

Permanent Field Plot Methodology and Equipment¹

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Abstract: Long-term research into the composition, phenology, yield, and growth rates of agroforests can be accomplished with the use of permanent field plots. The periodic remeasurement of these plots provide researchers a quantitative measure of what changes occur over time in indigenous agroforestry systems.

Permanent plot methodology can be used to conduct several different types of surveys. Two that are appropriate to the Pacific are island-wide and case studies. An island-wide survey is ideal for obtaining baseline information concerning agroforest composition. Remeasurement of the plots will provide growth rates and change information.

Product yields and phenological information from the agroforest are somewhat difficult to obtain from an island-wide survey. Many times the logistics of obtaining this information from all of the permanent plots is too difficult or time-consuming. Many times the plots have to be visited weekly or monthly to determine yields or the onset of flowering or fruiting. To overcome these problems, a subsample of the original plots can be randomly selected and used to collect the data. The information obtained from the subsample can then be expanded to an island-wide basis.

Conversely, case studies are used to focus in on ecological or cultural processes underway in the agroforests. A case study would involve the intensive study of a specific agroforest site. This research is not aimed at determining how many breadfruit or coconut trees there are on the island, but is concerned with broader processes such as plant interactions, nutrient cycling, cultural practices, competition, or other facets of the agroforest system.

Plot Referencing

A key factor when establishing permanent plots is the referencing of the plot and individual plants so as to be able to relocate them in the future. Appendix 1 lists procedures used by the USDA Forest Service to reference permanent plots. Plots established in this manner on Pohnpei have been relocated and remeasured after a 7-year period.

Two methods are commonly used to mark individual trees: metal tags or tree marking paint. In the forest, we mark trees with an aluminum number tag and nail. In addition we physically mark where the diameter is measured with a nail. Farmers probably would not approve the use of nails to mark their agroforest plants and trees. An alternative is the use of tree marking paint, although the paint will wear off eventually. Marking

each tree with a number on the base and at d.b.h. will help prevent remeasurement errors (Avery 1975, Spun: 1952). In addition to being tagged or painted, each plant has its physical location referenced by measuring the distance and compass bearing to plot center. If the tree tag is lost or paint rubbed off, the plot can still be reconstructed using this spacial^[sic] information. The plot center can also be relocated with this individual tree data. We need to know the location of plot center when the plot is remeasured to determine ingrowth and any new plantings.

Measuring the Tree Component

The measurement of the tree component (in contrast to crop component) of the agroforest can be accomplished by using a multi-resource inventory form (Appendix 2). The inventory techniques and field forms were developed by the Forest Inventory and Analysis for Pacific Coast States Research Work Unit of the USDA Forest Service's Pacific Northwest Research Station. They were used to conduct a forest inventory in the mangroves and upland forests of Micronesia and American Samoa (Cole and others 1988; MacLean and others 1988a, 1988b). This form will be useful if one of the objectives of the research is to determine tree volume. Field procedures, codes, and data items on the form are explained in Appendix 1.

Equipment needed for permanent growth plot work is common to the forestry profession and includes:

- diameter tape
- loggers tape (15 meter [m])
- cloth tape (30 m)
- compass
- bark thickness gauge
- Relaskope (or other hypsometer if volume is not determined)
- nails, hammer, numbered tags, or paint
- clip board and field forms
- map and aerial photographs

This equipment may be purchased from several suppliers, four of which are listed in Appendix 3.

Tree Volume

Determining the cubic volume of trees is a traditional method of reporting yield. One of its most common uses is in the estimation of the quantity of lumber or biomass which the tree contains. While it is unlikely that the agroforests will be harvested, select trees may be removed. This is especially true for breadfruit trees, which may become overmature, leading to low fruit yields. Other forest trees may be present in the agroforest which were specifically planted or kept by the landowner for timber. Volume is useful information for the farmer to have.

Volume is also a common measurement used for describing tree growth. Many models report growth as an increase in cubic

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volume (Goodwin 1986, Waring 1983). Using volume (cubic meters) to report growth or the size of the trees allows comparisons to be made between species and sites. Describing growth using only diameter and height measures is deceptive because a small increase in diameter equates to a large increase in the volume of the tree. Conversely, a large increase in height does not increase volume significantly. Two factors contribute to this phenomenon: First, height growth tends to occur in the branches, whereas the major volume portion of a tree is its stem. Secondly, the formula for area of a circle used in volume calculations (see volume formulas below) has a multiplicative effect. A doubling of diameter causes a fourfold increase in volume (1:4 ratio), whereas a doubling of height only doubles the volume (1:1 ratio).

Tree volumes are calculated by dividing the tree into conic or geometric sections (fig. 1). The tree is ocularly divided into logical segments and the diameter and height estimated at both the top and bottom of the segment (or at the mid-point). These measurements are then used to estimate the cubic volume of wood in the segment.

Various formulas may be used to calculate wood volume. One is Smalian's formula for a paraboloid frustum. Two others are Newton's and Huber's, which are based on measuring the diameter at the mid-point of the segment (Hunch and others 1972):

Smalian's: $\text{Volume} = H/2 (A_t + A_b)$ (overestimates volume)

Huber's: $\text{Volume} = H (A_m)$ (underestimates volume)

Newton's: $\text{Volume} = H/6 (A_t + 4A_m + A_b)$ (most accurate)

where: A_t = cross-sectional area at top

A_m = cross-sectional area at middle

A_b = cross-sectional area at bottom

H = length of the segment

The biomass of the branches are calculated in the same manner as calculating wood volume. The thickness of the bark is subtracted from each of the diameter measurements to compute the solid wood content of the tree.

Several types of hypsometers are available which may be used to estimate height. Most of these instruments operate on the

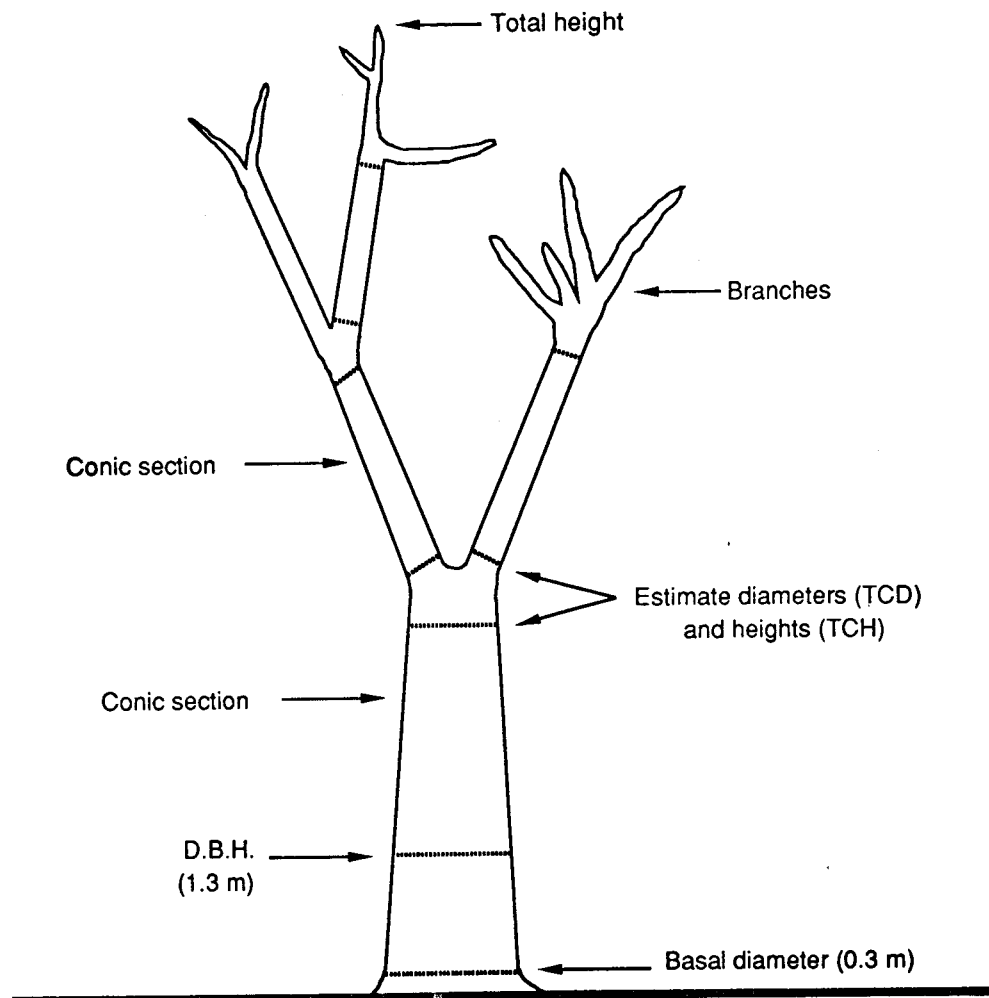


Figure 1-Tree ocularly divided into conic sections for volume estimation

theory of right triangles (fig. 2). A hypsometer is basically a device which reads angles from the vertical. Most are calibrated so that when you stand at a known distance from the tree, the height is read directly from the scale. Others read the angle in percent from the vertical. The reading is then multiplied by the distance from the tree to determine the height of the tree.

Besides knowing the height of the tree, the cross-sectional area of the top and bottom of the segment are needed to estimate volume. We use a instrument called a Relaskop, which—besides measuring heights—can be used to estimate upper stem diameters. The Relaskop is fairly simple to operate and very flexible. Instead of being calibrated to only one distance, diameters and heights can be read directly from the scales at five different distances (10, 15, 20, 25, 30 meters) from the base of the tree.

The Relaskop has three height scales: the 20, 25, and 30 meter (fig. 3). The name of the scale is also the base distance from the tree. Both the 20- and 30- meter scales can be divided in half to create 10 and 15 meter scales. At 10 meters from the tree the 20-meter scale is used to estimate the height or diameter, all readings are divided by two.

Upper stem diameters, depending on the base distance, are estimated by using the No. 1 wide band and the four narrow black and white bands (4 narrow bands =1 wide band). The wide and narrow bands correspond to the following upper stem diameters at various base distances:

Distance (m)	No. 1 wide band (cm)	Narrow band (cm)
10	20	5.0
15	30	7.5
20	40	10.0
25	50	12.5
30	60	15.0

When looking through the viewfinder, you can see the left side of the stem aligned with the edge of the No. 1 band (fig. 4).

The right side of the tree, if large, will then line up with one of the narrow bands. For example, if the stem of the tree covers the wide band and 3.5 narrow bands, then the diameter is 56.25 cm when 15 m from the tree. We can usually estimate to one-half of a narrow band.

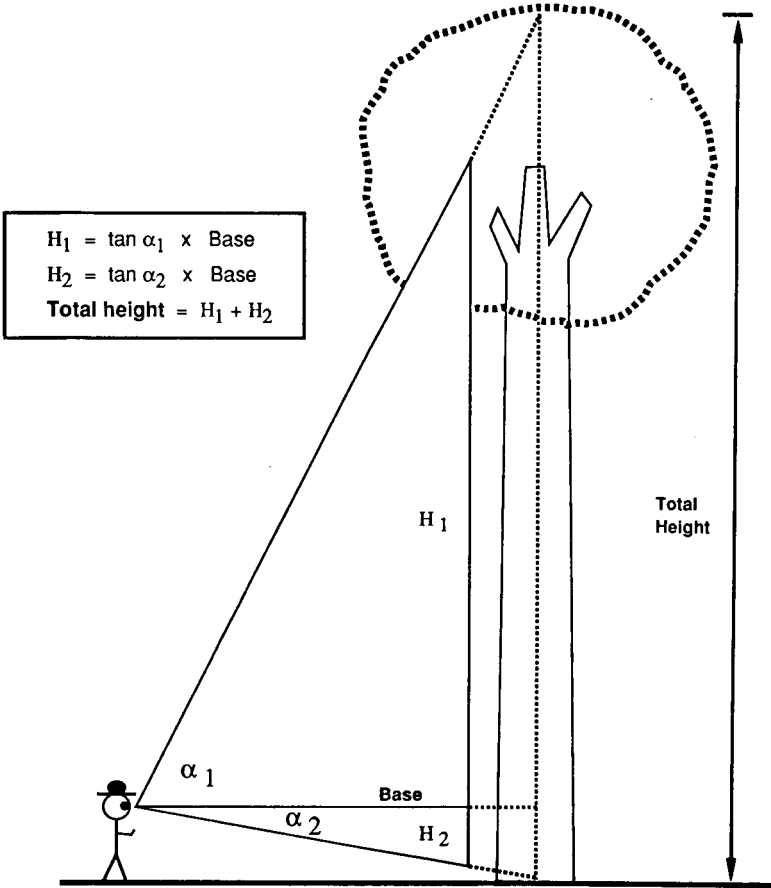


Figure 2-Right triangle theory behind operation of hypsometers

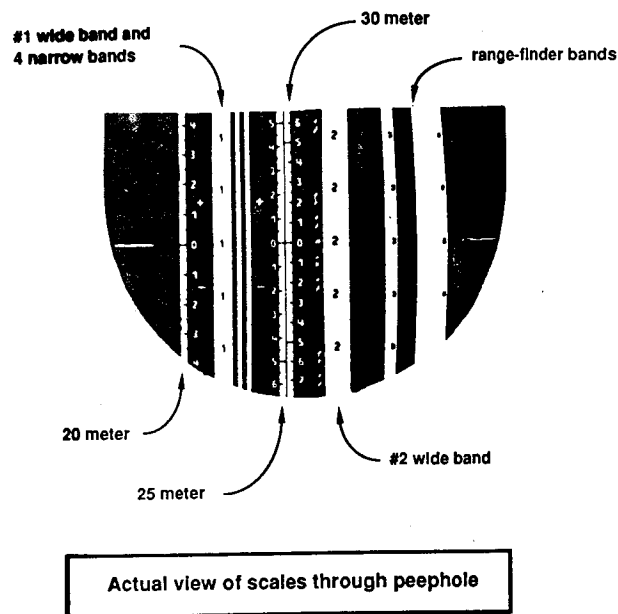


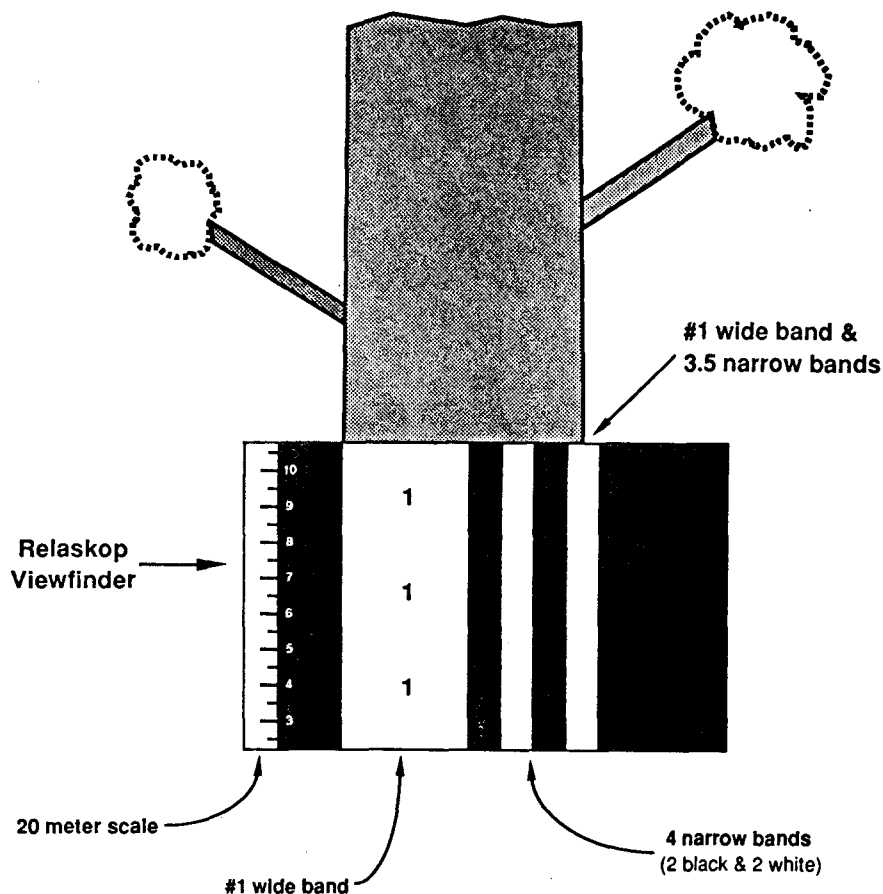
Figure 3-Relaskop scales, full length and as actually seen through viewfinder

Summary

Establishing permanent plots is costly and time consuming. Therefore, it is important to clearly define the objectives of the work long before it starts. The questions to be answered must be known so the work can be designed to answer them. I recommend the FAO's *Manual of Forest Inventory* as a good reference to read before attempting any survey. The worst thing is to complete a survey and find out you needed to take one more measurement or reading in order for the data to be valid. Proper planning will prevent this.

References

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Base distance (m)	Diameter of tree (cm)
10	37.50
15	56.25
20	75.00
25	93.75
30	112.50

Appendix 1—Field Procedures for the Establishment of Permanent Growth Plots

The sequence of the following procedures is presented in approximately the same order as the numbering sequence on the field form.

Locating the Plot on the Ground

Planning Travel

Before starting field operations, each field crew must have:

1. Maps - with field plot locations shown.
2. Aerial photos - with field plot locations, photo scale, and magnetic north arrow shown.

The plot location will be marked on the front of the photo. The ground plot number and the photo scale will be marked on the back of the photo. Maps are used in traveling to the general vicinity of the plot. Aerial photos are used to locate the plot as marked on the photo. Field crews will select the field plot locations to be visited each day before the day's work and determine the best and quickest route of travel to the plots.

Referencing Plot Location

The crew will first find a point on the ground (preferably a tree) in the general plot vicinity which can be readily identified on both the ground and the photo. This point, called the Reference Point or *RP*, should not be more than 200 m from the plot

point marked on the photo, if at all possible. However, a point of more than 200 m, if clearly identifiable, is preferable to one closer if the identification of the closer point is uncertain. *Crews should record on the field form any distinctive cultural or topographic features which will help in relocating the field plots.* Distances from key road, trail, or stream intersections, and changes since photography, such as cutting and roads, should be noted where these will help in future relocation.

Selecting RP Tree

Select a tree distinctive on both the photo and ground. Using a stereoscope, carefully prick the base of the tree if visible, or where it appears to be from the crown position and shadow on the photo, and circle and label it RP on the back of the photo. Also record the RP tree species and d.b.h. on the field form. This will be the *Reference Point* or *RP* which marks the beginning of the compass course to the plot. *Since this RP tree is a critical item in the relocation of the sample plots, it should be one not likely to die or be cut within the next 10 years.* Where a suitable reference tree is not available, another object may serve as a RP, e.g., a distinctive fence corner, building corner, etc. If such is used, indicate this on the field form and clearly describe it.

Determining Azimuth and Distance from RP to Plot Location

Determine the azimuth to the nearest degree and the distance to the nearest 5 m from the RP to the plot.

Record the distance and azimuth on the field form.

Referencing by Inspection

At times the plot center can be located on the ground by inspection much easier and more rapidly than by measuring from the RP tree. This will often be the case in open stands or when a plot falls in a small opening or other spot that can be located precisely by photo interpretation.

When referencing by inspection, the crew will first locate and *mark* the plot center. The distance to the nearest meter and azimuth will be measured on the ground rather than scaled off the photo. *All plot reference data must be filled out on the plot card.* Indicate that the plot was referenced by inspection.

Marking RP Tree

Survey crews will nail aluminum plot tags (square tags) on the RP tree at d.b.h. and below stump height. Drive the nails into the tree at an upward angle and always leave at least 5 cm of nail exposed. Scribe the RP information on this tag. Enter the symbol RP, plot number, azimuth from the RP tree to plot location to nearest degree and distance.

Example: RP

#020

325°

100 m

If the RP tree might be in the plot, tag the tree as above.

Plot RP Data

Before leaving the RP tree and moving to the plot, *record* photo number and required reference data on field form:

SP Record appropriate species code of plot reference tree.

DBH Record diameter of plot reference tree to the nearest centimeter.

AZ Record azimuth to nearest degree from plot RP to plot center.

DIST Record distance from RP tree to plot center.

Establishing the Plot

Measure from the RP to the plot center along the proper azimuth and distance. Flag and tag trees along the course of travel to aid in relocating the plot. At the end of the measured distance, mark plot center and double check photo to see if you are in the correct location. If not, move to correct location and not the direction and distance moved on the field form. Mark the plot with a meter length of PVC pipe leaving 0.5 m above the ground.

Referencing and Marking Plot Center

Begin plot establishment:

1. Select two witness trees which are near the plot center and which form, if possible, nearly a right angle with plot center and each other.

2. Scribe on the aluminum tags the plot number, witness tree number, and azimuth and distance to plot center pin.

3. Nail the tags at eye level and below stump height on each tree on the side facing the plot center pin. Leave at least 5 cm of the nail exposed.

4. For each witness tree, record the following:

Species

Diameter

Azimuth to the nearest degree from plot center to the witness tree.

Slope distance to nearest one-tenth meter from plot center to witness tree.

Tree Data

Point (PN) Record point number for plots that have multiple point.

Tree Number (TN) Record a 2-digit tree number for all plants or trees. The number will be tagged on the tree below stump height (> 0.3 m) on the side facing the center pin.

Species Code (SPC) Record the species code. This is usually the first two letters of the genus and species names (4-digit code). If a variety then add the first letter of the varietal name to the normal species code.

Azimuth (AZ) Record the azimuth as a 3-digit code. Starting from 0° (magnetic north), measure clockwise from plot center to the center of the tree or plant.

Distance (DIS) Record measured *slope* distance as a 3-digit code to the nearest tenth meter from the center of the tree at d.b.h. to the center pin.

History (H) Record a 1-digit history code as listed below:

Code	Description
1	Live plant or tree
2	Dead plant or tree (salvable)
3	Live plant or tree recorded on previous survey (i.e., a survivor).
4	New live plant or tree <i>not</i> recorded on previous survey (ingrowth).
5	Standing dead plant or tree recorded as alive on previous survey (salvable dead).
6	Nonsalvable dead tree, recorded as live tree on previous survey.
7	Plant or tree recorded as live on previous surveys, but now missing (stump present).
8	Plant or tree missed on previous survey.

Damage Code (DC) When something is wrong with a plant or tree that will prevent it from (1) living to maturity or surviving 10 or more years if already mature or (2) producing marketable products (e.g., fruit, straight logs), a damage code is appropriate. Damage codes are to be used for severe damage or pathogen activity on live plants or trees. When damaged by more than one serious agent, code the most severe one.

Code	Damage or Cause of Death
00	No serious injury or damage
01	<i>Insects</i>
11	Bark beetles
12	Twig borers
13	Defoliators
20	<i>Disease</i>
21	Conks
22	Mistletoe
27	Other disease or rot
30	Fire damage
40	Animal damage
50	<i>Weather damage</i>
51	Lightning
52	Wind
69	Suppressed
70	Natural mechanical injury
71	Top out, dead, or spike top
72	Leaves noticeable small and/or sparse or off color
75	Logging or construction damage (powered equipment)
80	Unknown

Cull (CU) Cull is used in the determination of net volume. For all trees estimate the percent volume loss due to rot, missing portions, or deformation. A 1-digit code is used:

Code	Cull (percent)
1	Less than 10
2	10-25
3	26-50
4	More than 50

Crown Ratio (CR) Crown ratio or percent of tree height in live crown is expressed as a percent of total tree height, including dead, broken, or missing portions of the tree (crown length divided by total tree height).

For trees of uneven length, ocularly transfer lower branches on the longer side to fill holes in the shorter side until a full, even crown has been generated. A 1-digit code is used:

Code	Crown ratio (percent)
2	less than 20
4	21 - 40
6	41 - 60
8	61 - 80
9	greater than 81

Crown Class (CC) Crown class is a designation of those trees in a forest having crowns of similar development and occupying similar positions in the crown cover. A 1-digit code is used:

Code	Crown class
1	Open grown
2	Dominant
3	Codominant
4	Intermediate
5	Overtopped

Descriptions of the five crown classes used are:

Open grown—trees growing in the open, receiving full light from above and from the sides; not crowded from the sides.

Dominant—trees with crowns extending above the general level of the crown canopy and receiving full light from above and partly from the side; taller than the average trees in the stand.

Codominant—trees with crown forming the general level of the crown canopy and receiving full light from above but comparatively little from the sides; usually with medium-size crowns more or less crowded on the side.

Intermediate—trees shorter than dominants or codominants, with crowns below or barely reaching into the main canopy foamed by dominant and codominant trees; receiving little direct light from above and none from the sides and usually with small crowns considerably crowded on the sides.

Overtopped—trees with crowns entirely below the general level of the canopy, receiving no direct light from either above or from the sides.

Form Factor (FF) Omit, not used.

Diameter at Breast Height (d.b.h.)

Record current d.b.h. to the nearest 1/10 cm as a 4-digit code for all plants or trees greater than 2.5 cm in diameter and 2.0 m tall. Diameters will be measured at a point 1.3 m above the ground level or root collar on the uphill side of the tree, except as

noted below for treefern or irregularities at d.b.h. A measured d.b.h. of 25.0 cm is recorded 0250.

Each plant or tree in the plot should be marked with an aluminum nail (painted) at the point where d.b.h. is measured. All trees should be nailed on the side of the tree facing plot center on level ground, or on the uphill side of the tree on slopes. Leave as much of the nail exposed as possible, provided it is solidly affixed to the tree.

Measure the diameter directly above the nail. Check for bole irregularities before measuring d.b.h.

When measuring d.b.h., it may be necessary to remove branches to make the measurement. Do not chop off limbs other than to make a more accurate, efficient measurement. To do otherwise treats the plot differently from other areas, offends some landowners, may harm the tree, and wastes time.

For treefern, diameters will be measured at a point 1 meter above the ground.

In case of irregularities at d.b.h.; i.e., swellings, bumps, depressions, branches, etc., diameter will be measured immediately above the irregularity at the place where it ceases to affect the normal stem form. If possible, mark the point of measurement with an aluminum nail.

Fork at or above 1.3 meters—consider it a single tree. Measure diameter below the swell caused by the fork, but as close to 1.3 m as possible.

Fork below 1.3 meters—consider each fork as a separate tree. Measure diameter 0.5 m above fork if possible or at 1.3 m above the ground, whichever is higher on the tree.

Two trees grown together—when two closely spaced trees grow together, they will sometimes have the appearance of a forked tree. This is common in some mangrove stands. Such trees should be treated as separate trees and recorded as such. Diameter will be determined by driving two nails half way around the circumference from each other, measuring the distance with a diameter tape, and doubling the result.

When the diameter is physically impossible to measure with a diameter tape because of forking, huge root collars, etc., then the diameter will be measured with a Relaskop. Record under remarks, “d.b.h. estimated.”

DBH Height (DBH HT) Record the height d.b.h. is actually measured at, usually 1.3 meters.

Treefern (TF) Merchantable length of a treefern trunk is taken from ground level to a point 1 meter below the base of the live fronds. Minimum length for treeferns is 1 meter. The length will be measured to the nearest half meter and recorded as a 3-digit code; e.g., 3.4 meters would be 035.

Double Bark Thickness (DBT) Measure and record double bark thickness at d.b.h. to the nearest tenth centimeter. Record as a 3-digit code. Use code 999 for treefern.

Basal Diameter (BD) Record current basal diameter to the nearest tenth centimeter as a 4-digit code for all trees. Diameters will be measured at a point 0.3 meters above the ground. A measured basal diameter of 26.3 is recorded 0263. In the event of excessive flutes or other deformities, estimate basal diameter.

Basal Diameter Height (BD HT) Record the height where basal diameter is measured or estimated.

Tree Volume Measurements

Due to extreme intra-species variability in growth form, tree volumes will be computed based on geometry or conic sections. The length of the conic sections will be determined by up to three taper changes (TC) in the tree form which affect volume.

For trees with sawlogs, a mandatory taper change is the top of the sawtimber portion which may be limited by defect, branches, dead top, deformity or minimum top diameter outside bark of 22.5 cm.

For trees with forks or excessive branches in the upper stem, the main crotch will be measured and a specific number of branches will be given an average upper/lower diameter and average length.

Taper Change Diameter (TCD) Record to the nearest cm the diameter outside bark at points along the bole above d.b.h. where taper changes occur (field form has space for recording two measurements).

Taper Change Heights (TCH) Record to the nearest half meter the height from the stump to points along the bole where taper change diameters are taken (field form has space for recording two measurements).

Sawlog Classification (SC) For each tree record the appropriate code to identify presence or absence of sawlogs.

Code	Quality	Definition
1	No sawlog	Trees with d.b.h. ? 27.5 cm with less than one 2.5 m butt log.
2	Sawlog	Trees with d.b.h. > 27.5 cm with at least one 2.5 m butt log.

Crotch Height (CH) Record to the nearest half meter the height to the top of the crotch.

Upper Stem Diameter (USD) Measure the top diameter outside bark to the nearest cm of the upper stem, usually to a 10 cm top.

Upper Stem Height (USH) Measure the height to the nearest meter of the upper stem to 10 cm top outside bark. The upper stem measurement is to be used only for the portion of the main stem above the sawtimber portion.

Tip Diameter (TiD) Record the diameter of the tip of the main stem, usually 0.1 cm.

Tip Height (TiH) Record the height to the tip of the main stem.

Number of Branches (NB) Record number of upper branches. Record 99 for no branches.

Lower Branch Diameter (LBD) When multiple branches occur, estimate the lower branch diameters, average them, and record to the nearest cm. Record 99 for no entry.

Branch Length (BL) Estimate the branch lengths to the tip, average them (if necessary), and record as a single entry to the nearest meter. Record 99 for no entry.

Upper Branch Diameter (UBD) Record the diameter of the tips of the branches, usually 0.1 cm.

Total Height (TH) Measure total height for all tally trees to the nearest meter. Total height is the height from the tree base to the top of the tree. Record as a two digit code, e.g., 25.4 meters would be 25.

Bolts

Record the number of craftwood bolts. A craftwood bolt is a 2-meter portion of a tree about the merchantable sawlog top, meeting a specified diameter. These bolts are used for production of handicrafts.

For all species with craftwood potential 27.5 cm d.b.h. and larger, record the number of craftwood bolts. In the case of high value trees with excessive forking, estimate craftwood bolts in the whole tree. Record the number of bolts by mid-diameter classes as follows: 25, 35, 45, 55, 65, 75.

Appendix 3—Sources of Forestry Equipment³

Forestry Suppliers
P.O. Box 8397
Jackson, MS 39284-8397
(phone 601-354-3565)

Ben Meadows Company
P.O. Box 80549
Atlanta, Georgia 30366
(phone 404-455-0907)

Bailey's Western Division
44650 Hwy. 101
P.O. Box 550
Laytonville, CA 95454
(phone 707-984-6133)

General Supply Corporation
P.O. Box 9347
303 Commerce Park Drive
Jackson, MS 39286-9347
(phone 601-981-3882)

³ Trade names and commercial enterprises on products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture or other agencies is implied.