.2 feet (15.9 m), equivalent to a girth of 164 feet (50 m). In 1999 the hollow tree split into two parts.[13] The Big Tree of Tule in Santa María del Tule, Oaxaca, Mexico (Taxodium mucronatum) has a girth of 119.8 feet (36.2 m) and a height of 116.1 feet (35.4 m), with a 144-foot (43.9 m) wide crown as measured by Dr. Robert Van Pelt in 2005. The Tule tree therefore has a diameter of 38.1 feet (11.62 m) as extrapolated from the tape wrap values. However, as the tree is heavily buttressed, and irregular in shape, a calculation of nominal diameter, defined as the cross-sectional wood area expressed as a circle, gives this tree a diameter at breast height of 30.8 feet (9.38 m)—a much smaller number, but a more accurate representation of the tree’s size.[13] Some have argued that the Tule tree is a multi-trunk tree consisting of three separate trunks emerging from the same root mass that have grown together to form the massive base of the tree and therefore its girth cannot be fairly compared to those trees with just a single trunk. Many of the large girth baobabs may be multi-trunk clusters as well. The General Grant Tree (Sequoiadendron giganteum) in King’s Canyon National park in California is clearly a single trunk tree. It was measured to have a girth of 91.2 feet (27.80 m) measured at a height of 4.5 feet (1.37 m).[14] There are historical accounts of trees with extremely large girths. These should not be just accepted at face value. In these older accounts the girths were often taken at ground level and incorporated considerable basal flare at the base of the tree. In other cases, the trees measured were multiple trunk masses or coppices treated as single trees in the girth measurements.

Single-trunk versus multi-trunk trees

In many, but not all champion tree lists, and for data collected for scientific purposes, there is a need to distinguish between a single trunk tree and a multi-trunk tree. Two smaller trunks that grow together will achieve a large combined girth much faster than will a single trunk tree growing in the same conditions, so if the data will be biased if combined into a single dataset. A single trunk tree is defined as one that would only have a single pith if cut at ground level. A multi-trunk tree would have two or more piths at ground level. In this definition it does not matter if the trunks have grown together, nor if they are genetically the same and growing from a single root mass. If the tree has more than one pith at ground level, it is a multi-trunk tree.[1][15] Separating data from single trunk and multi-trunk trees is critical to maintain a valid database of measurements. Data from both forms are worth collecting, but they should be considered different forms and the number of trunks included in the girth measurement should be listed for those trees with more than one trunk.

Direct girth measurement procedures

The girth measurement is commonly taken by wrapping a Measuring tape (tape) around, and in the plane perpendicular to the axis of the, the trunk, at the
correct height. In spite of the apparent simplicity of wrapping a tape around a tree trunk at breast height, errors in this measurement are common. The most common error is mixing measurements of single trunk trees with those of multi-trunk trees and not distinguishing between the two. Even with single trunk trees irregular bumps and hollows are common. Some trees have low branches that split below breast height. Other trees have epicormic sprouts, suckers, or dead branches. Some tree trunks stand slanted at an angle rather than vertical. Girths of trees with these features may be measured by competing methods by different surveyors and result in differences. The basic guidelines for dealing with the above difficulties were developed by American Forests, and most of the guideline used by other tree measuring groups around the world are based upon American Forests guidelines. The Native Tree Society measurement guidelines also generally follow the American Forests prescription, with some additional elaborations. Many trees have burls bumps, and knots along their trunk. If these occur at the 4.5 feet girth measurement height, including them in the measurement would falsely inflate the girth measurement. The girth measurement should then be taken at the narrowest point below the odd growth and the height of the girth measurement noted. In some cases a girth taken just above the odd growth will be more representative of the actual girth of the tree. In these cases the measurement should be taken there and the height above the base of the tree noted.

Some trees have branches at or lower than a height of 4.5 feet. Since the purpose of a girth measurement is to get a full measure of the tree’s trunk, measurements should be taken at the narrowest point below any significant branching. When taking a girth measurement at a non-standard height the height of that measurement above the base of the tree should be noted. Epicormic sprouts, suckers, and dead branches can be ignored. Some guidelines have suggested that if a tree branches below breast height, that the girth of the largest branch should be measured at breast height ignoring the other branches. However, if a good portion of the trunk volume or cross-sectional area has been split from the total by measuring above a significant branching, then this is not giving a full and fair measure of the trunk’s girth. If the pith of the branch does not intersect the pith of the main trunk above ground level, it is not a branch but a separate trunk and this tree should be considered a multi-trunk tree.

If the tree is leaning, measure the circumference at 4 ½ feet along the axis of the trunk. The distance should be measured along the side of the trunk from the base point of the center of the tree. The measurement is taken at a right (90 degree) angle to the trunk. Some groups recommend measuring the girth at breast height on the upper side when the tree is on a slope rather than from midpoint on the slope. One example is the Tree Register in the UK. There are advantages to either option. Measuring on the upslope side if often easier, it is also higher on the tree and likely will include less of the flare at the base of the trunk, and when measuring extremely large trunk on a slope the upslope side of the girth loop will always be above ground level. Measuring the girth from a reference point at mid_slope also has advantages. Consider, the tree started as a single sprout and grew upward and outward from that point. This is the point where the pith of the tree would intersect the ground surface supporting the tree. This is the logical base point from which to measure the height of the tree and by extension the girth should be
measured with respect to the same base point. This point is fixed at the same location over time as the tree grows. In addition this is a reference point that is present and consistent in all trees no matter the height of the girth measurement. Even if the tree is measured at a non-standard height because of low branching, a large burl, or even on the upslope side of a large girth tree on sloping ground, all heights can still be consistently referenced to this single point present on all trees. Measuring midpoint on the slope is the recommended option.[1][3][2]

Trees with very large girths, such as some of the sequoias growing the western United States, can also pose girth measurement problems. If they are growing on even a gentle slope, if girth is measured at 4.5 feet about the where the pith of the tree emerges from the ground, the upside of the tape could easily be below ground level. In this case a better option would be to measure the standard girth measurement at 4.5 feet above ground level on the high side of the tree and note this in the measurement description.[4][5] The height of this measurement point above the standard base point at midslope should also be noted. If measuring a mountaintop forest of stunted trees only six feet tall, a girth measurement made at 4.5 feet would be meaningless. In the case of these stunted trees a girth taken at 1 foot above the base might be more appropriate. The point is that the girth measurements should be taken at the standard heights whenever possible. Where this measurement is not meaningful, an additional girth measurement should be taken at a more appropriate position and that height noted.[6] Converting the girth measurement to a diameter will always overstate the cross-sectional area of the trunk, therefore it is best to record the raw girth numbers directly rather than convert them to diameters. The conversion of girth values to approximate diameters can always be done later if needed for other types of analysis.

Remote girth measurements

Girth measurements may be taken remotely using photographic means or through the use of a telescopic reticle. In these cases the diameter as seen from the surveyor’s position is actually measured and the girth is calculated by multiplying the diameter by \( \pi \) (\( \pi \)).

A **monocular w/reticle** is a telescope with a built-in scale that can be used to accurately measure the width of objects such as the diameters of trees from a distance. When sighting through the monocular the width of an object can be read as so many units of the scale. The farther away the object is from the surveyor, the smaller it will appear in the telescope and the width will read as fewer units on the scale. This change is constant with distance. The distance to the target can be measured with a laser rangefinder. The distance from the measured section of trunk multiplied by the reticle reading and divided by an optical factor results in the diameter of the target. For best results the scaling factor should be tested and calculated for each individual device rather than just using the manufacturer’s default value. This process can be applied to volume measurements, as noted below, in addition to basic girth measurements. A variety of monocular w/reticles are available from different manufacturers. They can be used as hand held instruments but more accurate reading can be obtained when mounted on a tripod.[12] Some higher end electronic surveying devices, like the Criterion RD 1000 have an electronic version of the reticle scale built into the device and can be used to measure diameters. Photographs of trees can be used to determine girth or other measurements if there is a something of known size in the photo to provide a scale. The following information must be known to approximate the measurements: 1) distance of the camera from the tree, 2) distance from the camera to the scale, and 3) size of the object to be used as a scale. An Excel spreadsheet can be used to determine the rate the apparent size of the scale changes with distance, and that value can be used to calculate the diameter of the tree given that the tree is circular in cross section and the distance to the front side of the tree is known. Girth then is calculated by multiplying the diameter by \( \pi \). The method may be used to calculate the girth of trees in historical photographs where the true dimensions are unknown. Assumptions would need to be made about the distances involved and the size of the people in the photograph, but reasonable estimates are possible.[19] Preliminary tests are being conducted by the NTS to apply the photographic process to volume modeling of trees.[19][20] A key consideration for many people is that only a minimal amount of equipment is needed
to make these calculations: A laser rangefinder, a reference object (ruler), a digital camera, and Excel. A telescopic reticle is not needed. Photos from multiple angles are required to generate better data for the volume estimates. This process will be less accurate than measurements taken with a telescopic reticle, but will be able to generate meaningful close approximations of tree volume.

Multi-trunk trees

Multi-trunk trees are the most common form after single trunk trees. Often these represent separate trunks growing from a single root mass. This occurs frequently in some species when the initial trunk has been damaged or broken and in its place two or more new shoots grow from the original root mass. These are genetically the same, but as their growth form is different they should be considered as a different measurement category than single trunk trees. These multiple trunks commonly will grow together to form a large combined mass at the base and split into individual trunk at greater heights. If they are individual trunks at breast height then the individual trunks can be measured separately and treated as individual single trunk trees. If they have grown together at breast height then a measurement of their combined girth should be made at that height the number of trunks incorporated into the girth measurement listed. If the tree splays outward dramatically at breast height, then the girth should be measured at the narrowest point between breast height and the ground and that height noted.

Double trunked Cherry Tree

Other girth measurements guidelines outlined for single trunk trees, such as low branches and burls, apply to multi-trunk girths as well. The height of the tallest trunk in the multi-trunk specimen would then be the height of the multi-trunk specimen and the combined crown spread of all the individual trunks the multi-trunk specimen collectively would be the multi-trunk crown spread. If one of the individual trunks is significantly larger than all the others, it can be treated as if it were a single trunk tree. Its girth is measured where it emerges from the combined mass, and the height and crown spread of that particular trunk is measured individually.

Trees with unusual forms

Not all trees have a single trunk, and other single trunk trees pose additional measurement problems because of their size or configuration. The odd forms include those forms that grew because of unusual circumstances that affected the tree, or those trees that simply have an unusual growth form not seen in most other tree species. Frank proposed a classification system for various tree forms: 1) Single Trunk Trees; 2) Multi-trunk Trees; 3) Clonal Coppices; 4) Clonal Colonies; 5) Conjoined and Hugging Trees; 6) Fallen Trees; 7) Tree complexes, and 8) Banyan-like trees; 9) Trees with Large Aerial Root Systems; and 10) Epiphytic Trees. This initial framework has continued to evolve in discussions within the NTS, but provides an initial beginning and suggestions on how to approach measuring these various tree growth forms. Since most of these trees are unique or unusual in their form and not amenable to easy measurement, the recommended approach is to write a detailed narrative description of the tree with what measurements that can be taken to amplify and better illuminate the descriptions. These trees should be documented even if the results are in the form of a written narrative rather than a collection of numerical measurements. There are some parameters that should be consistently measured whenever possible, height is one example. The cross-sectional areas occupied by the trunks and the crown are also parameters that are generally measurable. Other measurements could be taken where they seem to add to the narrative description of that particular tree. GPS locations should be taken whenever possible. Absent a GPS instrument, the locations
should be pulled from Google Maps, or topographic maps. Beyond these basics, values like number of trunks larger than a prescribed value, the maximum girth of the largest trunk, and whatever seems appropriate for that particular tree grouping should be recorded. Photographs of these unusual trees are important as they can immensely improve the understanding of what is being described, and help others to visualize the tree. A process or system is needed whereby the photos of a particular tree can be associated with the description of the tree in the researcher’s notes. The goal of the narrative and measurements is to document the tree or tree grouping.

Banyan tree Cleveland

An approach needs to be developed that is appropriate for each of these unusual forms. For example, clonal colonies, such as the Pando aspen, may occupy many acres. The area occupied by the colony should be measured as well as the size of the largest individual trunk present. Banyan-like trees similarly consist of multiple trunks spread across a large area. In many of these specimens the interior trunks are not easily accessible, if accessible at all. An approach to their measurement would be to measure the area occupied by the many trunks, the area occupied by the crown of the tree, the height of the tree, and any other measurements the investigator deems appropriate. These measurements would then be supplemented by a narrative description and photographs. The goal in all of these cases of trees with unusual forms is to document their characteristics. Girth can also be thought of as essentially a snapshot of the cross-section of a tree at one particular elevation. In some cases the base of the tree may be so complex that simply wrapping a tape around the base would misrepresent the true wood girth or character of the tree. An example of this would be Big Tree of Tule in Santa María del Tule, Oaxaca, Mexico described above. The Tule tree has a diameter of 38 feet 1.4 inches (1162 cm) as measured by tape wrap, but because of its irregularity a cross-sectional wood area expressed as a circle gave an effective diameter of only 30 feet 9 inches (938 cm). The base of the tree was mapped in three dimensions using a frame mapping technique. A rectangular frame was strung around the perimeter of the tree. A series of measurements from the reference lines to the edge of the trunk mapping the irregularities of the tree surface and converted to Cartesian x-y coordinates. The process was repeated at different heights to create a three dimensional model of the tree. This mapping process can be automated. Taylor has been developing a cloud mapping process using optical parallax scanning technology whereby thousands of measurements are made around the trunk of a tree. These can be used to recreate a three-dimensional model of the trunk and girth and diameter data are among the values that can be calculated.

Changes in girth values with age

For long term monitoring of girth, the exact point on the tree needs to be marked to assure the measurement is taken in the same place every session. Forestry data suggests that the slow down of diameter growth is correlated to a commensurate slow down in volume growth, but the association is not straightforward when whole tree mass is considered as opposed to the commercial part of the trunk. 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. Research by Leverett has shown that even older white pine trees continue to add significant wood volumes with 11 monitored trees adding average annual volume increase of 11.9 cubic feet. The Ice Glen pine, in Stockbridge, Massachusetts, which is around 300 years old or possibly older based on dating of nearby pines, shows a decline in annual volume increase to approximately half of that for the trees in the 90- to 180-year age class, but still averaged a volume increase of 5.8 cu ft
over the five-year monitoring period. Volume increase was a result of both an increase in height and in girth.

References


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