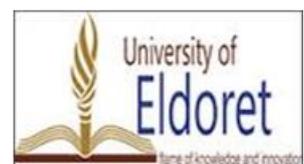


# Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA)



## Field Manual for Tree Volume and Biomass Modelling

May 2016



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**Cover caption:** Front page photograph by M. N. Muchiri: Processing *Grevillea robusta* tree for data collection

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## **PREFACE**

This manual is based on earlier tree data analysis and forest biomass estimation studies and FAO guidelines. Thanks to all staff of Kenya Forestry Research Institute (KEFRI), University of Eldoret (UoE) and Kenya Forest Service (KFS) involved in development of this manual. The authors wish to most sincerely thank Dr. Kalle Eerikäinen (Luke) for his work related to forest biomass estimation. This manual is based on instructions for collecting tree analysis data in the projects, *Forest Resource Assessment (FRA) in Nepal* and *Improving Capacity of Forest Resource Information Technology in Vietnam and Nepal* that were coordinated by Dr. Kalle Eerikäinen.

The workshop on Tree modelling held on 24–25 February, 2014 at KFS Mau Conservancy Headquarters in Nakuru contributed significantly to this guide. Selection of tree species for and approach for data collection was agreed during the workshop. We sincerely thank all workshop participants for the active participation in discussions. We are also most grateful for comments, suggestions and corrections by others who greatly contributed to improvement of this field manual.

## 1. INTRODUCTION

When collecting information in large-scale forest inventories, the general principle is to assess stand and tree attributes efficiently in terms of costs and accuracy. Due to limiting amounts of time and resources available for the fieldwork, it is necessary to determine an appropriate set of characteristics to be measured and a suitable sample size in terms of the units sampled and the individual parameters measured within them. It is often the case in large-scale forest inventories that only easily assessable characteristics (diameter at breast height) are measured for all trees, whereas difficult-to-measure variables (e.g., total height and height to the living crown) are measured for a sub-sample, i.e. tally trees. In order to obtain variables respective to the sampled (including sub samples for more detailed measurements), generalization techniques need to be applied. These may be either parametric (see Lappi 1991, Lappi et al. 2006, Temesgen et al. 2008, Eerikäinen 2009) or nonparametric (see Korhonen and Kangas 1997).

Some tree variables, including volume and biomass are extremely time consuming to measure in field inventories, and need to be predicted by using statistical prediction models prepared in surveys separate to those of operational forest inventories. However, in many cases, there are no models available for predicting different volume and biomass components that are country specific and based on data covering the entire target area of forest inventory. Due to the increasing importance of the carbon-sequestration and REDD+ related assessments, new demands are also set for the country-level forest inventories including up-to-date, accurate and multifunctional models for predicting biomass attributes for trees and forests comprising not only the above-ground but also the below-ground components of biomass.

Collecting data for developing tree volume and biomass models is very time consuming and expensive and requires a lot of precise measurements and sampling operations along a tree. In this Field Manual, the stem analysis refers to the measurements carried out for determining empirical stem taper curves over-bark and under-bark, i.e. diameters along the stem that are needed for estimating volumes for stem wood and bark. In statistical analyses, the stem analysis data are further utilized for modelling purposes (e.g., stem volume models and taper curve models for predicting stem volumes and diameters, respectively, over-bark and under-bark) (e.g., Eerikäinen 2001).

For estimating tree biomass, the tree analysis is conducted by measuring weights of different components of tree and by taking biomass samples of the components (e.g., Repola 2009). The general principle in biomass estimation is the relationship between fresh biomass of the tree components measured in the field, fresh biomass of the sample and oven-dried biomass of the sample. Because different parts of the tree have different density and moisture content, the tree is divided into the following compartments: the stem (trunk), the wood distinguished from the bark and saw logs to determine the wood density and moisture content in sections of different diameters; branches usually sampled by size classes; foliage, leaves and needles including buds, flowers and fruits; stump and lastly roots by diameter classes.

In this manual instructions are provided for organizing data collection to estimate the following individual-tree characteristics:

- 1) Total over-bark and under-bark stem volumes;
- 2) Utilizable over-bark and under-bark stem volumes in the case of commercially important tree species;
- 3) Total above-ground biomass (dry mass) in major components of stem wood, stem bark, living branches, dead branches, and foliage (leaves or needles); and
- 4) Total below-ground biomass (dry mass) in its major components of stump and roots ( $\varnothing \geq 0.5$  cm).

## 2. PAST STUDIES ON TREE AND STAND LEVEL MODELLING IN EASTERN AFRICAN COUNTRIES

A review of studies on tree and stand level modelling in Kenya and other Eastern African countries showed the focus has mainly been on plantation tree species including *Pinus patula*, *P. radiata*, *Cupressus lusitanica* and *Eucalyptus* spp, and on stand growth and yield rather than on individual trees. Furthermore, the models are often based on data from restricted areas and may not be relevant at the national scale. Equations to predict tree biomass have only been considered recently because of the increasing importance to estimate forest carbon stocks.

## 3. SAMPLING FRAME

A general principle while obtaining biomass and volume modelling data for purposes of large-scale inventory is to determine a sample of trees that is representative with respect to the entire population.

The mostly used tree variable for selection of trees to be analyzed is diameter at breast height (dbh) normally measured at 1.3 m height from the ground. The target is to obtain data covering the total range of the selected variation of tree species. For maximizing the variable by size classes in the data, the trees are selected from several stands with varying development stage, density, structure, management regime, and representing different site conditions. Trees growing in unrepresentative environment (forest edge, clearing, degraded forest) should be excluded because their size and form differ from those growing in normal sites. Likewise, damaged or abnormal trees (trees with broken crown, hollow or excessively knotty stem) should be excluded from the sample.

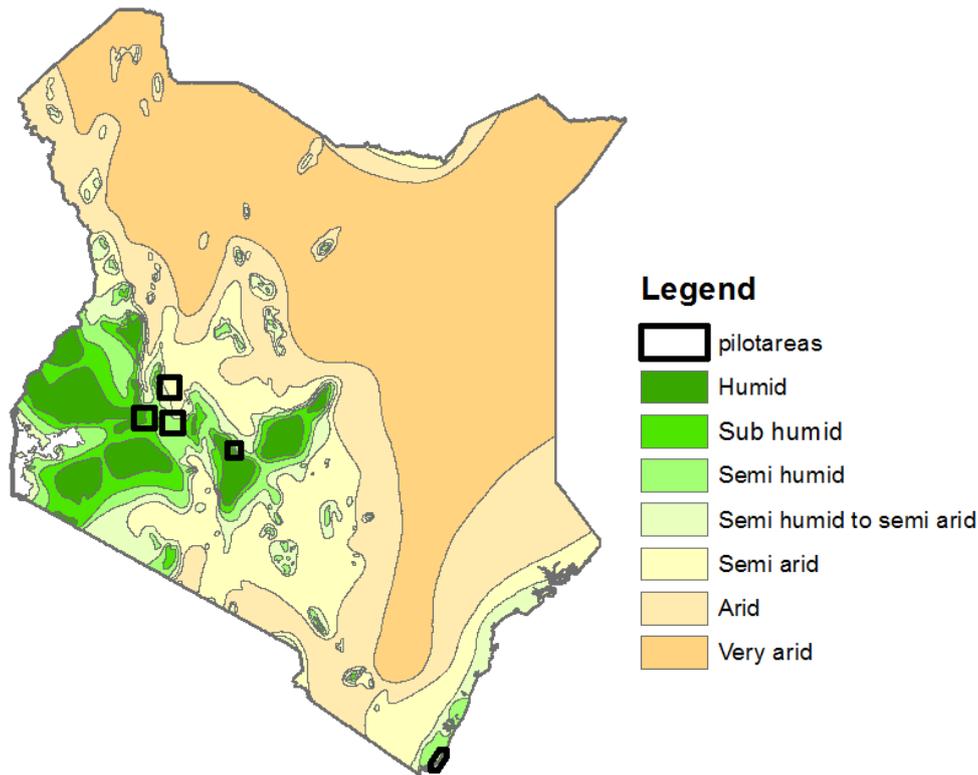
The sampling is targeted to the most important tree species and a pre-determined number of trees by the selected species is obtained by the end of field data collection. Sample trees for each species are obtained from varying climatic conditions and different agro-ecological zones (Figure 1).

The characteristics used in selecting sampling of trees to ensure data are collected from a representative sample of the whole population are:

- Agro-ecological zone,
- Vegetation type,
- Forest stand characteristics: diameter distribution, age, density, species composition and management regime.

The allocation of sample trees into size classes by species is directed by determining the species maximum diameters and by weighing matrix. The samples are directed towards larger size classes, and species specific weights are used for adjusting the number of analysis trees by ecological zones to equal their present target values if they are known.

The four tree species selected for biomass and volume modelling were: *Acacia mellifera*, *Grevillea robusta*, *Neoboutonia macrocalyx* and *Juniperus procera*). *Grevillea robusta* is the most popular trees on farms, and *J. procera* and *N. macrocalyx* were the most common trees in the natural forests in the pilot areas inventoried by ICFRA Project. *Grevillea robusta* is exotic species originally from Australia and the other species are native to Kenya.



**Figure 1.** Agro-ecological zones in Kenya and the test areas of the IC-FRA pilot inventory.

An appropriate sample size of trees to be analyzed for biomass per tree species is at least 40 individual trees and includes trees across the species diameter range and the other characteristics outlined above. Determining the number of sample trees by species and selecting them in the field is based on the prior information from previous inventories, species spatial distribution maps and local knowledge. The ICFRA pilot inventory data provided information on the selected species distribution by vegetation type, agro-ecological zone (Table 1) and diameter by Land use/cover (Appendix 2). An advance team consisting of specialists from KFS, KEFRI and UoE was responsible for selecting the representative sample sites across the species spatial distribution and allocating the sample trees by sample sites and tree size classes. The field team leaders were responsible for selecting appropriate sample trees on the sites.

**Table 1.** Distribution of the sample species by vegetation types and ecological zones.

Species	Vegetation type	Agro-ecological zone
<i>Grevillea robusta</i>	Farm forests	Sub-humid to semi-humid
	Farm forests	Sub-humid to semi-arid
<i>Juniperus procera</i>	Natural forests	Sub-humid to semi-humid
<i>Neoboutonia macrocalyx</i>	Natural forests	Sub-humid to semi-humid
<i>Acacia mellifera</i>	Woodlands	Semi-humid to arid

## 4. ORGANIZATION OF THE FIELDWORK

### 4.1 Field team composition

The maximum members of one field team are four fulltime members: one team leader, two foresters or technicians, one driver, one power saw operator, one local casual and one ranger. The ranger is needed to provide security to the team in areas known to be unsafe. One of the team members needs to be conversant with basic First Aid techniques.

Additional person includes locally hired helpers to assist in:

- Lopping the felled sample trees;
- Stripping leaves;
- Debarking the stems for measuring diameters under-bark;
- Excavating stumps and roots of felled trees; and
- Carrying biomass samples from the measurement site to the base camp or other place where the team is accommodating and storing items and equipment.

The team leader is responsible for:

- Day to day activities of the Field team, both quality and quantity control of measurements and sampling;
- Provision of the logistics to the team from preparations to data storing;
- overseeing that the work is proceeding smoothly and safely and all team members are kept occupied;
- Selection of appropriate sample trees on the preselected stands according to the agreed sampling strategy;
- Ensuring correct description of the stand, points of relative heights and lengths of tree stem sections; and
- Ensuring that fresh weights of biomass samples are measured without delay to avoid any loss of moisture; and
- Proper labeling and storing of field sample for onward transmission for and labeled for laboratory analyses.

### 4.2 Preparations before field work

A supervisor who is responsible for the field work shall create awareness by contacting county authorities and local communities to obtain authorization for access into the forests and farms where sample trees will be felled. The supervisor together with the nominated advance team is responsible for locating the selected sites by a GPS, marking them on the forest map, and checking that the selected sites and trees correspond to the sampling plan. The advance team also decides the number and size class of the trees to be selected on each sampling site.

The supervisor plans how the teams are distributed in the field, i.e. listing and measuring order of the sites, necessary equipment, distribution of field maps for navigating to the sample sites, and ensuring field teams are able use a GPS for navigation. The measuring tools and equipment required in tree analyses are listed in Appendix 1.

### 4.3 Definitions of tree variables

**Biomass:** Determined by the total above-ground (stem wood and bark, branches and foliage (incl. flowers, seeds and cones) and below-ground (stump and roots) living organic matter in trees. It is equivalent to the oven dry mass of the tree. It is referred to as biomass density when expressed as mass per unit area, e.g. tons per hectare.

**Breast height:** A fixed height of 1.3 m above the ground level. If the ground level cannot be defined, the breast height is determined as 1.3 m from the seeding point (see Appendix 4).

**Crown section:** Living crown is divided into three equal length sections. Living crown is calculated by subtracting “the height to the base of the living crown” from the “total tree height/length”. Some variables are measured / recorded by crown sections.

**Dead branch:** Branch can be considered as dead if it has no living foliage and the cambium seems to be dead (can be checked by removing the bark with knife).

**Forked tree: Is a tree which branches into several stems.** If the forking point (the point where the core is divided) is above the breast height, the tree is regarded as a single tree. The diameter at breast height (dbh) is measured below the fork intersection point, just below the bulge that could influence the dbh. If the forking point is below the breast height, each stem is regarded as a separate tree.

**Ground level:** Ground level is described as illustrated in Appendix 4.

**Living tree:** A living tree must have living branches and it must be able to survive until the next growing season.

**Primary branch:** Branch forking from the main stem.

**Secondary branch:** Branch forking from the primary branch.

**Seeding point:** Seeding point is usually at the ground level. For trees growing on the top of a stone or old stump, the seeding point is determined as the point where the seed has started to grow (see Appendix 4)

**Shrub:** A woody perennial plant, generally of more than 0.5 m and less than 5 m height on maturity, and often without a definite stem and crown: shrubs have a natural behavior to produce several shoots or trunks from the base. None of the several stems of the shrub is clearly dominating the others. When heavily branched and dense, it may also be called bush. These distinctions cannot be regarded as unambiguous. In fact, under favorable environmental conditions, some shrubs (e.g. *Rhododendron* spp.) may grow to the size of an arborescence having the dimensions and form of a (small) tree.

**Stump diameter:** Diameter at the stump height i.e. top of a stump(cutting point).

**Stump height:** Stump height is the level of the upper most root collar. If no root collars exist, stump height is expected to be 15 cm from the ground level. It is the point of cutting the tree during felling

**Tertiary branch:** Branch forking from the secondary branch.

**Tree:** A tree is a perennial woody plant with a distinct stem capable of reaching 5 meters height *in situ*. For purposes of biomass assessment, Cactuses Climbers such as *Ficus* and palms are regarded as trees. Though Bamboos and shrubs are not recorded as trees their biomass assessment follows the same guidance given for trees.

**Tree height:** Tree height is the length from the ground level to the tip of the tree and is measured before felling with a Suunto hypsometer or similar instrument.

**Tree length:** Tree length is measured after felling along the stem considering the pre-determined and marked measuring point of the diameter at breast height. (1.30 m point of the measuring tape is placed on the stem exactly on the mark of the breast height to obtain the total length between the ground (seeding point of the tree) and the tree tip. Note; in case tree tip is broken during felling procedure and it can be found in the ground, and the broken part is added to the total length of the tree.

## **5. PROCEDURE FOR ANALYZING SAMPLE TREES**

Tree analysis is a complex operation and includes different phases that should be organized efficiently in the field. The work includes measurements of selected variables on the standing tree, and after felling on all components of the tree; de-limbing and cross-cutting of the tree stem, stripping leaves and excavating roots; taking samples of the different components; weighing the samples in the field and storing them overnight and transporting them to laboratory for the determination of dry weight. The procedure in the field is described in detail below.

After the sample trees are located and marked for felling, some general information on the forest stand is recorded, and basic tree measurements including diameter at breast height, stump diameter and height are carried out and the points marked on the stem. A photo of the tree is taken to capture the tree architecture before felling.

Tree felling is done after clearing the area and removing bush that may hinder the tree's fall. A tarpaulin is laid on the ground may facilitate the trapping of all branches. Although branches from other trees' crowns may also be brought down by the falling tree, they should be separated. The tree is felled at the stump height which was marked on the tree.

After the tree is felled, under-bark diameter at stump height is measured. The bark is gently removed from those points by means of a knife or a machet. The principal axis of the tree is immediately identified and total length and other heights are measured (care should be taken for heavily branched trees). The principal axis always has the largest diameter at each forking point on the trunk.

The different components of the felled sample tree are then measured and biomass samples taken in the most efficient and convenient order: first branches and foliage, secondly the stem and lastly the stump and roots. Different phases can be done simultaneously depending on the capacity of the field team.

The tree stem height and both under and over bark diameters at 14 relative heights percentage of (1, 2.5, 5, 7.5, 10, 15, 20, 30... 80, and 90 %) and at breast height are measured. In addition, the tree stem is cross-cut at four points (breast height and relative heights of 15%, 50% and 80%) where sample disks are extracted for biomass estimation. Branches of commercial value (diameter  $\geq 2$  cm) shall also be measured for volume estimation. Measurements and biomass sampling are explained in detail in the following chapters.

### **5.1 Trees for total (100%) measurements**

During piloting, the trees for total (100%) measurements trees were nine. These were assessed for the following additional measurements:

- All living branches measured as sample branches;
- All roots measured as sample roots;
- Total stem weight; and
- Stump sample disks.

### **5.2 General description of the forest stand**

The variables recorded to indicate general description of the forest stand are outlined in Appendix 5 and are the same applied in the IC-FRA biophysical survey manual (Muchiri, et al. 2016). If several sample trees are selected from the same stand, only one sample site information form (Appendix 5 Site Form) is filled.

## 5.3 Tree measurements before and after felling

### 5.3.1 Tree measurements before felling

The following preparatory actions and measurements are undertaken before felling:

- Photographing the standing tree;
- Planning the felling direction;
- Marking the measuring level (by circling the stem with a marker at this point) of the diameter at breast height (see Appendix 4);
- Marking the point where the tree will be cut (stump height);
- Measuring the height and diameter of the stump (*Stump height/diameter 1*); and
- Measuring the tree height.

Digital photographs of standing trees are taken to ensure visual documentation of the architecture of individuals in connection to their natural forest habitats. A tag of white paper showing the sample site and tree identification numbers is put against the tree stem above the dbh measuring point is clearly visible in photograph and the whole tree must be visible. The photograph is transferred from the camera into the field computer and the image files are labelled. For, example, tree number 3 on sample site 4, is labelled 4-3.jpeg. The second photograph on sample site on the same site is 4-3.jpeg. The observed tree variables are outlined below and are recorded in Tree Forms 1–3 (Appendix 5).

#### **Tree number**

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Number one (1) is given sequentially for the first sample tree on each sample site, and the numbering continues without omissions to the last sample tree within the sample site.

#### **Species code (name)**

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Tree species are recorded by codes and names be written only if species code is not provided to field teams.

#### **Tree diameter at breast height 1 (1 mm)**

---

Tree diameter is measured over bark at 1.30 m above the ground with the exception of particular cases mentioned in Appendix 4.

#### **Tree height (0.01 m)**

---

Total height of the tree is measured before felling from the ground level to the tip of the tree (including dead tip) and recorded in m to two decimal places (e.g., 23.41 m). Measurement is carried out using a Suunto hypsometer (or similar) or with a measuring stick.

#### **Stump height 1 (cm)**

---

This is the vertical distance from the ground level on the uphill side or from the seeding point (see Appendix 4) to the point where the tree will be cut for felling.

#### **Stump diameter 1 over bark (1 mm)**

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Over-bark diameter at the height of expected cutting point of the tree, i.e. stump height 1.

#### **Crown class**

---

Crown class is determined by considering the size and condition of the crown of the tree and its position in relation to other trees in the forest stand (Figure 2).

**1 Dominant.** A tree with a larger crown than the average size in or above the level of the surrounding canopy and receiving full light from above and more than one side.

**2 Co-dominant.** A tree with a medium-sized crown at the level of the general canopy and receiving full light from above and at least on one side.

**3 Intermediate.** A tree with a smaller crown than the average, reaching the general level of the canopy but not above it and receiving some direct light from above but little if any from the sides.

**4 Suppressed.** A tree with a crown that is smaller than what is normal to a tree of this age. Receiving little or no direct sunlight and showing signs of retarded growth resulting from the competition of dominant trees.

**5 Understory.** A tree with a crown that is below the level of the general canopy layer. Receiving little or no direct sunlight, but not showing signs of suppression or retarded growth. Such trees may be tolerant to shade. Or saplings not yet seriously affected by the competition of other vegetation.



**Figure 2.** Picture of crown classes. Symbol “†” means a dead tree.

### 5.3.2 Basic measurements after felling

The tree variables assessed after a tree is felled are recorded in Form 2 (see Appendix 5) and the measuring units and recording accuracy are given in parenthesis after the variable name.

#### **Stump height 2 (1 cm)**

---

The vertical distance from the ground to the point where the tree was cut.

#### **Stump diameter over-bark 2 (1 mm)**

---

Over-bark diameter at the top (cutting point) of the stump.

#### **Stump diameter under-bark (1 mm)**

---

Under-bark diameter at the top (cutting point) of the stump. Measuring point must equal to that of the actual measuring point of the over-bark diameter at stump height. Measured from the cross-cut section by excluding the bark.

#### **Diameter at breast height under-bark (1 mm)**

---

Diameter at breast height under-bark is measured exactly from the same point as the over-bark diameter at breast height. **Note:** debarking of the stem at dbh is **not carried out at this point**. Biomass sample disk is extracted at the breast height and diameter under bark is measured.

### **Length to the base of living crown (0.01 m)**

---

Measurement is carried out using a measuring tape and by considering the pre-determined and marked measuring point for the diameter at breast height: place a measuring tape on the stem so that 1.30 m is exactly on the mark for the dbh to obtain the total length between the ground (seeding point of the tree) and the crown base. The crown base is defined to be the lowest living branch. However, living branches which are separated by two or more whorls of dead branches from other living branches are not considered in the determination of the crown base.

### **Total length (0.01 m)**

---

Measurement is carried out using a measuring tape and by considering the pre-determined and marked measuring point of the diameter at breast height: place a measuring tape on the stem so that 1.30 m is exactly on the mark of the breast height to obtain the total length between the ground (seeding point of the tree) and the tree tip (including the dead tip).

## **5.4 Collecting stem and tree analysis data**

### **5.4.1 Phases of data collection procedure**

Tree-level variables to be determined for every felled tree include data obtained from the standing tree, measurements on branches and foliage, lying stem, stump and roots. In addition, biomass samples are collected from these different tree components to estimate their dry mass.

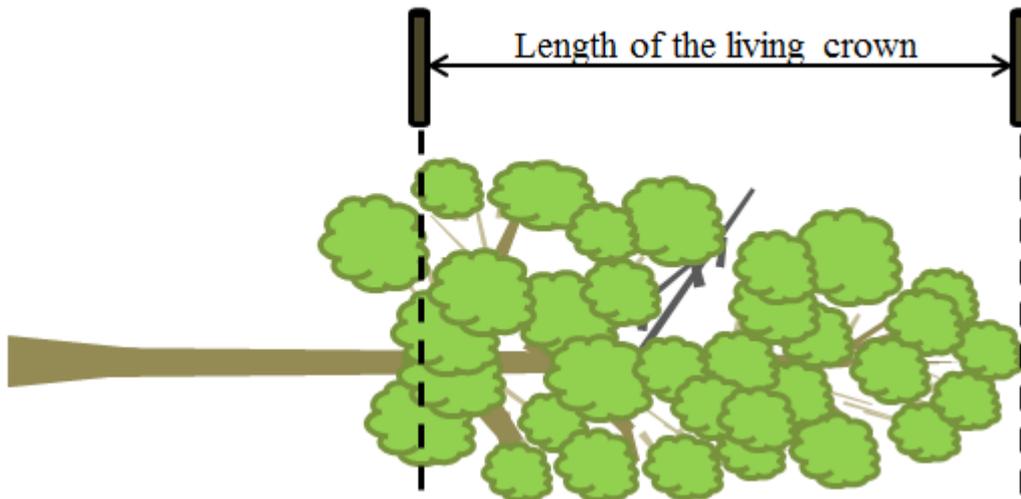
In order to avoid errors in estimating height and diameter measurement points along the stem and for convenience, branches and foliage characteristics are measured. After the measurement of branch diameters has started, delimiting of the felled tree can be done. Stem analysis is completed after all required characteristics are determined, recorded and biomass sample disks extracted and their fresh weights measured.

Stump and root biomass is measured and density samples collected. Digging out roots of large trees may take time requiring assistance by local casuals. It is advised to excavate the stump together with the whole tree because it is easier than after felling.

Special care must be taken when storing and labeling biomass samples of the tree components to avoid wrong labeling. All biomass samples are kept under shade after cutting and weighted for fresh biomass in the field without delay. They are then delivered to the laboratory as scheduled without unnecessary delays.

### **5.4.2 Measuring tree branches and foliage**

Collecting data on biomass variables starts with measurements of branches foliage followed by the stem wood and bark measurements, and roots and stump measurements. The branches are measured for volume estimation up to the top over bark diameter of 2 cm. For the small branches (over bark diameter less than 2 cm) branch biomass is obtained from the total fresh weight and the sample based dry-matter content. For the larger branches, biomass estimate (dry weight) is indirectly determined from the samples based on density estimates obtained for the branch wood and bark (density = dry biomass/fresh volume). Length of the living crown is needed for branch measurement as sample branches are measured in crown sections. Branches damage should be as minimum as possible before measurements; do not walk on branches or shake them. Length of the living crown can be measured as is shown in Figure 3. Put poles perpendicular to the tree and at equal distances from the center line of the tree at the beginning point of the living crown and at the tree tip. Distance between poles is the length of the living crown.



**Figure 3.** Method to measure crown length of the tree with large and difficult branches.

### ***Dead branches***

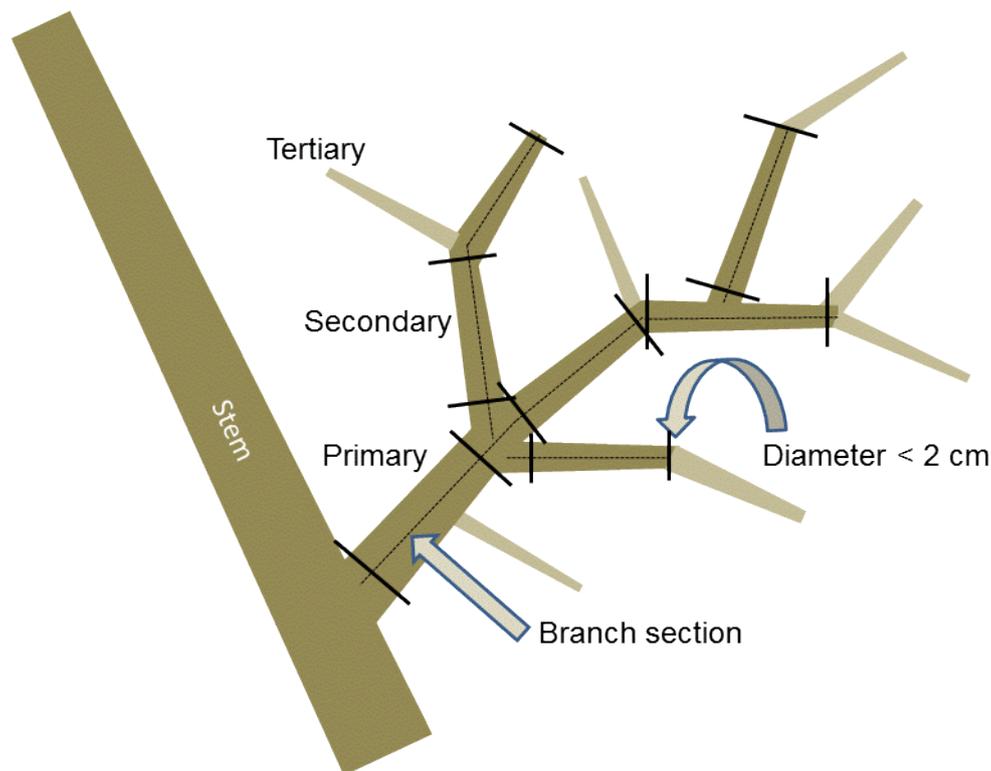
All dead branches along the stem are cut off and their total weight is measured using a spring balance with high reading accuracy (0.1 g). A composite biomass sample (500–1000 grams) of the dead branches is also collected; Take disks about 3–5 cm thick from the branches so that they evenly cover different sections of the crown and the whole size range of the dead branches. Weigh the composite sample with a spring balance of high reading accuracy (0.1 g). Put the biomass sample into a plastic bag and label it carefully as explained below.

### ***Living branches and foliage***

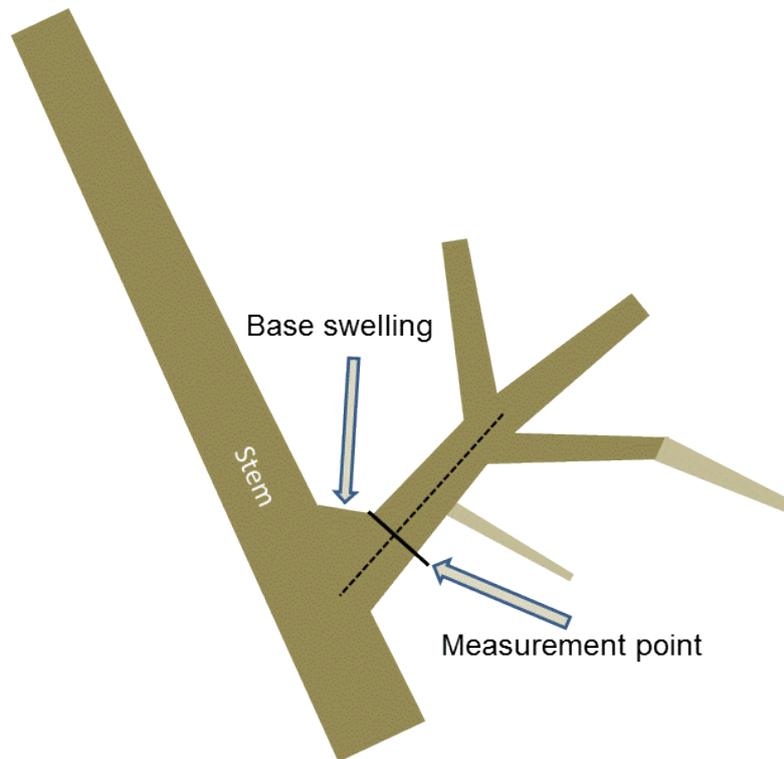
Measurements on the living branches (diameters) and on the sample branches (volume) and collection of the branch biomass samples are conducted as follows:

1. Measure diameters of living branches, starting from the lowest branch. Measuring tape must be held at the right angle to the branch. Measurement point is just next to the stem. In case there is a deformity or base swelling, diameter is measured immediately after these (see Figure 5).
2. Divide the living crown into three sections and select smallest, average and largest branch according to branch diameters a sample branch from each section; altogether 9 branches. Mark the sample branches using a sticky tape label with a hand written number of the sample branch.
3. Cut the branches off the stem and separate the dead branches from the living ones.
4. Measure the sample branches for volume by sections (
5. Figure 4). Identify the main branch at each forking and continue measuring the main branch by sections until the small end diameter is 2 cm. Note; primary, secondary and tertiary branches are numbered separately. Measuring branch volume and taking biomass samples of branch wood (diameter  $\geq 2$  cm) are carried out in a same way as for stem and are explained in the chapters 0 and 0.
6. At each forking of the main sample branch, measure the over-bark diameters of the other side branches.
7. Cut the branch top (diameter less than 2 cm) and set aside for weighing the fresh biomass. Strip first the leaves or needles off onto a tarpaulin to avoid losing any foliage, and weigh the branch wood and foliage separately. Flowers are included in foliage, but knots, fruits and pods are weighed separately. Note; foliage of the whole sample branch is included. For thorny trees the branch part with diameter less than 2 cm including leaves/needles, flowers, fruits and pods are weighed together.
8. After measuring all the sample branches, four biomass samples of the branch wood by branch diameter classes are taken: class1:  $0 < \varnothing < 2$  cm, class2:  $2 \leq \varnothing < 5$  cm, class3:  $5 \leq \varnothing < 10$  cm, and class 4:

- $\varnothing \geq 10$  cm. Note: the biomass samples for the four diameter classes, 2–4, are processed differently for volume estimation and their measurements are explained in the chapter 0.
9. Compile a biomass sample (500–1000 grams) for the branch size class 1 ( $\varnothing < 2$  cm) from the sample branches and take a few pieces about 10 cm long from the class 1 branch sections
  10. Weigh the biomass sample with a spring balance of high reading accuracy (0.1 g).
  11. Mix the foliage of the sample branches and take a composite sample (<500grams) weighing with a spring balance of high reading accuracy (0.1 g).
  12. Put the biomass samples of dead branches, living branches of size class 1 and foliage into separate plastic bags that are sealed and labeled carefully. Write the number of the sampling site (Sample site ID) and the tree number and the code of the sample (D = dead branch, L = living branch and size class 1, and F = foliage), separated by slash characters '/', on the waterproof paper tag enclosed in the plastic bag with the sample. Finalize labeling by attaching a sticky tape label onto the plastic bag and write the aforementioned codes with a waterproof pen on the sticky tape label.



**Figure 4.** Measurement of sample branches for volume by sections. The branch sections with top diameter less than 2 cm are weighed for biomass, separately for branch wood and foliage. However, for thorny species they are weighed together.



**Figure 5.** Measurement point of branch diameter in case of base swelling or other deformity.

Branch characteristics measured and recorded in **Form 1 (Appendix 5)** are as follows:

**Tree number**

Number one is given sequentially for the first tree to be analyzed on each sample site, and the numbering continues without omissions to the last tree to be analyzed within the sample site. Table “Tree-level information before/after felling”.

**Weight of dead branches (0.1 kg)**

All dead branches are cut off and loaded into a (plastic or fabric) sack or tarpaulin. Attention: before starting the weight measurement, the spring balance is set to zero mark while an empty tarpaulin is hanging on the spring balance. If branches cannot be measured at one go, i.e. they must for some reason be measured in different portions, then the weights of branch bundles are respectively recorded in Table “Dead Branch” Form 1.

**Table “Branch diameters”**

**Crown section**

Number of crown section; 1, 2 or 3.

**Diameter of living branch (mm)**

All main branches are measured for their diameters which are recorded individually in Form 1. The measuring point is just beyond the base swelling of branch. Diameter measurements are carried out using the diameter tape. Note, calipers can be used for quick checking of diameters of small branches, but actual measurement is done with the diameter tape.

**Table “Sample branches” in form 1.**

**Fresh weight of branch wood,  $\varnothing \geq 2$  cm (0.1 g)**

Weights of the sample branch sections with a diameter at least 2 cm are measured using the spring balance.

---

**Fresh weight of branch wood,  $\varnothing < 2$  cm (0.1 g)**

---

Weights of the sample branch sections with a diameter less than 2 cm are measured using the spring balance.

---

**Fresh weight of branch foliage (including flowers) (0.1 g)**

---

Weight of the foliage (only leaves and needles) is measured by sample branches using the spring balance. Note, all foliage of the sample branch is weighed.

---

**Fresh weight of fruits, cones, pods (0.1 g)**

---

Weight of the fruits, cones and pods is measured by sample branches using the spring balance.

**Table “Composite samples”**

---

**Fresh weight of composite sample for dead branches (0.1 g)**

---

A (small) composite sample (< 1000 grams) of dead branches is collected for the measurement of dry matter content, and the fresh mass of the sample is measured in the field using a portable digital scale with the reading accuracy of 0.1 gram. The sample should represent the whole size variation of dead branches and different sections of the stem. From small branches samples about 10 cm long and from large branches small sized sample disks are cut off. After weighing the composite sample is put into a plastic bag that is carefully sealed and labeled; use the code ‘D’ for dead branch composite samples.

---

**Fresh weight of composite sample for small living branches (0.1 g)**

---

A biomass composite sample (< 1000 grams) of the branch wood by branch diameter classes is collected for the measurement of dry matter content. From small branch sections ( $\varnothing < 2$  cm), samples about 10 cm long are cut off and their fresh mass is measured in the field using a portable digital scale with the reading accuracy of 0.1 gram. After weighing the samples are put into plastic bags that are carefully sealed and labeled; use the code ‘L’ for living branch samples and number 1 to indicated the size class of the branch section (L1).

---

**Fresh weight of composite sample for foliage (0.1 g)**

---

A (small) composite sample (< 500 grams) for the foliage (leaves or needles) is collected for the measurement of dry matter content and its fresh mass is measured in the field using a portable digital scale with the reading accuracy of 0.1 gram. After weighing, the composite sample is put into a plastic bag that is carefully sealed and labeled; use the code ‘F’ for foliage composite samples.

---

**Fresh weight of composite sample for fruits, cones, pods (0.1 g)**

---

A (small) composite sample (< 500 grams) of fruits, cones and pods is collected for the measurement of dry matter content and its fresh mass is measured in the field using a portable digital scale with the reading accuracy of 0.1 gram. After weighing, the composite sample is put into a plastic bag that is carefully sealed and labeled; use the code ‘FCP’ for fruits, cones and pods composite samples.

### 5.4.3 Collecting data for volume estimation

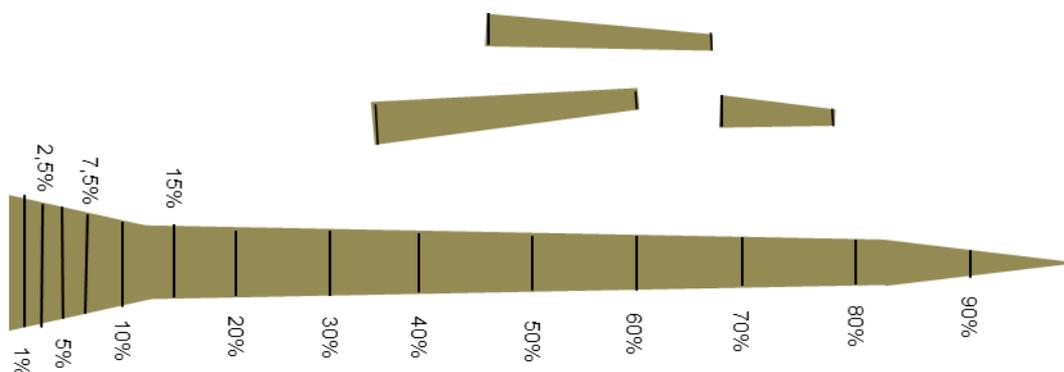
After completing the measurements of branch characteristics and collections of biomass samples of dead and living branches and foliage (leaves or needles) and fruits, cones + pods, the delimbed tree stem lying on the ground is ready for the stem analysis followed by the final stages of the tree analysis. In the stem analysis, diameters over- and under-bark are measured along the stem. In this data collection survey, diameters are measured at altogether 14 relative heights of 1, 2.5, 5, 7.5, 10, 15, 20, 30..., 80, and 90% to estimate the stem profile. The sample branches are measured for volume estimation up to the branch diameter of 2 cm.

Phases of the stem analysis are as follows:

1. Convert the relative heights used as measuring points of diameters to the absolute heights in metric scale using the measured and already recorded total length of the given tree. The relative height 7.5 % for the tree with the total length of 23.62 m is expressed in the metric scale as follows:  $7.5/100 \times 23.62 \text{ m} \cong 1.77 \text{ m}$ . The converted heights for measuring points are recorded individually in Form 2.

Note; if relative measurement point is moved to another point, both relative and absolute measurement points must be recorded on the form, see below (4).

2. Place a measuring tape on the stem so that 1.30 m is exactly on the mark for the breast height.
3. Mark the diameter measuring points, which were converted to the metric heights from the seeding point, on the stem using a waterproof marker or chalk.
4. In the case of branches, knots, scars or other possible irregularities, the measuring points are placed just below of the defective or irregular section of the stem and exceptional measuring heights and the diameters, respectively, are individually recorded in Form 2. Example: the total tree length is 23 m, thus the relative height of 20 % is 4.60 m. In case the measurement point has been moved 30 cm below the original point, the absolute value for measurement point is 4.30 m and the relative height is 18.7 %, respectively ( $4.3 \text{ m} / 23.0 \text{ m} * 100 = 18.7$ ).
5. Start measuring diameters over bark at previously marked measuring points using a measuring tape.
6. After the measurement of over-bark diameters has proceeded to the 3<sup>rd</sup> or 4<sup>th</sup> measuring point, debarking of the stem from the completed diameter points may start. Debarking stem should be implemented gently with the aid of the specific debarking tool, or knife or billhook or axe. Stem wood under the bark should not be damaged. **Note:** debarking of the stem at the relative heights of 1% ( $\approx$  bottom of the stem), 15%, 50% and 80% **ARE NOT carried out at this stage**. Sample disks for biomass are taken from these measurement points and under-bark diameters are taken in that process.
7. Measure the diameters under-bark exactly from the same points as the over-bark diameters.
8. Measure the sample branches for volume estimation by sections up to a branch diameter of 2 cm at the small end. The main sample branch is identified as instructed in the chapter0.
9. Use a fixed length, between two forks or a section length assuming a cylindrical log shape. Measure the base and top diameters, and the length of the branch sections until the top diameter is 2 cm. Note, also side branches of the sample branch are measured.
10. Debark the base and end of the branch sections, and measure the under-bark diameters from the same points as the over-bark diameters.



**Figure 6.** The 14 relative heights marked on the stem showing the points where the over- and under-bark diameters are measured for volume estimation. In addition, the sample branch sections with a diameter  $\geq 2$  cm are measured for volume estimation.

The characteristics recorded in the stem analysis are as follows (see **Form 2**):

#### Table “Stem analysis data”

##### Relative measuring height of the stem diameter (%)

Height percentile determining the diameter (over- and under-bark) measuring point. Altogether 14 relative heights (1, 2.5, 5, 7.5, 10, 15, 20, 30..., 80, and 90%) are used here for determining the empirical stem taper curves(stem profile) of individual trees. In the case of branches, knots, scars or other possible irregularities, exceptional measuring heights are used as explained before.

---

**Absolute measuring height of the stem diameter (1 cm)**

---

Absolute height used to determine the diameter (over- and under-bark) measuring point and converted from the relative measuring height with the known, i.e. measured, tree length as explained before.

---

**Stem diameter over-bark (1 mm)**

---

Stem diameter over-bark measured at the pre-determined relative height of the stem.

---

**Stem diameter under-bark (1 mm)**

---

Stem diameter under-bark measured at the pre-determined relative height of the stem.

---

**Table “Sample branch data”**

---

**Crown section**

---

Number of crown section; 1, 2 or 3.

---

**Sample branch**

---

Number of sample branch. Note; the number should be taken from the table “Branch diameters” in Form 1.

---

**Secondary branch**

---

Number of secondary branch, starting from 1 in each sample branch.

---

**Tertiary branch**

---

Number of tertiary branch, starting from 1 in each secondary branch.

---

**Diameter over-bark at the base of the branch section (1 mm)**

---

Diameter at the base of the section including bark is measured from each branch section of the sample branch. In the case of deformed base, the diameter is measured immediately before/below the deformed section.

---

**Diameter under-bark at the base of the branch section (1 mm)**

---

Diameter at the base of the section without bark is measured from the same point as the diameter over-bark after debarking.

---

**Length of the branch section (1 cm)**

---

Length is measured with a measuring tape. The tape is placed along the branch section so that it is following all the main sweeps of the branch to obtain the true length from the cross-cutting point to the end of the section, i.e. point of the minimum diameter (2 cm) or start of the next section. Note; the length is not the shortest distance between the top and base. Note 2; section length is measured from the starting point to the starting point of the next section.

---

**Diameter over-bark at the end of the branch section (1 mm)**

---

Diameter at the end of the branch section including bark is measured from each branch section, i.e. at the point where the minimum diameter is reached (2 cm) or start of the next section. Note; diameter at the end of the section is taken just before the branch fork in case the diameter in the beginning of the next section is clearly smaller due to forking.

---

**Diameter under-bark at the end of the branch section (1 mm)**

---

Diameter at the end of the section without bark is measured from the same point as the diameter over-bark after debarking.

#### **5.4.4 Collecting biomass samples from the stem**

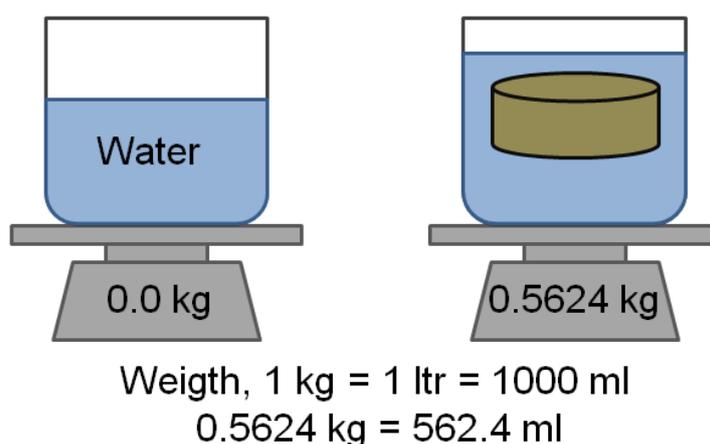
The fresh weights and volumes of the biomass samples extracted from the sample tree stems and branches are measured in the field. For practical reasons, it may also be justified to measure these characteristics in the base camp. However, both the fresh-mass and volume characteristics must be measured and recorded during the

same day when the tree was felled and measured for its diameter characteristics. The fresh weights of biomass sample disks or their further processed particles are weighed using a portable digital scale with the capacity of 3 kilograms and the reading accuracy of 0.1 grams.

Note that the volume estimates for the wood and bark proportions of the sample tree are obtained from the diameters measured at relative stem heights, after which the stem biomass estimate (dry weight) is possible to determine indirectly from the sample based density estimates obtained for the stem wood and bark (density = dry biomass / fresh volume).

The volumes of sample disks are measured using the water displacement technique as follows (see Figure 7):

1. Fill the appropriate sized bucket with the water and set the scale to zero. When filling the bucket, make sure that there is enough room for the sample to be forced below water: water should not leak over the edge of the bucket. On the other hand, the sample should not touch the bottom of the bucket when pressed below the water surface, i.e. enough water should be added.
2. The sample is forced gently but carefully below the water surface using a metal stick as thin as possible (e.g. needle or nail) to press it.
3. The reading in the screen of the digital scale shows the volume of the sample.



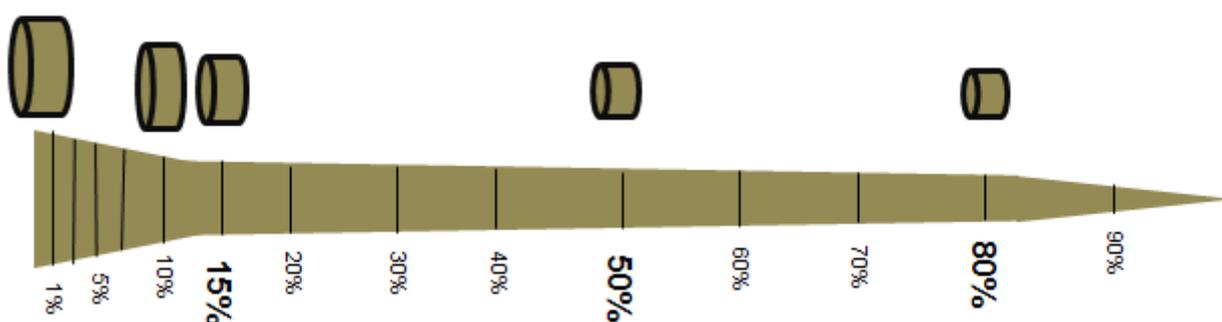
**Figure 7.** Water replacement method with weight. Note; scale must be set to zero before putting the sample disk into the water.

The procedure for collecting the stem biomass disks from the sample trees is as follows:

1. Sample disks are taken from the bottom of the stem, at the breast height (1.30 m) and from the relative heights of the 15 %, 50 % and 80 %, respectively. Note: measurement points of the relative heights are already measured in collecting data for volume estimation; see 0.
2. Extract a sample disk from each point. Sample disks are marked as follows: disk from the bottom: “B”, disks from breast height (1.30 m) “BH” and disks from the relative heights “RH15”, “RH50” and “RH80”.
3. Both the volumes and fresh weights are obtained for the stem samples in the field. If the size of the disk is too large for obtaining the volume estimate based on the water displacement technique, then the disk is divided into segments of which one with an appropriate size (ca. 500–1000 g) is used for further measurements.
4. Weigh the total fresh mass of the sample disk or its segment with bark and record the result in Form 3 (Appendix 5).
5. Measure the volume of the sample disk or its segment with bark using the water displacement technique and record the result into Form 3.
6. Extract the bark from the disk or its segment above a plastic or tarpaulin, for instance, and weigh the total fresh masses of the sample disk or its segment without bark and record the result in Form 3. All

bark pieces by disks or segments are carefully collected and placed into labeled plastic bags, respectively. The number of the sampling site (Sample site ID), the tree number, the disk number and the code “B” (Bark) are written on a waterproof paper tag enclosed inside the bag and on a sticky tape attached on the bag.

7. Measure the under-bark diameter of the sample disks (BH, R15, R50 and R80) and record the diameters on Form 2. Note; under-bark diameters must be measured precisely from the same points than over-bark measurement has been done in collecting data for volume estimation.
8. Measure the volume of the sample disk or its segment without bark using the water displacement technique and record the result in Form 3.
9. The sample disks or their segments are put into the separate plastic bags that are labeled carefully. The number of the sampling site (Sample site ID), the tree number, the disk number and the code “S” (Stem) are written on a waterproof paper tag inside the bag and on a sticky tape label on the bag.
10. Take biomass samples of branch wood from the branch diameter classes 2–4. Class 2:  $2 \leq \varnothing < 7$  cm, class 3:  $7 \leq \varnothing < 20$  cm, and class 4:  $\varnothing \geq 20$  cm. Note: the biomass sample for diameter class 1 ( $0 < \varnothing < 2$  cm) is processed differently as explained in the chapter 5.4.2.
11. Compile biomass samples (500–1000 grams) from the branches by crown sections; take disks about 3–5 cm thick from the diameter classes 2–4. Keep the biomass samples of each diameter class separate. Note; the distance from the stem, where the sample disk is extracted, should be at least 20 cm (in case of primary branch).
12. Measure the fresh weights and volumes with and without bark for the branch biomass samples in a same way as for the stem biomass samples (steps 5–9).
13. After measuring the fresh weights and volumes and debarking, the branch disks are put into separate plastic bags and labeled. The number of the sampling site (Sample site ID), the tree number, the text “Branch”, the crown section (CS1, CS2, CS3) and the branch diameter class 2–4 are written on a waterproof paper tag inside the bag and on a sticky tape label on the bag. The bark of each branch disk is put into a separate plastic bag and labeled with the number of the sampling site, the tree number, the text “Branch Bark” and the branch diameter class 2–4.



**Figure 8.** Stem biomass sample disks.

First disk (from the left) is taken from the bottom of the stem, second from the breast height, and the other three from the relative heights of 15%, 50% and 80%, respectively.

Analyses on the wood and bark samples continue in the laboratory for measuring their dry-weights. The instructions for measuring dry weights are given in the chapter 6.2. The characteristics recorded for the stem biomass samples are as follows (see **Form 3 in Appendix 5**):

**Table “Stem and branch characteristics”**  
**ID of wood samples**

Sample disks are extracted from the bottom of the stem, from the breast height (1.30 m) and from the relative heights of 15%, 50% and 80% and they are marked (labeled) as “B”, “BH”, “RH15”, “RH50” and “RH80”, respectively. The sample disks from the branch size classes 2–4 are numbered as “2”, “3” and “4”.

#### **Fresh weight of sample with bark (0.1 g)**

Total fresh weight of the sample disk or its segment including bark is measured using a digital scale or accurate spring balance with a reading accuracy of 0.1 g.

#### **Fresh weight of sample without bark (0.1 g)**

Total fresh weight of the sample disk or its segment without bark is measured using a digital scale or accurate spring balance with a reading accuracy of 0.1 g.

#### **Volume of sample with bark (0.1 ml)**

Volume of the sample disk or its segment with bark is measured using the water displacement technique as instructed above.

#### **Volume of sample without bark (0.1 ml)**

Volume of the sample disk or its segment without bark is measured using the water displacement technique as instructed above.

#### **Oven-dry weight of wood sample (0.1 g)**

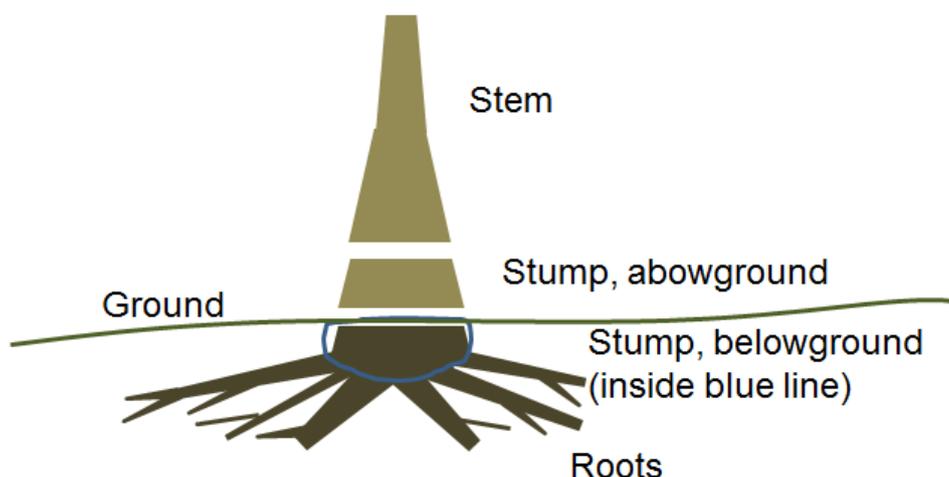
Oven-dry weight for the wood sample is measured in the laboratory after leaving the sample in the oven set at the temperature of 100 °C for 1 to 3 days (1–3 days × 24 hours/day) or as long as it takes to reach a constant dry-weight for them. Resulting value for the weight is recorded in Form 3.

#### **Oven-dry weight of bark sample (0.1 g)**

Oven-dry weight for the bark sample is measured in the laboratory after leaving the sample in the oven at the temperature of 100 °C for 1 to 3 days (1–3 days × 24 hours/day) or as long as it takes to reach a constant dry-weight for them. Resulting value for the weight is recorded in Form 3.

### **5.4.5 Measuring biomass for stump and roots**

Biomass characteristics for stump (belowground) and roots (see Figure 9) are measured for a 10–20 % sample-set of the trees to be analyzed. Sampling should be implemented by maximizing their species-specific size and stem form variation and geographical distribution. Stumps selected for the biomass analysis are excavated using either manpower or, if available, excavator. Sample of the roots to the minimum diameter of 0.5 cm are collected. **Note; in case of “100%” sample tree, all roots (not just sample roots) are measured.** The procedure for measurements is same in both cases; diameters, primary/secondary roots etc.



**Figure 9.** Definition of the belowground stump part.

The phases of the stump and root measurements are as follows:

1. Excavate the stump and its roots. In case only sample roots are measured, remove enough soil so that base diameters of the main roots can be measured and the below ground part of the stump can be excavated.
2. Clean the mineral soil particles from the stump and roots using a sturdy brush, for instance, and with water, if available.
3. Measure the base diameters of the main roots. Measurement point is within 10 cm from the stump. Where it is not possible to measure within 10 cm, measure as near to the 10 cm mark as you can.
4. The root system is thereafter divided into two components: *i*) stump and *ii*) roots.
5. Select two representative main roots from the opposite sides of the tree as a sample roots (and dig up them from the soil).
6. Remove the stump (belowground) from the roots.
7. Weigh the total fresh mass of the stump (belowground) using a spring balance.
8. Extract a vertical segment from the stump (ca. 1/8 or < 1000 g) and measure its fresh weight using digital scale. Note; stump must be properly cleaned from the soil and other extra particles. Put the sample into a large and sturdy plastic bag which is labeled (sample site ID/tree number/STUMP, where the letters ‘STUMP’ are identifying the stump sample). Finalize labeling by attaching a sticky tape label onto the plastic bag and write the aforementioned codes with a waterproof pen on the sticky tape label.
9. Follow the primary sample root and at each forking, measure the base diameters of the secondary roots and the secondary roots length up to 0.5 cm.
10. Measure the primary sample root’s diameters at the base and at the end of sections (forking or other reason) and section length. Continue along the sample root till the end of the root or at least up to the diameter of 0.5 cm.
11. Cut the sample roots into three size classes by the small end diameter; class 1:  $0.5 < \varnothing \leq 2$  cm, class 2:  $2 < \varnothing \leq 10$  cm, class 3:  $\varnothing > 10$  cm,
12. Weigh the sample roots by size classes for fresh biomass using a digital scale or accurate spring balance with a reading accuracy of 0.1 g.
13. Extract biomass sample disks from each root size class; take pieces about 10 cm long from the class 1 roots and disks about 3–5 cm thick from the other size classes and measure their fresh weights. Put the root samples into sturdy plastic bags which are labeled. Write the number of the sampling site (Sample site ID), the tree number and the code of the sample (R = roots and size class 1–3, for example R3 for a biomass sample from the roots in size class 3 diameter >10 cm), separated by slash characters ‘/’, on the waterproof paper tag enclosed in the plastic bag with the sample. Finalize labeling by attaching a sticky tape label onto the plastic bag and write the aforementioned codes with a waterproof pen on the sticky tape label.
14. In laboratory, the oven-dry weights of the stump and root samples are measured.

The characteristics recorded for the stump and root characteristics are as follows (see **Form 3 in Appendix 5**):

#### **Fresh weight of the stump (0.1 kg)**

---

Total fresh weight of the stump (belowground) excluding roots is measured using a spring balance with a capacity of 100 kilograms and the reading accuracy of 100 g. It is recommended that large-sized stumps be cut into pieces after which the fresh weights are respectively measured and recorded.

#### **Diameter of the main root (1 mm)**

---

Root diameter at the base of the main root. Table “Main roots”.

#### **Table “Sample roots, section data”**

#### **Diameter of the sample root (1 mm)**

---

Root diameter at the base of the section of the sample root.

---

**Length of the sample root section (1 cm)**

---

Length of the section of the sample root.

---

**Diameter of the side root (secondary root) (1 mm)**

---

Root diameter at the base of the side root.

---

**Length of the side root (secondary root) (1 cm)**

---

Length of the secondary root, from the base up to the diameter of 0.5 cm.

---

**Fresh weight of the sample root (0.1 g)**

---

Fresh weight of the sample root by size classes 1–3 is measured using a digital scale or accurate spring balance with a reading accuracy of 0.1 g. Table “Stump and root characteristics”.

**Table “Sample weights”**

---

**Fresh weight of the stump biomass sample(0.1 g)**

---

Total fresh weight of the vertical stump sample including bark is measured using a digital scale or accurate spring balance with a reading accuracy of 0.1 g.

---

**Fresh weight of the root biomass sample (0.1 g)**

---

Total fresh weight of the biomass samples of each root size class 1–3 is measured using a digital scale or accurate spring balance with a reading accuracy of 0.1 g.

## **6. DATA STORING AND PROCESSING OF BIOMASS SAMPLES**

### **6.1 Storing measured data**

While measuring the sample trees, all the characteristics are recorded on printed Forms 1–3 (Appendix 5). If field computers are available, it is recommended that the data entry is done immediately in the field. Original copies of the field recordings comprising the data sheets and their electronic file duplicates and further processed laboratory data should be maintained in their original form and stored in a secure location. One of the main responsibilities for the crew leader is to control the data entry and to secure the safety of the data.

### **6.2 Laboratory analyses**

In the laboratory, biomass samples are oven-dried at 100 °C for 1 to 3 days (3 × 24 hours) or as long as it takes to reach a constant dry-weight. It is extremely important that both the dry weight characteristics measured in the laboratory and the drying temperature and period (starting date and ending date) are recorded in the Forms 1 and 3 (Appendix 5) completed individually for each analyzed tree. In addition, the type of oven used in drying is recorded in the section ‘Additional recordings’ of the Form 3. Finally, the laboratory technician dates and signs in Forms 1 and 3.

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## **APPENDICES**

Appendix 1: Measuring tools and equipments for conducting tree analysis

Appendix 2: Diameter distribution of tree measured in the IC-FRA pilot inventory

Appendix 3: Sampling site variables to be recorded

Appendix 4: Determination of ground level and seeding point, and measurement points of diameters at breast height of leaning trees or those growing on slopes

Appendix 5: Field forms

Item	No. of items	Purpose of use
- GPS device	1	For recording the coordinates of the sample tree
- Bussol or compass	1	For measuring bearings
- Densiometer	1	For canopy coverage measurements
- Fiberglass measuring tape		
o logger type 20 m	1	For measuring heights, lengths and distances
o manual rewind, 50 m	1	- , , -
- diameter tape	1	For measuring diameters
- spring balances		
o capacity ~1 kg, readability: 10 g	1	For weighing biomass samples
o capacity ~10 kg, readability: 100 g	1	- , , -
o digital balance; capacity ~100 kg, readability: 100 g	1	- , , -
- portable digital scale; capacity ~3 kg, readability: 1 g	1	- , , -
- chainsaw, 16" ( + spare chains and file)	1	For felling and pruning, and cutting sample discs
- helmet and ear blocks	1	For safety work with chainsaw
- safety trousers	1	For safety work with chainsaw
- safety boots	1	For safety work with chainsaw
- handsaw	1	For felling trees and pruning stems
- pruning shears	1	For cutting small branches
- billhook or axe or panga	2	For cutting branches
- debarking tool (knife or panga)	1	For measuring under bark diameters
- electronic pocket calculator	1	For calculating measuring points along stems
- digital camera	1	For photographing trees before felling
- waterproof drawing pen	2	For recording
- chalk or marker or spray (red color)	1	For marking measuring and cutting points
- pencil	2	For recording
- plastic bags:		
o 1 litre	<i>n</i>	For storing individual biomass samples
o 3 litre	<i>n</i>	- , , -
o 10–15 litre	<i>n</i>	For storing stemwise biomass samples
o refuse bags, 50 litre	<i>n</i>	For storing biomass samples
- sticky tape	<i>n</i>	For labelling plastic bags of biomass samples
- cool box	<i>n</i>	For storing samples

**Table 2.** Diameter distribution of trees measured in the IC-FRA pilot inventory. A: Aberdare, G: Gazi, K: Kericho, M: Marigat, N: Nakuru.

Diameter class (cm)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-50	50-60	60-70	70-80	80-90	90-100	100-	Total
A	3	23	75	59	62	58	37	21	22	7	8	2	4	1	5	387
G	109	165	196	151	193	96	51	16	22	6	3	-	-	-	1	1009
K	4	26	88	94	184	193	162	107	94	36	5		2	1	5	1001
M	46	100	49	18	16	7	3	1	1	-	2	-	-	-	-	243
N	24	40	15	4	7	4	1	-	1	-	-	-	-	-	-	96
All	187	354	423	326	462	358	254	145	140	49	17	2	6	2	11	2736
%	6.8	12.9	15.5	11.9	16.9	13.1	9.3	5.3	5.1	1.8	0.6	0.1	0.2	0.1	0.4	100

**Table 3.** Diameter distribution of measured trees by Land use/cover classes. Note, number of trees in sample plot is converted to number in hectare (n/ha) values.

Land use/cover	Sample plots	Diameter classes (cm)					
		2-5	5-10	10-20	20-50	50-100	100-
Natural forest	22	1.9	114.3	221.4	80.4	12.2	1.9
Bamboo forest	4	-	-	8.0	-	7.1	3.5
Mangrove forest	34	55.3	578.6	275.3	124.0	2.9	0.4
Plantation forest	37	1.9	101.5	165.7	310.5	14.1	1.5
Woodland, closed	10	62.2	824.4	60.5	1.4	-	-
Woodland, open	29	31.7	225.0	46.1	10.7	0.5	-
Combined	166	23.4	259.4	141.9	115.8	6.5	0.9

**SITEFORM****Date**


---

Date when the measurements on the stand/sample site are done.

**Group leader**


---

Name of the group leader.

**Sample site id**


---

Identification number for sample site.

**County**


---

Name of the county.

**District name**


---

Name of the district.

**Division**


---

Name of the division.

**UTM map zone**


---

UTM map zone of the sample site (e.g. 37N).

**Elevation (1 m)**


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Elevation readings from the GPS, e.g. 1623 m.

**GPS Coordinates of the sample site**


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Location of the sample site is recorded in meters with no decimals. Coordinates are taken from the GPS receiver.

GPS X (Easting): East coordinates.

GPS Y (Northing): North coordinates.

**Bearing to stand border or nearest road**


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Bearing from the sample site to the nearest stand border or road in degrees (0-360) is measured from the sample tree closest to the boarder or road.

**Distance to stand border or nearest road**


---

Distance from the sample site to the nearest stand border or road in degrees (0-360) is measured from the sample tree closest to the boarder or road.

**Slope**


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Slope is recorded as average of two measurements; 20 meter downhill and 20 m uphill. The Unit is percentage.

**Slope orientation**


---

Main slope orientation downward is estimated in degrees (0–360). E.g. slope to west (downward) should be near 270 (degrees).

**Photo ID**


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Digital photos are taking from the standing tree and nearby environment before felling the sample tree. A tag, i.e. white paper with the Sample site id and Tree number written on it, is put against the tree stem above the measuring point of the DBH. Photo identification number in camera:

Photo ID: image ID number in camera's memory card

### Ownership

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Ownership refers here to the legal right to exclusively use, control, transfer, or otherwise benefit from a forest. Ownership can be acquired through transfers such as sales, donations, and inheritance. Forest ownership refers here to the ownership of the trees growing on land classified as forest, regardless of whether or not the ownership of these trees coincides with the ownership of the land itself.

- 1 Central government land. Land is owned by central government, or by government-owned institutions or corporations.
- 2 Community. Land is owned by local community.
- 3 Private. Land is owned by private individuals or families, private co-operatives, religious and educational institutions or other private institutions.
- 4 General land. Public land that does not belong to any of the above categories.
- 99 No information available on the land ownership.

### Canopy coverage

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Canopy coverage **caused by trees** is measured using the spherical densiometer at the sample site centre and then at the cardinal points (N, E, S and W) 15 meters apart from the sample site centre. If coverage is caused for instance by banana leaves, these are not recorded as canopy cover. The average of measured values will be recorded in the form.

### Land use class

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Land use class refers to the dominant land use purpose at the time of observation.

- 1 Production forest: Land designated for production and extraction of products. E.g. wood, fibre, bioenergy, and/or non-wood forest products.
- 2 Protection forest: Protected forest lands. Including also nature reserves, soil conservation, water and watershed protection, protection against erosion and landslides.
- 3 Wildlife reserve: National parks, game reserves etc.
- 4 Shifting cultivation: Land where there is evidence of slash and burn or recent farming activities but area is abandoned.
- 5 Agriculture, including agro forestry: Land with crops and trees or livestock in the same management unit.
- 6 Grazing land: Land with livestock on it or pasture land.
- 7 Built-up areas: Urban or rural or mixed. Including roads, buildings, power lines etc.
- 8 Water body or swamp: Permanent, seasonal or swamp.
- 99 Other land: To be specified in Remarks.

### FRA land cover class

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According to the FRA guidelines, the land is divided into *forest* and *other wooded land* according to the tree height and crown coverage. Land falling neither into the *forest* nor the *other wooded land* classes is classified as *other land*.

- 11 Forest: Land spanning more than 0.5 hectares with **trees higher than 5 meters and a canopy cover of more than 10 %**, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. (This is the FAO definition for forest)
- 12 Forest: Land spanning more than 0.5 hectares with **trees higher than 2 meters (but not 5 meter) and a canopy cover of more than 15 %**, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. (This is Kenya's definition for forest)
- 2 Other wooded land: At maturity stage the height of trees are at least 5 meters and a canopy cover of 5–10 %; **or** with a combined cover of shrubs, bushes and trees above 10 %. Other wooded land must exceed 0.5 hectares in size. It does not include land that is predominantly under agricultural or urban land use.
- 3 Other land: All land that is not classified as "Forest", "Other wooded land" or "Other land with tree cover".

- 4 Other land with tree cover (sub-category of “Other land”): Land classified as “Other land”, spanning more than 0.5 hectares with a canopy cover of more than 10 % of trees able to reach a height of 5 meters at maturity. E.g. parks, wooded yards, groves.
- 5 Inland water bodies: Inland water bodies generally include major rivers, lakes and water reservoirs.
- 6 Unknown: Crew could not reach/observe the sample plot.

### Vegetation type

Code (numeric)	Code (text)	Land use	Land cover	Crown cover	Description
101	FnD	Forestland	Natural forest	Dense	Crown cover $\geq 65\%$
102	FnM			Medium	Crown cover 40–64%
103	FnL			Low	Crown cover 10–39%
111	FbD		Bamboo forest	Dense	Crown cover $\geq 65\%$
112	FbM			Medium	Crown cover 40–64%
113	FbL			Low	Crown cover 10–39%
121	FmD		Mangrove forest	Dense	Crown cover $\geq 65\%$
122	FmM			Medium	Crown cover 40–64%
123	FmL			Low	Crown cover 10–39%
131	FpD		Plantation forest	Dense	Crown cover $\geq 65\%$
132	FpM			Medium	Crown cover 40–64%
133	FpL			Low	Crown cover 10–39%
134	FpP				Pelvis
201	WcD		Woodland	Closed	Dense
202	WcM	Medium			Crown cover 40–64%
211	WoM	Open		Medium	Crown cover 15–39%
212	WoL			Low	Crown cover $< 15\%$
301	Ca	Cropland	Agro-forestry		Home gardens with multi-storey tree covers shading e.g. bananas, coffee etc.
302	Cpc		Perennial crops		Monocultures and mixed crops of, e.g., tea, oranges, nuts etc.
303	Cac		Annual crops		Various herbaceous crops, e.g. cotton, flower plantation, maize, millet etc.
401	Gw	Grassland	Wooded		Grazing, hunting, recreation
402	Gb		Bushed		
403	Go		Open		

### Erosion

Erosion refers to the condition in which the earth's surface is worn away by the action of water and wind.

- 0 No erosion: No evidence of soil erosion.
- 1 Light erosion: Slight erosion where only surface erosion has taken place.
- 2 Moderate erosion: Where mild gullies and rills are formed on the top surface of the soil.
- 3 Heavy erosion: Areas which have deep gullies, ravines, land slips etc.

### Grazing

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Grazing refers to the intensity of grazing in the forest land or bush land. It refers to the impact animals have on forage growth and reproduction and on soil and water quality (see e.g. Holechek & Galt 2000).

- 0 No grazing. There is no evidence of grazing.
- 1 Occasional. Only choice plants and areas show use. There is no evidence of use of poor forage plants.
- 2 Frequent. Most range shows use. 1/3 – 2/3 of primary forage plants showing use.
- 3 Extensive. Lands can be severely hedged. There is evidence of life-stock trailing to forage. More than 2/3 of primary forage plants showing use.

### Damage

---

Damage refers to the causative agents that have been identified to cause damages to several **live trees** in the sampling site (diseases, insects, animals, etc.). There are three data input fields in the field form to record this variable (and associated damage severity + history of damage).

- 0 No damage: Naturally open area, or normal tree vegetation where there might be some individual trees damaged by insects, fungus or other reason but otherwise forest is in good condition.
- 1 Fire: Disturbance caused by fire.
- 2 Insects, fungus or diseases: Disturbance caused by insect pests or by fungi. Disturbance caused by diseases attributable to pathogens, such as bacteria, fungi, phytoplasma or virus.
- 3 Other biotic agents: Disturbance caused by biotic agents other than insects or diseases, such as wildlife browsing, grazing, physical damage by animals, etc. Specify in Remarks.
- 4 Wind or other abiotic factor: Disturbances caused by abiotic factors, such as storm, drought, air pollution, etc. Specify in Remarks.
- 5 Human activities: Cuttings, firewood collecting, debarking, other human-made damages.

### Damage severity

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Damage severity parameter is recorded adjoining with *Damage* code. Damage severity is an estimate of the prevalence of damages **to the living trees**. If substantial numbers of living trees are classed as very severely damaged (class 3), mortality is likely to remain high for a long time.

- 0 No: No damage.
- 1 Slight: Evidences of damage are visible, but not causing long-term damages. Only few trees are affected.
- 2 Serious: Damages are clearly visible, probably causing long-term damages or loss of growth. Several trees are affected.
- 3 Very serious: Damage is finally causing wide mortality of trees, or hinders them from healthy growing. Mortality is likely to remain high for a long time.

### History of damage

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Estimated timing of occurrence of damage, indicated as years (**1–5**). If the occurrence is estimated to be older than 5 years, mark **5+**.

**Human impact**

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Human impact is recorded on Forest, Woodland and Cropland vegetation types. Human impact or influence refers to a disturbance or change in ecosystem composition, structure, or function caused by humans. There are three data input fields in the field form to record this variable (and associated history of human impact).

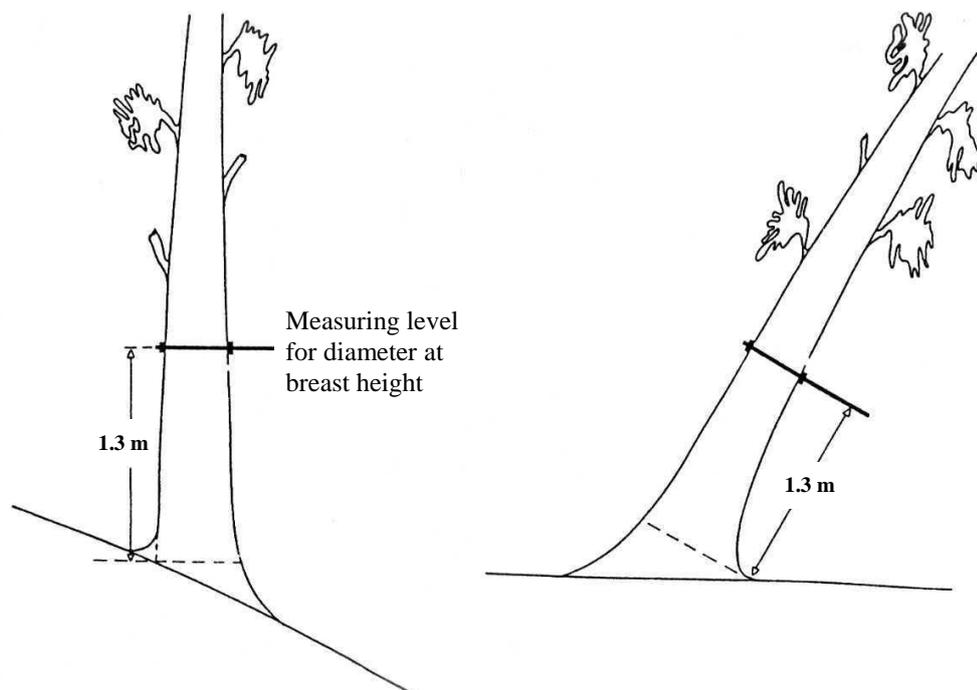
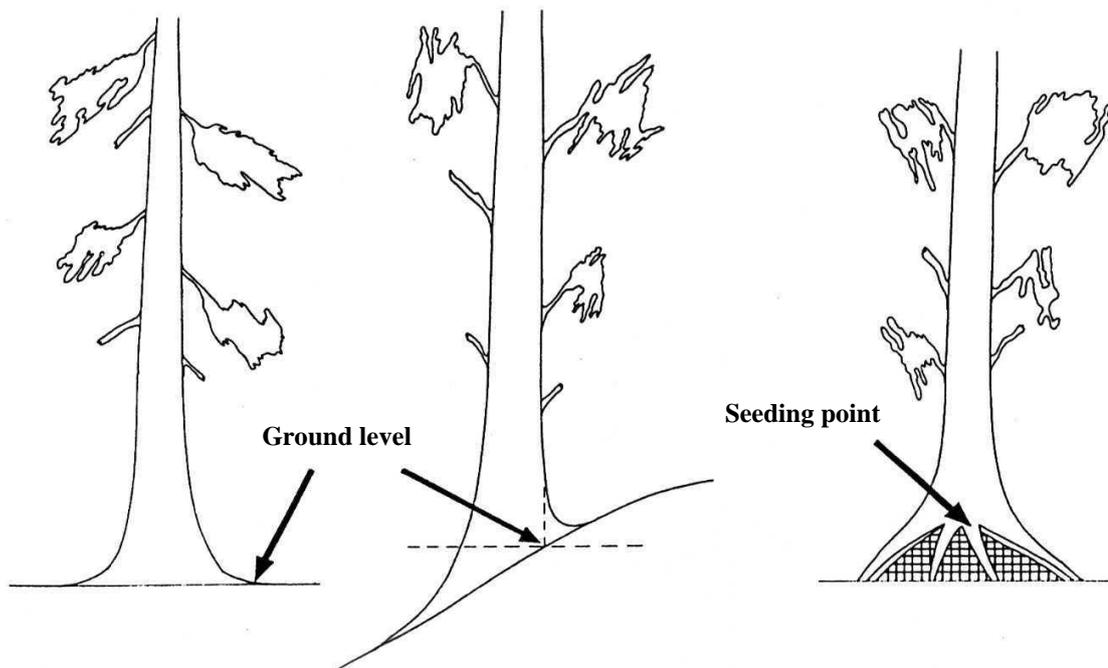
- 0 No impact: No cutting or other impact; or the cutting has happened more than 5 years ago.
- 1 Selective cutting in government forest.
- 2 Selective cutting in farm- and wood lands (and in mangroves).
- 3 Clear felling: Removal of all trees has been carried out. The generation of forest is done by planting, seeding or coppicing.
- 4 Shifting cultivation.
- 5 Silvicultural treatment: E.g. pruning, planting, climber cutting, weeding, boundary clearing, fire line construction.
- 6 Burning.
- 7 Charcoal production.
- 8 Medicinal activities: Collecting of medicinal plants used in traditional medicine and/or for pharmaceutical companies.
- 9 Mining, Sand collection: Mining and land extraction activities.
- 10 Agriculture. E.g. cattle grazing.
- 11 Pelis
- 12 Afforestation/reforestation
- 99 Other. Specify in Remarks.

**History of human impact**

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Estimated timing of occurrence caused by a human, indicated as years (**1–5**). If the occurrence is estimated to be older than 5 years, mark **5+**.

Determination of ground level (A, B) and seeding point (C), and measurement of diameters at breast height of trees growing on the slope (D) and that are leaning (E).





IC-FRA Stem and tree analysis (May, 2014)

## Form 1

## General data

Date			Group leader
dd	mm	year	

## Stand-level information

Sample site ID	County	District	Division

## Tree-level information before felling

Tree Nr.	Species Code	name	Diameter at 1.3 m (mm)	Tree height (0.1 m)	Stump height 1 (cm)	Stump diamet.1 (mm)	Crown class
Photo ID	SiteID_TreeNr_#						

## Branch diameters

## Sample branches, weights

## Dead branch

Crowns.	Diameter		Crowns.	Diameter		Crowns.	Diameter		Crown section Nr.	Sample branch Nr.	Weights of branch data (0.1 g)				Bundle Nr.	Fresh weight dead branch (0.1 kg)
	Nr.	mm		Nr.	mm		Nr.	mm			wood	fol	fpc	kg		
											≥ 2 cm	< 2 cm				
	1		41			81										
	2		42			82										
	3		43			83										
	4		44			84										
	5		45			85										
	6		46			86										
	7		47			87										
	8		48			88										
	9		49			89										
	10		50			90										
	11		51			91										
	12		52			92										
	13		53			93										
	14		54			94										
	15		55			95										
	16		56			96										
	17		57			97										
	18		58			98										
	19		59			99										
	20		60			100										
	21		61			101										
	22		62			102										
	23		63			103										
	24		64			104										
	25		65			105										
	26		66			106										
	27		67			107										
	28		68			108										
	29		69			109										
	30		70			110										
	31		71			111										
	32		72			112										
	33		73			113										
	34		74			114										
	35		75			115										
	36		76			116										
	37		77			117										
	38		78			118										
	39		79			119										
	40		80			120										

## Composite samples

## Dead branches

Weights (0.1 g)

fresh dry

## Small living branches

Weights (0.1 g)

fresh dry

## Foliage

Weights (0.1 g)

fresh dry

## Fruits, pods, cones

Weights (0.1 g)

fresh dry





IC-FRA Stem and tree analysis (May, 2014)

Form 3

Page 1/2

## General data

Date			Group leader		
dd	mm	year			

## Stand-level information

Sample site ID	County	District	Division	Tree No.	Species code	name

## Stem and branch characteristics

Stem and branch sample discs		Wood sample				Oven-dry sample	
		Fresh weight (0.1 g)		Volume (0.1 ml)		Weight (0.1 g)	
		with bark	without bark	with bark	without bark	wood	bark
Section	Label	g	g	ml	ml	g	g
Bottom	B						
1.3 m	BH						
Relative 15%	RH15						
Relative 50%	RH50						
Relative 80%	RH80						
Crown section 1	CS1-1						
	CS1-2						
	CS1-3						
Crown section 2	CS2-1						
	CS2-2						
	CS2-3						
Crown section 3	CS3-1						
	CS3-2						
	CS3-3						

## Stump and root characteristics

Portion / bundle	Fresh weight (0.1 kg)			
	stump, kg	roots, kg		
Nr.		cl 1	cl 2	cl 3
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

## Sample weights

Sample type	Weight (0.1 g)	
	Fresh	Oven-dry
Stump		
Roots class 1		
Roots class 2		
Roots class 3		

Remarks

## Main roots

Main roots, diameter			
No.	mm	No.	mm

