

How to Measure Woody Biomass in Your Forest



CREDITS

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ACRONYMS

The following acronyms are used in this guidebook:

BA: Basal area is the cross-sectional area of a tree 4.5 feet above ground.

DBH: Diameter at breast height is the measurement of tree diameter 4.5 feet from the ground.

HDR: Height to diameter ratio is the ratio between a tree's total height and its DBH.

LCR: Live crown ratio is the percent of a tree's total height that has live, green branches.

MBF: Thousand board feet

QMD: Quadratic mean diameter is the measure of average tree diameter related to basal area.

RD: Relative density is the comparison of current density to some maximum.

SDI: Stand density index estimates the RD of uneven-aged, mixed species forests at large scales.

TPA: Trees per acre

These terms are explained in [Appendix 2 - Glossary](#).

INTRODUCTION

The goal of this guidebook is to provide landowners with a practical inventory system for estimating the volume of timber and woody biomass in their forest. By using these guidelines, landowners can more easily collect information to inform their forest management decisions. Such decisions may include whether to commercially or pre-commercially thin a forest, when to do it, which trees to remove when thinning, and what to do with the thinned woody biomass.

Thinning involves removing a portion of the trees growing in a forest. Thinning is a recommended practice particularly for forests where the trees are crowded together and show signs of decline due to competition for limited resources such as sunlight, nutrients and water. **Thinning is one of the most important practices forest owners can carry out to improve the health, productivity, and diversity of their woods.**

Many forests are not currently as productive as they could be for either biodiversity or wood products. As forests have changed ownership over the last century, management goals and objectives have also changed. Many forests once managed for industrial timber production, for instance, are now managed for a variety of goals including beauty and enjoyment, nature, recreation, and income. Trees that were planted under a previous set of objectives (e.g. short-rotation timber plantation) continue to grow under new goals (e.g. long lived diverse forest). Today there are many acres of overstocked forests that consist of a high percentage of poor quality trees, and often these stands are dominated by a single species and age of trees.

One of the first steps in making informed management decisions about a forest is to get a better understanding of the stocking and composition. However, conducting a forest inventory may sound a little daunting to most new and beginning forest owners. This guidebook, along with NNRG's Woody Biomass Calculator (<https://www.nnrg.org/wp-content/uploads/2019/01/Woody-Biomass-Calculator.xlsx>), is a simple and practical method for estimating the volume of timber and woody biomass in a forest. This guidebook provides simple steps for collecting basic tree measurements and forest data, as well as instruction on



Left: A dense stand crowded with suppressed trees. Right: A recently thinned stand. Plot data generated with NNRG's Woody Biomass Calculator would reveal more information about the biomass stored in these two stands.

Photos: Matt Freeman-Gleason

how to use the calculator to convert this information into estimates of timber and biomass volumes.

Common questions that forest owners ask when they think about thinning their forest include:

- How much timber volume is in my forest? How much should I remove? How much should I retain to meet my management goals?
- Which trees have merchantable value? Which ones do not?
- How much wood should I leave on the ground during thinning to improve soil health and wildlife habitat?
- Will I increase fire risk if I leave too much dead wood in my forest?
- How much woody biomass can I remove from my forest to use for firewood, biochar, and other projects?

Please note, the guidebook and calculator are only intended to produce volume estimates to help you make basic forest management decisions – the calculator may not produce statistically accurate results and should not be used in place of a formal timber cruise or appraisal.

By inventorying your forest and using the Woody Biomass Calculator you will be able to answer the following questions about your forest:

- How many gross tons of biomass are in my forest? How much of this volume is merchantable? How much is non-merchantable?
- How many tons of biomass are in the tree trunks vs. the limbs and bark? How much biomass is in dead trees (snags) vs. live trees?
- How many board feet of merchantable timber do I have?
- How many trees per acre are there in my forest? What is the average tree diameter? What is the diameter range of trees in my forest?
- How much wood volume of each tree species is there in my forest?
- And more



Structure of This Guidebook

This guidebook is organized into four sections:

- Forest inventory
- Office preparation
- Field instructions
- Office analysis

This sequential structure introduces concepts and techniques, helps you prepare for efficient fieldwork, gives instruction for collecting field data, then provides guidance on how to analyze the field data using the *Woody Biomass Calculator*.



Photo by NNRG

Required Skills

You will need the following basic forestry skills to use this guidebook. These skills can be gained through training workshops provided by Northwest Natural Resource Group or coached stewardship planning classes offered by state forestry extension services.

- Identifying tree species
- Using basic forestry tools including: clinometer or laser range finder, increment borer, and diameter tape.
- Using Microsoft Excel

Equipment List

The following items are recommended for conducting a forest inventory:

Items for field data collection

- Plot Data Card(s) ([Appendix 1](#))
- Tree diameter tape
- Clinometer or laser range finder
- 16" Increment borer (if aging trees)
- Roll of plastic flagging
- Pencils
- Small pocket sized notebook
- Map of your forest stand

Items for permanent plots (Optional)

- Hatchet or hammer
- Numbered tree tags (check for numbers that have not been used)
- Aluminum nails
- 4' stake for marking center of permanent plot (e.g. a firm stick or rebar with white PVC pipe)

Other optional Items

- Field vest or backpack to carry field tools
- Aerial Photo or contour map of forest
- GPS or smartphone with GPS app
- Compass
- Binoculars
- First-aid kit
- Machete for heavy brush
- Snacks and water
- Clipboard or datum
- Stand map w/plots mapped out
- Digital camera
- Plant ID book



Photo by Matt Freeman-Gleason

FOREST INVENTORY

As it is impractical to measure every single tree in a forest stand, a forest inventory measures small samples of the stand and extrapolates the results to characterize the entire stand.

The basic process involves setting up inventory plots in a random grid across your forest; stopping at each plot to measure and record variables such as tree species, diameter, and height; averaging these values for each variable per acre; and multiplying the average by the number of acres in the forest to generate forest-scale totals.

Different Types of Inventories

Permanent vs. Temporary Plots

Temporary plots are the simplest inventory method and involve measuring plots once without the need for permanent marking. This method is recommended for quick, one-time evaluations of a forest as a whole.

Permanent plots are a more precise inventory method and involve marking plot centers and tagging trees with numbers so that variables can be measured again within the same plot over many years. This method is recommended for monitoring how the forest changes over time in the exact same location.

Fixed Area vs. Variable Radius Plots

Fixed area plots are simple to work with and consist of a predetermined and unchanging sample area on the ground. Fixed area plots are typically defined by their fraction of an acre, such as a 1/20th acre plot (26.3' radius), or a 1/10th acre plot (37.2' radius), etc.

Variable radius plots are not compatible with the Woody Biomass Calculator, because the calculator depends on using the same plot radius throughout the stand. To learn more about how to use variable radius plots to create your forest inventory, please consult this fact sheet from the Forest Service:

https://www.fs.fed.us/nrm/documents/fsveg/cse_user_guides/userguide_fsveg_apdx_j_var-plot.docx

Inventory Frequency

Ideally, an entire ownership should be inventoried when a management plan is written, and re-inventoried at approximately 10-year intervals. Other smaller inventories may be needed to inform management decisions, such as before and after a timber harvest, before a pre-commercial thinning, after planting, or after a major storm or other disturbance event.

OFFICE PREPARATION

Create a Stand Map

Every forest inventory starts with a desk exercise where you will divide your forest into stands, and map these stands to determine your basic inventory framework. A stand is an area of the forest that is relatively uniform and can be managed as a single unit. Stands can be delineated by age, species, forest structure, soil, management goals, or other criteria. For more information on how to divide your forest into stands, please see pages 5 to 7 of WSU's Basic Forest Inventory Techniques for Family Forest Owners

(<http://cru.cahe.wsu.edu/CEPublications/PNW630/PNW630.pdf>).

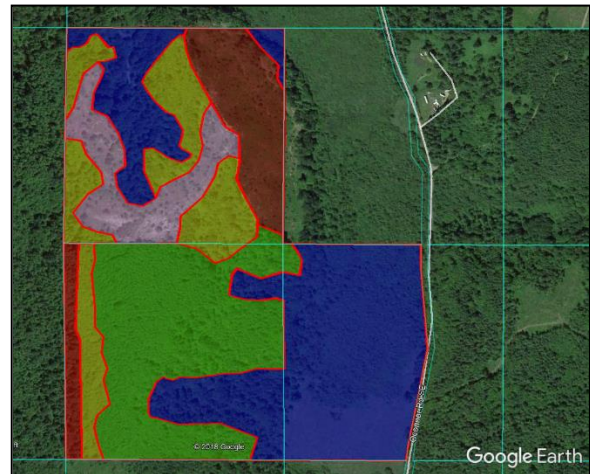
You will need to create a map of the various forest stands on your property that you can easily carry during field work. It may help to place your map in a zip-lock bag to protect it, especially on rainy days. You may already have this map if you've previously developed a forest management plan. The stand map needs to identify the boundaries and acreage of each discrete stand. Your property may have many different stands, or it may all be comprised of a single stand type (e.g. Douglas fir plantation).

A stand map can be easily created online for free using Google Earth Pro

(<https://earth.google.com/download-earth.html>).

This software also allows you to calculate the size of a stand in acres, export data to your GPS unit or smartphone for use in the field, and store and analyze data collected in the field.

There are many free apps available for smartphones that allow you to download aerial photos and contour maps, download property and stand boundaries from Google Earth, and then map and record data while walking in your woods. These tools are invaluable for navigating in the woods and recording plot locations. Two common mapping apps are Avenza Maps PDF and Backcountry Navigator.



Example stand map created in Google Earth

Determine Your Inventory Plot Strategy

Determine type of plot (temporary or permanent)

Decide whether plots will be temporary or permanent. You may choose to put permanent plots in a few select stands that will receive specific treatments you wish to continue monitoring, and temporary plots in stands which you do not necessarily need or want to monitor single tree growth.

Determine plot size

Each plot should contain an average of 6 - 10 dominant overstory trees. For example, if the stand is predominantly comprised of Douglas fir greater than 6" DBH, each plot should contain 6 - 10 dominant Douglas fir trees. If there are small 1" - 3" DBH saplings in the stand, you can include them in your inventory if you choose, but focus primarily on the main cohort of overstory trees. If you know the approximate average density (trees per acre)

use the table below to select the appropriate plot size. The plot size must be the same for all plots in a stand but can vary between stands. If you don't know the density of the stand, you will need to visit the stand and measure the trees per acre, then choose the appropriate plot size (see box above).

Plot Radius Chart		
Trees per Acre	Recommended Plot Size	Plot Radius
800+	1/100 th acre	11.8'
400-800	1/50 th acre	16.7'
150-400	1/20 th acre	26.3'
75-150	1/10 th acre	37.2'
75 or less	1/5 th acre	52.7'

How to Estimate TPA

1. Select an area that is representative of the stand and mark a point at plot center.
2. Using the plot radius chart below, measure out a sufficient radius to obtain a minimum of 6– 10 dominant trees within the circular plot.
3. Count the total number of overstory trees in the plot and multiply by the plot size to determine TPA.
4. Example: 9 trees within a 10th acre plot. $9 \times 10 = 90$ TPA.

Determine the number of plots per stand

The number of plots you choose to install per stand depends on how accurate you need the resulting data to be and how much time you have. If you only need a ballpark estimate, are looking for a range, or have a very

limited amount of time, you can install fewer plots. If you want to achieve a statistically valid sample of your forest, you will need to install more plots. Furthermore, if your forest has a highly variable composition, you will want to install more plots. Conversely, if the species and composition of your forest is very homogenous, you can reduce the number of plots. In all cases, make sure that you use enough plots to adequately represent the entire stand area.

The table below suggests the number of plots that should be installed based on the size of the plot and the size of the stand in order to achieve a highly accurate forest inventory. For heterogeneous stands, install more plots. For homogenous stands, install fewer.

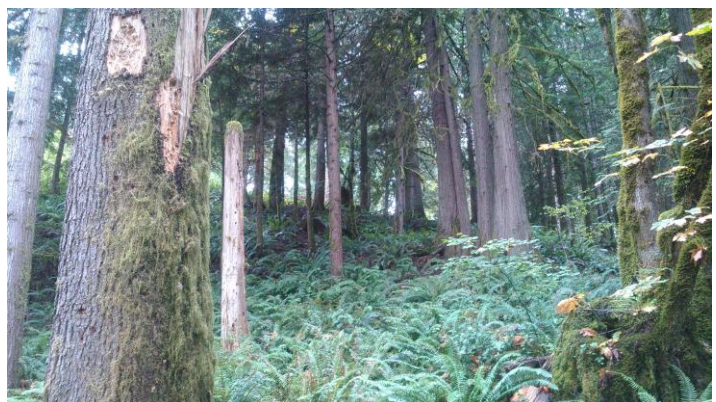
Suggested minimum number of plots per stand				
Plot size	Stand Size			
	5-20 Ac	21-40 Ac	41-80 Ac	80+ Ac
1/100th	10	15	20	25
1/50 th	10	15	20	25
1/20th	8	10	12	15
1/10th	6	8	10	15
1/5 th	5	8	10	12

If you plan to choose plot locations in the field, you're ready to head out into the woods! However, it is standard practice to use randomly located plots in order avoid subjectivity when collecting forest inventory data. If you would like to use a randomization procedure for locating plots, NNRG's *Forest Inventory & Monitoring Guidelines* provides detailed instructions to ensure that no bias affects the location of plots. These need to be mapped out in advance of fieldwork to produce a map like the one to the right. This resource is available here:

<https://www.nnrg.org/wp-content/uploads/2015/02/NCF-Inventory-Monitoring-Guidelines.pdf>



Example of plot locations in a 41 - 80 acre stand.



These two stands within the same forest have very different densities (TPA) and require different plot sizes.

FIELD DATA COLLECTION

You are now ready to head into the field and conduct the inventory. Be sure you have the following:

1. Aerial photo, GPS, and/or smartphone maps
2. Plot data cards, notebook and pencils
3. The required field equipment listed in the Equipment List

Locate the plots

The two most important factors in locating a plot is identifying an area that is representative of the stand while avoiding personal bias in plot location. The best way to accomplish this is to have a predetermined plot map as described above. If you have not prepared a plot location map, here is a simplified approach to installing plots in a non-biased grid in the field:

1. Choose a location along the edge of the stand that has easy access. From the stand edge, travel on a straight compass bearing to a location that is 100 feet from the stand edge. This location is plot center for the first plot. This distance can be abbreviated if the stand is small or narrow, or increased if the stand is larger.
2. Subsequent plots should then be located on a grid using straight compass bearings from the initial plot. Determine a distance between plots that will result in your predetermined number of total plots and will cover the entire stand. Walk this grid pattern, stopping at the chosen distance to establish each plot.

Mark plot center

Temporary plots

Mark plot center with any method that will reliably maintain an easy-to-find plot center while you collect data, like hanging flagging from a

shrub or tree branch or scuffing the forest floor to



Left: Mark plot center with rebar topped with PVC and flagging noting the plot's identification number. Right: Label trees with pre-numbered tags in a permanent plot.

expose bare soil. If you are working alone, inserting an 18" piece of re-bar in the ground at plot center can be helpful to hold a measuring tape while measuring out distances from plot center. You can remove the rebar and re-use it on every plot. In case you need or want to return to the plot in the near future, hang flagging nearby so it is visible and write the plot number and date on the flagging.



Photo: Matt Freeman-Gleason

Permanent plots

Drive a two-foot piece of rebar into the ground at plot center and place a PVC pipe over it. Hang bright flagging from the tip of the PVC pipe, and label the pipe with the appropriate plot identification number. If using GPS, record the location of the plot center. Tag each tree with a pre-numbered tag facing plot center. The first tree tagged should be the first tree east of due north (from plot center); proceed in a clockwise direction marking all remaining trees. Place tree number tags at DBH height on the tree bole, facing plot center. You may also choose to place a tree number tag at the base of the tree, 10" off the ground, so the stumps can be identified after thinning operations.

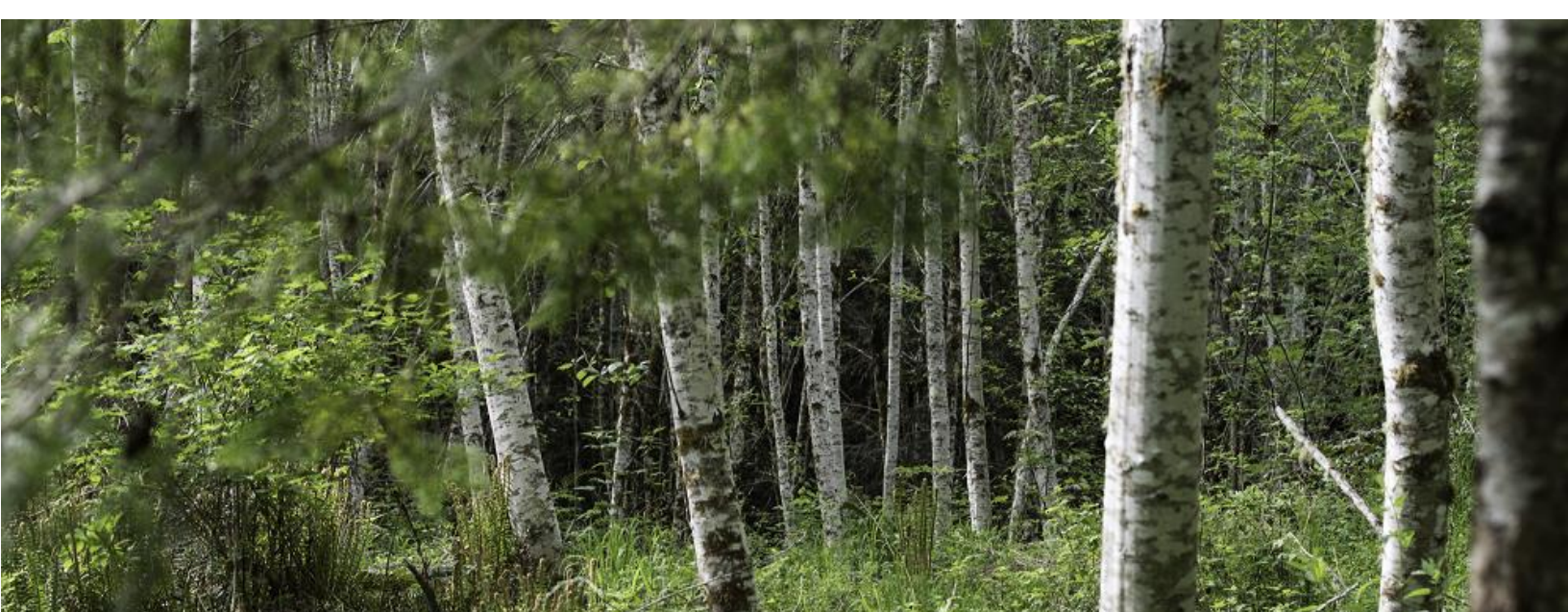
Record Plot data

Plot data

Using your plot data card ([Appendix 1](#)), enter the following plot data (**data in bold is required**):

1. **Date**: record the date when the data was collected, at least to the nearest month and year.
2. Name (*optional*): name of data collector(s).
3. **Stand ID**: usually expressed as a number, but can be a name, letter, or other ID, as long as the convention is unique to that stand and remains the same wherever “Stand ID” needs to be entered.
4. Stand type (*optional*): use the two letter tree code in the table (right) for the most dominant tree species in the stand, plus a reference to the age of the stand (e.g. DF, RC - young, mid, mature).
5. **Acres**: record the stand’s total acres that you calculated in the office to the nearest tenth of an acre.
6. Age (*optional*): if you don’t know the age of the stand, this data can come from your tree data if you choose to measure age. If you do not measure tree age, estimate the stand’s age by looking at historic photographs on GoogleEarth. This information may also be available in past management records.
7. **Plot #**: a unique number to identify the plot.
8. **Plot radius**: enter the plot radius to the nearest tenth of a foot. For instance, a 1/20th acre plot will be entered as “26.3”.

Species	Code
Alaska Yellow Cedar	YC
Aspen	AS
Big leaf Maple	BM
Bitter Cherry	CH
Black Cottonwood	CW
Douglas-fir	DF
Engelman Spruce	ES
Gary Oak	GA
Grand fir	GF
Lodgepole pine	LP
Noble fir (WH)	NF
Oregon Ash	OA
Pacific Crabapple	PC
Pacific Madrone	MD
Pacific Silver fir	SF
Pacific Yew	PY
Paper Birch	PB
Red Alder	RA
Sitka Spruce	SS
Western Hemlock	WH
Western Larch	WL
Western Red Cedar	RC
Western White Pine	WP
White fir	WF
Other	OT
Unknown	UN



Tree data

Find a north bearing from plot center. Start with the northern-most tree and move in a clockwise direction, measuring all live trees over 3" DBH. If there's a question about whether a tree is in or out of the plot, measure the distance from plot center to the center of the tree perpendicular to plot center. If the majority of its diameter is within the plot, include the tree.

Using your plot data card, enter the following data for each tree in the plot:

1. **Tree ID:** assign each tree a number. If you're establishing permanent plots, tag each tree with that number.
2. **Species:** use the species codes to right. If you find a species not on this list, enter "OT" for Other on your plot card, and note the species in the "Notes" field. If you can't identify the tree, you can enter "UN" for Unknown. Note, OT and UN will be combined in reports generated by the Woody Biomass Calculator.
3. **DBH:** measure the diameter at breast height to the tenth of an inch. For instance: 12.3".
4. **Status:** enter L if the tree is alive, or D if the tree is dead.
5. **Percent defect (optional):** Record defect as a percent of total tree height. For example, if 30 percent of tree is defective and non-merchantable, enter "30". This takes practice to observe and calculate. If you see obvious signs of rot, large crooks, scars, or cracks on the bole, simply: estimate the length of the bole affected by the observed damage, divide it by the total tree height, and multiply by 100 to produce a rough estimate.
6. **Harvest (optional):** If you know you will be removing a tree during a future thinning project, you can enter "Y" in the Harvest column. This will be important to generate metrics before and after a harvest scenario with the calculator.
7. **Height:** record total tree height to the nearest foot.
8. **Age (optional):** You don't need to measure the age of every tree within a plot. If the stand composition is uniform (e.g. even-aged plantation), you may only need to core one or two trees. If the stand is more complex (e.g. mixed species/age), you may need to core several trees in each species and/or age class to establish an age range. Although age is important to understand in forest inventories and growth predictions and analysis, the age of a tree has no



bearing on the amount of wood volume *currently* in the tree, and therefore is an optional measurement when calculating woody biomass.

9. Live crown ratio (optional): Enter LCR as the percent of total tree height which has live, vigorous branches.
10. Notes (optional): record any unique or notable features about the tree. Notes might include evidence of wildlife use, type of defect (e.g. forked top, bear damage), disease or insects, etc.
 - a. If there are multiple trees of the same species that have the same diameter and height, you can record all of them in one line on your plot card and write the number of similar trees in the “Notes” field to save time and space. This number can then be entered in the calculator’s “Count” column, and the calculator will multiply these trees for you and present their combined totals in the subsequent reports.
 - b. During thinning operations, trees that are suppressed or have a defect are more likely to be harvested. If your inventory goals include calculating potential harvest volumes, note which trees are suppressed or defective so you can identify this tree later when analyzing your data under different harvest scenarios. You can also use the “Harvest” column (#6 on this list) for this function. Keep in mind that retaining a few trees that have signs of defect can enhance structural complexity and wildlife habitat.



Photo: Matt Freeman-Gleason

OFFICE ANALYSIS

Once you complete the field portion of the inventory, you are ready to use NNRG's Woody Biomass Calculator to synthesize your data. The calculator can be used on any computer that runs Microsoft Excel. The calculator allows you to convert simple forest inventory data into woody biomass volumes, expressed in both tons and board feet.

This calculator determines the volume of biomass in a tree using generalized algorithms that express averages for each species and should not be relied on when highly accurate measurements are required for timber cruising or appraisals.

Get Familiar with the Calculator

1. Open the calculator by double-clicking on the file. The calculator should open to the "Instructions" tab. If it doesn't, click once on this tab to open.
2. Save a new copy of the calculator before you begin entering data. **This is highly recommended to ensure you retain a clean copy of the original in case an edited version becomes corrupted.**
3. Familiarize yourself with the cell color-coding scheme. It is critical to the functioning of this calculator that data only be entered or altered in the appropriate cells. If data is added or altered in any orange cell, the calculator may not function correctly. Be sure to only enter data in a green (required) or gray (optional) cell.

Do not enter data
Autocalculated

Enter data
Required User Input
Optional User Input

4. Next, click on the Stand, Tree, Plot, and Merchantability tabs respectively to familiarize yourself with the data that will need to be manually entered. Only enter data into cells colored either green or gray.
5. Next, click on the following tabs and familiarize yourself with the variety of reports that will automatically populate with summarizing data once you've completed entering your forest inventory data: Plot, Stand, Species, MBF, Biomass.
6. Finally, review the Stand Table tab. This is a simple worksheet you can use to determine how many trees per acre there are within pre-defined DBH ranges (e.g. 5"-10", 15"-20", etc.).

Entering Data into the Calculator

With your plot data cards handy, you can now enter your forest inventory data into the calculator.

Stand Tab

This tab records data on all the individual forest stands where inventory plots were installed. You can transfer the information directly from your plot data card.

Required data:

1. Stand ID
2. Acres (to the nearest tenth of an acre)
3. Plot radius (to the nearest tenth of a foot)

Optional Data

1. Date
2. Name
3. Stand Type
4. Age
5. Log Length: if known, enter the preferred merchantable log length using “Short” for 16 foot long logs and “Long” for 32+ foot logs. The calculator will default to using Long if nothing is entered in this cell.

Do not enter or change!

Number of Plots: this will populate itself automatically, after the subsequent tabs are completed.

	C	D	E	F	G	H	I	J	K
1	Stand Information and Plot Size Settings								
2	Stand ID	Date	Name	Stand Type	Acres	Number of Plots	Age	Log Length (Long/Short)	Plot Radius
3	1	Mar-18	Kirk Hansor	DF - mature plantation	24.5	0	40.0		16.7
4	2	Mar-18	Kirk Hansor	RA - young	11.5	0	10.0		11.8
5	3	Mar-18	Kirk Hansor	WH, RC - multi-age	5.1	0	40-90		26.3
6									

Tree Tab

This tab records data on each of the trees within each of the inventory plots. Each line is assigned to a unique tree. Simply transfer the data from your plot data card to the cells in this tab.

	A	B	C	D	E	F	G	H	I	J	K	L
	Stand ID	Plot #	Tree ID	Spc	Dbh (0.1")	Status (L/D)	Count	% Defect	Ht (ft)	Live Crown	Harvest (Y/N)	Notes
1												
2	1	1	1	DF	10.2	L	1	5	61	30	Y	Sign of bear damage
3	1	1	2	DF	12.5	L	1	0	70	30	N	
4	1	1	3	DF	11.9	L	1	5	68	40	Y	
5	1	1	4	RA	14.1	L	2	10	72	55	N	Minor species - retain
6	1	1	5	DF	8.2	D	1		45	0	N	Snag for wildlife
7	1	1	6	DF	12.8	L	1	20	68	35	N	
8	1	2	1	DF	14.0	L	2	0	70	50	N	
9												
10												

Required data:

1. Stand ID
2. Plot #
3. Species
4. DBH
5. Status
6. Height

Optional Data

1. Tree ID
2. Count
3. % Defect
4. Live Crown Ratio
5. Harvest
6. Notes

Do not enter or change!

All cells to the right of Column L



Photo: Matt Freeman-Gleason

Plot Tab

This tab records data on the number of stands in your forest, and the number of plots per stand. Each line is assigned to a unique plot in your forest. If a stand has multiple plots, record the stand number the same for each of the plots (e.g. Stand 1, plot 1; Stand 1, plot 2; Stand 2, plot 1, etc.).

Required data:

1. Stand ID
2. Plot #

	C	D
1	Stand ID	Plot #
2	1	1
3	1	2
4	1	3
5	1	4
6	1	5
7	1	6
8	2	1
9
10		

Merchantability Tab

This optional tab allows you to define the parameters of a merchantable tree based on your own criteria or your knowledge of local markets. This allows you to segregate certain tree species and certain diameter limits from the total volume of your forest so you can calculate merchantable volume more precisely.

Optional Data:

1. Merchantable (Y/N): the default in this column is set to "Yes". You can change it to "No" if you know the species to not be merchantable.
2. Min DBH (Inches): enter the minimum DBH for what you consider to be a merchantable tree, to the nearest inch. Minimum diameter could be 10" where markets for either

pulp logs or chip-and-saw logs are in close proximity, or 12" where mills are further away and hauling costs are higher.

3. Max DBH (Inches): enter the maximum DBH for merchantable logs to the nearest inch. This is typically between 30" and 36" depending on available markets. You may also choose to set the maximum lower if you want to retain all trees over a specified DBH (e.g. 24") and want to reflect this harvest strategy in your biomass calculation.

Running the Calculator

NNRG's Woody Biomass Calculator should automatically update and calculate your data as you enter it. Therefore, once the Stand, Tree, Plots, and Merchantability tabs have been fully populated with data, the calculator will automatically update the various Reports tabs. If this does not happen automatically, simply click the "SAVE" button, and the calculator will run and update all reports.

Analyzing the Data

NNRG's Woody Biomass Calculator analyzes a variety of forest stand and timber volume variables, and summarizes this data in the following five reports: Plot, Stand, Species, MBF, Biomass.

Note: Do not make changes to any cell within the Reports tabs. Doing so will cause the calculator to malfunction.

Plot Reports

There are two plot reports: pre-harvest and post-harvest. The Pre-Harvest Report provides a summary of the inventory data collected within an individual plot, extrapolated out to the acre. Individual plot data are listed in the "Live Tree Metrics" fields, and the extrapolated data for each plot is summarized in the "Biomass and Volumes" fields in the respective row for that plot. The Post-Harvest Report provides this same data excluding trees marked for "Harvest" in the Tree Tab. In other words, this report shows the volume of timber remaining in the woods following a timber harvest. If no trees are identified as "Harvest" trees in the Tree Tab, the Pre- and Post-Harvest Reports will be identical. Biomass volumes in these reports include the defective trees, whereas timber volume (MBF) excludes the defective percent of the tree.

The following metrics are included in each Report:

Live Tree Metrics

1. TPA: trees per acre
2. Avg. DBH: average diameter at breast height
3. QMD: quadratic mean diameter
4. BA: basal area (in feet squared at DBH per acre)
5. HDR: height to diameter ratio
6. SDI: stand density index
7. Curtis RD: Curtis relative density

Live Biomass and Volume

1. Gross Biomass Tons / Acre: total tons of biomass per acre, including both live and dead trees, merchantable and non-merchantable.
2. Merch and Non-merch Stem, Branch and Bark Biomass Tons / Acre: tons of biomass per acre solely within the stem (trunk), branches, or bark of the merchantable or non-merchantable trees. Non-merchantable trees are defined within the calculator by assigning a DBH threshold and/or identifying specific tree species in the Merchantability Tab.
3. Total Merch Biomass Tons / Acre: total merchantable tons of biomass per acre, including stem, branches, and bark.
4. Net Merch Volume / Acre (MBF): total volume per acre, in thousand board feet, for the merchantable logs. This volume only includes the stem for trees within the designated merchantability DBH range on the Merchantability tab. This net value also subtracts defect.
5. Non-Merch Volume / Acre (MBF): total volume per acre, in thousand board feet, for the non-merchantable logs. The non-merch volume is a measure of the total gross volume minus the net merchantable volume of the stems only, including defect.

Snag Biomass and Volume

1. Snags / Acre: number of snags per acre, or all the trees marked as “Dead” in the Tree Tab.
2. Snag QMD: quadratic mean diameter of the snags
3. Snag BA: basal area of the snags
4. Snag Biomass Tons / Acre: total tons of biomass of snags including stems, branches and bark.
5. Snag Net Merch Volume MBF: total volume of snags in thousand board feet including stems, bark and branches.

Stand Report

This report averages all the plots in a stand to present inventory data at the stand level. You can only calculate this information for one stand at a time. You can choose to combine all plots within a stand or look at each individual plot. To use the Stand Table, enter the Stand # you want to analyze, then enter either the plot #, or enter "ALL" to combine all the plots within the stand.

The metrics are the same as the Plot Reports. If there is only one plot per stand, the data will be the same in the Stand Report and the Plot Report. The Pre-Harvest averages appear at the top, scroll down for Post-Harvest averages.

This report shows the post-harvest data for retained trees and summarizes gross biomass and net merchantable timber volume (MBF).

Species Report

This report summarizes data for each individual tree species at the stand level by averaging all of the plots within a stand. Only trees per acre (TPA) and basal area (BA) are summarized for each tree species. The tree species are identified using the two-letter code on page 16.

Volume Report

The Volume Report summarizes timber volume data in both thousand board feet (MBF) and tons for only the trees defined as merchantable within the stand. The MBF tables summarize volumes of the stems only, *excluding* bark and branches, whereas the Tons tables summarize total volume, *including* stems, bark and branches. The report summarizes data for each individual tree species by averaging all the plots within a stand. This report shows that volume that is retained standing and summarizes gross biomass and net merchantable timber volume (MBF).

Stand Table

The Stand Table shows the number of trees by species and diameter range in a stand, as well as the tons of biomass and the volume of board feet also by species and diameter range. Although this tool can only be used to calculate data for one stand at a time, you can analyze the data from all of the plots within the stand, or by individual plot. The biomass and board foot volumes presented in the charts are for the gross volume in the stand *minus* the trees identified for harvest in the Tree Tab. Therefore, if you want to analyze total stand volumes, you should not identify any trees for harvest in the Tree Tab.

Next Steps

What now? It's up to you! Adjust the figures in the "Harvest" columns to see how different harvest scenarios impact the Post-Harvest Report. Use the "merchantable" and "non-merchantable" outputs to start planning what to do with thinned biomass, from timber sales to biochar manufacturing. Be sure to check out [Appendix 3](#) for how you can use the Woody Biomass Calculator to answer common questions like "Is my forest overstocked?"

Now that you know how much woody biomass is in your forest, you can use the information to inform your management decisions, consider practices to help reach your goals, and get a sense of reasonable outcomes for your land.

Remember, the methods presented here will not necessarily produce statistically-significant results, and therefore should not be used for formal appraisals of timber volumes and values. If you need a more accurate, statistically significant forest inventory please use the following resources or contact your forester for an official timber cruise:

- NNRG's Forest Inventory & Monitoring Guidelines: <http://www.nnrg.org/wp-content/uploads/2015/02/NCF-Inventory-Monitoring-Guidelines.pdf>
- WSU Forestry Extension's: Basic Forest Inventory Techniques for Family Forest Owners: <http://cru.cahe.wsu.edu/CEPublications/PNW630/PNW630.pdf>

Happy plotting!



APPENDIX 1 – Plot Data Card

[illegible]

APPENDIX 2 – Glossary

Forest Stand

Refers to sub-portion of a forest that is homogenous in age, structure, species composition and/or management goals. Your property may be all one stand or may have several different stands.

Basal area

Basal area (BA) is the cross-sectional area of a tree 4.5 feet above ground. The basal area of all trees in a given area describes the density of the forest, or the degree to which an area is occupied by trees. Basal area is generally expressed in square feet per acre (ft²/acre).

Diameter at breast height

Diameter at breast height (DBH) is the measurement of tree diameter 4.5' from the ground. On slopes, the diameter is measured from the uphill side of the tree. For more information on how to measure DBH: <https://www.climate-policy-watcher.org/carbon-stocks/aboveground-biomass-of-trees.html>

Height to diameter ratio

Height to diameter ratio (HDR) refers to the ratio between a tree's total height and its DBH. To determine this ratio, divide the tree's height by the tree's diameter (converted from inches to feet). This ratio is used to determine how vulnerable a tree is to bending, storm breakage, or other related defect. A general rule of thumb is that if the height to diameter ratio exceeds 80, the tree is highly susceptible to damage.

Live crown ratio

Live crown ratio (LCR) is the percent of a tree's total height that still retains live, green branches. For instance, in a very dense, young Douglas-fir stand, LCRs could average less than 30% of total tree height. The live crown ratio of a tree is a tree health metric and has no bearing on the amount of wood volume currently in the tree, and is therefore an optional measurement for calculating woody biomass.

Quadratic mean diameter

Quadratic mean diameter (QMD) is the measure of average tree diameter related to basal area, which is more accurate than arithmetic mean diameter.

Relative density

Relative density (RD) or Curtis relative density is a quantification of the current density of a forest stand (e.g., basal area or stand density index) in comparison to some maximum level.

Stand density index

Stand density index (SDI) has been proposed as a technique for estimating the RD of forests at large scales where uneven-aged and mixed species stands are typical. SDI is a stand density assessment tool based on the size-density relationships observed in fully stocked pure or nearly pure stands. A stand's maximum SDI is defined as the maximum density (trees per hectare) that can exist for a given mean tree size (25 cm) in a self-thinning population.

Thousand board feet

A thousand board feet (MBF) is the standard unit of measure for the volume of timber either standing in the forest or as saleable logs.

Trees per acre (TPA)

Trees per acre (TPA) is the measure of the number of individual trees, growing or dead, on an acre of land. For calculating timber volume, this number typically only reflects tree >5.9" DBH.

APPENDIX 3 – From Data Analysis to Forest Management: Common Questions

If you're not familiar with the various forest inventory metrics generated by the calculator, then the results may seem rather abstract. It may be difficult to translate them to what you're seeing in your woods, let alone to make management decisions based on them. Listed below are a series of questions you can ask yourself about the trees in your forest, with guidance for using the Woody Biomass Calculator to help answer them.

Is my forest overstocked?

The appropriate stocking density of your forest depends on many factors, including tree species, tree age, tree size, soil type, and management objectives. Given that every site and landowner are unique, optimal stocking densities will vary. Seek the opinion of a professional forester before making significant management decisions to ensure that your objectives are aligned with the natural potential of the forest.

The following chart has been extrapolated from the Natural Resources Conservation Service program in Washington's *Technical Note 10: Forest Stand Density Guide*. This chart details the optimal distance between trees and total trees per acre for the most common trees west of the Cascade Mountains, based on the tree's DBH.

Shade Tolerance Class	Species	Reforestation Density	Young Stand Density (2-9" DBH) Thin to:	Older Stand Density ($\geq 10"$ DBH) Thin To:
Very Shade Tolerant	Subalpine fir Pacific silver fir Western red cedar	9' x 9' or 538 TPA	9' – 11' or 360-538 TPA	D + 3 (see below)
Shade Tolerant	Western hemlock Sitka spruce Grand fir	10' x 10' or 436 TPA	10' – 12' or 302-436 TPA	D + 4 (see below)
Moderately Shade Tolerant	Douglas-fir (Coastal)	11' x 11' or 360 TPA	11' – 13' or 258-360 TPA	D + 5 (see below)

Moderately Shade Intolerant	Ponderosa pine Western white pine	12' x 12' or 302 TPA	12' – 14' or 222-302 TPA	D + 6 (see below)
Shade Intolerant	Red alder Western larch Lodgepole pine Black Cottonwood	13' x 13' or 258 TPA	13' – 15' or 194-258 TPA	D + 7 (see below)

Using the Woody Biomass Calculator

1. In the Stands Report in the Woody Biomass Calculator, look up the TPA for a particular stand.
2. If the stand is young (DBH <9"), you can compare the stocking density to the chart above. If the stocking density exceeds the range in the chart, then your stand may be overstocked, and you should consider thinning it to within the range listed in the chart.
3. If the stand is older (DBH >10"), then use the D+ formula, where D = the average DBH in the stand, and the corresponding number of inches in the chart are added to determine the optimal average spacing in feet. For instance, if the average diameter of a Douglas-fir stand is 11", then 11+3 = an average spacing of 14' between trees.
4. **NOTE:** When thinning a stand, it is important to not adhere to a strict spacing between trees. Instead, favor the most dominant and highest quality trees for retention, and thin out other trees to achieve the *average* spacing over the entire stand. The chart below shows what average distance between trees means in TPA.
5. You can further analyze stand composition by using the Stand Table and reviewing how many trees are in each diameter class. If the age of your stand is higher (>40 years), and the stocking density of your forest is either within or exceeds the Young Stand Density range in the Stand Density Table above, and the majority of the trees are in the 5-10 inch diameter class – your stand is overstocked.

Distance between trees	~TPA
13'	260
14'	220
15'	200
16'	170
17'	150
18'	130
19'	120
20'	110
21'	100
22'	90
23'	80
24'	70

How can I increase species diversity in my forest?

A forest's species diversity correlates strongly with structural diversity, forest resilience, and overall health. The main opportunities forest landowners have to manage species composition are during stand establishment (i.e. what species and how many trees to plant) and during thinning operations (i.e. what species to retain and how many of each).

Choosing which trees to harvest during any thinning operation has many variables: individual tree vigor, crown health, tree spacing, and tree species, among other factors. You can use the Woody Biomass Calculator to identify species that are underrepresented in the stand, and prioritize these trees for retention. For example, you might have a stand comprised primarily of Douglas-fir trees, with a few red alder, western hemlock or red cedar trees scattered throughout the stand. You may choose to thin very few, or none at all, of these underrepresented species and focus on selecting Douglas-fir for harvest.

Using the Woody Biomass Calculator

1. In the Species Report tab, look up the TPA and BA of the different species for a particular stand. This can give you a general idea of the dominant tree species in the stand, by number of stems.
2. In the Volume Report tab, look up the Volume per acre, by species. This will reveal the dominant tree species by biomass volume. Both numbers are important.
 - a. For example, you may have a main 40-year-old Douglas fir stand that has hundreds of western hemlock saplings in the understory. By simply looking at the TPA in the Species Report, you may decide that western hemlock is dominant. The Volume Report will reveal that Douglas-fir is in fact dominant because of its volume.
3. These reports will help you determine which species are *underrepresented* in the stand, and you can choose to prioritize these species for retention when selecting which trees to harvest, or replanted with underrepresented species following harvest.

How do I determine the volume of non-merchantable timber that I have that can be converted to biochar, firewood or other uses?

What you define as non-merchantable timber will be subjective to your forest, how you choose to thin your stand, and available markets. Non-merchantable timber may include trees below a certain DBH (e.g. <10" DBH), trees with significant defect (e.g. >25%), certain species, etc. You can define non-merchantable timber in the Woody Biomass Calculator using either of the following methods:

Defining non-merchantable trees in the calculator:

1. In the Tree tab, enter percent of defect in Column H for a particular tree.
2. In the Merchantability tab, identify the species that are not merchantable, as well as the DBH threshold below and above which the tree is considered merchantable.

Using the *Pre-Harvest Plot Report*, the Live Biomass and Volume section summarizes the total non-merchantable volume of biomass in stem, branches and bark of the trees. Volume of stems can be converted to cords of firewood using conversions you find online for the tree species. The combined volume of non-merchantable stems, branches and bark can give you a starting point for how much green biomass you have that can be converted to biochar or other uses.

Selecting non-merchantable trees for harvest in the calculator:

1. In the Tree tab, using Column H, mark Y for any tree you intend to harvest for means other than selling logs.
2. In the Merchantability tab, identify the species that are not merchantable, as well as the DBH threshold below and above which the tree is considered merchantable.

Using the Stand Report, compare the various Non-merchantable estimates (Columns Q –T, & X) in the Pre-Harvest Stand section to the same numbers in the Post-Harvest Stand Section. Subtracting Post-Harvest Stand volumes from Pre-Harvest Stand volumes will yield the volume of non-merchantable biomass you plan to harvest.

Can I use the calculator to estimate potential revenue for a harvest?

The Woody Carbon Calculator is not intended for formal or informal timber appraisals. It is intended for woody biomass volume estimates to help guide management decisions. Timber appraisals require a high degree of expertise in merchandising timber, harvest operations, and local log markets, along with a statistically valid analysis of the timber cruise.

If you wish to develop a timber sale appraisal, reach out to your forester for more information.



NNRG's mission is to strengthen the ecological and economic vitality of Northwest forests and communities by connecting landowners with the knowledge, skills, and markets they need to steward their forests.

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