Combined Dendrometer Installation Protocol

CTFS Global Forest Carbon Research Initiative

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Table of Contents

Materials checklist

(The final section of this document contains additional information on specifications and suppliers.)

General census equipment and supplies

1. Diameter measuring tape (1 per person)
2. Wooden stick 1.4 m long, with marks at 1.0, 1.1, 1.2, 1.3 and 1.4 m (1 per person)
3. Ladder (1 per team)
4. Clipboard and datasheets (1 per person)
5. Permanent marker (1 per person)
6. Small container with paint and brush (1 per person; nail polish bottles work well)
7. Tree marking paint (sufficient for painting measuring point on each tree to be censused)

Band dendrometer equipment and supplies

8. Heavy-duty lever hole punch (1 per person)
9. Digital calipers (1 per person)
10. Diameter measuring tape (1 per person)
11. Snips/heavy-duty scissors (1 per person)
12. Stainless steel banding (length equal to tree circumference plus 8-20 cm per tree on which band dendrometers are to be installed, depending on tree size – see below)
13. Stainless steel springs (1 per tree on which band dendrometers are to be installed; length of 38, 76 or 127 mm depending on tree size – see below)

Dial-gauge dendrometer equipment and supplies

14. Drill (1 per team)
15. Drill bits, 2.78 mm (7/64 inch), 3.175 mm (1/8 inch), and 3.57 mm (9/64 inch) (1 set per team)
16. File (1 per team)
17. Metal template for locating the screws (1 per team)
18. Microdendrometer measurement gauge (1 per team)
19. Phillips screwdriver (1 per team)
20. Brass wood screws, Flat Phillips head, 7.6 cm long, thread size 14 (6 per tree on which these dendrometers are to be installed)

Preliminary observations

1. Locate the designated tree using the information on the maps and datasheet.
2. If the tree is dead or presumed dead (missing), record this under notes using the usual plot codes. For BCI, these are D for Dead, followed by:
   S = Dead trunk still standing
   C = Dead trunk lying on ground
   T = Tree missing, tag found
   N = Both tag and tree missing
3. Examine the stature and condition of the tree; record any special cases under "Notes" on the datasheet. For BCI, use the following standard plot codes where relevant, and also record if there are "Thorns" or "Bark peeling":
   B = buttresses extending to 1 m or higher
   M = multiple stems
   L = leaning
   Q = stem broken above 1.3 m
   X = stem broken below 1.3 m
   I = irregular stem
4. Assess and record the crown condition of the tree using the following categories:
   4 = 75-100% of the crown is intact (no or few branches lost)
   3 = 50-75% of the crown is intact
   2 = 25-50% of the crown is intact
   1 = 0-25% of the crown is intact (most of the crown is gone)
5. Evaluate and record the crown illumination index (CII) of the tree. The different values are defined as follows (Figure 1):
   5 = crown completely exposed (to vertical light and to lateral light within the 90 degree inverted cone encompassing the crown)
   4 = full overhead light (>=90% of the vertical projection of the crown exposed to vertical light; later light blocked within some or all of the 90 degree inverted cone encompassing the crown)
   3 = some overhead light (10-90% of the vertical project of the crown exposed to vertical light)
   2 = lateral light (<10% of the vertical project of the crown exposed to vertical light; crown lit laterally)
   1 = no direct light (crown not lit directly either vertically or laterally)

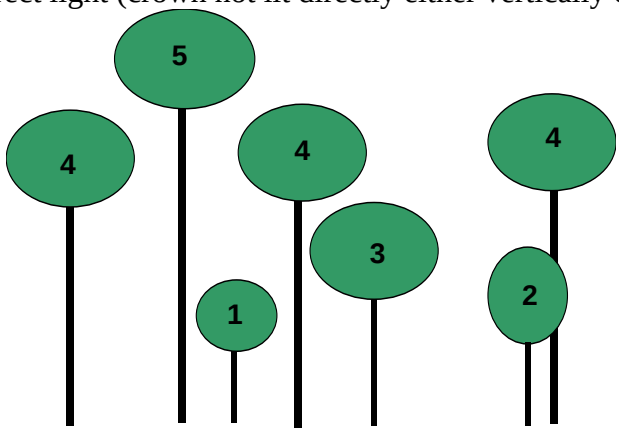


Figure 1. Examples of trees having different values of the crown illumination index.

Diameter tape measurement point

6. Locate the current measurement point for the main census. (The datasheet's POM column states this height.)
    a. If the measurement point is listed as 1.3 m, there will be no paint marks on the tree. Note that in determining where 1.3 m height is,
        i. On a slope, 1.3 m height is measured on the uphill side.
        ii. For a leaning tree, 1.3 m height is measured along the lower side
    b. If the measurement point is higher than 1.3 m, there will be an orange paint mark – the *highest* paint mark is the current measurement point.
7. Evaluate if the current measurement point is suitable for continued measurements with a diameter tape over the next 4 years. If it is not, choose a new measurement point. In most cases, if a measuring point is "good enough" for the main census, it is good enough for our purposes as well. But there are exceptions:
    a. If there are stem irregularities at the measurement point that can easily be avoided by measuring at a higher or lower position, then adjust the measurement point appropriately.
        i. First consider options up to 50 cm higher than POM, then if the current POM is at 1.3 m consider options up to 50 cm lower, and finally consider options further up.
        ii. In many cases, stems that are irregular at the measurement point are also irregular through most of their length. In this case, just use the regular census measurement point.
    b. If the buttresses have grown up since the last census so that they now end less than 10 cm from the current measurement point, then move the measurement point upwards.
        i. The new measurement point should be 50 cm above the top of clearly defined buttresses.
        ii. On many trees, buttresses do not have a clear ending. In this case, just use the main census measuring point.
8. Temporarily mark the measurement point with a permanent marker.
9. Measure the diameter of the tree at the chosen measurement point using diameter tape, and record it.
10. Paint-mark the measurement point if necessary (if not already painted, or if the paint is fading), and note on the datasheet whether the mark is newly painted or not.
11. If the measurement point is new, then measure the height of the chosen measurement point from the base of the tree (using the rules for measuring on a slope and on leaning trees as in 5a).

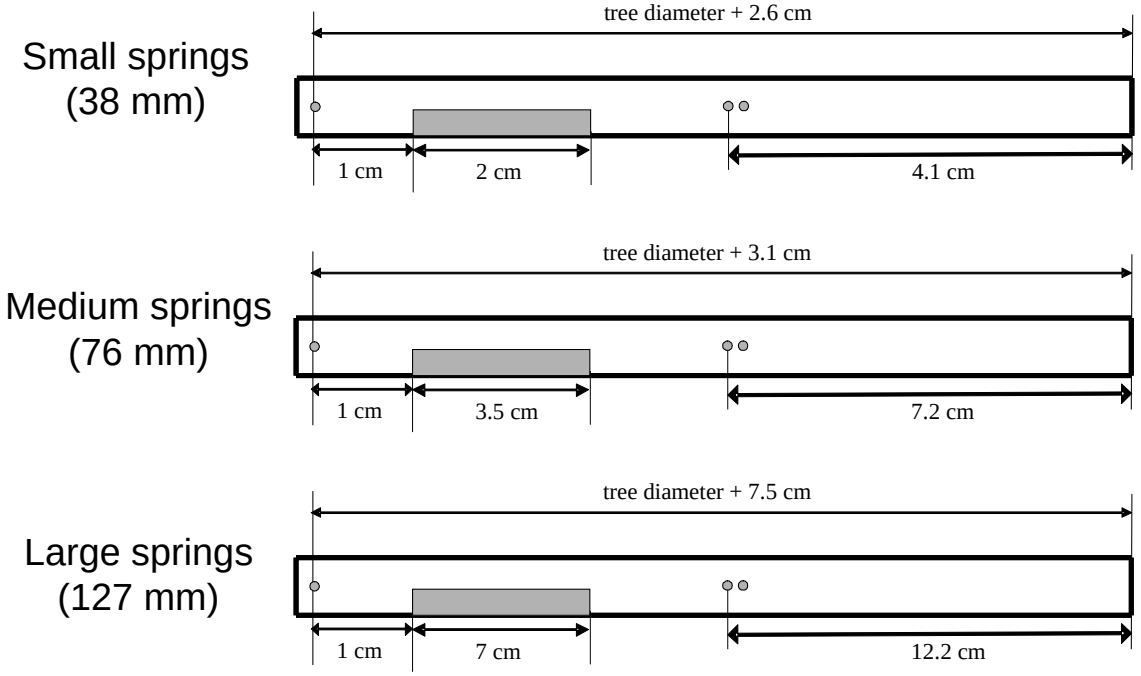
Choice of dendrometer type

12. Decide whether to use band or dial-gauge dendrometers on this tree. In most cases, band dendrometers should be used.
13. Dial-gauge dendrometers should be used in the following cases:
    a. The trunk has thorns that make placement of a band difficult. For example, on BCI, *Hura crepitans*, *Zanthoxylum* species).
    b. The trunk has clearly defined buttresses and nicely cylindrical trunk between the buttresses – a growth form conducive to placing dial-gauge dendrometers between the buttresses. For example, on BCI, *Ceiba pentandra*.
    c. The bark peels extensively, and thus accumulation of bark under bands could interfere with accurate growth measurements. For example, on BCI, *Astronium graveolens*, *Beilschmiedia pendula*).
14. Band dendrometers should be used for the following other "problem" tree categories:
    a. Trees with everywhere irregular trunk: in this case, there is no clear place to put dial-gauge dendrometers and be sure they will be representative of trunk growth. For example, on BCI, *Luehea seemannii.*
    b. Trees with stilt roots. Just place the band above the stilt roots.
    c. Infection of the tree trunk and/or insect nests in the tree trunk in the area of measurement. In these cases, use of the dial-gauge dendrometers is inadvisable because it could spread infection, damage the tree, and/or result in angry insects attacking the person installing the dendrometer!
15. When in doubt, use band dendrometers.
16. Record the type of dendrometer used on the datasheet.

Installation of band dendrometers

1. Decide on the location of the band dendrometer.
    a. Default location – 10 cm above the paint-marked measurement point.
    b. If there are stem irregularities at the default location that can be avoided by moving the location of the dendrometer, then move the installation point to the nearest possible location free of such irregularities.
2. Clean the circumference of the tree (remove mosses, loose dirt and bark, etc.) and pull lianas away from the bark at the dendrometer installation location.
3. Measure the diameter at the dendrometer installation location using diameter tape, and record on the datasheet.
4. Measure the height of the dendrometer installation point using measuring tape, and record on the datasheet.
5. Choose the spring and window size appropriate for the measured diameter and tree condition at the installation point:
    c. Dbh < 100 mm, small (38 mm) spring
    d. 100 mm <dbh<500 mm, medium (76 mm) spring
    e. Dbh> 500 mm
        i. If there will be spaces between the band and the tree trunk in some areas, use medium (76 mm) spring.
        ii. If the band will be in contact with the bark all the way around the tree, use large (127 mm) spring.

6. Construct a band dendrometer of the appropriate size, punching holes and cutting windows as directed below. *Note that all measurements are in units of cm on diameter tape.*



7. Attach one end of the spring to the middle of the band.

8. Put the band around the tree at the dendrometer installation point; attach the other end of the spring to the hole at the end of the band.
9. Check that the band is level and goes under lianas and epiphyte roots, and adjust it if necessary.
10. Make that throughout the area where the band is doubled, it sits snugly against the trunk (that is, there are no air spaces between the band and the trunk in this area). Rotate the band around the trunk if necessary.
11. Carefully take up slack in the band as much as possible so that the band sits tightly around the trunk.
12. Use the digital calipers to measure the distance between the end of the window and the trail end of the band (the actually exposed window). See figure below. Record on the datasheet. (Make sure the caliper is set to read in mm.)

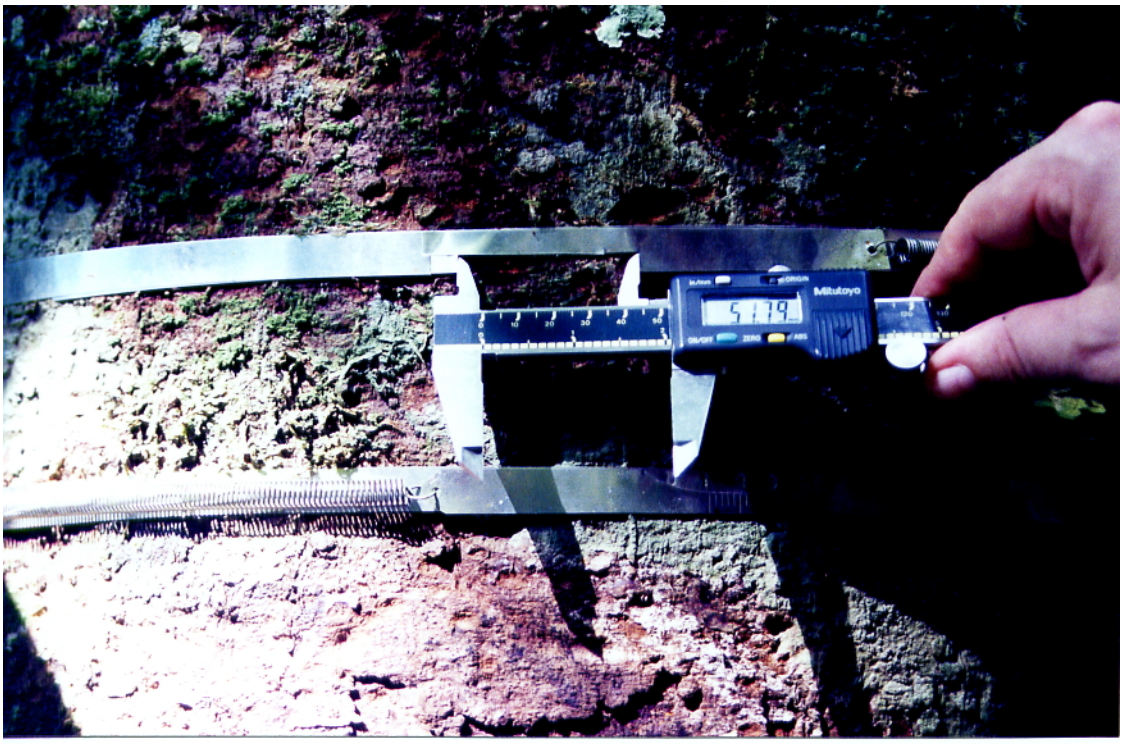


Figure: Picture of two band dendrometers (one above the other), and measurement of the window size of one of the dendrometers with calipers.

Installation of dial-gauge dendrometers

1. Decide on the height at which to install the dial-gauge dendrometers, keeping in mind that 2 dendrometers need to be installed on different sides of the tree.
    a) Default height: Installation so that the measurement point is at 1.2 m is preferred if the stem in this area is suitable.
    b) Screws should never be within 5 cm of the height at which the main census measures diameter, because deformities introduced by the screws could affect diameter measurements.
    c) Buttresses: If the trunk curves distinctly inward below the top of the buttresses, the dendrometer should be placed 50 cm (or more) above the point where the trunk begins to curve inwards.
    d) Trunk deformities: Avoid these by moving the measurement point the smallest possible distance up, down or sideways (as possible given the other constraints).
    e) Spines: Where easily avoided, place the dendrometers to avoid spines at the measuring point. In the case when it is not possible to find a flat space on the trunk at or near the desired measurement height large enough to install the dendrometer, remove the spines and smooth the surface at the measurement point using a knife or file. Always avoid the scars of spines when choosing the measurement point. It does not matter, however, if the screws have to be installed where the spines used to be. If the measurement point is not at 1.3m, measure and take notes of its height.
2. Decide on the locations around the trunk at which to install the two dendrometers (dial-gauge dendrometers should always be installed 2 to a tree):
    a) Ideally the two dial-gauge dendrometers should be installed on opposite sides of the tree, but they can be installed as close as 90 degrees (1/4 of the way around the tree) if there are reasons not to place them further apart. .
    b) The pair of locations should be chosen to best represent total trunk growth in combination. For example, if a tree is leaning, one should be placed on the side to which the tree is leaning, and one on the opposite side.
    c) Where there are buttresses, it is best to place dendrometers midway between adjacent buttresses. This should be done even if it means the dendrometers are not on opposite sides of the tree.
3. Record the approximate compass directions (N, NE, E, etc.) and the heights of the measurement points of the two dendrometers on the datasheets, starting with the one closest to N when starting at N and going clockwise around the tree.
4. Install the screws.
    a) Approximately 2.5 cm of each screw should be inside the trunk and 5 cm should extend out of the trunk.
    b) For very soft-wooded trees, simply use a screwdriver and the template to install the screws, making sure that the screws are placed in parallel.
    c) For (most) harder-wooded trees, first use the drill and template to drill the holes for the screws, again making sure the holes are drilled in parallel. Then use the screwdriver to install the screws.
    d) Check that each screw is well-fixed in the trunk (it should not be possible to jiggle it).

5. Clean the measurement point (see below). Use a file to gently remove moss, lichen, loose bark, spines, etc. from the trunk in an area of about 1 x 1 cm directly at the measurement point.

The upper two screws of the dendrometer and the cleaned measurement point above..

6. Place the microdendrometer measurement gauge on the screws to take the initial measurement (see below). The measurement gauge should sit stably on the screws. If the distance between the upper two screws is shorter than the indentation on the microdendrometer measurement gauge, slide the gauge so that the right screw is tightly against the right side of the indentation. (Always use the same side as it is very important to be consistent when making remeasurements.)

Taking measurement using the microdendrometer measurement gauge.

7. Take the microdendrometer measurement gauge off, then place it on the screws again. Repeat at least three times and record the average of the readings.

Specifications and suppliers for the materials

General census equipment and supplies

1. **Diameter measuring tape** (1 per person). Should use same kind used for regular census at the site.
2. **Wooden stick 1.4 m long, with marks at 1.0, 1.1, 1.2, 1.3 and 1.4 m** (1 per person)
3. **Ladder** (1 per team). We use a simple 3-m tall ladder on BCI. In plots where trees do not have buttresses, a ladder may be unnecessary. On plots where buttresses are rare, it may be better to simply go to all trees with buttresses as a separate campaign after covering all the other trees.
4. **Clipboard and datasheets** (1 per person)
5. **Permanent marker** (1 per person)
6. **Small container with paint and brush** (1 per person; nail polish bottles work well). Specifically, we buy nail polish bottles, empty them of polish, and refill them with paint. We have found that a ketchup disperser bottle works well for holding the paint and adding it to the nail polish bott.es
7. **Tree marking paint** (sufficient for painting measuring point on each tree to be censused). On BCI, we use a non-toxic blue paint suitable for outdoor use and purchased locally. There is no need to go with specialized "tree marking paints" sold by companies such as Forestry Suppliers (and indeed, not only are these more expensive, but it can take a very long time to ship them because they are considered hazardous materials).

Band dendrometer equipment and supplies

8. **Heavy-duty lever hole punch** (1 per person). We ordered from McMaster.com: Portable compact lever punch, cost $54.74. Item # 3461A22. Portable Compact Lever Punch W/ Adj Throat 1.2 Tons Pressure, 1/4"-1-3/4" D Throat. Note that a regular hole-punch for punching holes in paper is not sufficient to punch holes in the metal banding.
9. **Digital calipers** (1 per person). We have been using Digimatic calipers ordered from forestry-suppliers.com, cost $150, item #59601. Measuring range: 0 to 6"/0 to 150 mm. Accuracy: ±.001"/ .02 mm. Battery life (approx.): 2 years. We had problems with one of these malfunctioning after it became wet on a rainy day, so we recently ordered Mitutoyo Harsh Environment Electronic Caliper Number 500-672, 0-6" (0-150mm) Range from mcmaster.com for $140. (These "harsh environment" calipers "have a sealed IP-rated housing, protecting them from water, coolant, dirt, and dust" which we hope will perform better under wet forest conditions.)
10. **Diameter measuring tape** (1 per person). Use the same model employed in the main census at the site.
11. **Snips/heavy-duty scissors** (1 per person). We have just purchased these locally. Heavy-duty office scissors work okay, but snips designed for use with metal work better.
12. **Stainless steel banding** (length equal to tree circumference plus 8-20 cm per tree on which band dendrometers are to be installed, depending on tree size – see

below). We have been using stainless steel banding that is 1.27 cm (0.5 inches) wide and 0. 127 mm (0.005 inches) thick, which is sold as embossing tape in rolls of 6.4 m (21 feet). We buy this from mcmaster-com, item # 1598T62, $3.75 per roll for 10 or more rolls.

a. Note: It is also possible to use thicker stainless steel banding that is 0.254 to 0.381 mm thick, at least for the larger trees. Indeed, this may be the preferred material for larger trees. In this thickness, stainless steel banding is commonly used for strapping street signs onto poles, and is available in rolls of 100 feet or more. We purchased some from keyesdavis.com; however, we found it more awkward to work with because of the larger rolls.

13. **Stainless steel springs** (1 per tree on which band dendrometers are to be installed; length of 38 mm (1.5 inches), 76 mm (3 inches) or 127 mm (5 inches) depending on tree size – see above). Other specifications of the springs:
    a. Material: stainless steel (type 304, if there is a choice)
    b. Wire thickness: 0.66 mm (0.026 inches)
    c. Outside diameter of spring: 0.64 cm (0.25 inches)
    d. End style: Machine
    e. End type: Hook (if you need to specify the size of the gap, make it 0.25 cm = 0.1 inches)
    f. Relationship of ends: Random
    g. Finish: Plain or Passivate (if you need to specify this)

We ordered 38 mm and 76 mm springs from Lee Springs, leespring.com, who provided these quickly as standard production items (item # LE 026C 05 S for the 38-mm springs and item # LE-026C-11-S for the 76-mm springs). We ordered 127 mm springs from Gardner Springs, gardnerspring.com, and because these were made-to-order they were quite slow to be produced. It is possible to work with just the medium and small sized springs; indeed, we found that relatively few trees were really well-suited for the largest springs. In principle, longer springs allow for longer time before the dendrometer has to be replaced.

<u>Dial-gauge dendrometer equipment and supplies</u>

14. **Drill** (1 per team). Drill must be powered by a rechargeable battery, and there should be at least 2 batteries. This can be purchased locally. We originally purchased an inexpensive drill made by SKIL, and its battery life soon dropped so much that it could only be used on a couple trees before needing to be recharged. Finding a drill with a Nickel-Metal-Hydride (NiMH) or Lithium-Ion (LiO) battery instead of a Nickel-Cadmium (NiCd) battery might help. Purchasing a drill with more than one battery is essential.
15. **Drill bits**, 2.78 mm (7/64 inch), 3.175 mm (1/8 inch), and 3.57 mm (9/64 inch) (1 per team)
16. **File** (1 per team). This is a standard metal file for evening out rough bark at the measurement point.
17. **Metal template for locating the screws** (1 per team). This is custom-made. We had ours made together with the microdendrometer measurement gauge by the University of Minnesota machine shop.

18. **Microdendrometer measurement gauge** (1 per team). These are no longer available commercially. We had them constructed by the University of Minnesota machine shop. Additional identical gauges can be ordered from this source for around $650 each, and will take at least 1 month to be produced.
19. **Phillips screwdriver** (1 per team). Standard hardware.
20. **Brass wood screws**, Flat Phillips head, 7.6 cm long, thread size 14 (6 per tree on which these dendrometers are to be installed). We ordered these from mcmaster.com, where they are item # 92114A323 and cost $8.28 per Pack of 10. Additional specifications:
    a. Head Style Flat – this is very important! If the top of the screw is not flat, the microdendrometer measurement gauge will not work with the screw.
    b. Material Type: Brass
    c. Finish Plain
    d. Thread Size #14 (6.15 mm or 0.242").
    e. Drive Phillips
    f. Drive Size #3
    g. Head Diameter 12.9 mm (.507")
    h. Head Height 3.89 mm (0.153")
    i. Head Angle 82°
    j. Length 7.6 cm (3 inches)
    k. Drill Size (Hard Wood) 3.57 mm (9/64 inch)
    l. Drill Size (Soft Wood) 2/89 mm (7/64 inch)
    m. Thread Style For Wood
    n. Minimum Rockwell Hardness B55
    o. Note Length is measured from top of head.

Regarding the screws, clearly a somewhat different size screw, measured in metric units, could be used along with corresponding size drill bits. We found that the thinner #12 and #10 screws were not suitable for many trees – they were liable to bend. So the screw should be this thickness or larger.

Sample dendrometer installation datasheet and maps

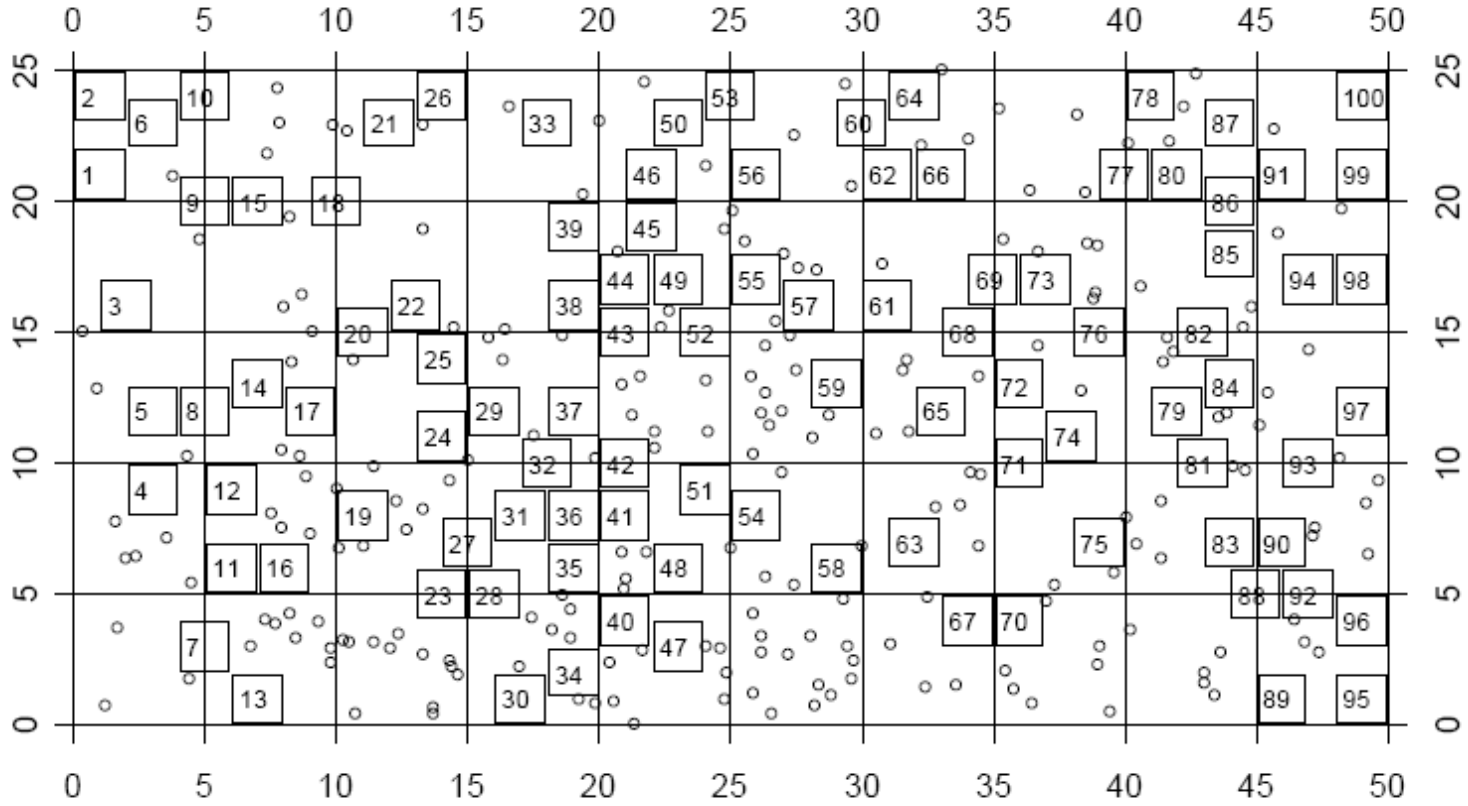


Figure: The locations of the randomly placed dendrometer subplots (squares with numbers inside), and of the large trees (>80 cm dbh) outside the subplots on which dendrometers are also to be installed (circles).

Technician Name _____ Day___ Month___ Year ____

q20	lx	ly	dbh	species	tag	POM ht	codes	use	Crown condition	Crown illumination	New paint (Y/N)	Height paint (m)	Diam paint (mm)	Type dend (B/D)	Pos dend NESW	Height dendro (m)	Diam dendro (mm)	Measure dendro (mm)	Notes
402	3.9	2.1	625	TAB1RO	7659	4	B	yes											
402	5.8	19.7	453	TRI2TU	7660	1.3	*	yes											
402	11.4	11	225	ALSEBL	240553	1.3	*	yes											
402	13.5	19.2	218	POUTRE	240566	1.3	*	yes											
402	15.6	5.6	781	POUTRE	7655	3.2	B	yes											
402	16.1	17	202	TRI2TU	240596	1.3	*	yes											
402	17.4	18	182	TET2PA	240599	1.3	*	yes											
403	6	5.9	418	GUATDU	7666	1.3	*	yes											
403	7	10.3	429	VIROSU	7665	3.8	B	yes											
403	7.6	19.1	428	QUARAS	7669	1.3	*	yes											
403	11.6	0.7	362	DIPTPA	240714	2.7	B	yes											
403	14.5	6.4	421	TAB2AR	7662	3.5	B	yes											
403	19.3	1.4	80	APEIME	240817	1.3	*	yes											
403	19.4	10.9	425	AST2GR	7663	1.3	*	yes											
403	15.4	19.6	413	QUARAS	7664	2.95	B	yes											
502	2.5	19.2	263	TRI2TU	235346	1.3	*	yes											
502	4.8	18.4	175	VIROSE	235350	1.3	*	yes											
502	5.7	6.9	696	GUAPST	7626	3.95	B	yes											
502	8.8	8.2	605	ALSEBL	7625	4.24	B	yes											
502	14.6	18	462	PRI2CO	7622	1.3	*	yes											
502	*18.9*	*6.2*	*365*	*GUATDU*	*235518*	1.3	*	*>=400?*											
502	18.7	19.3	750	BROSAL	7621	5.2	B	yes											
503	3.2	10.7	445	PRI2CO	7618	1.3	*	yes											
503	9	16.2	486	APEIME	7615	3	B	yes											
503	19.7	9.2	537	BEILPE	7330	3	B	yes											

Figure: Sample dendrometer installation datasheet (with data from subplot #7 on BCI).

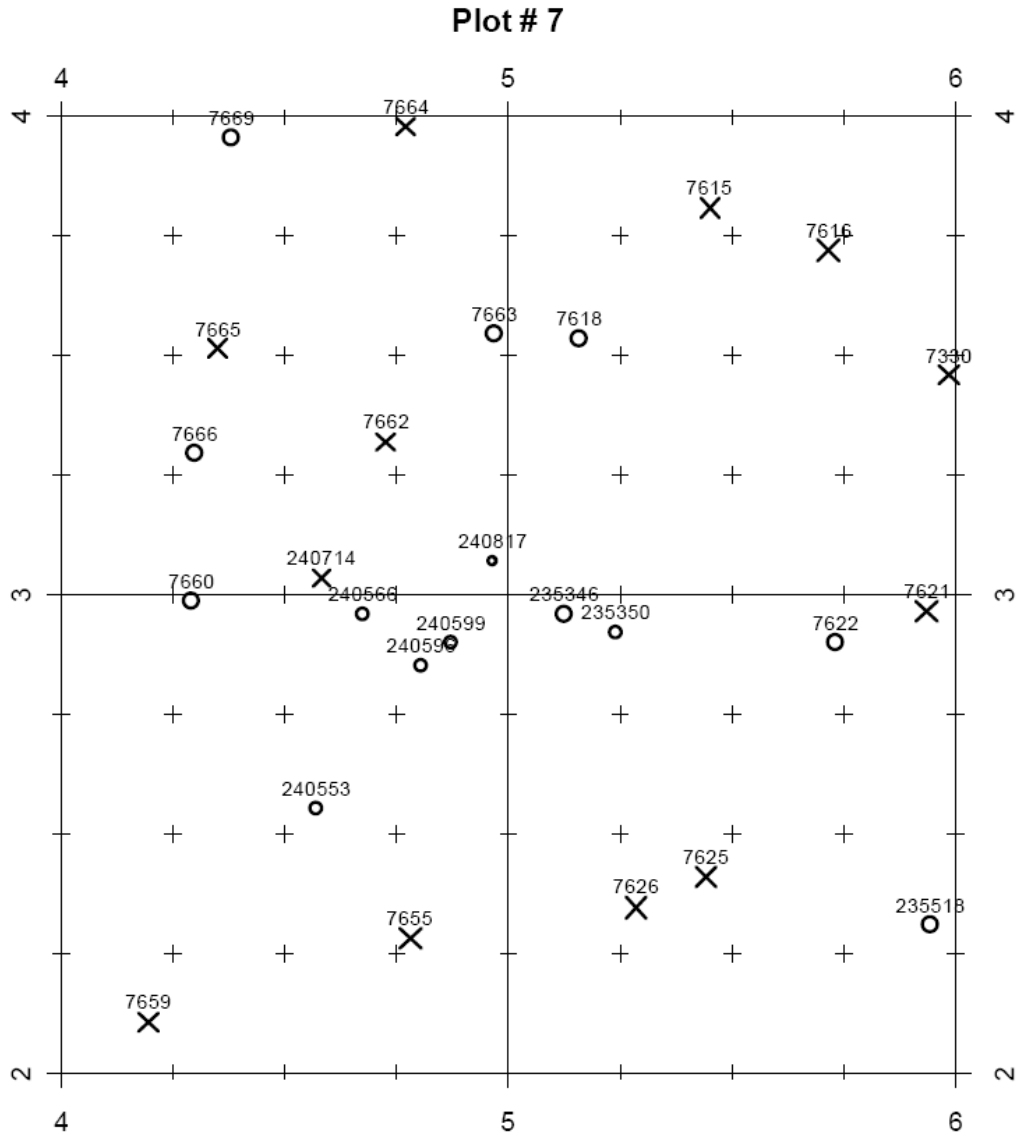


Figure: Sample map of a dendrometer subplot (corresponding to the sample datasheet). Circles mark trees measured at 1.3 m height, x's mark trees measured higher. The numbers on the axis give the 20x20 plot coordinates, with 20x20's delineated by lines, and the 5x5's by plus signs (+). The numbers above the circles and x's give the tree tags.