Guidelines for Determining Site Potential Tree Height from Field Measurements

Washington Department of Fish & Wildlife

January 24, 2025

Guidelines for Determining Site Potential Tree Height from Field Measurements

Author

Washington Department of Fish and Wildlife

Report acknowledgements

Adapted from Forest Measurements Copyright © 2016 by Joan DeYoung, licensed under a Creative Commons Attribution 4.0 International License

We are grateful for the peer review and feedback provided by Mike Gilgunn and Matt Provencher (Washington State Department of Natural Resources) and an anonymous reviewer.

Suggested citation

Washington Department of Fish and Wildlife. 2025. Guidelines for Determining Site Potential Tree Height from Field Measurements. Olympia, WA.

Cover photo by Alan Bauer.

Table of Contents

Introduction

The WDFW riparian ecosystem science synthesis[1] and management recommendations[2] full riparian function can be achieved by delineating a riparian management zone (RMZ) with a width of the Site Potential Tree Height at age 200 ($SPTH_{200}$). The Site Potential Tree Height Mapping Tool lets a user look up $SPTH_{200}$ values for their location, but the current version has gaps in coverage. In other cases, site-level verification is warranted for an available $SPTH_{200}$ value. For both reasons, we (WDFW) are providing this procedure for forestry professionals (Appendix A) to determine a site index and thereby $SPTH_{200}$ from field-based measurements for land use planning under the Growth and Shoreline Management Acts.

A site index value characterizes the quality of growing conditions (higher = better). This procedure combines tree age and height field measures (from trees that are not 200 years old) with established growth curves to arrive at a site index value. This site index then allows estimation of $SPTH_{200}$ using our "$SPTH_{200}$ Calculator."

To determine site quality using tree height as the indicator, appropriate site trees of each species are selected in a stand. The site trees' heights and ages are measured in the field, and then plotted or indexed on species-specific growth curves or tables (see Figure 1). These tree height-to-age relationship curves are derived from growth and yield field data and show how the best trees from a variety of sites have grown over time.

Key Concepts

1. Select site trees
   - Dominant species, healthy, 'full potential'
   - Largest DBH
   - Well distributed around the site
2. Measure age and height
   - Extract clean core(s)
   - Clinometer/laser from horizontal distance
3. Calculate $SPTH_{200}$
   - Using $SPTH_{200}$ Calculator

[1] Quinn, T., G.F. Wilhere, and K.L. Krueger, technical editors. 2020. Riparian Ecosystems, Volume 1: Science Synthesis and Management Implications. Habitat Program, Washington Department of Fish and Wildlife, Olympia.

[2] Rentz, R., A. Windrope, K. Folkerts, and J. Azerrad. 2020. Riparian Ecosystems, Volume 2: Management Recommendations. Habitat Program, Washington Department of Fish and Wildlife, Olympia.

For a given species, a tree that is 120 feet tall at age 50 typically has better growing conditions than a tree that is only 80 feet tall at age 50. As indicated by the growth curves, the shorter tree will likely continue to grow at a slower rate as it ages (Figure 1). There are exceptions to these generalized trends, of course, but for most sites the general trends are sufficiently reliable.

Site Index (SI) is defined as a species-specific measure of actual or potential forest productivity expressed in terms of the average height of trees included in a specified stand component (i.e., the dominant and codominant trees or the largest and tallest trees) at a specified index or base age (Helms 1998). Therefore, a stand with an average 50-year site index of 120 would indicate that the site trees can reach a total height of 120 feet at 50 years. By establishing a base age, stands of any age can be evaluated and compared, and thus the number "120" becomes an index to the site's productivity.

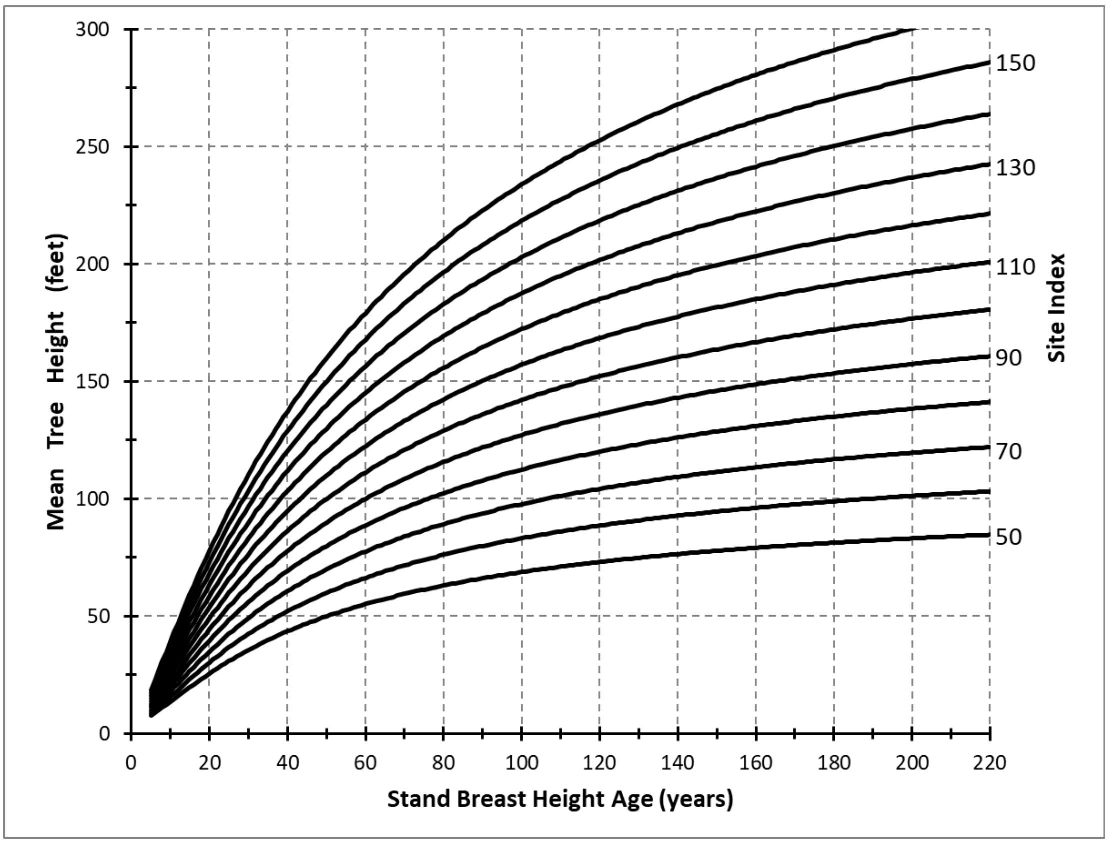

Figure 1.

Site index for Douglas-fir (Pseudotsuga menziesii) in western Washington extended out to year 200. Stand Breast Height Age is the age of the tree measured at 4.5' above the ground (redrawn by G. Wilhere, WDFW, from King 1966.)

Site index puts trees of all ages on a relative basis so that the index number has meaning, and comparisons can be made. The lower the index number, regardless of the tree's current age, the poorer the site; the higher the index number, the better the site.

Site index curves have been developed by fitting tree productivity data to site index functions. A commonly used set of site index curves in the Pacific Northwest are those published in King (1966). The curves for King's 50-yr site index for Douglas-fir, developed from stem analysis of trees in western Washington, are shown in Figure 1. Note that as site quality improves, the curves are steeper, particularly for young trees. Growth rates tend to level out as the trees mature. In practice, most second-growth stands are indexed to age 50. For some short-lived species, such as red alder (*Alnus rubra*), a base age of 50 years is also used (Worthington et al. 1960). The growth curves can use current height and age data to predict the height of site trees at a common or *index* age, which is the goal of this procedure. Specifically, we seek to estimate a stand's dominant trees' heights at age 200 ($SPTH_{200}$) to use as the width of a RMZ.

Site trees are used to assess a site's inherent ability to grow trees and therefore should be the best trees on the site. Trees expressing the full potential of the site are selected, not those that have been subjected to damage, injury or disease. A tree with a broken top obviously is not as tall as it would have been without the breakage, and using such a tree would falsely indicate a lower site index than the site can produce. Therefore, in selecting which trees to measure for obtaining site index, care must be taken to avoid those trees that misrepresent the true quality of a site. A site tree must meet *all* of the following criteria:

1. It must be the dominant tree species on the site. If more than one species may be dominant, then the site index should be determined for multiple species.

2. It must be in the *dominant or codominant* crown class.

3. It must be *free from injury or damage*. Site index trees cannot have broken tops, damaged or compacted root systems, insect injury, and so on. These occurrences reduce a tree's health and vigor so that it does not express the site's full potential for growth. Health of a tree can generally be determined by measuring the live crown ratio (LCR, Figure 2), and examining the crown, bole, and other components of the tree for defects.

4. It must be *free from past suppression* of growth. Some trees can tolerate heavy shade when they are young, and then put on rapid growth when the canopy opens up, allowing full sunlight to shine on them. This pattern is not acceptable for a site index tree, since light availability dominated the tree's ability to grow, and the tree was not expressing the site's full potential when shaded.

Live crown ratio (LCR) is the ratio of crown length to total tree height, or the percentage of a tree's total height that has foliage (Figure 2). LCR can be used to determine tree health when choosing appropriate site trees. Crown length is partly a function of species' shade tolerance. For example, Douglas-fir and most pines will self-prune (drop their lower branches as they become shaded). However, a shade tolerant species such as western hemlock will keep more of its lower branches in medium shade. Therefore, a western hemlock will have a longer crown (and higher LCR) under low light conditions than a Douglas-fir.

Dominant and codominant trees should be examined carefully for outward signs of injury or defect before measuring for site index. In addition, each increment core sample used to estimate age should be checked for evidence of significant past suppression or injury (Figure 3). *Dramatic* shifts in the ring sizes, presence of rot, charcoal, and other abnormalities can indicate previous impacts (Figure 4). It may be inappropriate to apply this site tree criterion where a bad weather year (e.g., a severe El Niño) has led to a narrow ring pattern within *all* trees in a given stand and/or region.

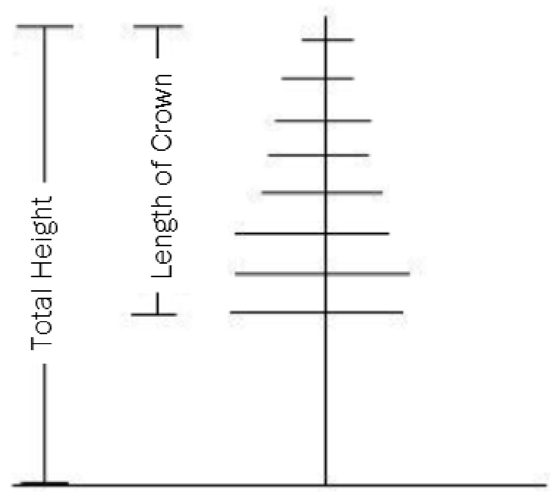

Figure 2.

Live Crown Ratio is the ratio of live crown length to total tree height, expressed as a percentage.

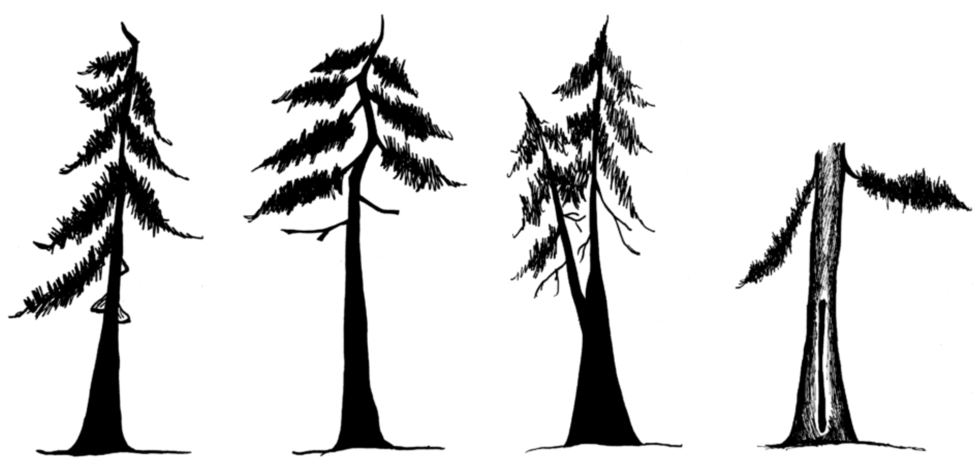

Figure 3.

Trees with abnormal growth or injuries do not reflect the full potential for growth on the site. From left: a tree with conks indicating internal rot; a tree with a deformed top indicating damage; a forked tree; a tree with a trunk scar indicating damage.

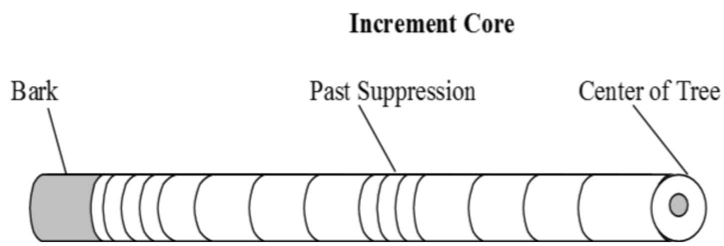

Figure 4.

An increment core sample showing evidence of past suppression. “Normal” growth rings display a gradual decrease in ring width from pith to bark, as the wood is laid down over a larger and larger diameter over time. Small ring widths followed by large ring widths (or vice versa) indicate a sudden shift in growing conditions.

Field Methods

Determining site index integrates the technician’s abilities to identify crown classes, measure tree height, and estimate tree age. This is one of the few cases in which a biased sample of trees is chosen to measure. The site trees are an indication of the site quality, so only trees that have been relatively unimpeded by neighboring trees or disturbances are measured. The objective is very different than a typical sampling scheme to get an average measure of stand volume, size, or growth rates. Therefore, the sampling method is different as well.

1. Select trees to measure. The number of trees to measure will depend upon how variable the stand is and the degree of accuracy desired. King (1966) recommends: a sample of 50 dominant and codominant trees per location, ten of which should be trees with the largest diameter at breast height (DBH) from a variety of locations in the stand. The greater the variability in size and species on the site, the larger the sample size needed to get an accurate estimate of site quality for each species present, to the extent feasible.

Criteria for selection:

a. <u>Dominant or codominant crown class</u>. Choose trees whose crowns are receiving full sunlight.

b. <u>Free from past disturbance</u>. Check *all* sides of a tree for signs of insect galls, conks, witches’ brooms, basal or trunk scars, breakage, etc. Check for signs of root disease (e.g., *Phaeolus schweinitzii* or *Heterobasidion* spp.). There may be instances in which a stand severely hit by an ice or windstorm will have very few suitable site index trees to choose from. Also consider the live crown ratio.

c. <u>Free from past suppression</u>**.** Check the inside. This may be difficult to assess on larger trees without looking at an increment core sample. Some people will core the tree first to make sure it is a usable site index tree before measuring the height to save time. On smaller trees, the distance between whorls can indicate general growth rate trends.

2. Extract a clean, intact core sample to estimate age (see determining tree age, below).

a. Check core for evidence of rot, charcoal, past suppression, or drought.

b. Make sure you can read the age – use a magnifying glass or hand lens on trees with tight rings. Look carefully at the regions indicating the center of the tree. Core samples that do not include rings within a few years of the pith should be resampled to include the center (Figure 6). Count the rings at least twice.

3. Measure total height (see determining tree height, below). Obviously, this is a critical measurement. Measure your distance from the tree. Make sure you can see the top. From a perspective that allows a clear view of the crown, look for evidence of breakage – flat tops, longer than expected side branches, etc. Also look for sucker limbs and forking in the crown.

4. Record your measurements. Record each tree as a pair of measurements – height and age. The two measurements are used together to obtain site index, so *keep them as a pair* (see App. B. Field Data Collection Form template). Always record breast height age in the field. This number can later be adjusted to total age by adding the number of years commonly needed for that species to reach breast height (Figure 1). This will vary by species and region. Typically, it is four to eight years for most low elevation conifers.

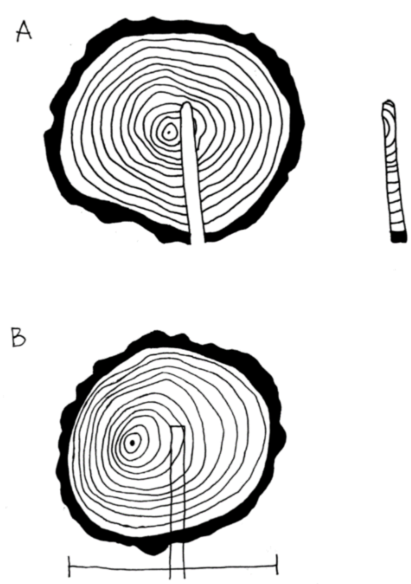

Figure 6.

(A) Off-center core sample showing curving rings near center. (B) Centered core sample on tree with off-center pith.

Determining Tree Age

Here are some tips and instructions for getting clean, usable core samples.

In the office

1. Inspect your borer bit! Make sure the bit is sharp and free of nicks. A jagged bit edge will result in a torn-up core sample. It is extremely important to keep the bit edge clean and protected to get a smooth core sample that you can read easily (Figure 7).

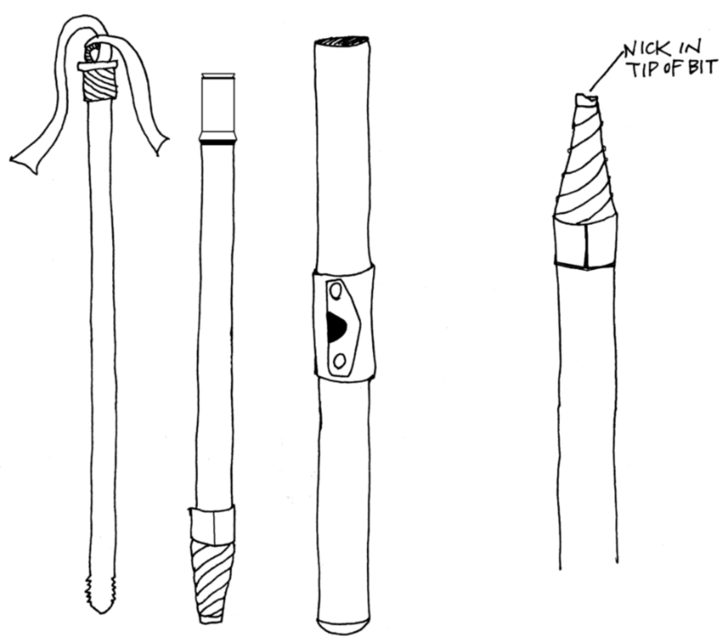

Figure 7.

The far-left image shows a jagged bit surface. This will chew the wood as it bores and result in an unreadable core sample.

In the field

1. Determine DBH. Note – the core sample does not have to be taken from the uphill side of the tree, but it *does* have to be taken at DBH. If you are standing on a slope, it is best to bore the tree on the side slope to diminish the effects of the tree's off-center pith.

2. Choose a spot on the trunk free of knots or bulges.

3. Put the extractor in a safe place while you are boring. Never put it in the ground! Abrasion of the extractor teeth by minerals and rock particles in the soil will dull them, making them unable to "grab" the core sample when it is time to extract the core. It is also too easy to lose or step on the extractor when it is under your feet. Some people stick the extractor into the bark of thick-barked trees, but most manufacturers discourage this as well. A nice place for it is in the pencil slot of your cruiser's vest. It is also a good idea to wrap brightly colored flagging on the end of

the extractor to make it more visible. This is particularly important when working in heavy brush.

4. Getting the bit started is often the most difficult part. You will be able to tell when the bit gets through the bark, “catches” the wood and begins to wind its way to the center. Lubricating the bit with beeswax or WD40 can make that initial catch easier to accomplish.

5. Estimate where you think the center of the tree is and bore two or three inches past that point. This accomplishes a couple of things.

a. It is easy to misjudge how far to bore. Adding a few inches reduces the chance that you will come up short in trying to reach the pith.

b. Most trees are not perfectly round, nor is the pith always in the geometric center of a tree. A tree growing on a slope or where there are strong winds, will likely have an off-center pith. Boring past the pith will result in a better chance of hitting the center (Figure 6).

c. Generally, it is easier to tell where the center of the tree is when you can see several rings past the pith. The rings on the core sample will start curving a little when you get close to the center; they then curve the opposite direction once you have passed the pith. Seeing the curves in both directions can help pinpoint the center.

6. After inserting the extractor into the borer, turn the handle in a reverse direction *crisply* to break the wood and allow the core to be extracted. (If the extractor is inserted on top of the core sample, make 1.5 reverse turns; if the extractor is inserted below the core sample, make two full reverse turns.)

7. It may be difficult to pull the extractor out. Use your foot on the tree for leverage or use two hands, but *never twist the extractor*! This will not help get it out and will result in a broken extractor. Wear gloves to protect your hands from cuts as the extractor comes out of the tree. Completely remove the extractor before inspecting the core sample.

8. Remember that a growth ring representing one year’s growth consists of both the light-colored earlywood (laid down in the spring) and the dark colored latewood (laid down in the summer). It is the contrast of the previous year’s latewood to the current year’s earlywood that allows the rings to be counted. Many people train their eye to simply count the dark latewood bands in each ring.

9. A hand lens or magnifying glass will help with distinguishing the rings, particularly on old or slow-growing trees where the rings are narrow. Also, wetting the core sample will make the rings stand out more.

10. If the pith is missed, try to “reconstruct” the center of the tree by placing your core sample on a piece of paper and drawing circles to extend the centermost rings visible on the core (Figure 8). Using the width of the growth rings closest to the center as a guide, estimate how many rings

are missing from the center, and draw them in. Add these missing rings, if few in number, to the annual ring count. If you are adding more than three or four years, it is best to get a new sample.

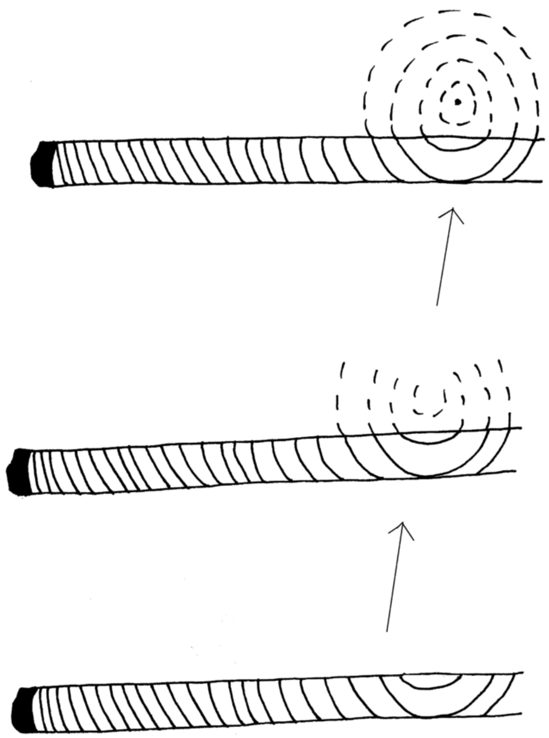

Figure 8.

Use inner ring width and curvature to reconstruct “missing” center rings. For this core sample, one more year would be added to the ring count.

Determining Tree Height

Estimating total tree height is very easy to do correctly but does require some thought about how the measurements are taken. Here are some tips.

1. Always walk to where one can *clearly* see the treetop. This can be tough to do, especially in dense stands, on extremely foggy days, or in stands with heavy brush. It is rare to have a tree whose crown is impossible to see *somewhere* within 150 feet. This is why it is important to remain flexible in selecting horizontal distances. Commonly, errors in measuring tree height come from measuring a branch instead of the tip, measuring the wrong treetop, or guessing where the treetop is in a dense canopy.

2. Do not always rely on that magical distance of 100 feet (Figure 9). Once you get comfortable with the instruments in the field, find a method that allows you to be flexible in choosing your

horizontal distance from a tree. Discover a fast way to adjust your heights with varying horizontal distances. Some people prefer to follow a formula. If you don't want to use the formula, just think of 66 (for Tslope) and 100 (for %slope) as "calibrating" distances. For example:

a. Tslope: A horizontal distance of 33 feet from a tree is one half of the calibrating distance of 66 feet from the tree, so tree height is half of the combined Tslope readings.

b. Percent slope: Likewise, 50 feet is 50 percent of 100; so, a tree height measured from a horizontal distance of 50 feet is 50 percent of the slope readings. At 90 feet, the tree height is 90 percent of the slope readings, etc.

c. Example (Figure 9): A technician measures a tree, getting +74% to the top, and –22% to the stump. 74+22 = 96. At 60 feet from the tree (60% of 100), the tree height is 60 percent of 96 or 58 feet. At 80 feet from the tree (80% of 100), the tree height is 80 percent of 96 or 77 feet. At 120 feet from the tree (120% of 100), the tree height is 120 percent of 96 or 115 feet.

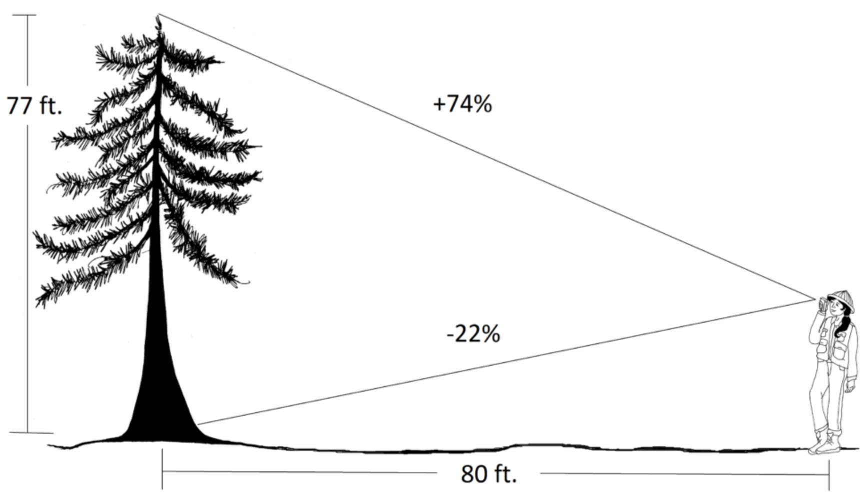

Figure 9.

A tree is measured from a horizontal distance of 80 feet. Note that the tree height is less than the sum of the two slope readings (96). If one is closer to the tree than 100 feet (the calibration distance), the slope readings will be steeper than at 100 feet. Therefore, the tree must be shorter than the sum of the readings. Another way to think of it is that 80 feet is 80 percent of the calibration distance of 100 feet, so the tree has to be 80 percent of the sum of the slope readings. Likewise, if one were 150 feet from the tree, the total tree height would be 150 percent or 1.5 times, the sum of the slope readings.

3. When the canopy is very dense, it may be difficult to discern which top belongs to the tree you are trying to measure. A partner can push repeatedly on the tree trunk at shoulder height. The force will reverberate up the trunk and make the tip wiggle, so you can pick out your tree among the other crowns.

4. A good rule of thumb is to walk out a distance that is approximately equal to the tree's height. One should not try to measure 130-foot-tall trees from a distance of 50 feet.

5. When determining height, always record measurements to the precision of your instrument. When holding any instrument to your eye, it is extremely difficult to hold it steady enough to measure between marks. Therefore, heights are always recorded to the nearest foot. Even though a calculator or laser may report distances and heights to one or two decimal places, the actual precision is not that great due to arm and head movements during measurement.

6. Make sure your run measurement is a *horizontal* distance, *not* a slope distance. An incorrect run can result in an incorrect height estimate (Figure 10).

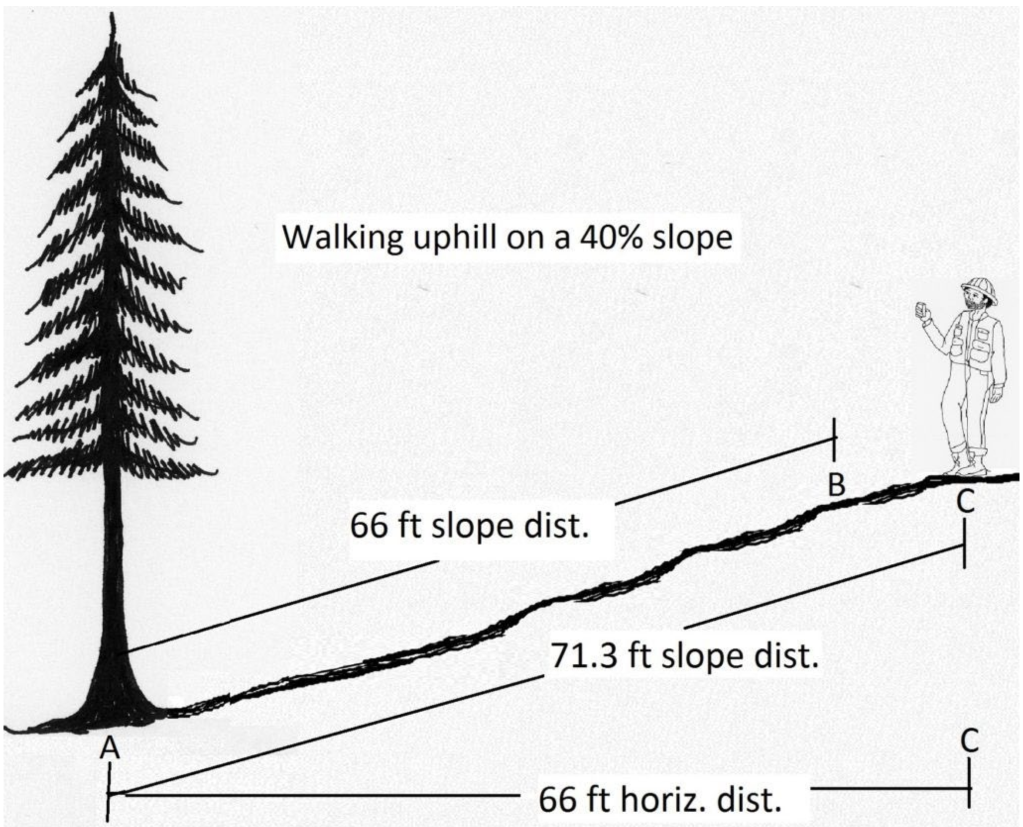

Figure 10.

Slope distance is always longer than horizontal distance. On this 40% slope, taping out 66 feet parallel to the slope (AB) does not result in a run of 66 feet (AC). To reach 66 feet horizontal distance (AC), a technician would have to walk 71.3 feet slope distance. Measuring tree heights from Point B would result in an error of nearly 10 percent.

7. On slopes, walk out from the tree along the contour (i.e., level). If possible, do not walk upslope and especially do not walk downslope (Figure 11). Walking downhill will put you beneath the tree and make the angle to the tree top even more obscure.

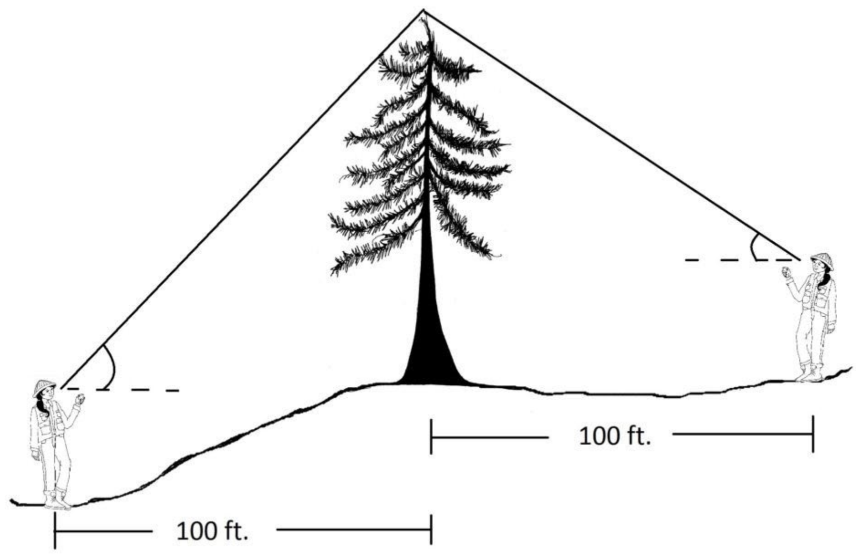

Figure 11.

Walking downhill from a tree to measure height increases the possibility of mistaking a side branch for the top, thus overestimating the tree's height. In addition, because the top measurement will be steeper than a reading taken from the same horizontal distance on flat ground, it is possible that the slope readings will be "off the scale" on the clinometer.

8. In a pinch, it may be necessary to walk either uphill from the tree or downhill from the tree. In these cases, the *horizontal distance* must be determined, either by using trigonometry, the Pythagorean theorem, slope distance conversion charts, or a laser rangefinder (Figure 10). Also note that if you measure from a place where the stump is below eye level, the bottom slope reading is *subtracted* from the top reading as explained in Figure 12.

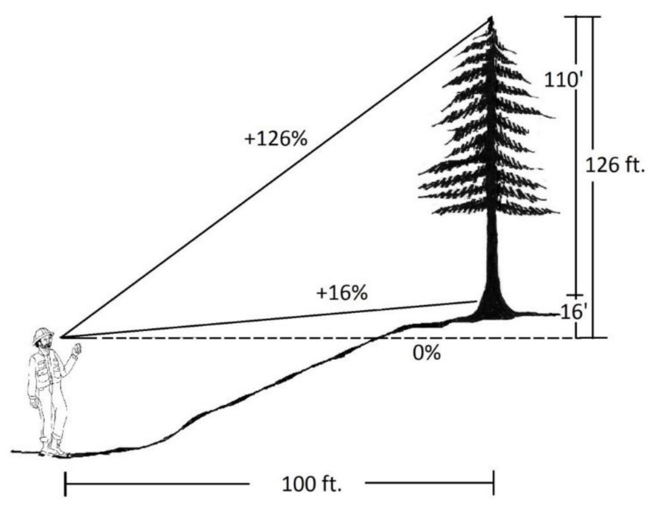

Figure 12.

Measuring total height from below stump height. Sometimes, a tree may have to be measured from its downhill side. Slope readings will include everything between your eye and the point of measurement. If eye level is below the stump, then your reading to the stump is actually a measure from a point below ground up to the stump. Therefore, this reading must be subtracted from the top reading (which also includes the ground) to obtain a measure of the actual tree height. In other words, (tree + stump) – (stump) = tree. Or 126 — 16 = 110 feet.

9. In situations with very thick brush, it may be impossible to see the stump of the tree. In this case, sighting on a partner's hard hat or some other target, and adding in that height at the end, will result in a more accurate tree height (Figure 13). The technician sights to the top of the tree and reads +98%. She then sights to the top of her partner's hardhat and reads +3%. Since both readings were taken while looking uphill, the second reading is subtracted from the first to obtain the tree height above the hat. At 100 feet horizontal distance, 98%-3% =95 feet. The height from the stump to her partner's hardhat is then added, or 6 feet, for a total of 101 feet.

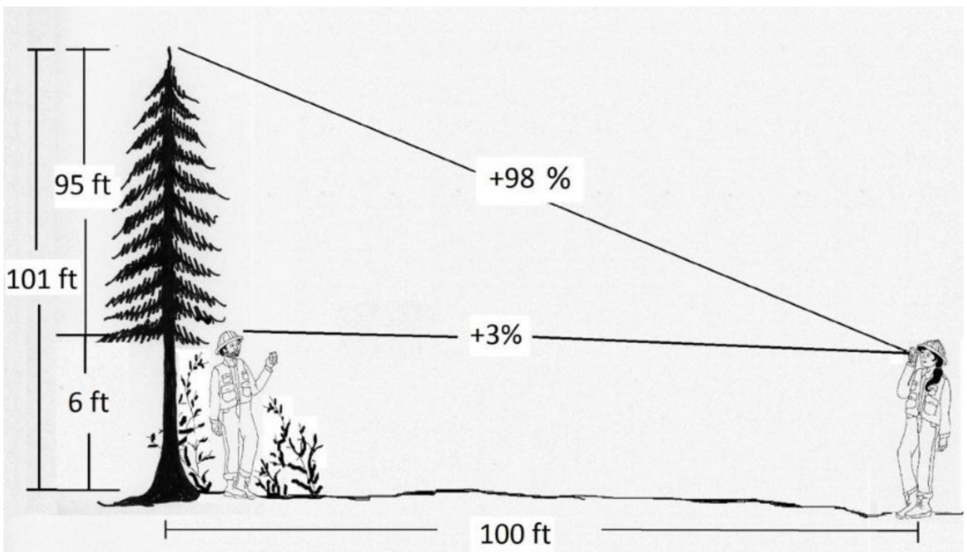

Figure 13.

Using a partner or target to determine tree height when brush or ground obscures the tree stump reading.

10. As with all field data collection, when working with a partner, echo back your measurements to make sure the correct number is written down or entered into the data collector.

Calculate $SPTH_{200}$

Once you have sampled enough site trees, you can enter your tree age and height data into the [$SPTH_{200}$ Calculator] (or plot your data onto the appropriate growth curves manually) to determine the $SPTH_{200}$ value for the dominant tree species at the site (Figure 14). You can then use the $SPTH_{200}$ value to delineate a RMZ with the potential to achieve full riparian function.

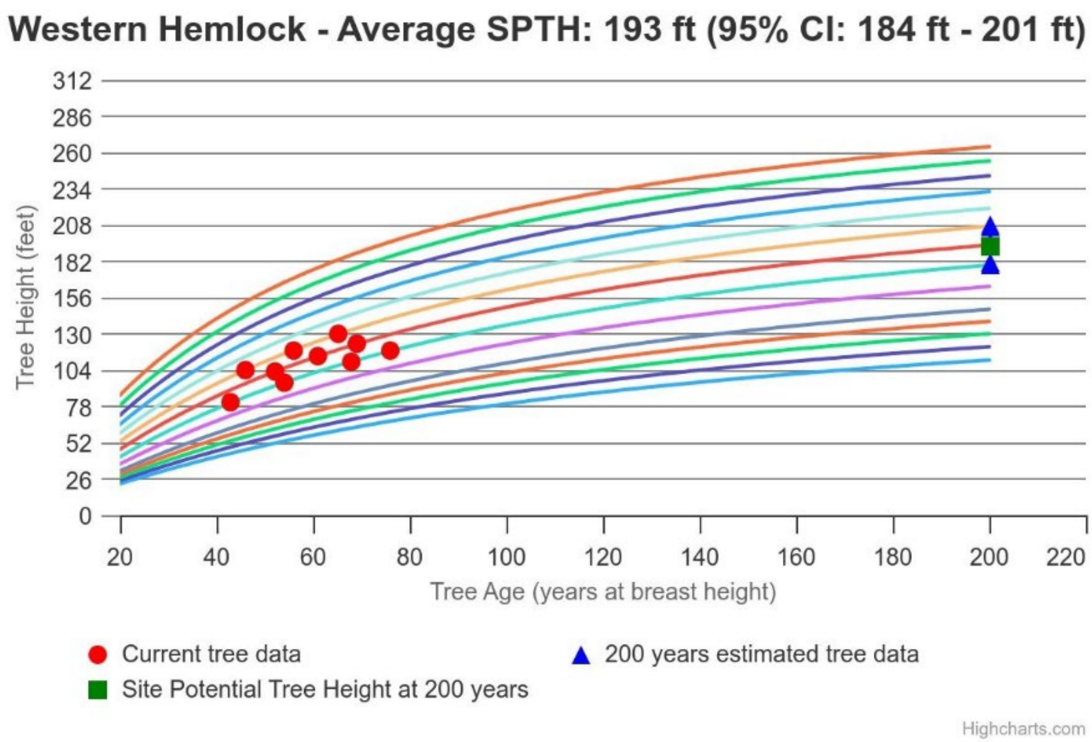

Figure 14.

$SPTH_{200}$ Calculator output. The $SPTH_{200}$ value (green square) for the ten Western Hemlock trees measured in the field (red dots) is 193 feet with a 95% confidence interval (CI) of 184-201 feet (blue squares).

Literature cited

DeYoung, J. 2016. [Forest Measurements: An Applied Approach](). Creative Commons [Attribution 4.0 International License](), except where otherwise noted.

Helms, J.A. (ed.), 1998. The Dictionary of Forestry. The Society of American Forester, Bethesda, MD.

King, J.E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Forestry Paper 8. Weyerhaeuser Company, Forestry Research Center, Centralia, Washington.

Worthington, N.P., F.A. Johnson, G.R. Staebler, and W.J. Lloyd. 1960. Normal yield tables for red alder. USDA, Forest Service. Pacific Northwest Forest and Range Experiment Station Research Paper No. 36.

Appendix A

There are several sources for finding a qualified forestry professional, below are a few options:

Association of Consulting Foresters

"ACF consulting foresters are independent professionals who manage forests and market forest products for private woodland owners, called upon by landowners across the country to advance their forestland ownership goals."

Society of American Foresters - Certified Foresters

"SAF is the largest national scientific and educational organization representing the forestry profession in the United States. SAF members include forestry and natural resource professionals, who work in public agencies (state and federal) and private businesses (corporate and consulting). Members are also involved with research, education, public relations, policy, and more."

Washington State Consulting Forester and Silvicultural Contractor Directory

"The Washington State Consulting Forester and Silvicultural Contractor Directory is a compilation of forestry professionals around Washington State who provide the professional services to private forest landowners. The directory includes specific information for each of the professionals, including contact information, services provided, bonding and insurance information, experience, and counties served. Inclusion in the directory is voluntary. All information is provided by the forestry professionals themselves."

WDFW neither recommends nor endorses any individuals from these lists.

Appendix B

Field Data Collection Form template

Tree Species:

Site/Location:

Age, breast height (years)	Horizontal distance from tree (feet)	% Slope to trunk	% Slope to top	Total height (feet)	Notes