Measuring wood density for tropical forest trees
A field manual for the CTFS sites

February 16th 2005

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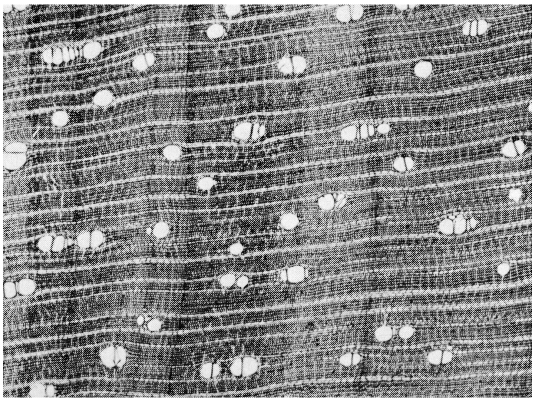
1. Introduction

Wood is a biological tissue made of cells, or tracheides, and of walls composed of lignin. The tracheides are like pipes, that transport the sap along the stem and they are filled by water. The density of tree wood is an interesting variable because it tells how much carbon the plant allocates into construction costs. Wood density varies within the plant, during the life of the plant, and between individuals of the same species. Also the branches and the outer part of the trunk tend to have a lighter wood than the pith.



Cross-section of wood, where the tracheides are clearly visible.

There are many definitions of wood density. Foresters measure the weight of a given volume of wood that has been 'air-dried'. Depending on the country, conventions differ about air drying: the fraction of water remaining in the wood sample may be 12%, or 15%. This causes considerable trouble in the literature. In the present study, wood density is technically defined as the ratio of the oven-dry mass of a wood sample divided by the mass of water displaced by its green volume (wood specific gravity, or WSG). This can be calculated from measurements of oven-dry weight combined with measurement of green volume.

2. Collecting wood samples in the field

Small pieces of wood are extracted from the tree using a device called an **increment borer**. This equipment comes in three parts (cf. figure 1): a handle, a coring bit, and an extractor. An increment borer is like a hollow auger, extracting a small dowel-like piece from a tree. The handle is hollow, and the drill bit and extractor can be stored inside the handle when not in use. The extractor is a long half-moon shaped blade that slips inside the hollow auger and allows you to pull out (extract) the core sample. The coring bit is made of a special alloy and is very hard. However, it remains the most fragile part of the equipment and breaks easily if the user attempts to force the device into a dense wood with too much force. We are using a 16’’ Suunto borer with two threads. The inner diameter of the bit is 5.10 mm.

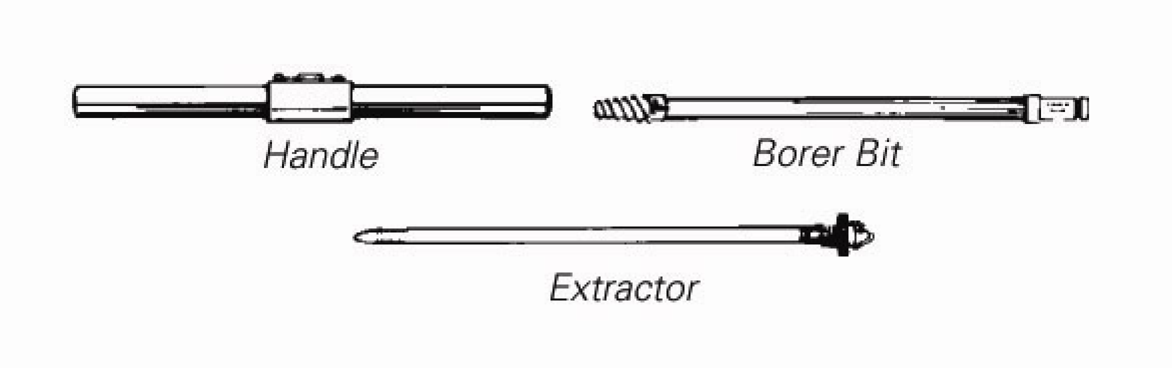


Figure 1. Three parts of the increment borer.

Figure 2. How to assemble an increment borer.

Here are the different steps required to collect a wood sample with an increment borer.

1. Choose an appropriate tree (outside the Forest Dynamics Plot). Report the tree’s species ID as well as its exact dbh. The tree should be in the range 10-30 cm in dbh. With a knife, remove mosses, aroids, and the outer bark of the tree at the location where the trunk will be cored. Ideally, the trunk should be cored at a height such that the user is stable enough to push the corer using his body weight. For a person of ca. 1m70, an adequate height is about 1m10. Below this height the user would have to bend over, above he could not lean on the corer. A single person should be in charge of coring the tree other persons in the crew should help him by preparing the bag in which the sample will be stored, by keeping the extractor during the coring process.

2. Unscrew the knob at the end of the handle (figure 2). This is the extractor that holds the bit inside the handle. The next step is to insert the bit/core auger/borer into the handle. Put the square end through the hole in the handle and secure the flip lock over the bit to hold the borer to the handle. The borer is now ready for use.

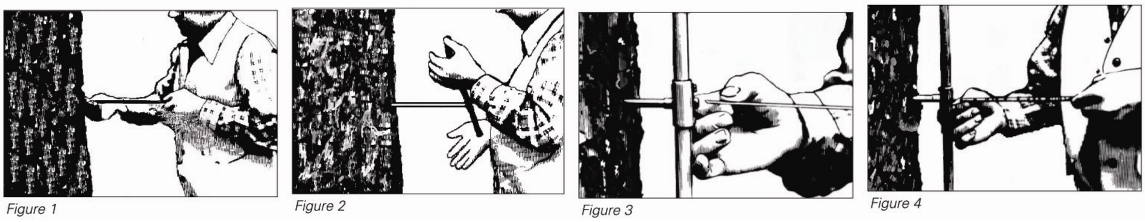


Figure 3. Different steps in coring a tree.

3. The greatest difficulty is to get the corer started into the tree. To begin coring, hold the bit just behind the threads and lean into the borer to provide as much body pressure as possible (figure 3). Slowly turn the bit until the threads have become fully engaged. **NEVER** use brute force to get the corer started into the tree. The corer should NOT be the strongest of the field crew, but he should have a sense of stability. If you cannot get the end bit into the wood after three attempts, the wood is too hard. Don't insist, as you will probably break the corer. For hardwoods, it helps a lot to tie a rope around the tree and the borer (figure 4). When you start turning the handle, the tension on the rope will increase and this will help the bit into the tree.

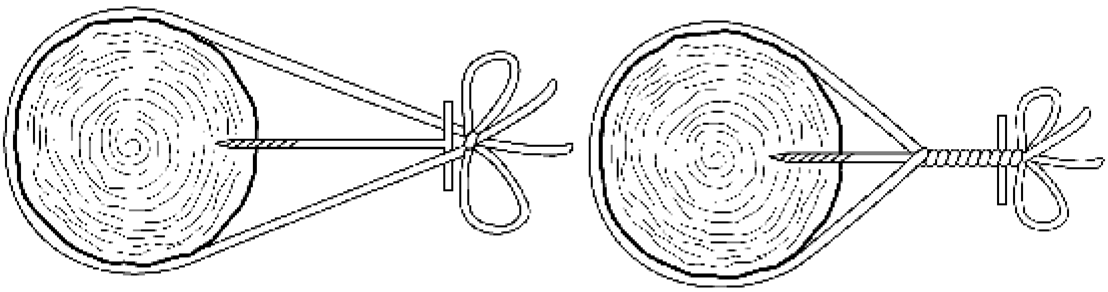


Figure 4. Using a rope to facilitate the corer into the tree.

4. After the threads have engaged, you may step back from the increment borer and turn the handle (figure 3). The bit will proceed into the tree. Hardwoods will require a considerable use of strength and energy. If you hit a rot pocket (you will know immediately because of the ease of turning), back out immediately or else your bit may be incredibly difficult to remove (the threads do not engage in reverse unless they already have a bite in the wood). You should try to core the tree slightly past the pith (center) of the stem. To gauge your depth at any given time, you can hold the extractor up to the side of the tree (it is the same length as the bit and will inform you of your progress).

5. When the proper depth has been achieved, back the bit out one full turn, then insert the extractor into the hollow increment corer bit. Note: place a slight up-pressure on the back of the extractor to ensure the leading tip stays under your sample. Insert the extractor to its full length. Depending upon the species, this may require that you apply some pressure with the heel of your hand near the end. Never drive the extractor in with a hammer or other implement.

6. Slowly withdraw the extractor from the increment handle and you should retrieve an intact core. Remove your borer from the tree as soon as possible to prevent it from being "frozen" in the tree. A wooden golf tee works well for dislodging material at the tip of the borer bit. If you experience twisting or breaking of the cores, clean and oil the borer bit (inside and out).

7. Current wisdom suggests that the hole you left will scar over quickly and no attempt should be made to treat or plug the hole with any type of substance or object. Plugging the hole may facilitate the development of fungi.

Figure 5. Wood core on the extractor.

8. Immediately place the core into a plastic drinking straw, seal the ends, and mark the straw with the sample ID number (this should code to your field data sheets that contain additional information about the tree and site). If the core breaks, you may choose to keep only two or three of the largest parts (we do not intend to read growth rings). Store the straws in a protective container while in the field.

9. Increment borers should be cleaned between sample collections, and before storage. The collection of good increment cores from trees, poles, or ties depends mainly on the condition of the increment borer. Tree sap and moisture can etch, pit or otherwise damage the borer making it ineffective. In particular, species in the Sapotaceae, Euphorbiaceae, Apocynaceae, Moraceae, tend to produce an abundant sap. To clean it, use a brand lubricant or any light oil and a tissue or cloth. If the bit starts to rust, substitute a fine steel wool for the tissue. As with other cutting tools, the increment borer must be well sharpened to perform suitably. A well-sharpened borer will, if properly used, cut numerous cores before resharpening is required. High-density woods will dull the borer sooner than will lower-density woods. Make sure that all of the parts are dry prior to storage. To store the borer, push the flip lock in the opposite direction and take out the bit. Put the bit back into the handle and put the extractor inside the bit and screw the knob tight. Make sure to store the borer in a dry place.

Before going to the field, the crew should review that the following items are available:

(1) an increment borer
(2) a piece of rope (at least 2 m)
(3) a dbh-tape
(4) a list of the targeted trees
(5) a standard spread sheet to write the results
(6) plastic straws to hold the wood samples

The results should be entered as spreadsheets (Excel) with the following columns:

Data collected in the field					***Data contributed in the lab***	
Sample number	**Tree tag (if available)**	**Species binomial**	**Diameter**	**Remarks**	***Fresh volume***	***Oven dry weight***

The sample number should be attached to the sample, and should be unambiguous. For instance, sample 1 for Korup can be called KOR-WD001 (first sample for the wood density project in Korup), the second KOR-WD002, and so forth. If the core has been broken, record one reading per part (for instance KOR-WD002a, KOR-WD002b, etc). If the tree tag exists, then report it, but this column may be left empty. Species name and tree diameter (dbh) is an essential variable in the field Additional remarks in the field may report the shape of the tree (irregular, buttressed, hollow, …).

3. Laboratory measurements

For measurements of green volume, the sample should be maintained at constant humidity. In the laboratory place the full core into water for ½ hour to ensure adequate swelling. Green volume can be measured using two different methods:

(1) In the dimensional method, one calculates the volume of a tree core assuming a regular cylindrical shape. This requires measuring both the total length and its diameter at different points, with a calliper, avoiding pressure of the calliper blades on the wood. If L is total length of the sample and D the mean diameter, then the volume of the sample is given by the formula $\frac{\pi}{4}D^2L$.

(2) The water-displacement method allows for easy and reliable volume measurement for irregularly shaped samples. A container capable of holding the sample is filled with water and placed on a digital balance of precision at least 0.01 g. The balance is then re-zeroed (the reading should be zero). The sample is then carefully sunk in the water, such that it is completely underwater. You should not fill the container completely with water; enough room should be made for the sample. The sample should not contact the sides or bottom of the container, and it should be forced underwater with a thin needle. The measured weight of displaced water is equal to the sample's volume (since water has a density of 1 – this is known as Phytagora's theorem). The electronic balance should be re-zeroed after every measurement.

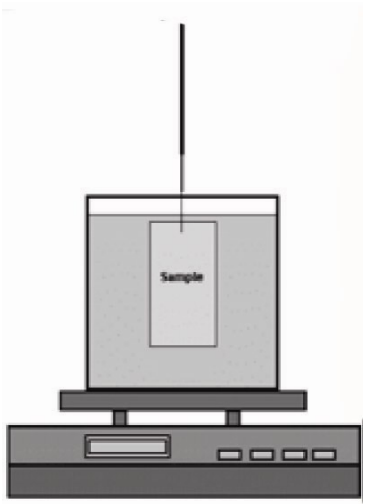


Figure 6. Diagram of water displacement method for measuring wood core volume. The core is forced underwater with a needle. The core should not touch the edges of the container. When the sample is sunk underwater, the level of water raises, and, for the balance everything is as if one had added the amount of water equivalent to the volume of the sample. Therefore the reading on the digital balance is equal to the volume of the core (with the equivalence 1 g = 1 cm^3).

Oven-dry weight is measured from the same sample by drying it in a well ventilated oven until it achieves constant weight (this usually takes 48 to 72 hours). Drying depends on the quality of the drier, and it is necessary to test the constant weight hypothesis by weighing the samples at regular intervals. The samples should be weighed immediately after being taken out of the drying oven, because tropical air is often water-saturated.

We carried out a direct comparison of the geometrical method and of the water displacement method on 26 samples belonging to 17 species in French Guiana (J Chave, unpublished results). The correlation coefficient between the two methods was very high ($r^2 = 0.976$) and the water displacement method yielded smaller estimates than the geometrical method (ratio 0.94). The water displacement method seems to be a more reliable and also a simpler method than the geometrical method.

4. Schedule for wood density collection at Korup

The species list below ranks the species in decreasing order of priority. *Oubangia alata* is the highest priority. Core at least 10 trees (in different environments and/or size) for the 10 most important species, and at least 5 for the remaining 40 species. This is a total of 300 cores. In general, try to follow the forthcoming rules:

1. Some of the species below may never or very rarely achieve 10 cm in dbh. Since the advised dbh range for carrying out the wood sample collection is 10-30 cm, please ignore these species.
2. inasmuch as possible, try not to restrict your measurements to a few genera/families, but try to sample as many (important) genera as possible. For instance, the list below has four species of *Cola*. One or two may suffice to improve our knowledge of the wood density in this genus.
3. Some species might be very hard. Try to do the soft species first, then the hard ones, as the likelihood of breaking the borer is higher for the latter.

DO NOT THROW AWAY THE SAMPLES AFTER THE MEASUREMENTS. Carefully keep them, and ship them to the following address:

Dr. Jerome Chave
Laboratoire Evolution & Diversite Biologique
Batiment 4R3, Universite Paul Sabatier
31062 Toulouse, France

I will perform additional physical and chemical analyses on the samples, as part of the project. All shipping charges will be covered.

It should be possible to collect at least 20-30 cores per day, so the agenda above would amount to 15 full days of field work. Additional lab work may amount to an additional 5 days of work, that is a total of 20 days. Including vacations, this would correspond to a full month of work. It is essential that field workers are very careful with the equipment.

	sp	Genus	Species	family	Basal area	Trees
1	OUAL	*Oubanguia*	*alata*	Scytopetalaceae	4.26	14918
2	LEKL	*Lecomtedoxa*	*klaineana*	Sapotaceae	1.98	303
3	DIGL	*Dichostemma*	*glaucescens*	Euphorbiaceae	1.56	17251
4	PRST	*Protomegabaria*	*stapfiana*	Euphorbiaceae	1.40	3367
5	STPU	*Strombosia*	*pustulata*	Olacaceae	0.69	4119
6	COSE	*Cola*	*semecarpophylla*	Sterculiaceae	0.63	24518
7	OCT2	*Cola*	*praeacuta*	Sterculiaceae	0.62	15471
8	KLGI	*Klaineanthus*	*gaboniae*	Euphorbiaceae	0.62	2031
9	DIGA	*Diospyros*	*gabunensis*	Ebenaceae	0.55	3899

10	HYAF	*Hymenostegia*	*afzelii*	Fabaceae	0.55	4025
11	DRST	*Drypetes*	*staudtii*	Euphorbiaceae	0.50	4100
12	DEGL	*Desbordesia*	*glaucescens*	Irvingiaceae	0.50	83
13	ERIV	*Erythrophleum*	*ivorense*	Fabaceae	0.49	79
14	CORO	*Cola*	*rostrata*	Sterculiaceae	0.49	3287
15	STTE	*Strombosiopsis*	*tetrandra*	Olacaceae	0.46	1763
16	ZATE	*Zanthoxylum*	*gilletii*	Rutaceae	0.35	282
17	VIT2	*Vitex*	*sp._1*	Verbenaceae	0.35	77
18	SOTA	*Soyauxia*	*talbotii*	Medusandraceae	0.33	3182
19	COLA	*Cola*	*lateritia*	Sterculiaceae	0.32	465
20	STRO	*Strombosia*	*sp.*	Olacaceae	0.32	2523
21	HYZE	*Hypodaphnis*	*zenkeri*	Lauraceae	0.32	299
22	TABR	*Tabernaemontana*	*brachyantha*	Apocynaceae	0.30	3583
23	ALBO	*Alstonia*	*boonei*	Apocynaceae	0.30	66
24	STPO	*Strephonema*	*pseudocola*	Combretaceae	0.28	146
25	STSC	*Strombosia*	*scheffleri*	Olacaceae	0.28	1216
26	EREX	*Erismadelphus*	*exsul*	Vochysiaceae	0.28	249
27	DIIT	*Diospyros*	*iturensis*	Ebenaceae	0.27	4794
28	STAU	*Staudtia*	*kamerunensis*	Myristicaceae	0.27	194
29	POOL	*Poga*	*oleosa*	Anisophylleaceae	0.27	11
30	BAPI	*Baphia*	*capparidifolia*	Fabaceae	0.25	1767
31	DIOG	*Diogoa*	*zenkeri*	Olacaceae	0.25	3219
32	PHSP	*Phyllobotryon*	*spathulatum*	Flacourtiaceae	0.23	26728
33	SCCO	*Scottellia*	*klaineana*	Flacourtiaceae	0.23	599
34	GACO	*Garcinia*	*conrauana*	Guttiferae	0.23	1287
35	TAAF	*Tapura*	*africana*	Dichapetalaceae	0.22	418
36	TAEK	*Talbotiella*	*eketensis*	Fabaceae	0.21	922
37	IRGA	*Irvingia*	*gabonensis*	Irvingiaceae	0.20	132
38	LOAL	*Lophira*	*alata*	Ochnaceae	0.20	39
39	UAST	*Uapaca*	*staudtii*	Euphorbiaceae	0.19	1183
40	XYAE	*Xylopia*	*aethiopica*	Annonaceae	0.18	217
41	HOLO	*Homalium*	*longistylum*	Flacourtiaceae	0.18	535
42	ANFR	*Anthonotha*	*fragrans*	Fabaceae	0.18	247
43	RILE	*Rinorea*	*lepidobotrys*	Violaceae	0.17	5492
44	ENCH	*Annickia*	*chlorantha*	Annonaceae	0.17	707
45	RIN2	*Rinorea*	*oblongifolia*	Violaceae	0.16	3020
46	GUAR	*Guarea*	*thompsonii*	Meliaceae	0.16	116
47	CADI	*	*	Fabaceae	0.15	3066
48	VITI	*Vitex*	*sp._3*	Verbenaceae	0.15	135
49	HUUM	*Hunteria*	*umbellata*	Apocynaceae	0.15	873
50	SATR	*Santiria*	*balsamifera*	Burseraceae	0.15	138