Monitoring Assisted Migration Plantings in the Pacific Northwest

A Manual for Landowners and Practitioners

Produced by Oxbow Farm & Conservation Center and the Forest Adaptation Network

Contents

I. Introduction

Summary

Many restoration and reforestation practitioners are experimenting with non-local species and seed sources (a practice called *Assisted Migration,* or *AM*) with the goal of establishing climate-resilient plant materials in their target systems. Sharing and aggregating monitoring data from these experimental plantings could help researchers and practitioners to evaluate the success of this climate adaptation approach, but a shared set of methods and metrics is needed to meaningfully compare data from many plantings across the region.

We suggest these considerations and measurements when planting assisted migration plant materials:

1) **Plan and Design**
   a. **Evaluate**: Consult the Forest Adaptation Network's publication "Assisted Migration Best Management Practices for Pacific Northwest Habitat Restoration Projects" to see if assisted migration is a good option for you and to help you consider what species or seed sources might be appropriate. Consider using the Seedlot Selection Tool to help select appropriate materials for population assisted migration.
   b. **Control**: If possible, design plantings so that assisted migration plant materials grow alongside local-source "control" plantings. Local seed source Douglas fir can serve as a good native comparison for upland forest AM species such as incense cedar or chinkapin. For assisted population migration (i.e. movement of seed sources of a native species), seedlings from a local seed source should be the comparison (e.g. local seed-source western redcedar could be planted side by side with a more southern seed source of western redcedar).
   c. **Replicate**: If possible, plant several of each AM seed source or AM species (and the same number of local controls).
   d. **Randomize:** Vary the locations of individuals (or groups) of each seed source/species in your plantings to avoid biased results.
2) **Record site and layout information**
   a. **Tag**: Assign a unique ID to each plant and create a "key" document that can be used to decode species and seed source.
   b. **Monument**: Install durable field markers bearing these IDs (e.g. by using pre-printed aluminum tags wired to rebar markers).
   c. **Map**: Produce detailed maps of planting arrangements that will allow you or others to re-locate and accurately identify each plant years into the future.
   d. **Annotate**: Record other pertinent site information (Site name, project purpose, site history, soil type, etc. - See Appendix 2).
3) **Gather growth and health data**
   a. **Schedule monitoring**: Plan to monitor most frequently for the first few years after you install AM plant materials, as seedlings are most likely to fail in these years. We recommend monitoring in August of years 1, 2, 3, and 5, and every 5 years after that.
   b. **Gather data**: Gather at least the most basic plant growth and health data.

i. **Vigor:** Record whether the plant is thriving, healthy, stressed, or dead (see Section II).
ii. **Height:** Using a survey rod (for trees <2m) or a clinometer app (for trees > 2m), to measure vertical tree height (see Section III).
iii. **Diameter:** Using a diameter tape, measure the girth of the tree at breast height (1.3m) (see Section IV).
iv. **Health notes**: Note all indicators of tree stress or death.

Assisted Migration

In response to hotter, drier summers and warmer winters in the Pacific Northwest, some land managers are diversifying their tree plantings by including species or seed sources adapted to somewhat warmer areas to the south or downslope of the planting area. This is a form of **assisted migration (abbreviated AM)**, which can be broadly defined as "the human-assisted movement of species in response to climate change" (Ste-Marie et al. 2011). The practice of assisted migration in forestry and restoration is still young and is still a topic of vigorous debate among ecologists. There is a growing body of research and practice indicating that, if done thoughtfully, assisted migration may be part of a suite of management actions that help forests and ecosystems become more resilient to the changing climate.

The term "Assisted Migration" refers to movements of plant materials that range in magnitude and potential ecological impact. Movement of propagules (or the reproductive materials for plants, including seeds and sprouts) far beyond the borders of a species' current range (often with the intent to relocate or save a failing population) is known as "**Assisted Species Migration**," or "**Conservation Assisted Migration.**" In comparison, the movement of propagules of a species just beyond the edge of its current range is called "**Assisted Range Expansion**," which aims to mimic and accelerate natural expansion processes. "**Assisted Population Migration**" is the most subtle kind of assisted migration, in which plant materials are moved between populations within the current range of a given species. The theoretical basis for **assisted population migration** posits that plant populations often adapt to local environmental conditions (weather patterns, moisture availability, summer heat, etc.), and that in a rapidly changing climate, populations in one section of a species' range may be pre-adapted to a larger area within that range in under future projected climate conditions. Moving propagules from these pre-adapted populations (often northward, or upslope) could improve average species health and survivorship of trees in the receiving population, particularly as new climatic shifts further reflect the originating climate.

There remains multiple risks associated with moving seeds and (especially) seedlings, including the introduction of forest diseases from other regions, introduction of invasive plant species or varieties, and failure of plantings due to poor match between plant material and local conditions. Most forestry experts warn against moving tree species long distances from dissimilar biomes and many prefer **assisted population migration** for this reason. To avoid maladaptation of planted seedlings, seed transfer zones were established across the Pacific Northwest in the 1950s and 1960s. These original zones served as guidelines for PNW tree species. During the 21st century, seed transfer zones were updated to reflect new, species-specific zones. Because species-specific seed zones remain uncommon, researchers developed provisional seed zones based on ecoregional divisions and plant hardiness zones (Bower et al.

2010). Others have suggested that transfer limits, or the magnitude of climatic difference between the seed source and planting locations, may be the most important consideration for seed movement.

Due to the complexity of seed movement and locality, it is difficult to know the single 'best' way to record seed source. Fortunately, the US Forest Service and Oregon State University have designed the Seedlot Selection Tool (https://seedlotselectiontool.org/sst/) to help project managers find seeds adapted for future projected climates at a given planting site. It is also an excellent way to find seed zone information by site location. A user guide is available on the tool website to assist new users.

Before you consider assisted migration plantings, we encourage you to consult your local extension forester and/or some of these resources:

- A Practical Framework for Applied Forestry Assisted Migration: An excellent introduction to Forestry Assisted Migration, including an overview of project planning, species and seed source choices, and risk analysis by Bower et al. 2024.
- To help decide if assisted migration is a good choice for your project, consult: Assisted Migration Best Management Practices (Forest Adaptation Network).
- To assess various other options to improve project resilience beyond assisted migration, see Northwest Natural Resources Group's white paper, "Climate Adaptation Strategies".

Seed Zone and Seed Transfer Resources

- Seedlot Selection Tool (US Forest Service, Oregon State University, the Bureau of Land Management, and the Conservation Biology Institute)
- Washington Tree Seed Transfer Zones (Randall and Berrang 2002)
- Forest Tree Seed Zones for Western Oregon (Randall 1996)

The Purpose of this Manual

For AM to become a successful strategy, it will be necessary to keep track of how well plantings of various species and genetic types succeed in our region, share observations among a community of stewards and managers, and adapt our approach based on our collective observations. This manual has been produced to help landowners, community scientists, foresters, and restoration practitioners to:

1) Monitor the establishment and health of assisted migration plantings and locally adapted "control" plantings in a simple, consistent, and repeatable manner that will facilitate assessing long-term success.
2) Share the resulting monitoring data through the **Forest Adaptation Network**, a group of land managers and restoration practitioners with a mission to help our forests adapt to the expected impacts of climate change.

Our collective tree health data are of the greatest value if we share them as a community and are able to analyze and evaluate those shared data. For that reason, we encourage you to share your data with the Forest Adaptation Network each year.

To share your data with the Forest Adaptation Network, please select one of the following options:

1) **Printed Version**: Please find and complete the printable datasheet templates at the end of this manual. The first sheet contains project-level information from before you begin monitoring, to

be completed once. The second sheet catalogs individual plant data for each year that monitoring data is collected. Scans or clear photos of these datasheets can be emailed to: outreach@nnrg.org.

2) **Digital Version**: If you would like to enter and share data digitally, please email outreach@nnrg.org to receive a link to an online datasheet.

In the near future, we hope that data will be shared through an open-source online portal which will allow community members to easily access anonymized regional planting success data. Likewise, we hope this portal will provide new insights regarding the success and trends of various plant species and seed sources over time.

Designing and Installing a Monitoring Trial

Recording project information

Monitoring tree survival is a long-term process. To be successful, it is important to record project and site information so that you (and others) will still be able to accurately interpret the planting plan and project many years in the future.

To ensure accurate monitoring, we recommend recording: a short narrative description of the project (purpose, land use and history, timeframe), site geographic coordinates, project area, plant species and provenance, number of plants installed, year of installation, plant care regimes (watering, herbicide, herbivory deterrent infrastructure), the name of the organization conducting the trial, and the contact information of project owners. More detail is provided on how to record these important elements of project information in “Appendix 2: Tips and definitions for filling out datasheets.”

Spatial arrangement and experimental design of plantings

The plant materials you install and their arrangement each influence the potential information quality garnered from monitoring projects. Here are a few aspects of the planting plan you should consider:

Experimental Controls:

- **Planting non-local species or seed sources alongside local equivalents** allows for direct comparison of their success under the conditions of your planting site.
    - If you are trialing non-local upland trees species in the Pacific Northwest, especially with the intent to introduce more drought- or heath-tolerant tree species in the Puget Sound area, local seed sources of Douglas fir are suggested as a good “control”, because Douglas fir is widely distributed, commonly planted, relatively drought tolerant, and well-studied.
    - If you are planting a plant that requires very different conditions than Douglas-fir (for example, deep shade or wet soils), it is recommended that you choose an ecologically-similar species that is locally-native as a control planting.
    - If you want to test the success of non-local seed sources of locally-native tree species, consider planting locally seed sources of this species as a control. (e.g. If you are planting bigleaf maple seedlings from southwestern Oregon in the Puget Sound area, it would be informative to plant local Puget Sound seed sources of bigleaf maple as a control).

- **Replication** allows you to estimate variability among seedlings of a given type, which in turn allows you to use statistical tests to look for meaningful differences between groups (Kuehl 2000).
    - o The fundamental experimental unit from which you will collect data is often referred to as a plot. This can be a single tree or a group (often a row) of the same type of tree. In the latter case, data is often averaged across the several trees of the plot.
    - o Planting and monitoring more than one plot of each seed source or species is called replication, an element of experimental design that allows you to differentiate between the "noise" of individual variability and meaningful "signals," such as the average difference between growth rates of two different species. The number of replicates needed to find meaningful differences between types depends on how subtle the differences are between the species or seed sources you are testing. If the difference is likely to be small, you will need many replicates to find a significant difference.
- **Randomization** reduces bias from spatially clustered (autocorrelated) environmental variation.
    - o Randomizing the location of different "treatments" (in this case, species or seed sources) within a planting area is crucial to avoid bias from environmental gradients or patchy environmental conditions (Figure 1).
    - o Complete randomization of the locations of trees within a planting area is statistically simple, but can sometimes make record-keeping, re-location of individuals, and recording data complex, one of the reasons experimentalists use block designs (see below).

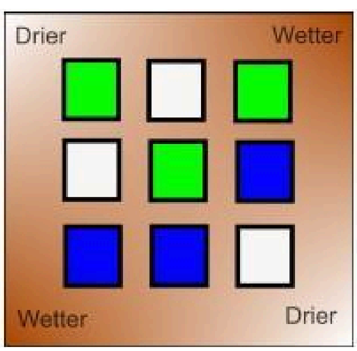


Figure 1 (left): Schematic of a small, replicated and randomized planting trial where colored squares represent treatments (for an AM trial, usually different species or seed sources) and where treatments have been randomly assigned to locations on a planting grid. Randomization helps to reduce bias from (often invisible) sources of variability, like soil homogeneity, illustrated here with varying background colors.

- **Blocking** can help avoid bias that stems from environmental variability (Kuehl 2000).
    - o Grouping your plantings into several blocks, each of which contains a single instance of each treatment (e.g. each species or seed source), is a way of reducing noise and bias from environmental gradients. For example, if you are planting on a sloping field with wetter, lower areas and drier, higher areas, you could create low, medium, and high elevation blocks where each species experiences similar moisture conditions within each block (Figure 2). The blocks ensure that no species is disproportionately affected by wet or dry conditions and allows you to remove the influence of moisture statistically. At its simplest, a blocked planting trial could contain a local and non-local seed source of a given species planted in a lower, wetter area, and the same pair of seed sources planted in a higher, drier area.

- Blocks can also make plantings more tractable and organized for mapping and record keeping.

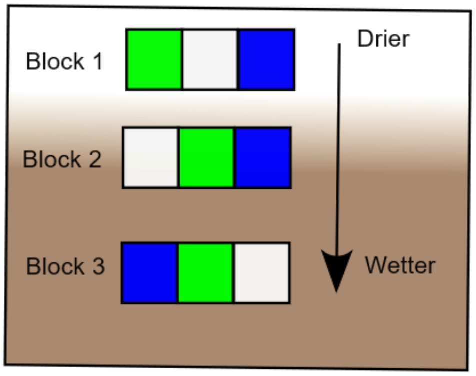


Figure 2 (left): Schematic of a small, randomized and blocked trial, with color squares representing different treatments (for an AM trial, usually different species or seed sources). Each treatment occurs in every block and is randomly assigned a location within the block. Though the environment varies across the experimental area, blocks are arranged so that conditions within each block are relatively homogeneous, allowing for statistical reduction of error from this source of variability.

Spacing

Planning for sufficient space between trees to avoid strong competition between trees for at least 10 years will ensure that growth and health data are more comparable to other trials. We recommend 10-15' spacing for large or fast-growing tree species.

Sightlines

If possible, consider planting trees with sufficient space around them to allow visual sighting to their tops once they have grown too tall to measure by hand. This may not be feasible if dense tree canopy is desired in the planting area, or if existing vegetation closely surrounds the planting area. Keeping mowed sight lines to tree bases can facilitate sighting to bottoms as well as tops of trees for height estimation.

Marking and creating spatial reference data for trees

Accurate relocation and identification of monitored trees is critical to any monitoring effort. This can be surprisingly difficult over long time-horizons, during which landmarks can change, trees grow and/or die, land ownership changes, and landowners, monitoring staff, or volunteers leave, taking their institutional knowledge with them.

Here are recommendations for identifying, recording data on, marking, and relocating trees:

1. **Create a clear, concise system and key for assigning unique ID codes to each seedling.**

   For trials with small numbers of seedlings and simple designs, these could simply be consecutive numbers that correspond with entries in a seedling metadata key document, in which each number is associated with the plant and its associated information (species, seed source, seed zone or location, stock type, nursery that grew seedling to size).

   For more complex trials with numerous species and blocks, these elements of the treatment and design could be coded with an alphanumeric code that captures these aspects of the treatment (including species or seed zone), block number, and a site abbreviation. Additional details should be included in a metadata key.

Table 1 (below): example of an experimental layout key, with 3 taxa, 3 blocks, and alphanumeric ID codes that provide information on these three characteristics of each tree.

Block 1									
Douglas fir (SW WA)	DFS-1-1	DFS-1-2	DFS-1-3	DFS-1-4	DFS-1-5	DFS-1-6	DFS-1-7	DFS-1-8	DFS-1-9
Douglas fir (Puget)	DFP-1-1	DFP-1-2	DFP-1-3	DFP-1-4	DFP-1-5	DFP-1-6	DFP-1-7	DFP-1-8	DFP-1-9
Grand fir	GF-1-1	GF-1-2	GF-1-3	GF-1-4	GF-1-5	GF-1-6	GF-1-7	GF-1-8	GF-1-9
Ponderosa Pine	PP-1-1	PP-1-2	PP-1-3	PP-1-4	PP-1-5	PP-1-6	PP-1-7	PP-1-8	PP-1-9
Block 2									
Ponderosa Pine	PP-2-1	PP-2-2	PP-2-3	PP-2-4	PP-2-5	PP-2-6	PP-2-7	PP-2-8	PP-2-9
Douglas fir (Puget)	DFP-2-1	DFP-2-2	DFP-2-3	DFP-2-4	DFP-2-5	DFP-2-6	DFP-2-7	DFP-2-8	DFP-2-9
Grand fir	GF-2-1	GF-2-2	GF-2-3	GF-2-4	GF-2-5	GF-2-6	GF-2-7	GF-2-8	GF-2-9
Douglas fir (SW WA)	DFS-2-1	DFS-2-2	DFS-2-3	DFS-2-4	DFS-2-5	DFS-2-6	DFS-2-7	DFS-2-8	DFS-2-9
Block 3									
Grand fir	GF-3-1	GF-3-2	GF-3-3	GF-3-4	GF-3-5	GF-3-6	GF-3-7	GF-3-8	GF-3-9
Ponderosa Pine	PP-3-1	PP-3-2	PP-3-3	PP-3-4	PP-3-5	PP-3-6	PP-3-7	PP-3-8	PP-3-9
Douglas fir (SW WA)	DFS-3-1	DFS-3-2	DFS-3-3	DFS-3-4	DFS-3-5	DFS-3-6	DFS-3-7	DFS-3-8	DFS-3-9
Douglas fir (Puget)	DFP-3-1	DFP-3-2	DFP-3-3	DFP-3-4	DFP-3-5	DFP-3-6	DFP-3-7	DFP-3-8	DFP-3-9
Explanation of individual ID: GF-2-1 signifies Grand fir, block 2, replicate 1									

2. **Install durable tags on or adjacent to each tree (or replicate) to allow field re-location and identification.**

   For a small number of trees, we recommend installing rebar rods or t-posts (4-7’ long, installed with 3-5’ protruding above ground) offset 5-8 feet (1.5-2.5 meters) from each tree in a pre-determined, consistent direction (See figure 2a,b). Rebar markers should be topped with safety caps. We recommend pre-printed stiff aluminum tags (not thin, hand-embossable aluminum label strips) wired to these stakes with corrosion-resistant wire. In our experience, labels attached to lower branches fall off over time (often when the branches are shed), wooden stakes rot and inscribed numbers become unreadable, thin, embossable aluminum tags tear and are destroyed by wildlife, and permanent marker lettering wears off of plastic tags (See figure 2c).

   For a large number of trees in rows or blocks, we recommend marking row and column ends or corners of blocks or replicates with steel t-posts or rebar rods affixed with permanent durable labels (as above). With durable markers at column ends or block corners and with clearly drawn maps of plot arrangements available, individual trees or plots can be labeled with cheaper, slightly less durable markers (such as pin flags or wire tags with plastic plant labels) without fear of irretrievable loss of location information.

Figure 2a (below): a durable, capped rebar marker wired to a pre-printed thick aluminum number tag will last well over a decade.

Figure 2b (below): A "t-post" can also be a durable, relatively inexpensive marker, and paired with plastic or (better) thick aluminum tag, can last many years.

Figure 2c (below): Plastic plant tags marked with ink will fade over the course of several years and need to be replaced, though embossment during labeling will increase longevity. Connection to degradable plant tubes or stakes can lead to loss of tags.

3. Create both digital and hard copy maps of plantings.

Maps should ideally include both a <u>locator map</u> meant to show the site location within the larger landscape and <u>an experimental design map</u> showing positions of blocks, replicates, and individual treatment plots, as applicable. Err on the side of excessive detail, redundant labeling, and retaining metadata in multiple formats, as information can be lost and field labels damaged over time. These maps should include these elements:

a. A title box with these pieces of information
   i. Project name
   ii. Very brief location description (at least city and state)
   iii. Date planted
   iv. Number of replicates, plots, and trees
b. Legend of treatment symbols/codes
c. Scale bar
d. North arrow
e. Labeled landmarks that could help to relocate project site and plots (buildings, streets, streams and rivers, large trees or rock outcroppings)

Note that GPS coordinates for trees can help with re-location depending on the accuracy of the GPS equipment and the spacing of trees.

For urban tree monitoring, where the build environment provides useful landmarks and a framework for spatial organization, block numbers and distances can be used to re-locate trees (see Table 3 in Van Doorn et al. 2020).

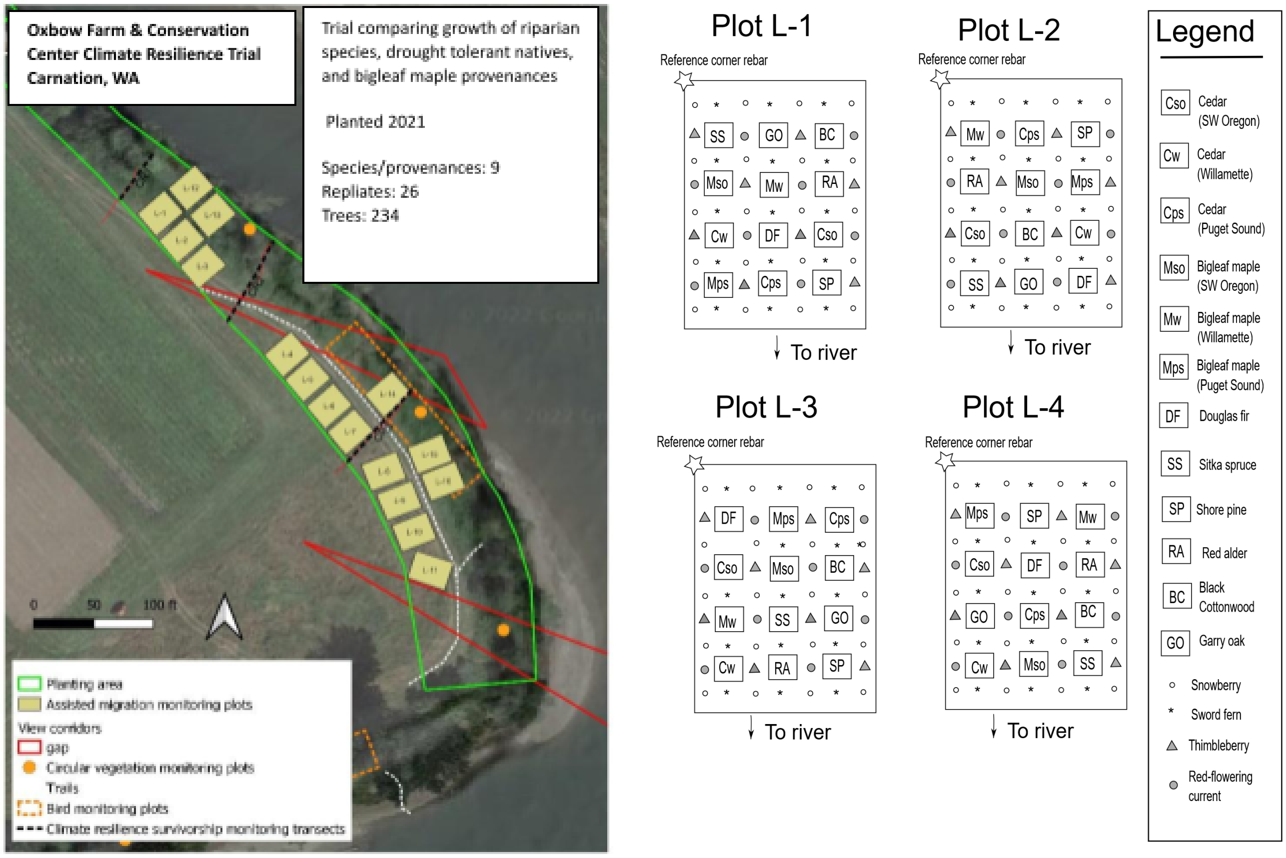


Figure 3 (above): Example of a project map and plot schema from Oxbow Farm & Conservation Center Climate Resilience Project.

4. **Create data sheets with metadata on each experimental unit**.

   Data sheets should capture these pieces of information (see example datasheets, Appendix 2):

   a. For small plantings (1-20 trees) with sufficient spacing, collection of GPS coordinates for each tree ID is recommended, if not too onerous.
   b. For larger (or more tightly-spaced plants, where spatial error is too great for GPS coordinates to be helpful), collection of GPS coordinates for block centers or a site centroid is recommended. In these cases, detailed planting maps/diagrams, paired with durable tree labels, are the primary means for keeping track of plant locations over the long-term.

Monitoring Tree Health and Growth

How often should I monitor?

The duration and frequency of monitoring must, of course, serve the particular objectives of the monitoring project. In the interest of aligning monitoring data in the region, however, we offer several recommendations. We recommend gathering baseline or "as-built" data on seedling size and health just after planting. This allows for meaningful growth data in the first year and can help control for differences in initial size of planted stock. Then, because seedlings are most vulnerable in their first 5 years (Franklin et al. 1987, Preece et al. 2023), we recommend measuring annually toward the end of the first, second, third, and fifth growing season after planting. After year 5, the timestep may be lengthened to every 5 years. For a suggested schedule, see Table 2.

Table 2 (below): Suggested monitoring schedule for first 10 years after planting. Note that Year 1 refers to the year that the plant experiences its first growing season in the planting location (so planting could occur in the fall of "Year 0" or late winter of "Year 1."

Action:	Tree(s) planted	Monitoring event 1 (baseline)	Monitoring event 2	Monitoring event 3	Monitoring event 4	Monitoring event 5	Monitoring event 6
Schedule	February* Year 1	February, Year 1	August, Year 1	August, Year 2	August, Year 3	August, Year 5	August, Year 10

**Suitable planting times could vary. Trees are best planted in the Pacific Northwest during the rainy season, from November ("Year 0", in this schema) to February or March ("Year 1").*

After initial baseline monitoring, we recommend all other monitoring be done near the end of the growing season (mid to late August), after most of the season's growth has been added on, but before the tree begins to senesce for the fall. Leaf color changes and loss of leaves later in the summer and fall could bias evaluation of plant health and vigor.

What should I measure?

The measurements and observations we recommend are quite simple, and fall into these categories:

1) **Vigor:** a visually estimated 4-category indicator of the general health of the tree.
2) **Height***:* a measurement of the vertical height of the tree above the ground.
3) **Diameter**: a measurement of the thickness of the tree's main stem at 1.39 m above the ground.
4) **Health notes**: notations on any of several possible symptoms of disease, injury, or poor growth.

These measurements are explained in detail in Sections II, III, IV, and V.

Measurement units

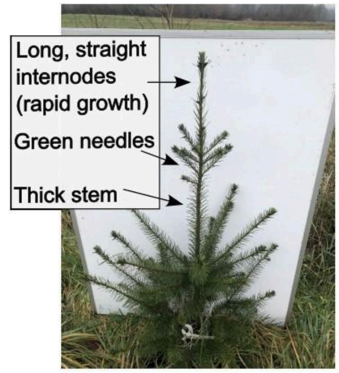
Though it may seem obvious, it is critical to specify whether U.S. customary units (inches, feet, yards) or metric units (centimeters, meters) are used when taking measurements. We recommend metric units in this guide and in the datasheet templates attached.

It is similarly important to be clear if circumference data (rather than diameter) is presented for girth measurements. In this guide, we recommend calculation of diameter by dividing circumference by π (3.1416).

II. Vigor

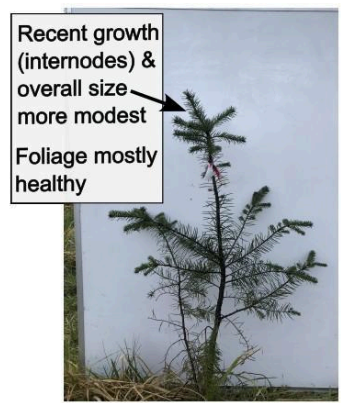
Vigor is a qualitative description of the overall health of the plant. We recommend a simple 4-tier scale based on careful observation of the plant during the main growing season (June-August). Choose a vigor score (thriving, healthy, stressed, or dead) for each tree you monitor based on this chart:

THRIVING



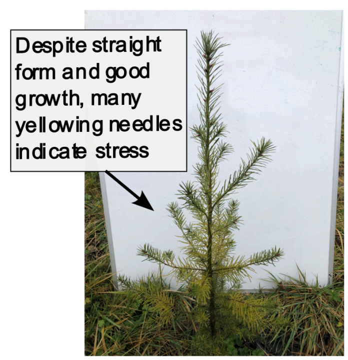
- Leaves or needles vibrant or deep green
- Little to no yellowing, browning, or wilting of leaves or needles
- Signs of rapid growth:
    - o Thick, straight stems
    - o Long internodes (distance between buds/branching stems)
    - o Buds, if visible, large and plump
- No substantial insect damage or disease
- If resprouting from past damage, new growth rapid and robust

HEALTHY



- Leaves or needles mostly green
- Little or modest yellowing, browning, or wilting of leaves or needles
- Signs of moderate growth:
    - o At least moderate size
    - o Relatively straight stems
    - o Growing tips not excessively stunted, but internodes short
    - o Only modest signs of insect damage or disease
    - o If resprouting or recovering from past damage, new growth is healthy and suggests eventual recovery of size and structure

STRESSED



- Majority of leaves or needles yellowing or large proportion turning brown
- Canopy is thin (large proportion of leaves/needles missing)
- Multiple major branches or top of tree has died back without vigorous regrowth
- May have substantial signs of insect damage or disease
- Small in size (in combination with one or more other stressed characteristics, above), or vigor visibly reduced by past damage

DEAD

- Leaves or needles brown, withered, and dry, or have fallen from tree
- Twigs lack flexibility, snap when bent
- Bark may be peeling from dry twigs or branches
- Lack of green cambium layer below bark if upper bark peeled

III. Height

For trees especially, height growth is an important and easily measured indicator of health and biomass. Vertical growth correlates with successful establishment and resource acquisition, and greater height indicates greater ability to compete for light. For seedling trees (less than 2m, or ~6') height measurement is easily and accurately accomplished by one person with a measuring stick such as a telescoping stadium rod (which are available from online retailers and cost as little as $16 USD). As the seedling becomes a sapling between 6 and 15', two people can accurately read the same telescoping rod. Above 4.6m (15'), an inclinometer or an inclinometer app on a smartphone can be used to measure the tree optically, as described below.

Height Measurement from 0-15' (0-4.6m):

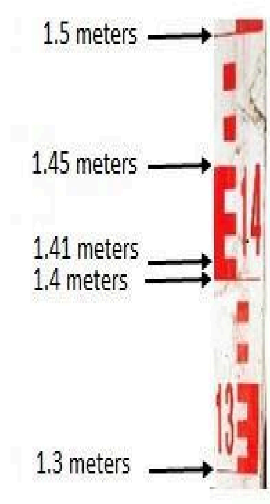
Materials:

Telescoping survey rod (or similar measuring rod)

Protocol:

For trees from 0 to 2 m (0- ~7'), one observer may work alone and get accurate measurements with a survey rod/measuring stick. Standing next to the tree, place the stadium rod directly beside the tree and measure vertically from the ground surface to a point even with the highest part of the tree, regardless of whether the tree itself is vertical. Attempt to measure from consolidated ground surface, not the top of piled mulch, if mulch is used at planting site (Figure 4).

For trees between about 2 and 5 m (approximately 7' and 15'), two people should work together. While one person keeps the rod vertical, have another observer stand approximately 1-2 tree heights away from the tree (often 10-20') and read the point on the stadium rod that is even with the highest part of the tree. (We have found that a single observer at the foot of the tree cannot accurately compare rod and tree heights, especially at tree heights above 10'). Note that survey rods are marked in various ways that may not be familiar to the average user, so some practice is necessary. Rods may be in metric, feet and inches, or feet and tenths. We recommend a metric rod (see Figure 5 for notes on how to read an example rod), but regardless of the scale, make sure you understand how to read your rod before starting.



Figures 5 and 6 (right): Reading metric survey rod markings. On this rod, Thin red lines below a number indicate each tenth-meter, and every other 0.05 meter section is shown in solid red block to facilitate reading. As with most marking systems, each 0.01 meter increment is read at either the top or bottom edge of a tick mark.

Height Measurement for Trees Greater than 15’ (4.6 m)

Materials

- Measuring tape (25-100’ long)
- Smartphone with angle-reading app (two suggestions below)
- Clinometer (optional)

Protocol

Measuring tree heights greater than 4.6 m (15’) is most easily done using optical equipment such as a clinometer, a tool that allows you measure angles based on a line of sight. While a professional clinometer, relaskop, or other surveying equipment provides the most accurate readings, relatively accurate measurements (within a few percent of true height) can be recorded using a smartphone loaded with inexpensive or free software apps. Here we recommend three options that give comparable results:

1) Clinometer app by plaincode™: This simple app can be purchased from the Apple App Store or Google Play for a small fee and does not require the user to create a log-in.
2) NASA GLOBE Observer app: This app is free but requires the user to create a log-in as part of the NASA citizen scientist project. With a log-in, users can contribute various kinds of environmental data to advance NASA’s environmental monitoring efforts. However, the user can also choose not to submit collected data to NASA, as described below (see Option 2: Using NASA GLOBE Observer App to Measure Height).
3) Clinometer device: Using a physical clinometer is the most expensive option, but provides the most accurate measurements. Popular among professional practitioners, Suunto clinometers (or similar) are the preferred choice for projects requiring a high degree of precision and accuracy.

Option 1: Using the Clinometer app to measure height

Once downloaded, the accuracy of the Clinometer app can be improved by simple calibration motions described in the app's info page. In the app's settings menu, a Motion Sensitive Lock can be set which will lock in a reading once the phone position has stabilized for a sufficient length of time. The sensitivity of the locking function can also be set (see Figure 9), to which we recommend relatively high tolerance (~3 degrees) as a hand-held phone otherwise may not stabilize and lock.

Figure 7 (above): The Clinometer app logo

1) Find a spot that you estimate is 1-1.5 times the tree height away from the base of the tree and where you can clearly see both the top and base of the tree. Measure and record the distance from the base of the tree to your location. Placing a bright object (e.g. flagging tape) at the exact base of the tree can be helpful if the base is shaded.
2) Face the tree and open the Clinometer app. Hold the phone with one edge up, so that the clinometer (not bubble level) screen shows. Before using the inclinometer to sight at the tree, touch the "Motion Sensitive Lock" button (near the info button of the bottom bar, circled in red in Fig. 8) so that it turns red. This starts the timer and motion sensor that allows the phone to lock once it has stabilized on a reading.

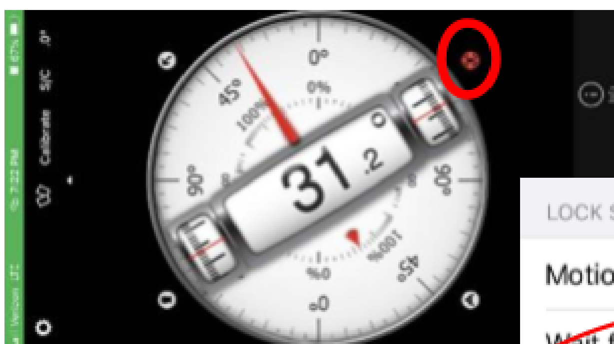
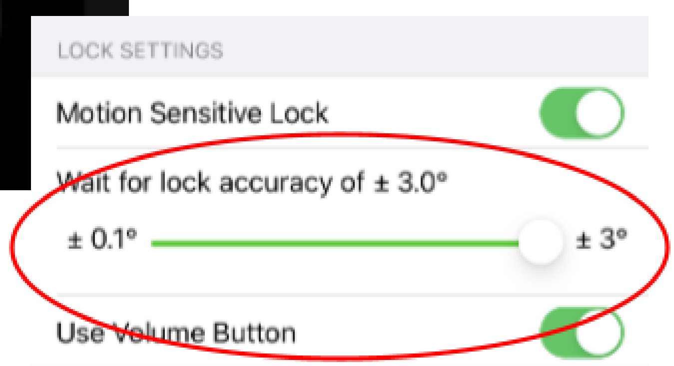


Figure 8 (left): The Clinometer app's sensitivity button circled in in red.

Figure 9 (below): The Clinometer app's Motion Sensitive Lock scale, set to 3 degrees.



3) Quickly bring the phone up to your eye so that you can sight to the top of the tree along the top edge of the phone (Fig. 9). Once you have aligned the edge of the phone with your eye, hold steady a few seconds and the lock function will lock in the reading. Especially as you are first learning the app, recording and averaging several readings is a good practice.
4) Record the reading(s) of the angle to the tree's top.
5) Repeat steps 2-3, but sighting instead at the base of the tree.
6) If the elevation of your eye is above the base of the tree* (which will be most of the time, unless you are on a steep slope below the tree), calculate Height 1 and Height 2 from the equations below, then add them together for total tree height:

Height 1 = tan(angle to top) * distance to tree

Height 2= tan(angle to base)* distance to tree

Height 1 + Height 2 = total tree height

If eye level is below the base height of the tree, subtract height 2 from height 1 for total tree height.

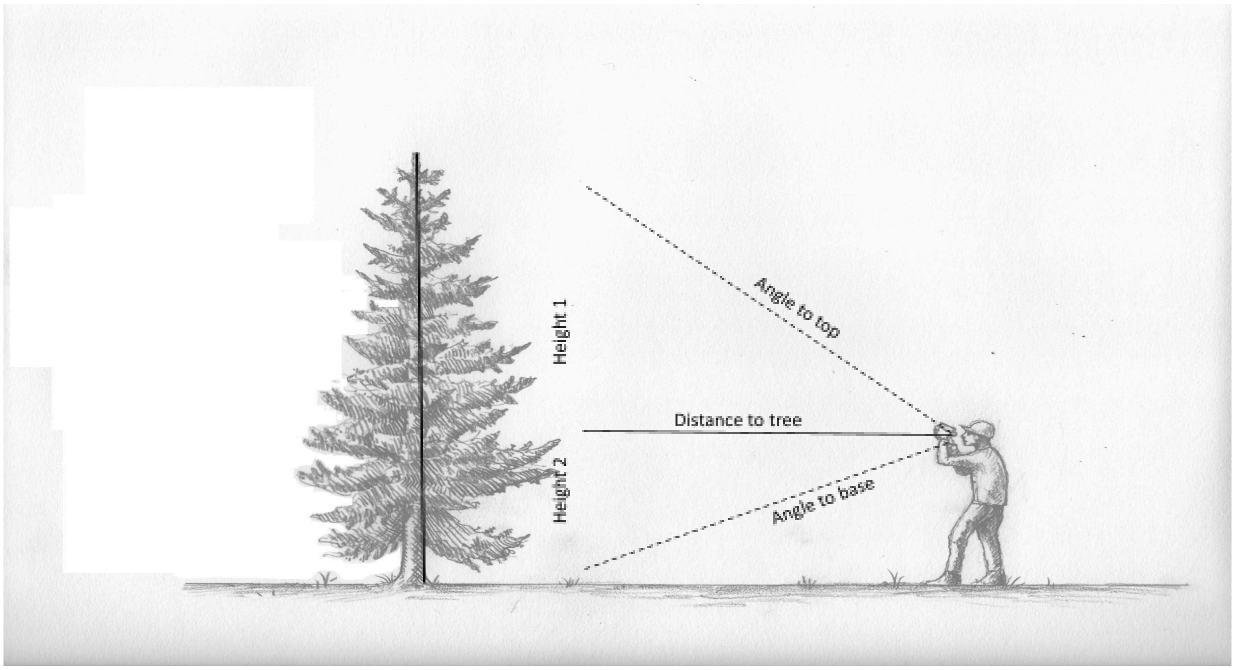


Figure 10 (above): A visual guide to using a clinometer, including how to measure the tree distance top and base angles and distance.

A couple of notes on smart phone calculator use:

- Access your iPhone’s scientific calculator (and tan function) by turning the phone horizontal (landscape-orientation) while in the calculator app.
- Android phones usually have a “scientific calculator” button that allows you to view and use the full suite of functions.
- To calculate the tangent of angles, type in the angle in degrees, then press the “tan” button.

Option 2: Using NASA GLOBE Observer app to measure height

NASA's GLOBE Observer app

1) Turn on location services in the app.
2) Enter your pace length.
3) Open GLOBE Observer app and select Trees protocol.
4) Select New Trees Observation and enter the date and time.
5) Select conditions (if you are not submitting data to the observer, these selections don't matter).
6) Follow the app directions: select your tree to measure, and move to where you can see both its base and top.
7) Holding the phone out at eye level, follow app instructions and tilt the phone down so the dashed line aligns with the tree base.
8) Following app instructions, then tilt the phone up so that the dashed horizontal line aligns with the top of the tree.
9) You may then photograph the tree, or skip this step.
10) Enter your latitude and longitude (or you can enter any numbers if you don't intend to submit data to NASA).
11) Record the calculated tree height provided in the yellow box. At this point, you may either submit these data or close the app without submitting.
12) The app suggests pacing distance to tree, but to be consistent with our protocol, we recommend measuring distance to the tree with a tape measure. Divide this number by the pace length you entered into the app in Step 2, and enter the resulting number (distance/pace length) when the app asks for the number of paces to the tree.

Option 3: Using a clinometer to measure height

For a full-length guide on using a clinometer (including Suunto clinometers), check out these guides by the Minnesota Department of Natural Resources and by Forestry Suppliers.

IV. Diameter (DBH)

Tree diameter at breast height (DBH) provides complementary data to tree height, with the potential to aid in estimating tree biomass if desired. Increasing tree diameter indicates healthy growth and biomass accumulation. Additionally, though height measurements become less accurate as a tree attains greater height, diameter remains easy to measure accurately.

Foresters use D-tapes (diameter tapes, available for $40-$60) which automatically convert tree circumference to diameters and accommodate large diameter trees. An inexpensive fabric measurement tape ($1-$2) can serve quite well for young trees and is recommended here as an inexpensive alternative.

Materials

- Fabric measurement tape (check against telescoping rod to ensure no stretching has occurred), or diameter tape ("D-tape")
- Paper card (optional)
- Spray paint (optional)
- Calipers (optional)

Protocol

1) Once seedling has reached 1.37 meters (4.5 feet) height or greater, begin measuring the main stem circumference at this height.
    a. In the first few years (when the stem diameter is less than 2 cm or 1"), the tree's needles may prohibit accurate measurement with a tape measure. Instead, the diameter may be estimated using engineer's calipers or by holding the measuring tape up against the stem and providing a visual estimate.
    b. Once the diameter at 1.37 m (4.5 ft) is greater than 2 cm (1"), the diameter may be measured accurately by wrapping the fabric measuring tape around the stem and reading the number/tick mark that aligns with the "zero" end of the tape (Figure 11).

2) Calculate diameter using this equation:

    Diameter = circumference / π

    (where π is approximately 3.1416, and is available as a function in scientific calculators)

    Important notes:

    - Make sure you wrap the measuring tape tightly and horizontally around the trunk with no gaps/branch stubs underneath the tape.
    - You can ensure that you measure the same exact height year after year by marking the height with spray paint on the trunk (using the edge of a piece of paper to help create a sharp line on the trunk). This may need to be remarked annually.
    - If one or more branches protrude or other abnormal swelling exists in the trunk at 1.37 m (4.5 ft) you may move your measuring height just above or below this feature, and carefully note the height (or mark with spray paint to mark) for future years.

- We recommend using a metric tape and reporting in centimeters (for consistency and ease of computations). If you use the English system (inches) please be sure to note units clearly when you record data!

Figure 11 (far left): Using a straight edge and spray paint to create a sharp and re-samplable line for diameter measurements

Figure 12 (left): Wrapping and overlapping a fabric tape measure to measure diameter. This stem is 9 cm in circumference. Divided by π, this gives a diameter at breast height (DBH) of 2.86 cm.

V. Health Notes

Keeping track of tree symptoms can help us understand the causes of tree stress or death and help us make better choices related to plant material selection or cultural practices. In this section, check all the boxes that describe symptoms you observe in your tree.

It is useful to note that many tree species naturally lose some leaves or needles from lower branches (and eventually lose the branches themselves) as they become deeply shaded by healthy upper branches. Assessing in the summer before leaf-turn is also important for assessment of leaf health, as noted above. Toward the end of summer and into fall, leaves of many trees begin to prepare for winter by resorbing pigments, leading to color changes that could be mistaken for disease or deficiency.

Leaves/Needles

- ☐ L1: Discoloration: Leaves yellowing/browning/blackening (>10% of leaf area)
- ☐ L2: Spotting: Leaves or needles spotted with yellow, brown or black spots (>10% of leaf area)
- ☐ L3: Size: Leaves or needles (on >10% of tree) much smaller than those on healthy trees
- ☐ L4: Misshapen: Substantial portion of leaves or needles curled, twisted, or misshapen
- ☐ L5: Insects: Substantial portion of leaves or needles consumed by insects (producing ragged, perforated, or skeletonized leaves or shortened or missing needles with evidence of insect consumption).

Branches

- ☐ B1: Topkill: leaves or needles missing from top (leader) of tree (>10% of top of tree losing or bare of leaves or needles)
- ☐ B2: Dieback: Branch dieback on multiple branches other than top (i.e. leaves or needles missing from branches that, together, make up >10% of canopy)
- ☐ B3: Thinning: Thinning canopy (entire canopy of tree seems sparse due to loss of needles or leaves).

Trunk

- ☐ T1: Insect: Insect entry holes, which may be marked by pitch streams or sawdust (visible at tree base or clinging to trunk)
- ☐ T2: Swelling: Swollen sections of main stem or multiple branches (often accompanied by pitch in conifers)
- ☐ T3: Conks: Shelf-like mushroom fruiting bodies or other kinds of fungal fruiting bodies on trunk
- ☐ T4: Cankers: Cankers or lesions (swollen, eroded, and/or blackened areas) on trunk or branches

Physical injuries

- ☐ P1: Trunk injury: Damage to trunk or base (girdling by rodents or beaver, elk or deer rubbing damage, damage from equipment). Please describe below in the “additional notes” section.
- ☐ P2: Main stem killed: trunk (below last 1-2 years growth at leader) killed or severed (eg. by beaver).
- ☐ P3: Branch injury: Damage to branches or twigs (from wind, falling trees)

- ☐ P4: Herbivory: Herbivory on leaves/twigs by elk, deer, or other animals (please describe below in “additional notes” section).

Flowers and fruit

- ☐ F1: Stress crop: Fruit/cone crop excessive, indicating stress (in combination with other stress symptoms)
- ☐ F2: Fruit size: Fruit/cones undersized, diseased or malformed (give details under “Additional notes”).

Additional notes (Please write other health observations here)

Especially, note if there is evidence of frost damage (a combination of the below symptoms/conditions):

- Browning of leaves or needles on outer portion of crown
- Discoloration or leaf/needle loss especially toward south or west side of tree
- Discoloration or leaf/needle loss on young, tender new shoots
- Presence of unusually low temperatures in winter or spring, especially later than normal in spring

Also, note combined evidence of heat injury (a combination of the below symptoms/conditions):

- Wilted or yellowing leaves
- Scorched leaves (turning brown around leaf edges or needle tips)
- Singing (reddening/browning) of needles/leaves on sunny side of tree or near objects that reflect heat (house, rocky ground, roadway)
- Cracking, scalding of bark on south and west side of tree

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Contact

Questions and feedback can be directed to Northwest Natural Resource Group as the Forest Adaptation Network's coordinating organization: outreach@nnrg.org.

Appendix 1: Datasheet Templates

Migration Monitoring – Project Information Data Form (Pg. 1 of 2)

Project short description (Purpose, background)

Project Contact Information

Project Name: ______________________________

____

Organization:______________________________

Contact person for this project:

____

Contact email: ____________________________

Contact phone (optional):___________________

Contact Address (optional):

____

____

Other entities collaborating on this project:

____

____

____

Project Descriptive Information:

How many sites are part of this project?___________

Latitude for site 1* centroid (decimal degrees to five decimal places) ___________________

Longitude of site 1 centroid (decimal degrees to five decimal places) ___________________

*If you have multiple sites, please enter additional site centroids on Page 2 of Project Information Form.

Project area (acres) __________________

Number of plants installed (whole project) _________

Year(s) when plants were installed: _______________

Planned or executed maintenance actions (circle one)

Watering: *No* | *Yes, which years?*_________________

Frequency:_____________

Herbicide: *No* | *Yes, pre-planting* | *Yes, post planting*

Other site preparation actions (mow, scarify, etc.)

____

Project Setting

Setting (circle one):

Urban | suburban | rural residential | working forest | wildland

Landscape position (circle one)

Valley Floodplain Plateau Hillside Hilltop

Elevation range: ________ to ___________

Aspect (circle one)

N | NE | E | SE | S | SW | W | NW | flat | multiple

A site diagram/map is attached, showing all locations and IDs of plants to be monitored: *Y | N*

Assisted migration species or seed sources installed as part of project:

Species (Cont'd on Pg. 2 of Project Information Data Form)	**Seed source/provenance** (e.g. "Oregon (1996) western redcedar Zone 1")	**Nursery where stock was grown**	**Number planted**

Assisted Migration Monitoring – Project Information Data Form, Continued

(Overflow, Pg. 2 of 2)

Additional Site Centroids:

Site # (Cont'd from Pg. 1 of Project Information Data Form)	**Latitude** (see Appendix 2, Part 1 for data format)	**Longitude** (see Appendix 2, Part 1 for data format)

Additional Species Data:

Species (Cont'd from Pg. 1 of Project Information Data Form)	**Seed source/provenance** (see Appendix 2, Part 1 or 2)	**Nursery where stock was grown**	**Number planted**

Site Map

If reporting one or a few trees, tree locations can be drawn here in relation to useful landmarks. For large or spatially complex projects, a separate, clearly labeled diagram or map of plots or planting areas should be included.

Assisted Migration Monitoring – Plant Monitoring Data Form

(See data entry tips in Appendix 2, Part 2. Form may be copied to record data on additional plants).

	Plant 1	**Plant 2**	**Plant 3**	**Plant 4**
Plant ID number				
Location of tag				
Date of monitoring (YYYY_MM_DD)				
Date plant installed (YYYY_MM)				
Species scientific name				
Subspecies (if appropriate)				
Seed zone/ provenance of seedling				
Stock type				
Herbvivory protection type				
Height (cm)				
DBH (cm) ***Note if other than 1.3m*				
Exact height of DBH measure (m)				
Vigor				
Health Notes Codes (all that apply)				
Additional notes				

Appendix 2: Tips & Definitions for Completing Datasheets

Part 1: Project information definitions and tips for entering data

	Definitions and data entry tips
Project short description	A brief summary of the purpose of the planting project.
How many sites are part of this project?	If there are multiple planting areas overseen by a single organization for a similar purpose, or installed at the same time by a single organization, or funded by a single grant, but separated by a mile or more, these would generally be considered separate sites within a single project.
Latitude for site centroid	Please use NAD83 datum (this is the default for Google Earth), enter in decimal degrees to five decimal places
Longitude of site centroid	Please use NAD83 datum (this is the default for Google Earth), enter in decimal degrees to five decimal places
Project area (acres)	Project area in acres. A project is considered a planting installed by a single entity or a collaborating group of entities in a pre-defined window of time for a particular purpose. For this question, include all planted areas installed as part of a particular project, as long as some proportion of these plants are AM plants.
# of plants installed (whole project)	How many plants were planted (or are planned to be planted) as part of this project?
Year(s) when plants were installed:	What year were plants planted or scheduled to be planted? (Note: if the project is or was planted in phases, enter the first year of planting on the project. For those sharing plant-level data, detailed planting year information will be entered in the Plants Monitoring Data sheet, details below.)
Watering: *No | Yes, Frequency*:__________	Do you water these plants? In which years (with planting year = year 1) and how many times per year?
Herbicide	Do you use herbicide to control weeds in this planting? If not, circle "no". If yes, circle to indicate whether you used herbicides to control weeds "pre-planting", "post-planting", or circle both if both apply.
Other site preparation actions	Briefly list other site preparation actions used prior to planting. These might include: fabric (weed control fabric), mowing, scarifying, tilling, fabric squares, or sheet-mulching, for example.
Project name, organization, contact person, email, phone, address	Enter the name for the project. If there is an organization/agency/or other entity leading project, enter the name. If you are an unaffiliated individual, enter "N/A". Please enter a contact email and (optionally) phone number and address to reach a contact person for this project.
Other entities collaborating on this project	List the most important collaborating organizations or agencies, and funders.
Setting	Circle the land use type that most reflects the environment the trees are growing in.
Landscape position	Circle the topographic context that best describes the setting of the planting. You may circle more than one if more than one apply.

Elevation range	Write in the lowest and highest elevation of the project. A single elevation will do if the range is less than 100’.
Aspect	If plantings are predominantly on a slope, what direction does the slope face?
Species	Enter the full scientific species name for the tree species. If you only know the common name, or are unsure of the accepted scientific name, please use the itis.gov (integrated taxonomic information system) website, enter the common or other name into the quick search field, and look for and use the accepted scientific binomial. (For example: Searching for black hawthorn produces two not-accepted names and the accepted name: *Crataegus douglasii*. It is not necessary to include the abbreviated authority suffix after the binomial).
Seed source/ provenance of seedling	This refers to the seed transfer zone assigned to the place where the seeds for this plant were collected. Ask your grower or seed collector for this information or for a geographic area. For major commercial tree species, we prefer zones delineated by Randall and Berrang 2002 (WA) or Oregon Department of Forestry 1996 (OR). For other species use provisional zones delineated by Bower et al. 2014. If you know the geographic seed source location but not the seed zone for your materials, you can identify the seed zones using the online seedlot selection tool. Navigate to the tool website. Pick the "tool" tab on the left bar, zoom in to the map, and right-click on the map at the seed source location. Wait for a list of "available seed zones" to load in the dialogue box by your cursor, and enter the appropriate seed zone to the datasheet. If your tree has not been assigned a species-specific 1996 or 2002 seed zone, use the “Provisional Zone”. For example: Seeds of western redcedar collected in the city of Portland OR, would be assigned Oregon (1996) western redcedar Zone 1, 0’-999999’. Bigleaf maple collected from Portland would be assigned the Provisional Zone 35-40 Deg F./2-3 Willamette Valley).
Nursery where stock was grown	Enter the name of the nursery that provided the plant materials.
Number planted	How many plants (AM or local provenance) were planted as part of this project (including multiple sites, if applicable)?

Part 2: Plant data definitions and tips for entering data

	Definitions and data entry tips
Plant ID number	A unique code for each plant, which should be recorded on a permanent marker affixed to the plant or to a stake associated with the tree. We recommend it begin with a short site abbreviation followed by a number (Ox-21 for monitored plant number 21 at Oxbow Farm) and recommend printed aluminum tags for maximum longevity.
Location of tag	Where can surveyors look to find labels with plant ID numbers? Please include part of tree or direction from tree (e.g. “lower limb, S. side of tree”, OR “rebar stake 5’ N. of tree”).
Date of monitoring (YYYY_MM_DD)	Enter the date on the day you are taking data (e.g. “2025_02_04” = monitoring on February 4th, 2025).
Date plant installed (YYYY_MM)	Enter the month and year the plant was installed (to your best estimate).

Species scientific name	Enter the full scientific species name for the tree species. If you only know the common name, or are unsure of the accepted scientific name, please use the itis.gov (integrated taxonomic information system) website, enter the common or other name into the quick search field, and look for and use the scientific binomial marked as accepted. (For example: Searching for black hawthorn produces two names that are not accepted and one accepted name: *Crataegus douglasii*. It is not necessary to include the abbreviated authority suffix after the binomial).
Subspecies or variety (if appropriate)	If the species has a designated subspecies or variety, enter only the subspecies or variety name prefixed with "subsp." or "var."(West-side Douglas fir is Pseudotsuga menziesii var. menziesii, so you'd enter "var. menziesii").
Seed zone/ provenance of seedling	This refers to the seed transfer zone assigned to the place where the seeds for this plant were collected. Ask your grower or seed collector for this information or for a geographic area. For major commercial tree species, we prefer zones delineated by Randall and Berrang 2002 (WA) or Oregon Department of Forestry 1996 (OR). For other species use provisional zones delineated by Bower et al. 2014. If you know the geographic seed source location but not the seed zone for your materials, you can identify the seed zones using the online seedlot selection tool. Navigate to the tool website. Pick the "tool" tab on the left bar, zoom in to the map, and right-click on the map at the seed source location. Wait for a list of "available seed zones" to load in the dialogue box by your cursor, and enter the appropriate seed zone to the datasheet. If your tree has not been assigned a species-specific 1996 or 2002 seed zone, use the "Provisional Zone". For example: Seeds of western redcedar collected in the city of Portland OR, would be assigned Oregon (1996) western redcedar Zone 1, 0'-999999'. Bigleaf maple collected from Portland would be assigned the Provisional Zone 35-40 Deg F./2-3 Willamette Valley).
Stock type	Enter "plug", "bare root", "ball-and-burlap", or enter a volume of container ("2-gallon pot"). See these resources from the Iowa state extension or the US Forest Service to learn more.
Herbvivory protection type	Enter "none", "tube" or "cage" + the height in feet (e.g. "tube-2ft"). For small vole protection tubes, simply enter estimated height (For example: "tube-0.3ft").
Height (cm)	Enter tree height in meters at the time of this survey, measured according to instructions in Section III of this manual.
Vigor	Enter "thriving", "healthy", "stressed", or "dead" according to the instructions in Section II of this manual.
Health Notes Codes (all that apply)	Enter all health note codes that apply based on section V of this manual, separated by semicolons. For instance, if the survey tree exhibited yellowing leaves and damage to the trunk, you would enter: "L1: discoloration; P1: Trunk injury".
Additional notes	Write a succinct summary of special health-related or other notes, including evidence of frost or sun damage (the individual symptoms of which would also be reflected in the "health notes" field above). Any details to clarify health notes codes are also helpful here. (Example: if you enter "P3 Herbivory" code in the health notes field, you might clarify by writing "Elk herbivory to branch ends protruding above protector tube" in this field.