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SPC Land Resources Division

Monitoring, Assessment and Reporting for Sustainable Forest Management in Pacific Island Countries

MANUAL

MAR-SFM

Monitoring, Assessment and Reporting

for

Sustainable Forest Management

in

Pacific Island Countries

Manual

by

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for SPC

October 2010

Acknowledgements

The Monitoring, Assessment and Reporting Programme could not come up without the productive collaboration of so many people.

First of all, we want to thank the Government of Japan and the Food and Agriculture Organization of the United Nations for funding the programme, especially Mr. Otsuka Masahiro for his continuously support.

Special credit goes to the “Forest and Trees Programme” team of the Land Resources Division of the Secretariat of the Pacific Community, especially to Mr. Sairusi Bulai and Ms. Bale Wilikibau for their invaluable organizational and management effort around MAR. Simultaneously, we want to express much gratitude to the Forestry Department of the Ministry of Primary Industries of Fiji and the Agroforestry Section of the Ministry of Environment, Lands and Agriculture Development of Kiribati for contribution in field testing the methodology.

We want to thank Mr. Marika Tuiwawa, Dr. Wolf Forstreuter and Dr. Heinz Frommhold for technical advice on special methodological problems.

Furthermore we are obliged to Mr. Georg Hohberg, Mr. Konrad Hennersdorf, Ms. Christine Fung, Mr. Felix Ries, Mr. Joseph Donnegan, Ms. Doreen Kangas, Dr. Martin Guericke and Dr. Barbara Wolff for providing literature sources.

Thank you all very much.

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Formulary

Abbreviations and Acronyms

BD	Basal Diameter
BU	Biomass Plot
CP	Center Point
CU	Circular Plot
DBH	Diameter at Breast Height
DC	Diameter at Crossing
DAP	Difficult Access Plot
EBD	Equivalent Basal Diameter
EAP	Easy Access Plot
FAO	Food and Agriculture Organization of the United Nations
FRA	Global Forest Resources Assessments
GIS	Geographic information systems
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
MAR	Monitoring, Assessment and Reporting
NFI	National Forest Inventory
NTFP	Non-Timber Forest Products
P	Plot
PIC	Pacific Island Country
R	Recorder
S	Surveyor
SFM	Sustainable Forest Management
SPC	Secretariat of the Pacific Community
SU	Sub-Unit
T	Treespotter
U	Unit

Introduction

Monitoring, assessment and reporting (MAR) are crucial tools for any kind of professional and successful management. Also for sustainable forest management (SFM) MAR measures may enhance its efficiency. But not only forest managers may profit. Also on the national and international political level MAR results can support decision makers.

The Pacific Regional MAR Workshop in 2008 recommended the development of a concrete MAR design suitable for the conditions in the participating Pacific Island Countries (PIC). Cost effectiveness and a design harmonized amongst the very different countries (atolls to big islands) were defined as challenging preconditions.

Due to the fact that all PIC joining the Forest Resource Assessment (FRA) process it was decided to orientate the criteria to monitor mainly to the FAO criteria of FRA[1].

A MAR system was developed during 2009 and presented in January 2010 to PIC representatives. After field tests and final modifications the MAR system was found to be feasible for the PIC demand, even if in certain cases specific solutions must be developed in the future.

According to the basic philosophy behind the development process - to orientate on the possibilities of the “lesser developed” countries - all implementation aspects should be kept as simple and as functional as possible – sophisticated requirements on methods, skills, and equipment were avoided as much as possible. However, this does not mean that a country with more sophisticated possibilities shall not use its resources and replace a method with a more scientific one. Also some monitoring methods especially for carbon estimation are currently in a fast international development process. Therefore regular actualization of methods might be necessary in the future.

1 FAO 2004

About this Manual

The aim of soon implementation of the standardized MAR system leads to the development of this manual.

The manual is addressed to readers who have only few formal forestry education as well as to forest technicians. Therefore it was tried to describe the process as much in detail as possible without much complicated technical terminology. The reader can decide by himself how much information he or she needs to perform the complex assessment.

The manual shall be a helping guideline to nearly all aspects of MAR-SFM but its main focus is on field work. If atoll island situations require adapted solutions the manual provides specific methodologies.

First the monitoring criteria and the sampling design is introduced. The further structure of the manual reflects the chronological strategy of MAR from the preparation process (*Phase 1 p.23*) and the monitoring fieldwork (*Phase 2 p.40*) to the calculation of the results (*Phase 3 p.64*).

Also the Appendices provide more detailed information on the different aspects of MAR as e.g. the underlying definitions. All methods mentioned in the text are described in more detail and also supporting tools like correction tables for slope *(p.101)* and control tables for height measurements *(p.107-109)* are provided.

Criteria List

The following list (*Tab. 1*) of MAR concerning criteria was an outcome of the MAR-Workshop 2008. Definitions are based on the definitions used in FRA 2005[2] of the mentioned criteria are listed in Annex Underlying Definitions for Data Collection *(p.88).*

Tab. 1: List of proposed Criteria

Criteria	Sub-Criteria	Criteria	Sub-Criteria
Forest Extent	• Forests • Other wooded land • Other (agriculture) land with tree cover • Coconut forests • Coconut plantations	**Growing stock**	• Total growing stock • Commercial growing stock • Growing stock composition
Forest ownership/ management rights	• Private owned land (individuals) • State owned land • Customary owned land • Other	**Carbon stock**	• Total carbon • Carbon in above-ground living biomass • Carbon in below-ground living biomass • Carbon in dead wood • Carbon in litter • Soil carbon[*]
Designated forest function	• Production • Protection of soil and water • Conservation of biodiversity • Social and cultural services • Multiple purpose	**Biomass stock**	• Above-ground biomass • Below-ground biomass • Dead wood biomass
Designated functions of other wooded land	• Production • Protection of soil and water • Conservation of biodiversity • Social and cultural services • Multiple purpose	**Removals and benefits from forest**	• Industrial round wood • Wood fuel • Other (NTFP) plant products • Animal Products • Other socio-economic benefits
Forest Characteristics	• Primary • Secondary with natural regeneration • Secondary with enrichment planting • Plantations	**Disturbances**	• Disturbance by cyclones • Disturbance by fire • Disturbance by insects • Disturbance by invasive species • Other
Diversity	• Total number of native tree species • Number of tree spec. according to IUCN “red list” • (other bio indicators)[**]		

2 FAO 2004

* not yet included

** separately to identify for each country

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MONITORING, ASSESSMENT, REPORTING
MAR SFM
SUSTAINABLE FOREST MANAGEMENT

Monitoring, Assessment and Reporting for Sustainable Forest Management in Pacific Island Countries

Sampling Layout

1 Sampling Layout

The Plot (*Fig. 1 p.16*) is a simplified and modified version of the FAO National Forest Inventory (NFI)[3] design, and is designed as such that it suits the Pacific Island Countries situations in terms of topography, vegetation, human resources, financial resources, monitoring parameters and the requirements of the participating PIC. The cross-shaped Plot design is determined by the coordinates of the Center Point (CP) and the crossing center lines on which 4 strip-shaped Sub-Plots are aligned.The Sub-Plots are placed 80 m from the center of the Plot (CP), i.e. they have 160 m distance to their opposite Sub-Plot either in north-south or east-west direction and at minimum 106 m distance in diagonal direction to their rectangular neighbouring Sub-Plots. It is assumed that for the most criteria to monitor, the Sub-Plots can be seen as statistically independent, if a minimum distance of 100 m will be secured.

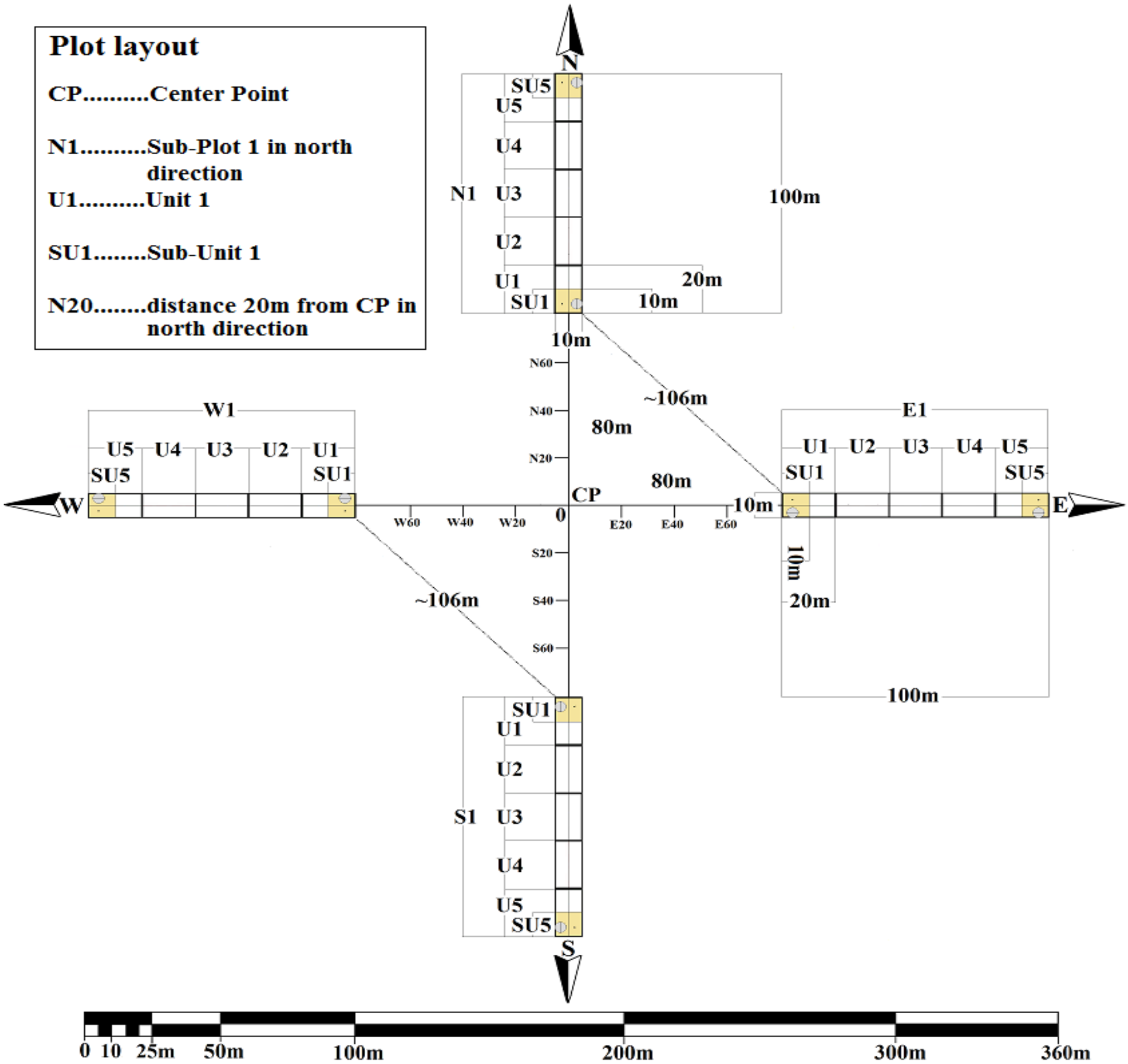

Fig. 1: Sampling Layout

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3 FAO 2008

The Sub-Plots (*Fig. 2*) are strips of 100 m by 10 m. The width is determined by the established center line, measuring 5 m to the left and 5 m to the right of it. Thus, the outer boundaries of the strips are imaginary lines only and will not be established by line cutting or pegs. Each Sub-Plot is further subdivided into five 20 m by 10 m recording **Units**.

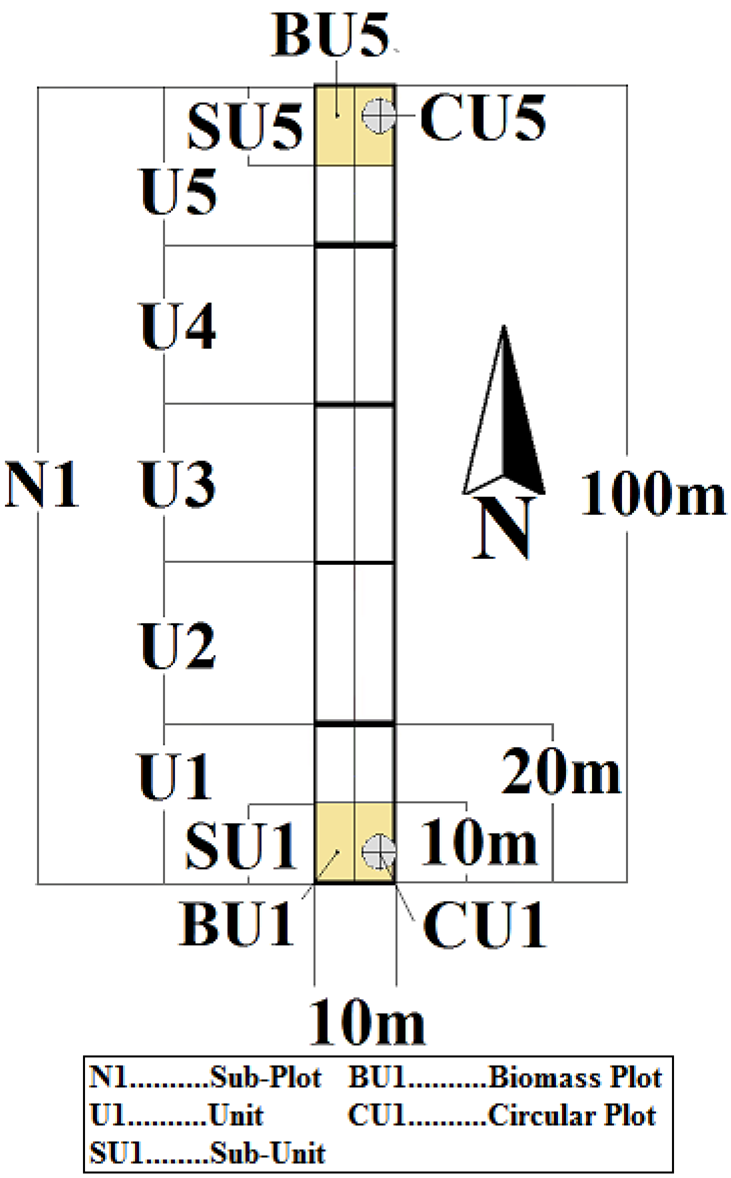


Fig. 2: Sub-Plot

The further partition of the recording Units is caused by the different recording levels (*see p.33*). Every first and last 10 by 10 m of a each Sub-Plot forms one **Sub-Unit** (dividing Unit 1 and 5 by half, *see Fig. 2 p.17 and Fig. 3*).

Within this Sub-Unit two opposite Circle Plots are placed. Their center are located on the facing edges of an imaginary isosceles triangle which is oriented at the center line. The first one is oriented with the right angle to the start of the strip and the second one to the end of the strip. The so called **Circular Plot** on the right will have a radius of 2 m, and the so called **Biomass Plot** on the left will have a radius of 0.3 m.

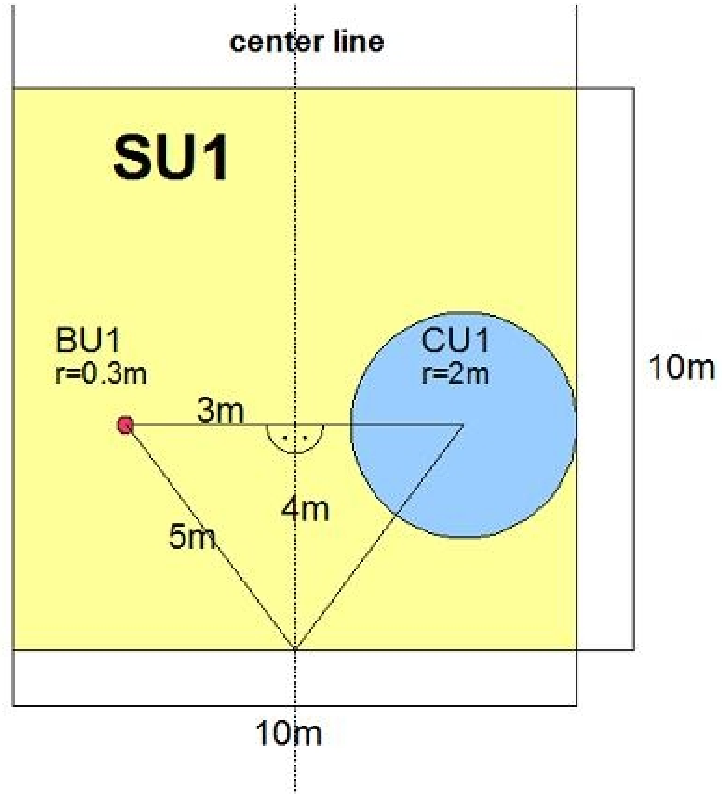


Fig. 3: Sub-Unit

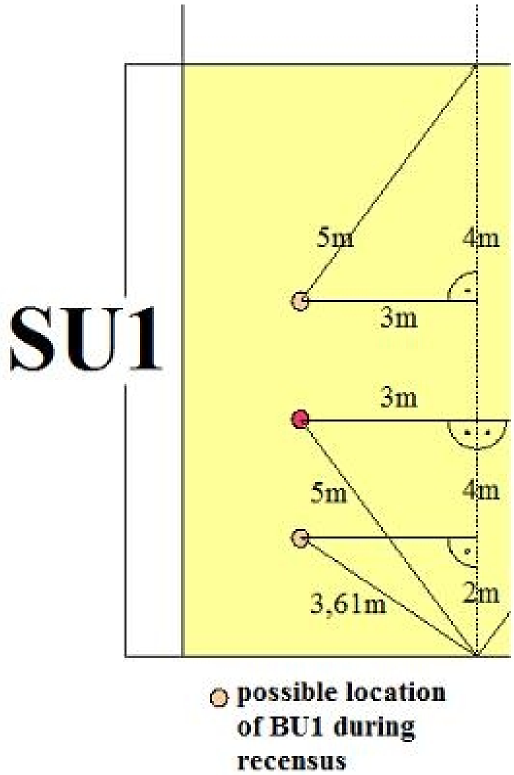


Fig. 4: Relocation of Biomass Plot

According to the destructive sampling of biomass *(see Sub-Task 3f: Sampling of Biomass Plot (e.g. BU1) p.45)****, the Biomass Plot needs to be relocated during the recensus. It should be moved 2 m parallel to the center line during each following census (Fig. 4). It is important that the shifting of the Biomass Plots is carried out systematically for all strips.***

To ensure correct recensus all Plots will be permanently marked (*see Permanent Demarcation p.20*).In terms of better orientation on the Plot the further partition of the center line and the Sub-Plots will be marked as well and numbered, but with temporary posts *(see Temporary Demarcation p.21)*.

A big advance of the cross design is its flexible extension: In case that more information or more replications for statistical purposes are required in the future, it is easily possible to add more Sub-Plots to the basic cross-design. More details are provided in Annex Additional Sub-Plots *(p.93)*.

1.1 Adaptation to Small Island Situations

Narrow atoll islands and small islands can lead to the problem that they can not host a full cross Plot. Also the cross Plot would not be suitable for monitoring the zonal vegetation types.
This can be solved if the cross-wise arrangement of the Sub-Plots is changed to a “snake-wise” design, i.e. a line of at least 4 stringed Sub-Plot strips that cross the island (if necessary several times). Therefore the northerly orientation of the Plot is left. The proportion of the Sub-Plot strips and the data collection within them is not affected by the change of arrangement.

However the arrangement of the Sub-Plot is changed, the statistically comparableness of the collected data is secured, if following rules of Sub-Plot placement will be applied:

- The Sub-Plots have a distance of 100 m to their next following Sub-Plot on the center line and also 100 m distance to parallel running Plots.
- Parallel running Sub-Plots where placed on the longer side of the island.
- If a strip ends in the sea, it will be ripped at the border of the last complete Unit, and continued also in 100 m distance parallel to the rest.

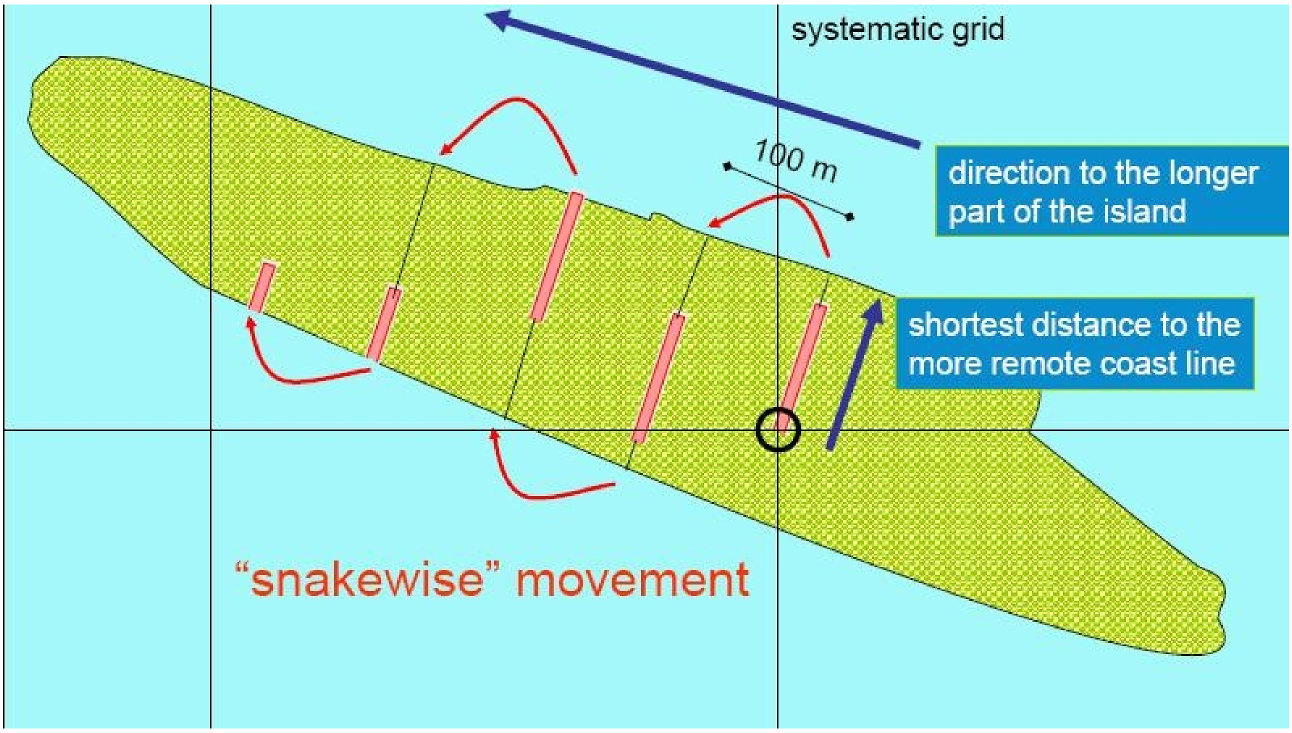


Fig. 5: Sampling design adaptation to small island situations

1.2 Numbering

The Plots have to be numbered with a serial number, e.g. P1, P2, P3 etc, which is indicated at the CP. The four Sub-Plots of each Plot shall be named with the initial of their direction: Sub-Plot in north direction: N1, south: S1, east: E1, west: W1 *(see Fig. 1)*

The center line is divided into 20 m sections which will be numbered also with the initial of the direction and their distance to the CP. (e.g. N20 = 20 m distance to CP in north direction; W120 = 120 m distance to CP in west direction). Units are numbered also with serial number from U1 to U5. Within one Sub-Plot U1 is closest to the center point, U5 is furthest. A Sub-Unit (SU), Circular Plot (CU) and Biomass Plot (BU) will always be indicated with the number of the Unit in which they are found, e.g. CU1 is situated in U1.

> ***Example: Numbering***
> The last Unit in south direction of the 38th Plot will be named as P38|S1|U5 and the first circular Plot of the same Sub-Plot P38|S1|CU1.

1.3 Permanent Demarcation

The Center Point (CP) has to be trackable to ensure the permanently aspect of the Plot and the comparableness of data from remeasurement.

The CP is therefore marked permanently with a short metal stick or rod (ca. 30 – 50 cm) which is punched in the ground. This is tracked with a metal detector and is durable for long time. If no metal demarcation is available, durable (treated) wooden posts with (diameter 8 -10 cm, length 1.5 – 2 m) should be dug approx. 70 cm in the ground.

Also the start point (80 m form CP) and end point (180 m from CP) of each Sub-Plot shall be marked permanently in the same way. The markers will be placed on the center line of the Sub-Plot.

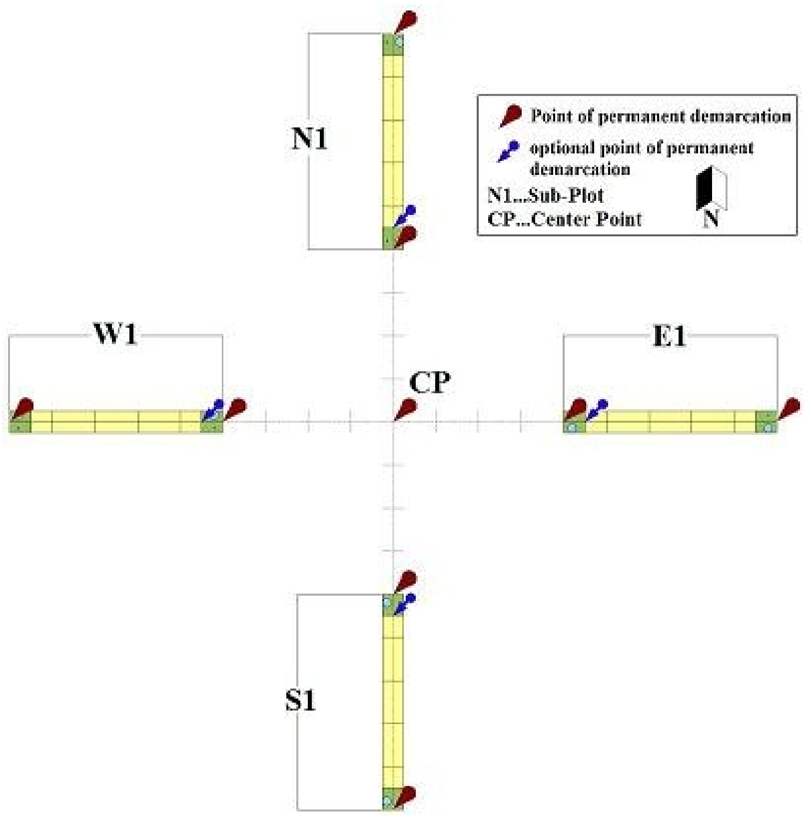


Fig. 6: Permanent demarcation

Additional, the end of the first Sub-Unit (90 m from CP) should be marked permanently. The fixed 10 m line of the first Sub-Unit can be used for calibration of alignment.

When remeasuring the Plot you try to find the exact GPS coordinates and use a metal detector to locate the exact center of the Plot and the starting of the Sub-Plots. That will safe you time by avoiding the again aligning of the 80 m distance from CP.

1.4 Temporary Demarcation

To achieve good performance in work quality and quantity it is essential to have a good orientation on the Plot during the fieldwork. It can easily happen that you do not know in which Unit you are because of the similarities of the Units within the longish Sub-Plots.

This can cause substantial error e.g. if Units are left or too much are established. Therefore every 20 m distance from CP, the start and end of the Units, the Sub-Units and the center of the Circular Plots are temporary marked with a post (*see Preparation of Posts p.35*) and numbered. They will be numbered with the initial of their direction and the distance to the Center Point (e.g. 20 m in North direction is numbered N20). Within the Sub-Plot, additionally the number of the both neighbouring Units is indicated (*Fig. 7*).

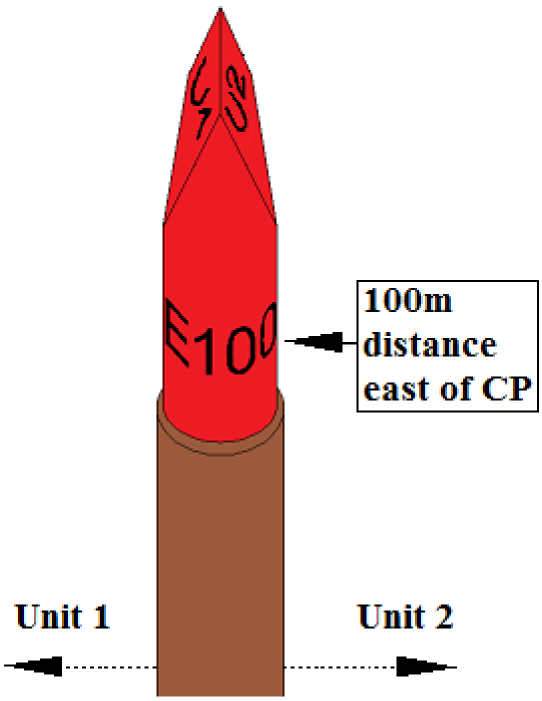
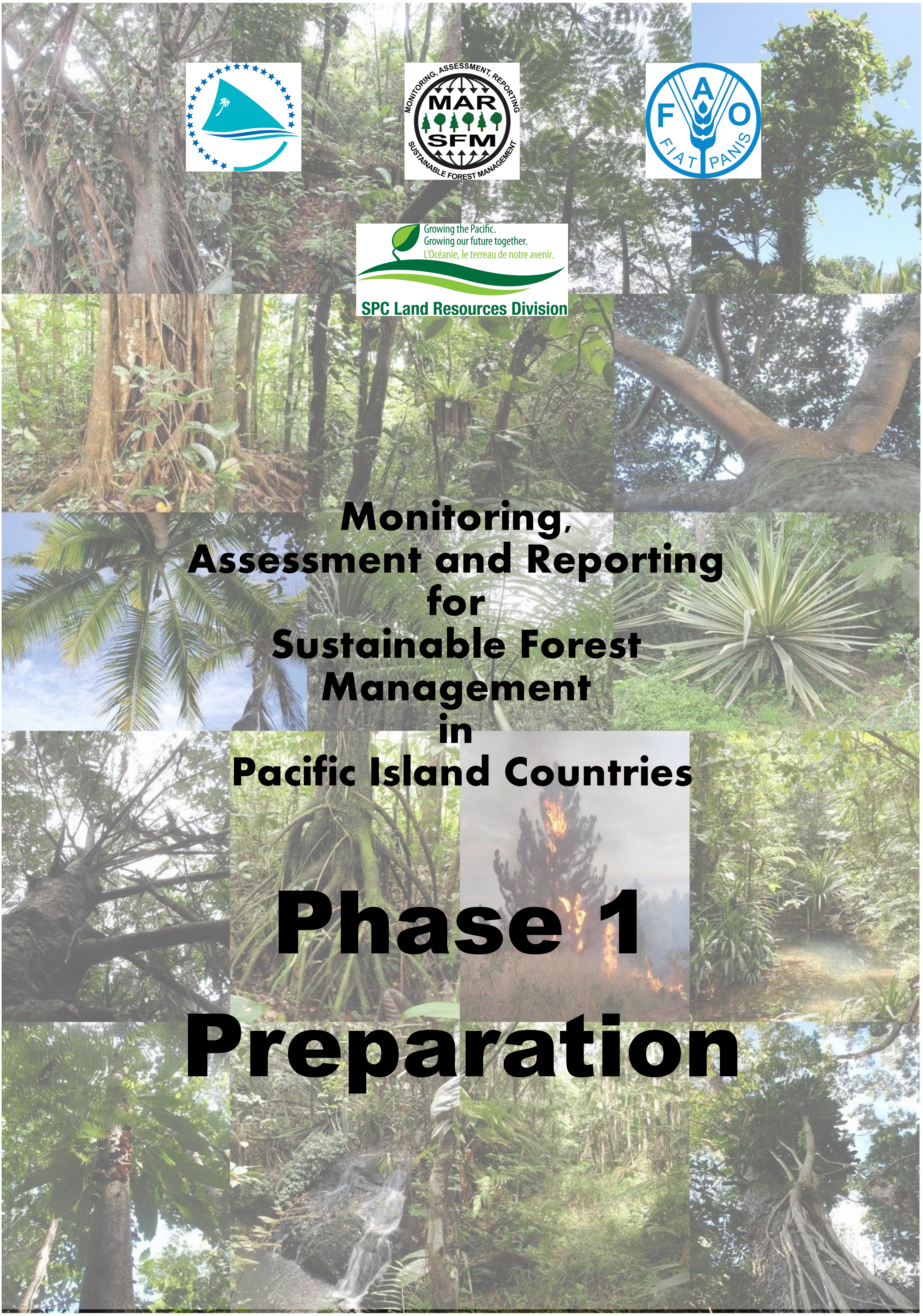


Fig. 7: Temporary demarcation

All recorded trees inside the recording Units (U) and Sub-Units (SU) shall be marked with signal colour (e.g. a dot with spray paint) good visible from the center line. That will reduce the number of distance checking during the remeasurement.

Keep in mind: During the remeasurement "new" (unmarked) trees may have reached the DBH recording limits. This trees need to be measured and marked as well.



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Phase 1 Preparation

2 Preparation (Phase 1)

A National MAR Project will contain a lot of prepared documents and gather lots of data. In future it is planned to create a database to manage all relating documents and data together.

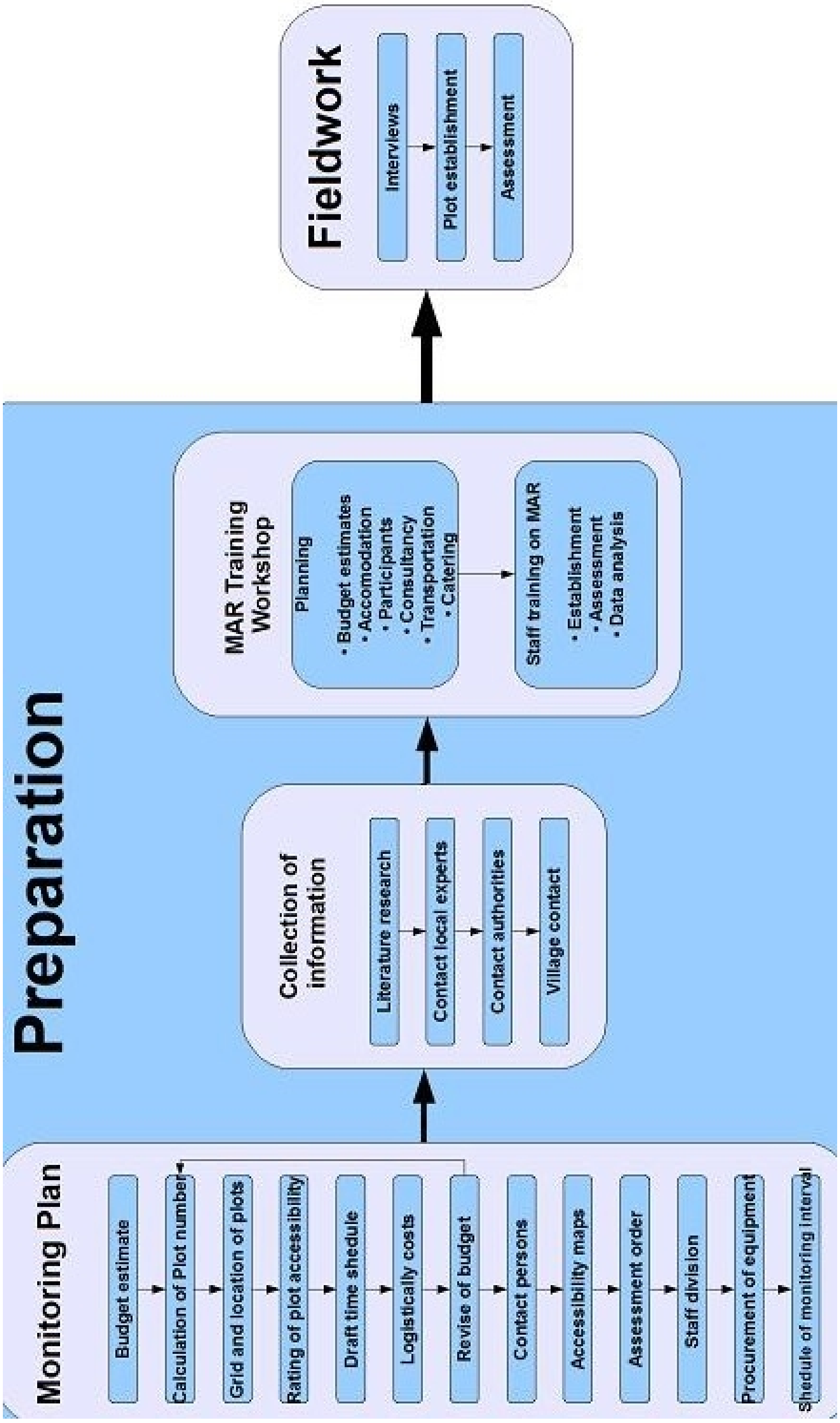


Fig. 8: Work flow diagram (Phase 1)

The responsible authority has to fix the monitoring plan which can be adopted by the PIC specific needs and resources. It includes the number of Plots and their regional distribution (regional distribution maps; CP coordinates; accessibility maps; classification), a time schedule for establishment and assessment as well as for recensus (Plot assessment order; time frame) and budget estimates (staff training and wages; equipment; transportation; etc.).

2.1 Location and Calculation of Plot Quantum

All Plots will be set up systematically over the territory of a country (or region/island) on a map grid, following the global geographical coordinate system (longitudes and latitudes), i.e. all Plots will have the same distance to their neighbouring Plots. Therefore the CP's of the Plots are located on the cross points of that map grid.

The distance between the Plots is determined by the number of Plots. In practice, the number of Plots depends mostly on available budget and capacity but, in the ideal case, on the statistical parameters (heterogeneity of data, desired precision)[4].

For orientation purposes it is suggested to have not less than 7 Plots per monitoring Unit (e.g. district, province, island) and a maximum of about 100 Plots per country[5].
Formula 2 will be used to determine the distance between the CP's.
The starting point of the grid is randomly chosen. In some cases, especially within scattered Island situations, it can happen that you will not get the achieved number of CP's on land. That is not a problem if the derivation is not so big from your calculated number of Plots. But either the grid starting point or the number of Plots can be adopted to the situation.

Formula 2: Grid distance calculation

$$d = \sqrt{\frac{A}{n}}$$

d = grid distance

A = area of land surface

n = desired number of Plots

Example: Grid distance calculation

A = 18,300 km²   n = 100

$$d = \sqrt{\frac{A}{n}} = \sqrt{\frac{18300\text{km}^2}{100}} = \sqrt{183\,km^2} = 13.5\,km$$

[4] For statistical calculation of the Plot quantum the following formula is usable:

$$n = \frac{t^2 * cv^2}{E^2}$$

Formula 1: Plot quantum

n = number of samples needed
t = t-value (≈ 2)
cv = coefficient of variation
E = tolerated sampling error (≈ 5 – 20%)

Keep in mind that you need a pre-study to estimate the coefficient of variation (cv) regarding the relevant parameters.

[5] Big countries like Papua New Guinea should consider more than 100 Plots

2.2 Preparation of Center Point Coordinates

After the calculation of the distance of the Center Points (CP) and setting the grid on the map, the coordinates of each CP have to be prepared. Therefore any GIS Software will be usable as e.g. MapInfo ™. These coordinates can be later used with other waypoint coordinates in the handheld GPS.

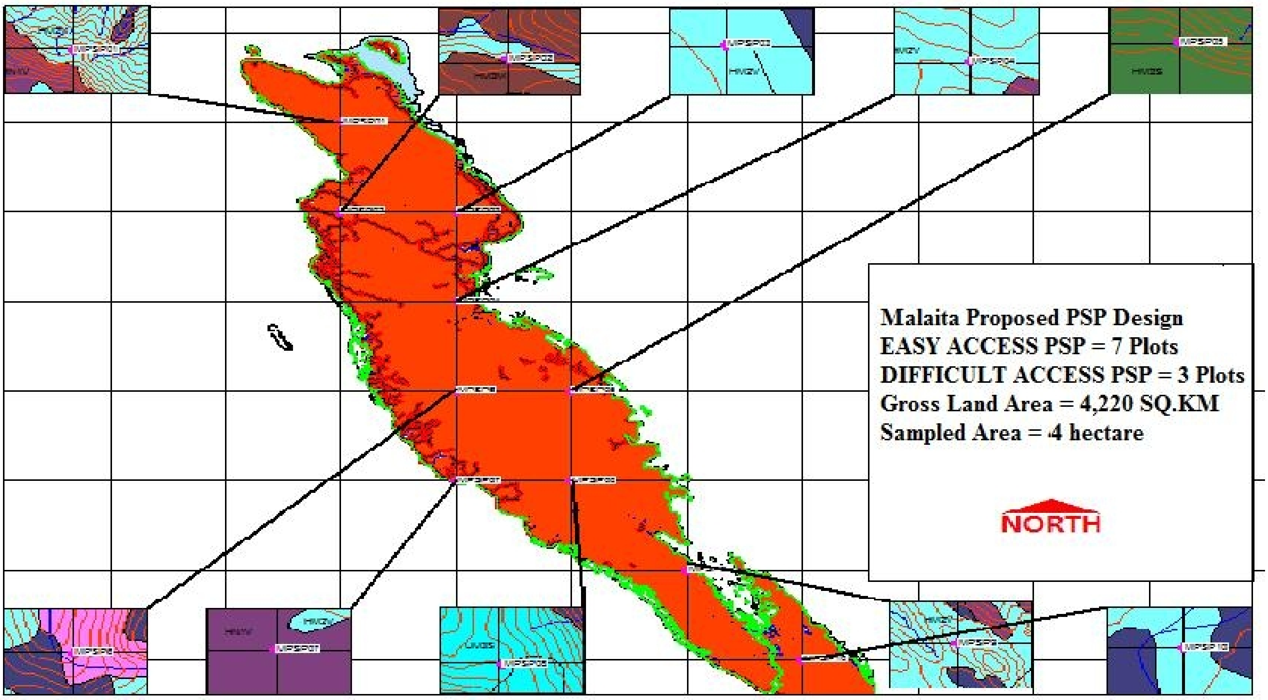


Fig. 9: Example grid map from Solomon Islands (Malaita) (Picture source: Irokete, J.W. 2010.)

2.3 Accessibility of the Plot

When you plan an inventory some questions occur which have to be cleared before one can start. *How can we go there? Are there streets, bridges etc. ?*
How close can we go by car? How far we have to walk? Are there tracks? How much time it will take to go there before we can start the measurements? All these information are important to make the monitoring efficient because it ensures that you do not loose more time than necessary to go there.

It is advisable to classify your Plots in terms of accessibility, into “Easy Access Plots” (EAP) and “Difficult Access Plots” (DAP) *(see Fig. 9)*. Categories for the classification can be defined in reflection of the available resources of time, personal and money. In general a Plot will be classified as DAP if it is situated on remote islands, in the mountainous interior of big islands, in regions with bad infrastructure and so on. An EAP will normally require less travel time and costs and also the establishment and assessment of these Plots would be normally faster. Thus classification has a direct influence to the monitoring schedule.
The accessibility is also important for the monitoring plan concerning the order of assessments of Plots. It is not necessary to measure them in numerical order but in the most practical or suitable order. (e.g. P1 in a mountain side is finished but P2 is situated on the other side of the mountain, you ought to drive around. It is more efficient to go to a Plot which is more fast accessible.) So you create your own order according to the locations and conditions.

An accessibility map *(see Fig. 10: Example Accessibility Map (Picture source: Google Earth ®, self edited) p.27)* have to be prepared for every Plot. That will help you and your successor to find the Plot, and again when remeasurement is initiated. (Keep in mind: You could have to measure 100 Plots and the last assessment can be 5 years ago). Notes can save you a lot of time and work.

The most favourable drive should be drawn on the map (or sketch) together with the CP, with short remarks of obstacles you have to face going there. Prepared way point coordinates will be useful to find the last part of the course away from infrastructure.
In addition, reference objects as e.g. Rivers, roads, houses etc. should be identified in order to contribute to better orientation.

During the first assessment, it is recommended to take pictures or notes of surrounding, landmarks and everything that will help to locate the CP in the recensus (e.g. a house just before a bad visible turning).

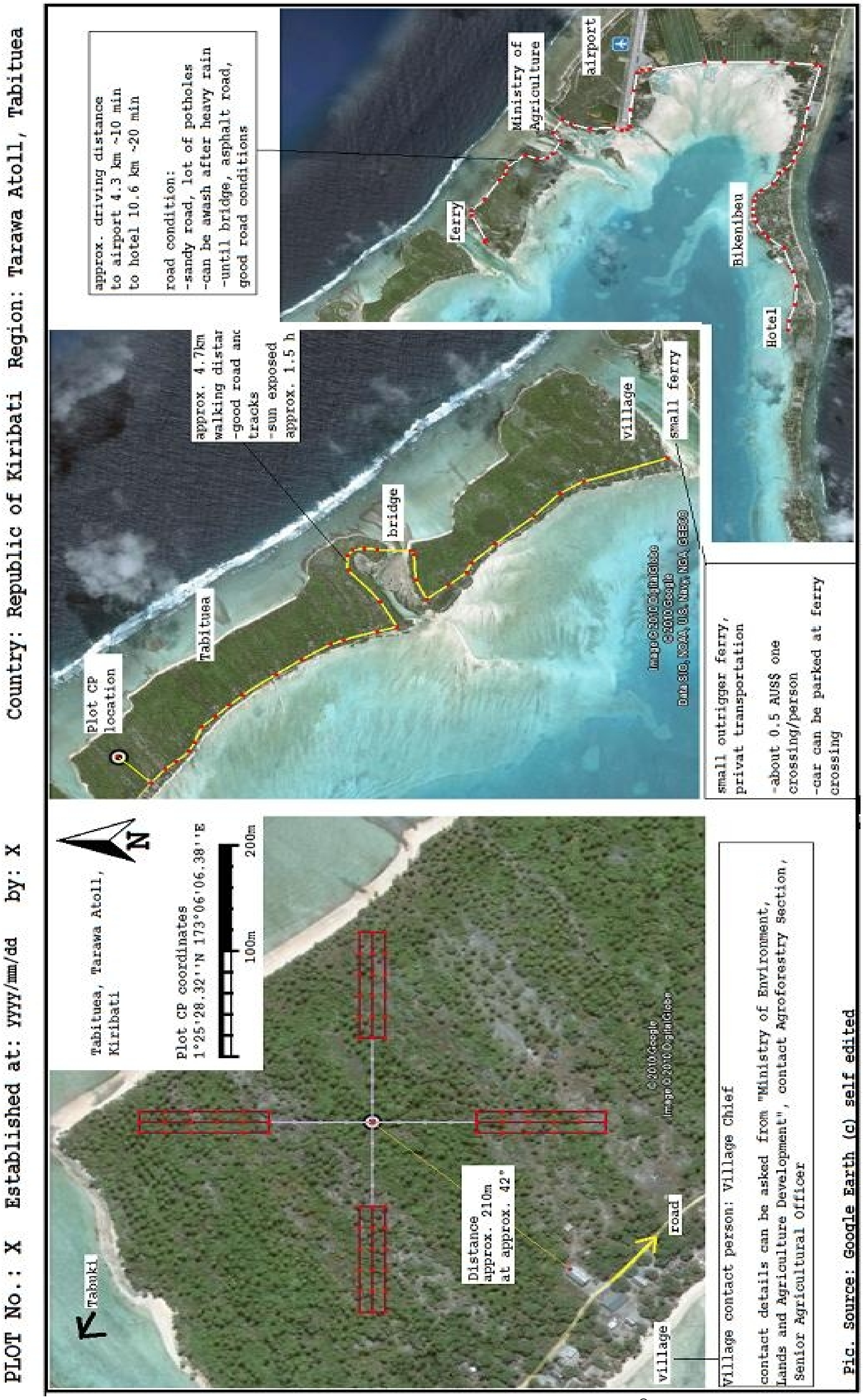


Fig. 10: Example Accessibility Map (Picture source: Google Earth ®, self edited)

2.4 Data Sources

The first step of every assessment is the collection of all relevant existing information. For logistical planning and possible data collection you should consult in advance:

- maps, areal photos, satellite images, existing data bases etc.
- landowners, responsible authorities about forest and other relevant public authorities, concession holders, local experts etc.

Out of this sources you might get information on topography, vegetation cover, ownership issues, land use activities, forest disturbances etc. *(see Tab. 1: List of proposed Criteria p.14).*

Also very practical things has to be cleared as e.g. *Are there any special restriction? Can posts be cut in the field, or do we have to carry them? Can we hire a tree spotter in the village? etc.*

For later processing and analysing of the data a list of tree species has to prepared which includes a column for local name, scientific name, status (protected, commercial,...), origin (native, endemic, introduced, invasive) and conservation status according to IUCN red list[6]. The conservation status can be requested in the Internet (www.iucnredlist.org). If a species is invasive it can be checked also in the Internet by “PIER – Pacific Island Ecosystems at risk” (www.hear.org/pier).

It is recommended to contact also local experts in your region on conservation status and invasive species. Also a list of possible biodiversity indicator species have to be prepared in cooperation with experts. In addition to the lists, a full set of pictures of rare, invasive and indicator species has to prepared for the interviews and as reference to the assessment.

[6] The IUCN red list does not give a complete overlook of the conservation status of all species.

2.5 Interviews

In addition to the collected information from the Sub-Plots, there will be personal interviews to gather data which is not measurable in the field. For this interviews please use the prepared questionnaire and a sketch map or better field map including the plot boundaries shall be prepared for each Plot. They will be used to show the location of the related area *(Fig. 12: Field form "Interview" p.30 and Fig. 13: Field form "Plot sketch" p.31).* Also these surveys can be used, in some cases[7], to complete data of the assessment. Preferable the interviews will be done prior to the Plot measurements. However, also during the assessment the direct cooperation with the local people is an important help. Whenever possible locals shall attend the Plot assessment and can be questioned on the Plot.

The Plot is included by an imaginary tract circle of a 500 m radius *(Fig. 11)* around the CP, to calculate area related figures later on. *These tract circle forms the reference area for the survey and all questions are only related to that area.*[8]

In case of small island situation where the "snake wise" plot setting was applied, the tract circle is formed around the starting point of the strips.

The locals normally know best about their forest. Therefore they shall be the reference persons for the questionnaire. First the ownership of the Plot has to be clarified. For this the responsible authority as well as the presumed landowner has to be interviewed. Probably in the most cases it is at least known to which village or settlement the Plot area belongs. Your village contact person will investigate in the question of ownership. If the ownership rights keep unclear, it is not necessary for further investigations on this topic. In this case categorize it just as "Unclear" and either the village contact person will be interviewed or a person identified by him/her, also the questionnaire can be completed with a group of concerned locals. The questions should be answered in general and short, also special observations can be drawn in the prepared field map. If answers are not available, please write down "N.A." on the field form.

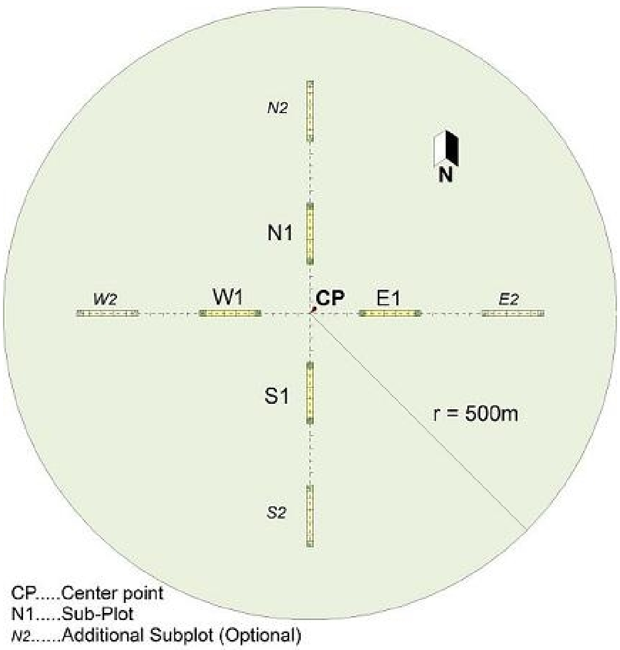


Fig. 11: Tract Circle

7 Not for tree related figures, but for site description (*Backward Movement p.47)*, biodiversity observations, designated functions, Social and cultural services, Removals etc.

8 Only exception is made for the category "industrial round wood production", i.e. the questions are related to the actual harvested area. Normally this is queried directly by the harvesting company or responsible authority. The proportion harvested land within the tract circle can be determined later by applying GIS Software.

Recorder:		**Date**		**Plot No:**	
Name of interviewee(s):		**Status:**		**Adress:**	

Ownership			
Who owns the land of the TC?			
State		Unclear	
Privat		Mixed	
Customary		Other	

Management Rights			
Who uses the land which the Plot is part from?			
Owner		Leased	
for period of			
How is the land used?	Subsistancial		
	Commercial		
If it is Commercial used, is there a management plan?			
Yes		No	

Plant products (NTFP)			
*Are **medical plants** collected on this plot?*			
Yes		No	
If YES, Which?			
Species list (local name):			
How often are those collected on this plot?			
Daily		Weekly	
Monthly		Annually	
*Are **edible wild plants/wild fruits** collected on this plot?*			
Yes		No	
If YES, Which?			
Species list (local name):			
How often are those collected on this plot?			
Daily		Weekly	
Monthly		Annually	

Industrial wood production	
When was the last logging operation?	
Year	Never
Who was the logger/ logging company?	
Name	
Adress*	
*Which species have been logged?**	
Species list (local name):	
*How much wood was removed?**	
Total Vol.(m³):	
Volume by Species (m³):	

Social and cultural services			
Does anybody use the site for social or cultural activities?			
Yes		No	
If YES, what kind of social or cultural activities?			
Is the site used for spiritural purpose?	Yes		
	No		

Biodiversity observations
Are rare animals or plants known in TC? (acc. to list)
Species list (local name):

Wood fuel			
Is wood fuel collected on this plot?			
Yes		No	
Is wood fuel only used (also combination with gas / cerosin / others)?			
Yes		No	
What kind of wood is used as wood fuel?			
Debris	Dead wood	Logged Wood	
How much wood fuel is collected within one month? (m³) (From TC)			
Debris	Dead wood	Logged Wood	

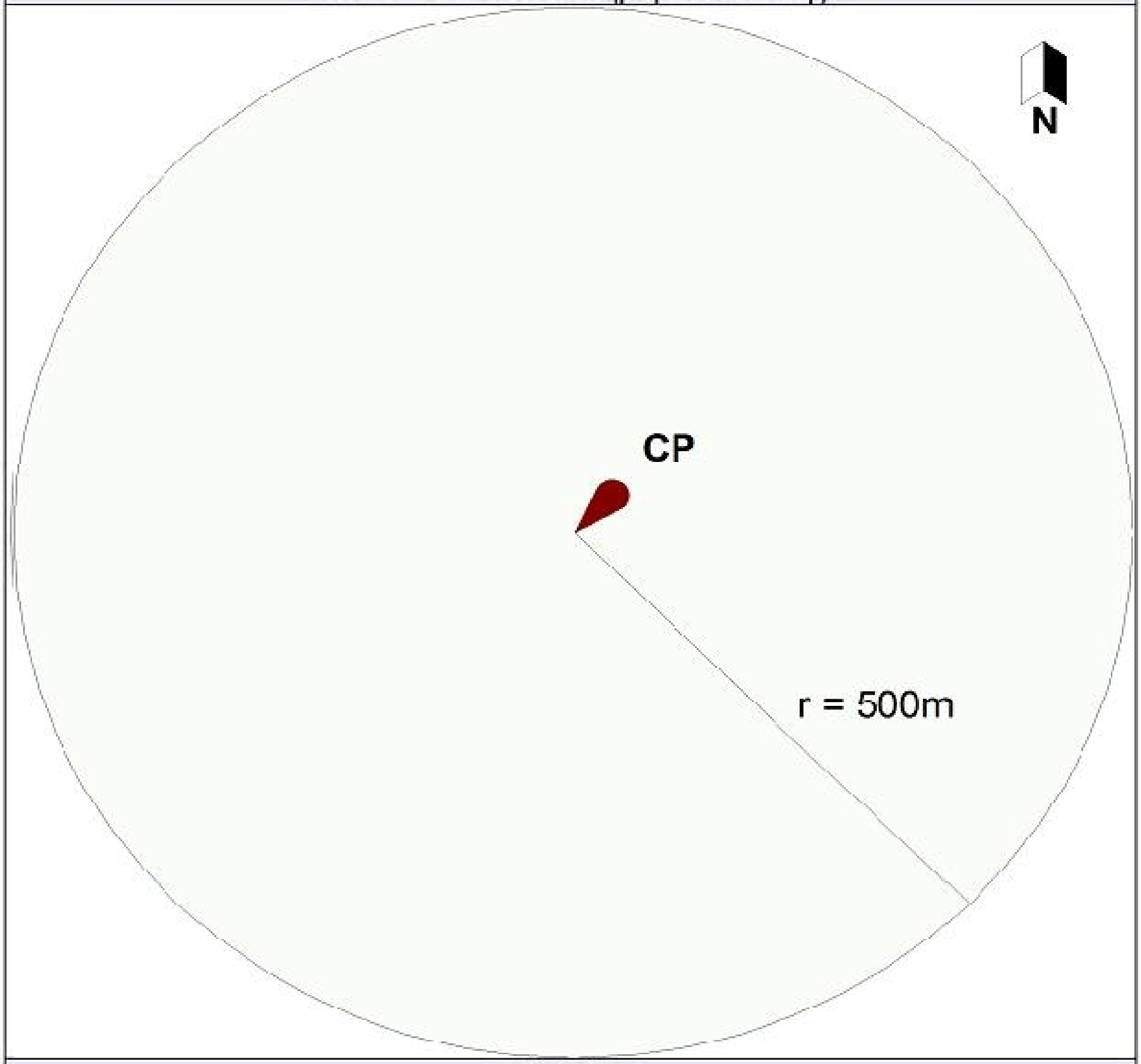
Animal products (NTFP)			
Is a hunting ground within the TC?	Yes		
	No		
If YES, which animals are hunted and how many?			
Species list (local name):			
How often is hunted there?			
Daily		Weekly	
Monthly		Annually	
Is a fishing ground within the TC?	Yes		
	No		
If YES, which fishes are caught and which amount?			
Species list (local name):			
How often is fished there?			
Daily		Weekly	
Monthly		Annually	
Is honey collected within the TC?	Yes		
	No		
If YES, which amount?			

Other socio-economic benefit	
Name any other kind of socio-economic benefits you have from the plot. (e.g. drinking water)	

Remarks:	**It is liable that the person maybe can not provide this information. Therefor contact the logging company.*

Fig. 12: Field form "Interview"

Recorder:		Date		Plot No:	
Plot sketch with Tract Circle (prepared field map)					



Remarks:

Fig. 13: Field form "Plot sketch"

2.6 Field Measurements

Most of the required MAR data need to be collected during the Plot assessment. Also the data collected with the questionnaire might be verified in the field.

Some information is directly assessable i.e. the collected data is equal to the required information. Such information includes forest extend, forest characteristics, forest ownership, designated functions, disturbances and removals and benefits from forest.

Other information can be assessed in an indirect way by calculating the required data from other measured parameters. Examples for such information are growing stock, biomass stock, carbon stock and biodiversity. Table 2 illustrates what kind of data need to be collected to allow statements on the required monitoring criteria.

Tab. 2: Data to be collected

Criteria	**Data needed for processing, calculating, analysis**
Growing Stock (total growing stock, commercial growing stock, growing stock composition)	– Number of trees – Tree species – DBH – Log Height
Biomass Stock (above ground biomass, dead wood) Carbon Stock (total carbon stock, carbon in above ground living biomass, carbon in deadwood, carbon in litter)	– Number of trees – DBH – Height – Samples to be analysed in laboratory
Biodiversity (Total number of native tree species, number of tree species according to IUCN “red list”)	– Tree species – Native Tree species list – request of IUCN “Red list” Database – indicator species for biodiversity (animals and plants)

2.7 Recording Levels

According to the partitioning of the Sub-Plot different recording levels has to be observed. The recording level *(Tab. 3)* shows which kind of data is collected in the particular parts of the Plot.

Tab. 3: Recording Levels

Recording Level	**Parameter**
Tract Circle (500 m radius)	• biodiversity observations • interviews
Sub-Plot Units (each 20 m by 10 m)	• Trees / Standing deadwood ≥ 25 cm DBH • Lying Deadwood ≥ 25 cm diameter at crossing • biodiversity observations
Sub-Units (10 m by 10 m)	• Trees / Standing Deadwood ≥ 10 cm < 25 cm DBH • Lying Deadwood ≥ 10 cm < 25 cm diameter
Circular Plots (2 m radius)	• Trees / Standing Deadwood ≥ 1.3 m height and < 10 cm DBH • Lying Deadwood ≥ 1 cm < 10 cm diameter at crossing
Biomass Plots (0.3 m radius)	• All vegetation < 1.3 m height originating on the biomass Plot and litter • Lying deadwood < 1 cm diameter • count Regeneration

2.8 Personnel

The team consists of 3 persons: the Recorder, the Surveyor and the Tree Spotter. At least one team-mate should be recruited from the local population. If possible the landowner should participate as resource person as well and might take over some assisting functions during measurements. Especially during the first assessment additional assistance can be useful (preparing and carrying posts etc.).

Table 4 gives an overview of the different tasks of the team-mates (for detailed information on the tasks, *see Data Collection (Phase 2) p.40*)

Tab. 4: The Monitoring Team

The **Recorder** is the team leader and preferable a forest technician from the responsible administration. **Tasks:**	The **Surveyor** can be also a forest technician or a lumberman. **Tasks:**	The **Tree Spotter** should be skilled and keen, and if possible recruited from a village close to the Plot. **Tasks:**
• coordinates the team work • records all data and information • measures slope and angles • samples the biomass • assists on distance measurements	• measures compass bearings • measures slopes and angles • executes “In or Out Judgements” • performs distance measurements • counts the regeneration in circular Plots • gauges the decay classes of deadwood • tags the posts • performs line cutting	• identifies trees, (regeneration and matured) • performs line cutting • cuts posts • paints with signal colour • assists distance and height measurements

2.9 Equipment

The survey team is equipped with the following Materials (Tab. 5) For more detailed information on the used material see Annex Materials p.94.

Tab. 5: Material list

<table>
<tr><th>Recorder</th><th>Surveyor</th><th>Tree Spotter</th></tr>
<tr>
<td>• GPS
• accessibility Map
• clinometer
• survey compass
• 30 cm long stick
• roll strong plastic bags
• secateurs
• knife
• clip board
• pencils
• waterproof black marker
• field forms (printed on waterproof paper)
• slope correction table (laminated) *(p.101)*
• height control tables (laminated) *(p.106)*</td>
<td>• tape measure (25 m)
• diameter tape (up to 5 m)
• “survey stick”
• clinometer
• survey compass
• calliper (25 cm)
• bush knife
• *Eventually during remeasurement:* metal detector</td>
<td>• bush knife
• compass
• diameter tape (up to 5 m)
• signal colour spray paint or can signal colour and brush (flagging tape)</td>
</tr>
<tr><td colspan="3">• Permanent and temporary markers
• ranging rods
• standard equipment (weatherproof clothes, tough foot gear, first aid set...)</td></tr>
</table>

2.9.1 Preparation of Posts

To completely establish one Plot you will need at least 5 permanent markers e.g. metal rods *(Permanent Demarcation p.20)* to mark the Plot (1x CP, 4x for start of Sub-Plots, optional 4x for the end of the Sub-Plots and 4x for end of first Sub-Units).

For the measuring work and aligning of one Sub-Plot you will need 4x coloured and straight ranging rods (aluminium, hard wood or plastic) for working procedure.
Another 12 temporary marker posts are necessary (6x for the Units, 2x Sub-Units, 2x Circular Plots, 2x Biomass Plots), which can be prepared in advance (e.g. sawn timber posts) or they will be improvised in the field (made from small trees).

Pay attention that it is not allowed to cut the posts inside the Sub-Plots.

Therefore prepare the posts before starting the establishment of one Sub-Plot. If there are no restrictions from the landowner or because of protection status, you can use all straight young trees with durable wood and a minimum diameter of 4 cm. It is not practical to use trees thicker than 7 cm in diameter.

The posts need to be approximately 1.8 m long. The bark around the top end will be removed and the unveiled wood will be painted with the signal colour or marked with flagging tape. *(Temporary Demarcation p.21)*

Nevertheless it is the temporary marking, the posts should remain there positions. Even in tropical rain forest it is likely that not all posts will be rotten when the recensus is initiated (about 2-5 years after last measurement, according to the monitoring plan). This will be a big help to orientate on the Plot and therefore make it easier and faster to re-establish of the Plot. Only rotten post will be replaced. However, if you have not enough material available or can not cut enough posts in the field, these temporary posts can be removed continuesly during “Backward movement” and again used for the next Sub-Plot. They should first be removed when the measurements of a Unit has been finished.

2.9.2 Field Forms

Data from each Sub-Plot will be recorded on two different Field Forms which are designed in order of work sequence as described in “Forward Movement” *(Forward Movement p.42)* and “Backward Movement” *(Backward Movement p.47)*. So you got the “forward sheets”*(Fig. 14 p.37)* and the “backward sheets”*(Fig. 15 p.38)*.

If there is not enough space for the collected data on one sheet, do not mix data from different Sub-Plots on one sheet, but take an empty sheet and number it!

Both data sheets include space for general information as: the names of the team members, the date and time of assessment, the Plot number, Sub-Plot number and page number. Also a blank map of the Sub-Plot is placed on the right side of both data sheets. In that map the recorder can sketch specific ground features, e.g. rivers, skid tracks, roads, fences etc. crossing the Sub-Plot. Also obstacles like big rocks and whatever is seen remarkable.

On the forward sheet columns for the Circular Plot, including Circular Plot number, local name of tree, amount and remarks, are found at the left side. The sheet is divided trough the column for lying deadwood recordings, including Unit number, the diameter at crossing (DC) *(Lying deadwood survey (line intersect method) p.61)* and decay class.

On the top left side columns for the biomass Plot are found, including Unit number, substrate description and gross weight. The weight columns are not filled in the field, they will be filled in the laboratory, the net weight after drying in Phase 3 *(Processing of samples and calculation of above ground non tree biomass p.77)*. Underneath, the very small regeneration section is found with Unit number and amount column. On the lower right side the columns for spotted biodiversity indicator species are found. The backward sheets will be filled on the way back to the Center Point.

It includes columns for Unit number, Local name (if the tree is dead fill in “dead”), the DBH, Height measurement section with 4 columns for the angles and the remarks column.
On the lower left side the columns for the site description are found. There will be only ticked which Unit fits in the prescribed condition.

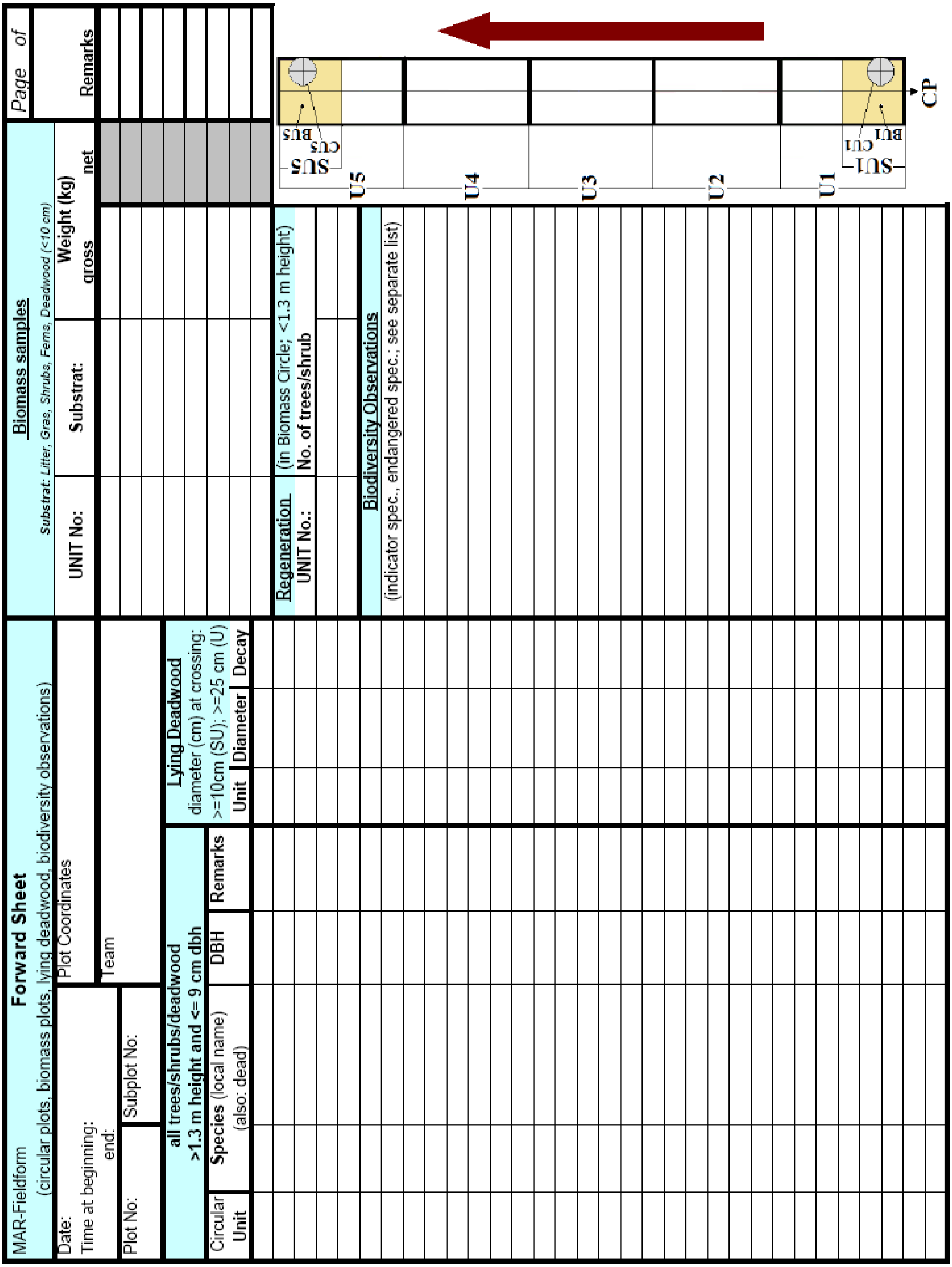


Fig. 14: Field form "Forward Sheet"

MAR-Fieldform **Backward Sheet**

(trees dbh 25+, 10+ in subunits, site description, biodiversity oberservations)

	U1	U2	U3	U4	U5	
Forest Extend						
Forest						
Other wooded land						
Oth. (agricultural)land with tree cover						
Coconut Forest						
Coconut Plantation						
Forest Characeristics						
Primary						
Secondary with natural regeneration						
Secondary with enriched planting						
Plantations						
Ownership						
State owned land						
Privat owned						
Customary owned						
Other						
Management rights						

Page **of**

Date:

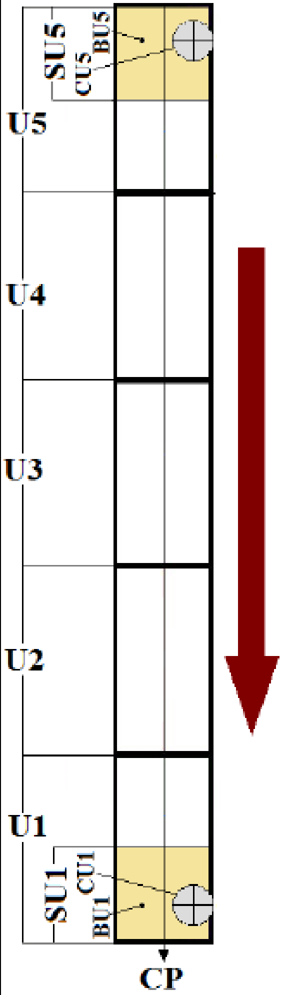
Time at beginning:

end:

Plot No.:

Subplot No.:

Team:



Biodiversity Observations indicator, endangered spec. (see also Forward Sheet)	U1	U2	U3	U4	U5
Disturbances					
by cyclones					
by fire					
by insects					
by invasive species					
by live stock					
Other					
For. Functions					
Production					
Protection of soil					
Protection of water					
Conservation of biodiversity					
Social and cultural services					

***Subplot:** dbh>=25cm; **Subunit:** dbh>=10cm*

Unit No.	**Species** (local name) (also: dead, stump)	**DBH** (cm)	**Stump** Diameter	Angle (degree) at: Tree **Bottom**	Angle (degree) at: **Refer-ence**	Angle (degree) at: **Log** height	Angle (degree) at: Tree **Top**	**Top** Height **(m)**	**Log** Height **(m)**	**Remarks** e.g. decay class: (sound, inter-mediate, rotten), damages etc.

Fig. 15: Field form "Backward Sheet"

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Monitoring, Assessment and Reporting for Sustainable Forest Management in Pacific Island Countries

Phase 2
Data collection

3 Data Collection (Phase 2)

3.1 General Work Sequence

In order to have a continuous work flow *(Fig. 16 p.41)* the Sub-Plot establishment and data collection is carried out simultaneously and not separated in two different steps, thus it saves time and walking distance. The survey is split up in a “Forward Movement” (to the end of the Sub-Plot) and “Backward Movement” (to the beginning of the Sub-Plot) recording direction-specific data. When moving twice (up and down) the center line, the risk of confusion due to the large number of parallel measured parameter is reduced and simultaneously the recorder gets a better overview on certain area-specific parameters (e.g. disturbances, forest functions etc.).

Due to the fact that the Center Point (CP) of the Plot will be past several times (after each Sub-Plot establishment) the CP is ideal as storage place for luggage and for occasionally not needed equipment, as rest place after finishing a Sub-Plot and as meeting point when working with two teams.

The 4 center lines of the Plot has to be carefully cleared with a bush knife, but only that much as necessary to walk on and see properly. The cutting will be made successively by Unit and in coordination with other activities.

The team will be working on one Sub-Plot at a time and should try to work and stay close together. The establishment of the assessment Unit (Sub-Unit, Circular Plot, Biomass Plot) has to be finished before every measurement. Data collection takes place successively as assigned.

When the team reaches the end of the Sub-Plot the moving direction is changed back to the coordinate point. A break can be held at the end post of the Sub-Plot. On the way back the team walks in a formation of a line covering the width of the Sub-Plot. The recorder walks on the center line of the Sub-Plot and the tree spotter and the surveyor, in 2 to 3 m distance beside him.

That will avoid the missing out of trees. The team comes together when a tree is measured and recaptures its position afterwards. In more open situations the formation is not necessary.

After finishing one Sub-Plot again a short break can be made at the CP and the procedure starts again with the next Sub-Plot.

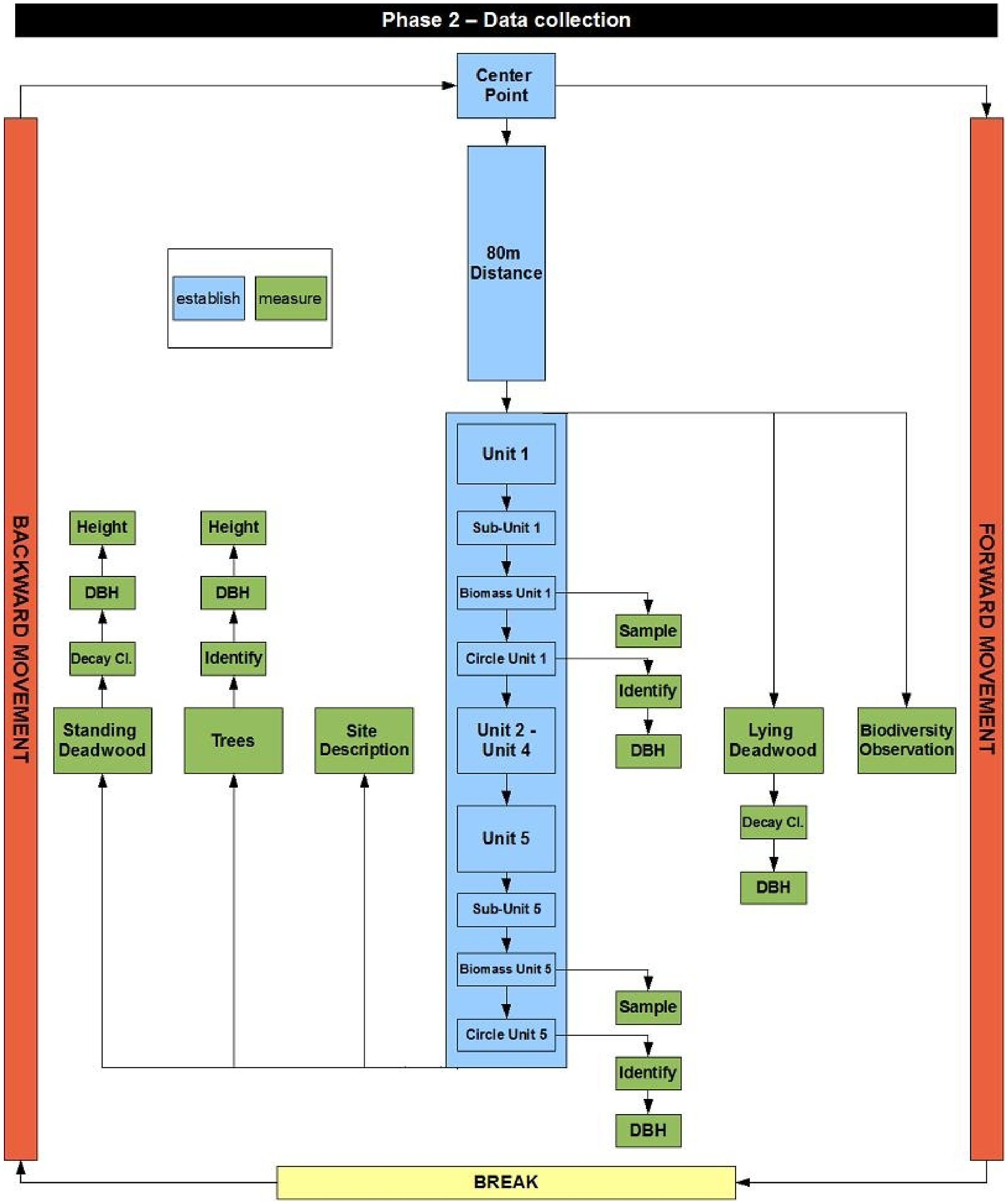


Fig. 16: Work flow diagram Phase 2

3.2 Forward Movement

The following chapter gives the sequence and the description of the different tasks to fulfil during the "Forward Movement". The Plot establishment must be soundly done because it provides the basis of all data collection. *The following procedure is described in example for Sub-Plot N1.*

3.2.1 Task 1: Identify the Center Point in the field

The center of the Plot (CP), has to be identified in the field by the assistance of the prepared accessibility maps, way points and directions and has to be determined by using a GPS .

1. Go on until the GPS coordinates are identical to the fixed CP coordinates on the map (the displayed deviation should never be more than 10 m).
2. Mark the point with a permanent marker and a temporary post.
   Or: During remeasurement, when the Plot is already established, locate the permanent marker (e.g. if a metal rod was used in first establishment use a metal detector) and replace the temporary post on the CP, if necessary.
3. The team decides which direction to go first.

3.2.2 Task 2: 80 m distance establishment

The 80 m distance will be established in stretches of 20 m length. It was not found practical to measure longer distances at once.

1. The Recorder (**R**) remains standing behind the post at CP and keeps the approach end of the distance tape.
2. The Treespotter (**T**) moves in the desired direction and (preliminary) clears the center line (if necessary) while carrying the distance tape and a ranging rod until he reach the 20 m distance (e.g. N20). The Surveyor (**S**) gives the bearing with the compass (and/or alignment) and instructs him. **T** should never be more than 20 m in front of **R.**
3. When **T** reaches N20 he stops line cutting and places a ranging rod.
4. If horizontal measurement of the 20 m distance is not possible, **R** reads out the slope *(Horizontal Distance Measurement and Slope Correction p.100)* and instructs **T** to move the ranging rod to the corrected distance.
5. **S** is checking the right placement of the post with the compass and instructs **T** if replacement is necessary. N20 is then marked with a temporary post and numbered. *(Numbering p.20)*
6. **R** and **S** moving to N20 while **S** can improve line clearing if necessary.
7. The procedure starts again with Step 1.
8. When the team reaches 80 m distance to the CP (e.g. N80) this point is marked with a permanent marker and a temporary post.

3.2.3 Task 3: Sub-Plot establishment

After aligning the 80 m distance the establishment of the Sub-Plot starts. The procedure of alignment, line cutting and distance measurement remains the same.

! Inside the Sub-Plots no post must be cut. Please move for post cutting at least 6 m (right angle) from the center line or carry on with you prepared posts.

3.2.3.1 Sub-Task 3a: Establishment of a Unit (e.g. U1) and Sub-Unit (e.g. SU1)

1. The Recorder (**R**) remains standing behind the post at N80 and keeps the approach end of the distance tape.
2. The Treespotter (**T**) moves in the desired direction and carefully clears the center line (if necessary) while carrying the distance tape and a ranging rod until he reach the 10 m distance (e.g. N90). The Surveyor (**S**) gives the bearing with the compass (and/or alignment) and instructs him.
3. When **T** reaches N90 he stops line cutting and places a ranging rod.
4. If horizontal measurement of the 10 m distance is not possible, **R** reads out the slope *(Horizontal Distance Measurement and Slope Correction p.100)* and instructs **T** to move the ranging rod to the corrected distance.
5. **S** is checking the right placement of the post with the compass and instructs **T** if replacement is necessary. N90 is then marked with a temporary post (optional also with a permanent marker) and numbered. *(Numbering p.20)*
6. **R** and **S** keep their position at N80 and the procedure starts again with Step 1 until N100 temporary post is set.
7. Then **S** moves to N100 and measures lying deadwood if occurs.*(Lying deadwood survey (line intersect method) p.61)*. **R** keeps his position and records the measurements.

3.2.3.2 Sub-Task 3c: Establishment of Circular Plot (e.g. CU1)

1. **R** remains standing behind the post of N80 and holds the approach end of the distance tape.
2. **S** rolls the distance tape while moving along the center line to **R**, but stops when he is 4 m away from him (N84).
3. **R** reads out the correct bearing (and/or alignment) and instructs **S** by placing the ranging rod on centerline.
4. **T** moves to N84 and holds the ranging rod while **S** takes the distance tape around the ranging rod and moves 3 m in right angle to the right of the center line. The reading of the tape is 7 m at this point. A ranging rod is placed, that will be preliminary the center of the Circular Plot (CU1).

   ! Pay attention that you do not trample the regeneration on the Circular Plot.
5. **T** moves to **S** and takes the distance tape around the ranging rod. Then **T** moves straight on to N80 and gives the end of tape to **R** and continues back to the rod at N84 on the center line.
6. **R** validates the correct position of CU1 while spanning the tape, **T** assists at N84. If the reading is 12 m at the ranging rod of **R**, the right angle is correct. If not, **S** has to move the ranging rod while the distance tape is kept spanned until it fits the 12 m reading.
7. When the position is validated a temporary post is placed at the center of CU1.

3.2.3.3 Sub-Task 3d: Measurement of Circular Plot (e.g. CU1)

Dissonantly from the other measurements taking place during the “Backward Movement” *(p.47)* the regeneration and other small woody plants will be measured right after establishing the Circular Plot.

By utilizing the Recording Level for Circular Plot *(Tab. 3: Recording Levels p.33)* all woody plants (trees/palms/shrubs/tree ferns), which are higher than 1.30 m but below a DBH of 10 cm and placed in CU1, are identified and the DBH *(for shrubs measure the basal diameter (BD) of each stem, Measurement of basal diameter (BD) of shrubs p.54)* is measured. The 2 m stick resembles the radius of the Circular Plot and serves for “In-or-out judgement”. If the woody plants are within the length of the 2 m stick, they will be recorded. Its marking at 1.3 m length also serves for “In-or-out judgement”, by placing the stick near by the plant.

Also lying deadwood will be measured within the Circular Plot with the line intersect method, if it has a diameter at crossing of minimal 1 cm and less than 10 cm. The diameter of the Circular Plot (4 m), laid out with the 2 m stick parallel to the center line of the Sub-Plot, will serve as reference line for the measurement.

1. The temporary post of CU1 will be marked at 1.3m height.
2. **S** stands next to the post and holds the 2 m stick horizontal in 1.3m height, with the end to the post at the marking level. In plane terrain this resembles the recording limit, on slope please check the height by placing the survey stick next to the tree (1.3 m mark on the stick.) Then he leads the 2 m stick clock wisely one full rotation around post.
3. If a woody plant is touched by the 2 m stick **T** identifies the species and measures the DBH (BD for shrubs) with the calliper. **R** records it in the “Forward sheet”.

   If a species is unknown or not possible to identify (e.g. because of its condition or shape), it has to be recorded as “unknown” in Species Column. If it is dead, the species will not be identified and it is recorded as “dead” in local name column.

4. **T** lays down the 2 m stick in direction of the Sub-Plot (e.g. north) at the temporary post of CU.
5. **S** gauges the decay class and measures the diameter of lying deadwood with the calliper at the point of crossing the stick. **R** records it. Then the 2 m stick is placed on the other side of the temporary post to complete the measurements of the 4 m diameter.

3.2.3.4 Sub-Task 3e: Establishment of Biomass Plot (e.g. BU1)

The Biomass Plot is established the same way as the Circular Plot (CU), but placed left handed from the center line (right angle to BU1 = direction of center line (°) - 90°) with a radius of 0.3 m length. In case of remeasurement the Biomass Plot will be moved. *(Fig. 4: Relocation of Biomass Plot p.18)* The temporary post should be thin, because of the small size of the Biomass Plot.

! ***Pay attention, not to remove litter or other biomass by stepping on it.***

3.2.3.5 Sub-Task 3f: Sampling of Biomass Plot (e.g. BU1)

By utilizing Recording Level for Biomass Plot *(Tab. 3: Recording Levels p.33)* all plant material which **originates inside** the Biomass Plot and will be collected , i.e. plants hanging outside the circle but originate from within are included in the sample. Plants hanging inside but originating outside the circle are excluded, also **woody plants higher than 1.3 m are excluded from collection**. Lying deadwood (if the diameter is less than 1 cm) and the litter found on the Biomass Plot will be taken, but has to be cut at the border of the circle.

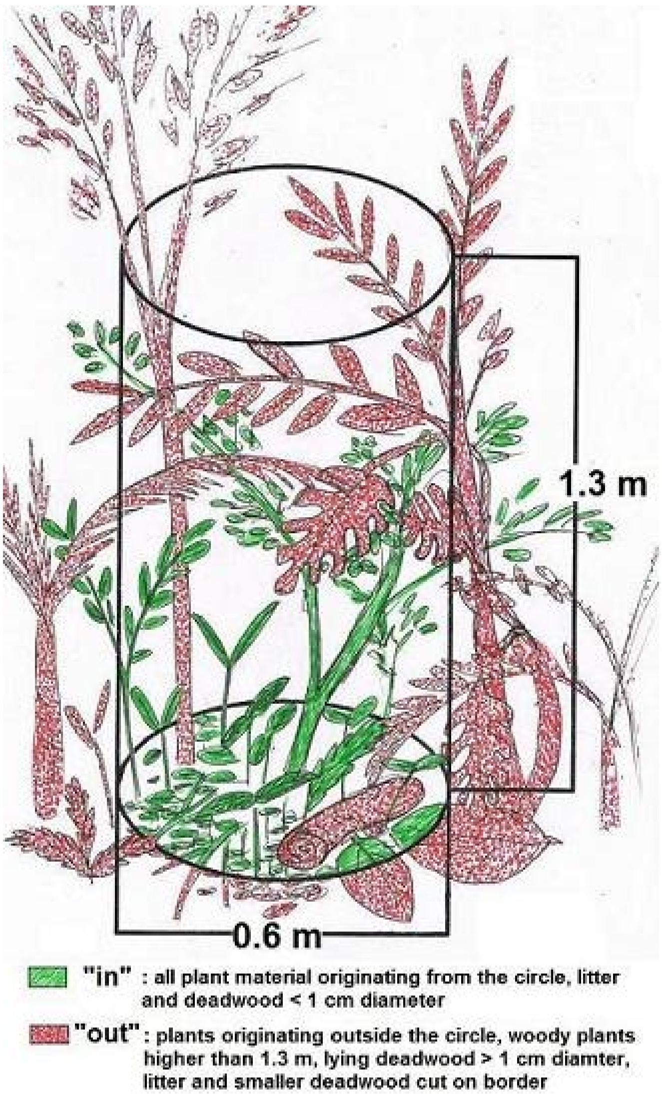


Fig. 17: In- and Out-Judgement of Biomass Sampling

The sample has to be taken conscientious. The prepared 30 cm stick resembles the radius of the Biomass Plot and serves for “In-and Out judgements”.

Fig. 18: Biomass sampling

1. **R** takes the sample little by little by utilizing the 30 cm stick, **S** and **T** assists him. It will be slowly moved clockwise one time around the post. The knife can be used to cut biomass away. Secateurs are used to cut of small regeneration and other plants at ground level. If necessary the sampled biomass can be cut in pieces.
2. If there are small tree regeneration **T** identifies species and the number will be indicated by **R** with bars in “Forward sheet” under Biomass Plot section.*(Fig. 14: Field form "Forward Sheet"p.37*
3. The sample has to be put into a strong plastic bag and inscribed with waterproof pen as follows: Plot No.|Sub-Plot No.|Unit No.
4. When the sampling is finished **R** drops the bag at the next post on the center line. It will be collected while “Backward Movement”.

3.2.3.6 Sub-Task 3g: Lying deadwood measurement

Lying deadwood is measured using the line intersect method.*(Lying deadwood survey (line intersect method) p.61)* The recording levels are similar with the diameter limits of the living trees (e.g. within the Sub-Unit all trees with 10 cm dbh as well as all lying deadwood with 10 cm diameter at crossing of the center line and above are measured).

1. While finishing line cutting during Unit establishing, **S** is looking for lying deadwood crossing the center line which can fit the recording levels.
2. **S** measures the diameter of the dead wood (calliper, diameter tape) at the point where the dead wood crosses the center line. The center line is still indicated by the distance measuring tape between **R** and **T**.
3. **S** gauges the decay class.
4. **R** records diameter and decay class on the “Forward Sheet”.The decomposition class of lying dead trees is gauged using table 6[9].

Tab. 6: Decomposition classification of lying deadwood

To determine what decay class a piece of dead wood fits into, each piece should be struck with the blunt side of a bush knife:	
Decay class 1 (sound)	If the blade does not sink into the piece (it bounces off), it is classified as “sound”.
Decay class 2 (intermediate)	If it sinks partly into the piece and there is more extensive wood loss, it is classified as “intermediate”.
Decay class 3 (rotten)	If the blade sinks into the piece, there is more extensive wood loss and the piece is crumbly, it is classified as “rotten”.

[9] Brown, S.; Person, T.; Walker, S. 2005.

3.3 Backward Movement

After establishing the last post in the end of the Sub-Plot the moving direction is changed back into CP direction. The different data will be collected simultaneously while moving to the start of the Sub-Plot.

3.3.1 Task 1: Site description

Site description shall be done for every Unit of the Sub-Plots. This will categorize the Units regarding to Forest Extend, Forest Characteristics, (Designated) Functions, Forest Ownership and Disturbances.

If there is any information available this data can be already prepared in the Preparation Phase *(p.28)*. If you have already information about the particularly category, it will be proofed while the field measurements.

For recording you find a prepared section at the top of the Backward sheet. (*Field Forms p.36)* If there is any uncertainty about the category of the required criteria you can call on locals or experts. It is very easy to assess this information and does not need any measurement. Only an optical inspection will be done. The recorder has to compare the found situation with the appropriate definition from FAO *(see Annex Underlying Definitions for Data Collection p.88)* while going through the Unit and has to tick the relevant square after he knows the whole conditions of the Unit.

3.3.2 Task 2: Measurement of trees[10]

The team walks in a formation of a line covering the width of the Sub-Plot. The recorder walks always on the center line of the Sub-Plot and the tree spotter and the surveyor, in 2 to 3 m distance beside him. This will avoid the missing of trees. The team comes together, when a tree is measured and recapture their position afterwards. In more open situations the formation is not necessary.

3.3.2.1 Sub-task 2a: In- and out-judgement

Easy to estimate trees, like those who are very close or very far from the center line of the Sub-Plot have not to be checked every time. But keep sceptic, and **do not only rely on visual checks.**

A tree is “In” or “Out” when the *centre* of the tree is inside or outside of the imaginary Sub-Plot boundary (5 m to the right/left of the center line). The centre of the tree is the imagined crosspoint between the tree axis and the breast height at 1.3 m.

Exceptional cases are the so called *borderline trees*. These trees have their centre exact on the imagined border of the Sub-Plot. Thus, they are not out and not in. Therefore they will be alternately measured and left.

[10] Also shrubs, palms, tree ferns, bamboo and also standing deadwood will be measured if they exceed the minimum diameter of the particular recording level.

It is very important that no mistakes are made when judging if a tree is within or outside the Plot. When Plots are small and therefore the number of trees per Plot is small, every wrong included or respectively wrong excluded tree can lead to serious mistakes in later calculations.

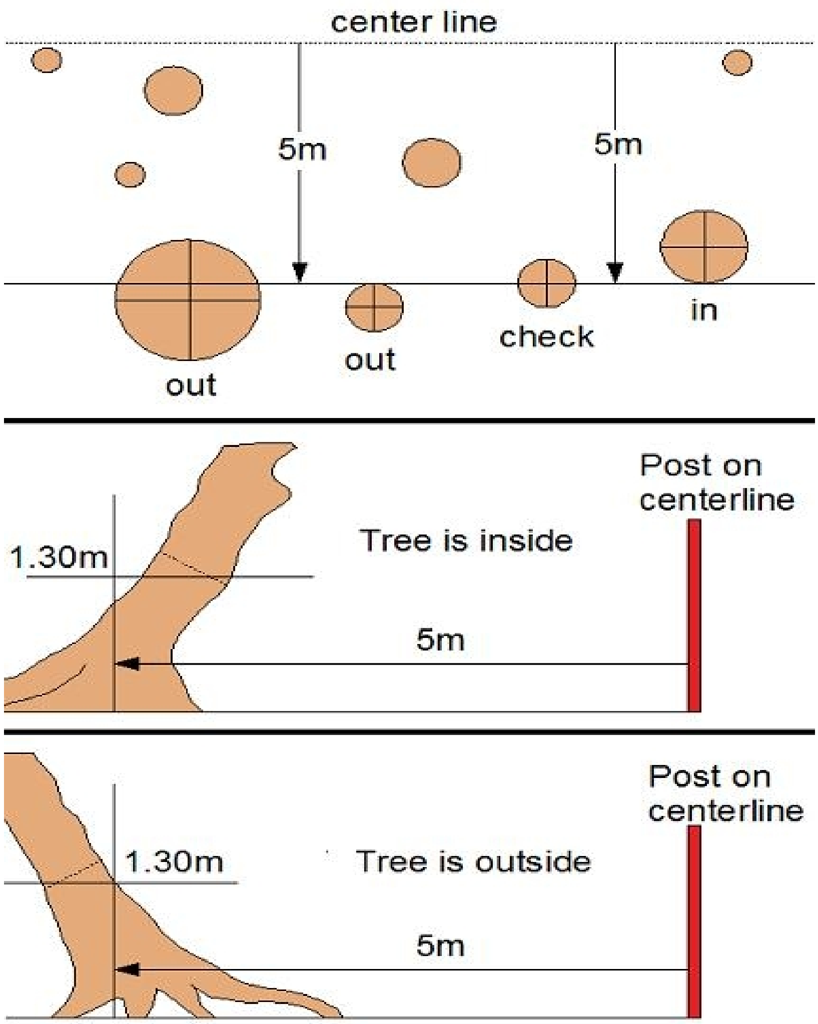


Fig. 19: In- and Out-Judgements of Trees

If there is any suspect if a tree could be in or out, it has to be checked in every case.

1. **R** stands on center line facing the tree to check and holds the approach end of the distance tape, while **S** is moving with the distance tape in right angle to the tree.
2. **R** reads out the correct bearing and instructs **S** on the direction. If horizontal distance measurement is not possible **R** measures the slope and gives the corrected distance to **S**.
3. **S** verifies if the tree is inside or not.
4. If it is inside, go on with DBH Measurement.

To check whether the suspected tree is inside one or the next Unit, bearing from the section post and estimation is enough. If the tree is suspected to be in/out of the small 10 m boundary (SU) on the start and end of the Sub-Plot it has to be checked like above, with the difference to start from the imagined line that cross the center line in right angle at the post of the Sub-Unit.

3.3.2.2 Sub-Task 2b: DBH measurement

Also for dbh carefully and precise measurement are necessary, because it provides the basis for a lot of calculated figures.

1. If necessary, pull stranglers and climbers away (also removing of thick moss cover could be necessary).

   ! Stranglers and climbers must not be cut because we need to leave the Plot as undisturbed as possible.

2. Put the diameter tape (or calliper) at exactly breast height (1.3 m) around the tree in right angle to the centre of the stem.
3. Read out the diameter rounded off to the next lower centimetre (e.g. 28.3 cm becomes 28 cm, 99.9 cm becomes 99 cm). *It is the decision of the responsible authority to which decimals the reading and recording is to be carried out.*
4. If there is any irregularity as e.g. a fork, branching palm, big hollows etc. or remarkable threats as e.g. visible big infestation of stranglers, insects and fungi etc. it is recorded in the "remarks column".[11] But also any other observation which is seen remarkable is recorded.

3.3.2.3 Sub-Task 2b: Tree identification

Every tree about to measure has to be identified through a keen tree spotter.

! If there is any unknown species it has to be recorded as Unknown.

It is very important that the species names are determined correctly. Otherwise the measurements will be needlessly biased. If it is possible samples of leafs of the unknown tree will be taken to a botanist and identified in laboratory.

The local name will be recorded and scientific name later added in Phase 3. Therefore prepared name lists are used.

[11] In some cases, these threats can also be good indicators for the site description as seen under *Task 1: Site description p.47.*

3.3.2.4 Sub-Task 2c: Height measurement

According to the Recording Level *(Tab. 3: Recording Levels p.33)* of the whole Plot, every tree above 25 cm DBH has to be measured in height. That has to be done straight after the DBH is measured to avoid confusions and mistakes.

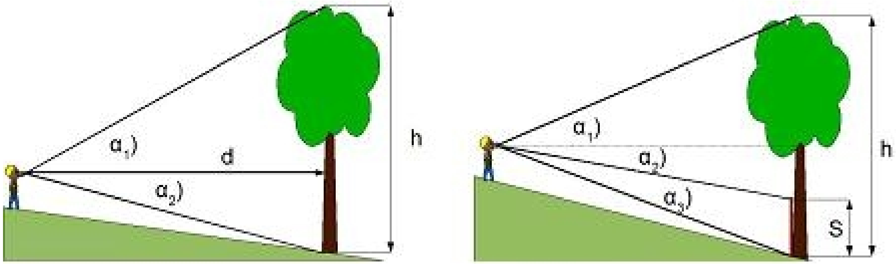


Fig. 20: Trigonometric height measurements

Two measurements will be taken, the **top height** of the tree and the **log height.**
If the stem is obviously degraded (e.g. curved) and not usable it is indicated as zero in "log height column" *(Field Forms p.36)*.

For height determination measurements are applied with the clinometer after the trigonometric principle. For more detailed information see Trigonometric height measurements p.56.

Option 1: Height measurement with distance measurement

The horizontal distance to the tree and two angles will be measured *(Fig. 20 left side)*: to the top of the tree and to the bottom of the tree.

1. **S** moves to a proper observing place.
2. **S** takes the angle reading to the bottom and top with the clinometer, **R** records it.
3. **S** remains position and holds the approach end of the distance tape while **T** is moving with the tape to the tree.
4. **S** and **T** have to hold the tape horizontal, **T** has to place the tape at the center of the tree when he reads out the distance. If horizontal distance measurement is not possible **S** measures the slope and the distance will be corrected.

Option 2: Height measurement without distance measurement

Tree angles will be measured: to the top of the tree, to top of the reference height and to the bottom of the tree *(Fig. 20 right side)*.

The height measurement without distance measurement will be described for a recommended reference height of 3.3 m.

It is most severe necessary that you record your applied reference height in the remarks column. And any changes of the method used.

1. **S** moves to a place from where he can most clearly see the top and the bottom of the tree and stands above the bottom of the tree[12]. ***It is recommended to go at least 10 m away from the tree, but not more than 25 m.***[13]
2. **T** stands besides the tree and places the 2 m stick at the tree front (If the tree is not straightly, he has to hold it in the straight position).
3. **S** takes the angle reading of bottom of the tree.

Do not rush and take the angle readings conscientiously.

4. **T** determines breast height by using the 1.3 m mark on the stick and lift it up to this height. The stick top will be then 3.3 m high.
5. **S** takes the angle reading of the stick top and tree top.
6. **R** records it

3.3.3 Task 3: Measurement of standing deadwood and stumps

Standing deadwood and stumps will be measured during the main tree assessment and underlay the same recording levels as living trees.

1. **S** measures the DBH and gauges the decay class *(Tab. 7)*. In case of a stump (lower than 1.3 m), the diameter just below the felling cut will be measured and its height will be measured directly.
2. It is not necessary to identify tree species but **R** has to write “dead” in “local names column”. If the species is still recognizable the name should be recorded in the “remarks” column. Also a short key point description of the shape of the dead tree can be made under “remarks” (e.g. broken underneath crown, burnt etc.)
3. The **team** will proceed with Height Measurement. As for living trees the top and log height will be measured (decay class 1-3). If only a standing trunk is left over measure its height and highlight it in remarks column.

The decomposition class of standing dead trees is gauged using the table below, for stumps the decomposition classification of lying deadwood is used. *(Lying deadwood survey (line intersect method) p.61)*

Tab. 7: Decomposition classification of standing dead wood

Decay class	Description of Dead Tree appearance
1	Tree with branches and twigs and resembles a live tree (except for leaves)
2	Tree with no twigs, but with persistent small and large branches
3	Tree with large branches only
4	Bole (trunk) only, no branches

[12] Measurements could also be made if the observer stands below the bottom of the tree, but it was found easier to measure from above.

[13] The normal rule for height measurements is, to go as far form the tree as its assumed height. But observation of angles will become very difficult, especially for the crucial angles of the reference height.

3.4 Required Methods

3.4.1 Measurement of diameter at breast height (DBH) of trees

Diameter at breast height is the measure easiest to undertake and probably the most important one in forest inventories. Nevertheless, mistakes in DBH measurements occur frequently.

Definition: Diameter at breast height (DBH) is the diameter of the tree at 1.3 m (or 4.5 ft) height horizontal to the axis of the tree. For this program we use the diameter above bark as DBH.

DBH measurement will be effected by the surveyor and/or tree spotter, applying a diameter tape (for trees with DBH >25 cm) and a calliper (for trees with DBH <25 cm). The DBH read will be rounded off to the next lower centimeter (e.g. 28.3 cm becomes 28 cm, 99.9 cm becomes 99 cm). *It is the decision of the responsible authority to which decimals the reading and recording has to be carried out.*

3.4.1.1 Rules for DBH measurements

Following rules have to be applied for every DBH measurement to avoid errors (worse bias) and achieve conciseness. Furthermore it makes the measurements comparable to following censuses.

- DBH has to be measured at exact breast height. In order to determine the exact measuring position, the breast height can easily be marked on the clothes of the measurer (badge, piece of of duct tape, etc.). Also the 2 m stick with the 1.3 m mark can be used.
- In case of sloping land the DBH position is always taken at the uphill side of the tree *(Fig. 21 No.1)*.
- The DBH has to be measured perpendicular to the tree axis *(Fig. 21 No.3 + 7)*.
- The diameter tape must not be twisted, tilted or sagged. Especially by measuring big diameters it is mostly not noticed by the observer. Assistance is needed.
- Liana, stranglers and epiphytes roots must be pulled away (never cut) from the trunk and the DBH-tape slid underneath whenever possible.[14] In case, also thick moss cover has to be removed, but only as much as necessary. When the epiphytes cannot be moved, the diameter will be estimated by using the normal distance tape. It has to be hold in right angle position to the stem axis and placed optically before the trunk. The read length is then the DBH. In this case assistance is needed for trees >25 cm dbh (The Treespotter holds the tape and the surveyor does the reading while standing in a distance to the tree of 3 times the assumed dbh (e.g. dbh is approx. 40 cm: reading distance is 1.2 m)

[14] Condit, R 1998

3.4.1.2 Rules for irregularity trees

The irregularity of tree shapes provides a lot of problems for DBH measurements and the point of measurement of DBH can be different from its normally definition. You have to pay attention to following rules of tree measurement (see Fig. 21), to ensure that the recensus can provide comparable data.

If measuring a different diameter than the DBH the point of measurement is ever marked with paint and must be recorded with the problem in the "Remarks column" of the data sheet.

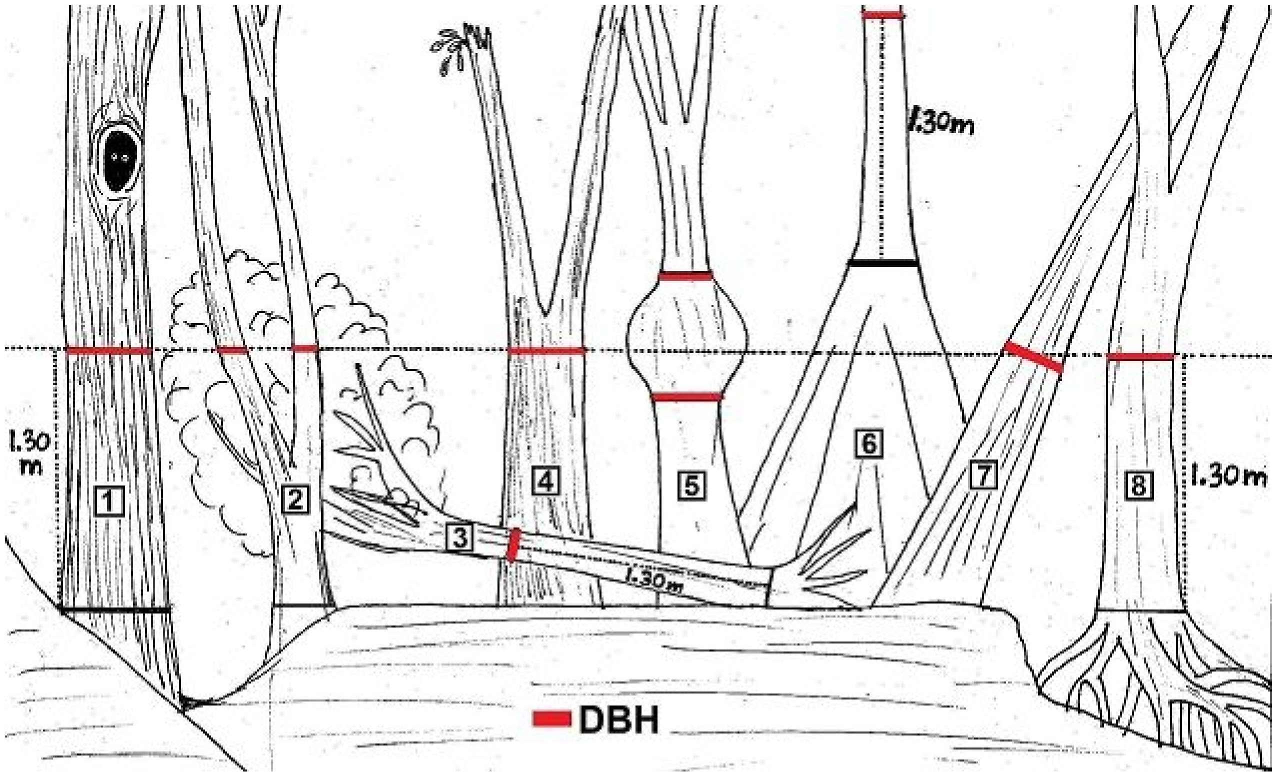


Fig. 21: Rules for DBH Measurement of irregularity Trees

- In case of a tree fork below 1.3 m, the forking branches are threatened as single trees *(Fig. 21 No.2)*, a tree fork above 1.3 m is threatened as branches and does not affect the DBH measurement *(Fig. 21 No.4)*.
- In case of a leaning tree the breast height is measured at the lower side and the measurement has to be taken also in right angle to the tree axis *(Fig. 21 No.3 + 7)*.
- In case of a swelling of irregularity at the 1.3 m position, two measurements have to be taken, below and above the swelling/irregularity and the average of these measurements is the DBH *(Fig. 21 No.5)*.
- In case of trees witch stilt (aerial) roots *(Fig. 21 No.8)* or buttresses *(Fig. 21 No.6)*, the diameter must be measured at 30 cm above the end of the stilt roots/buttresses[15,16].

[15] FAO 2008

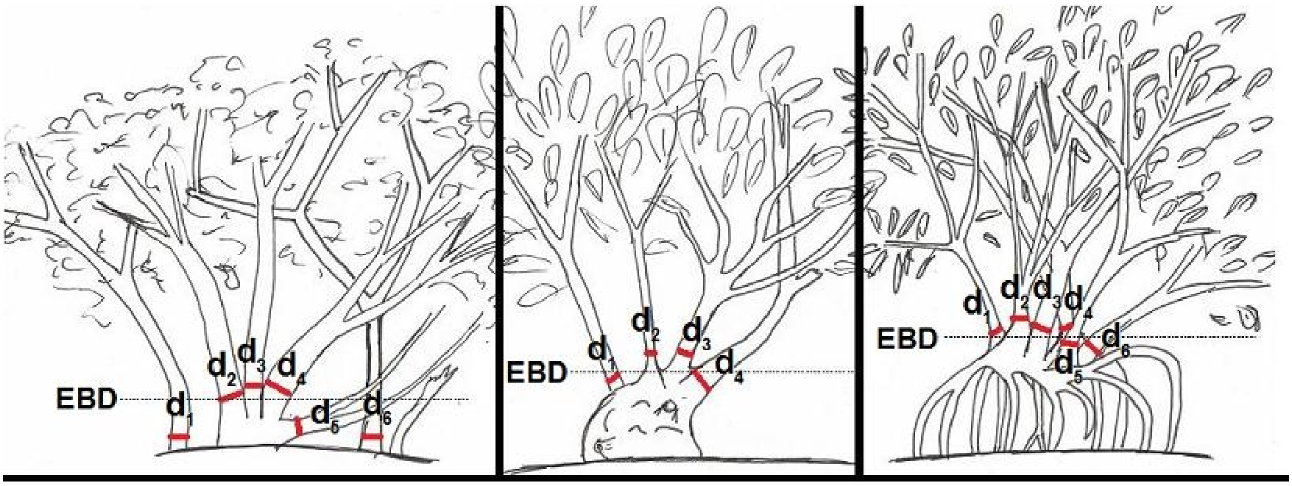
[16] There are different approaches on where to measure diameter above buttresses. It might be adopted to other common rules of the responsible authorities.(e.g.: Condit, R. 1998 measures 50 cm above, De Vletter, J. 1997 measures one hand width above)

- When a trunk is extremely irregular at all heights, the measurement point must be chosen as best as possible.
- If the tree is too big and the diameter tape is not long enough, the circumference measurement will be taken at 1.3 m height, with the normal distance tape and recorded. The true diameter can be calculated by dividing the circumference by Pi (Pi≈3.14). If a immediate conversion is not possible a remark such as “dbh is circumference” is necessary

3.4.2 Measurement of basal diameter (BD) of shrubs

For shrub measurements the point of measurement will be variant from the breast height , they will be measured at the *Basal Diameter (BD)*.

Definition: The Basal Diameter (BD) will be measured for each stem of the shrub near the root collar, but just above every abnormal swelling. To threat the shrubs as individuals in later data processing, a so called Equivalent Basal Diameter (EBD) (or just Equivalent Diameter) will be calculated from all BD's of each shrub.



Point of measurement of Basal Diameter

Equivalent Basal Diameter $EBD = \sqrt{d_1^2 + d_2^2 + ... + d_n^2}$

Fig. 22: Basal Diameter (BD) and Equivalent Diameter (EBD) of Shrubs

The measurements will be done normally with the calliper (in most cases the BD will be small enough for usage of the calliper) and follows in general the same rules as for DBH measurements. Also the diameter tape can be used if necessary, but it could be difficult to handle in a dense shrub.

3.4.3 Height measurement

The height of the tree is the second important measure in forest inventories and is needed especially for volume calculation.

Height Definitions:

Top height is the vertical distance between the base of the tree stem at ground level and the topmost tip of a tree.[17]

Log height is the distance between the base of the stem at ground level and upper end of the last merchantable section of the stem. This point is defined by product-specific minimum-diameter standards, or on the basis of qualitative features such as branches, irregular stem form, or stem injury. Its determination in field surveys is liable to subjective assessment errors.[17]

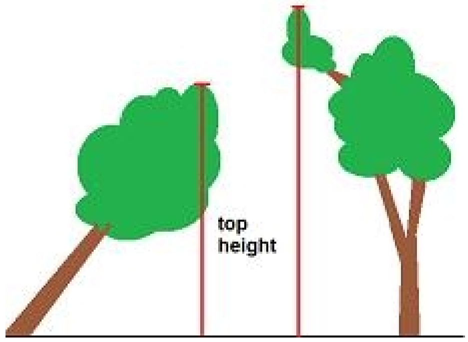


Fig. 23: Height definition

The end of the commercial usable bole will be for:

- Broad-leafed trees and broad-leafed shaped conifer trees (e.g. Agathis), the first big branch
- (typical) Conifers (e.g. Pine), the top diameter of 10 cm (has to be estimated)
- Palms, the Starting point of leaf crown (where the first leaf stalks put on stem)

[17] Köhl, M.; Magnussen, S.; Marchetti, M. 2006

3.4.3.1 Trigonometric height measurements

As its name indicates, this height measurement is based on trigonometric functions. A imaginary triangle is formed by the observers look on the tree top and base together with the tree. To calculate the tree height the angles of the top and the bottom of the tree will be related to a reference length.

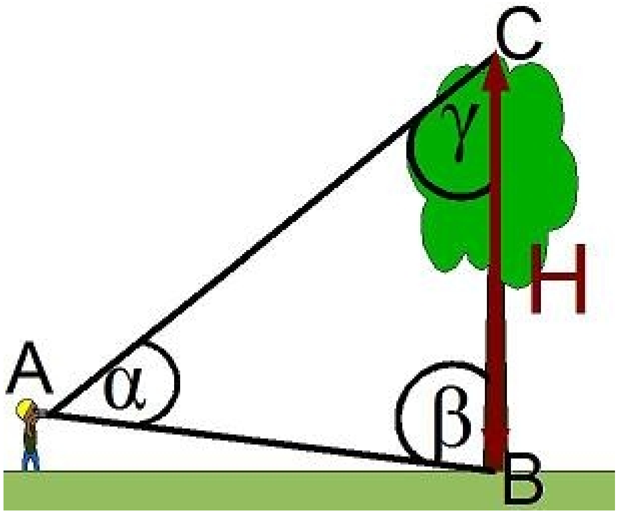


Fig. 24: Trigonometric height measurement

As reference length deals either the measured distance to the tree *(Height measurement with distance measurement p.57)* or a stick of fixed length placed at the tree *(Height measurement without distance measurement p.58)*.

The measurements will be taken with the handheld clinometer *(The clinometer p.98)* by the surveyor or recorder and by assistance of the tree spotter or surveyor.

! Do not rush and take the reading conscientiously to a precision of half a degree.

The observer has to find a good observing position, fitting the following rules:

- Clearly look at the top and the bottom of the tree is given.
- Observers eyes are above the base of the tree.
- Stand as far of the tree, as its estimated height.
- Keep your position for all angle and distance measurements. (Even try to do not move your head much during angle readings.)
- If the tree is leaning, stand in a plane perpendicular to the lean angle.

3.4.3.2 Height measurement with distance measurement

When the observing point is set, the observer aims with the clinometer at the tree base and takes the bottom reading in degree (left scale). It will be recorded in “bottom column” of backward sheet.

Then he aims at the top point (respectively for log height, the end of the commercial usable bole) and takes the top reading (log reading). The angle will be recorded in “top column” (“Log column”) of “backward sheet” *(Fig. 15: Field form "Backward Sheet" p.38)*.

Then the horizontal distance from the observing point towards the tree is measured. The observer will hold the approach end and the assistant will lead the tape to the tree center, by keeping the tape exactly horizontal. If this is not possible because of steep slopes, the distance will be measured at the ground and slope correction has to be applied by subtracting the correction to the measured distance. The distance is then recorded in “Reference Column”.
The heights will be calculated later in the office while Phase 3 *(Height calculation Method with distance measurement p.69).*

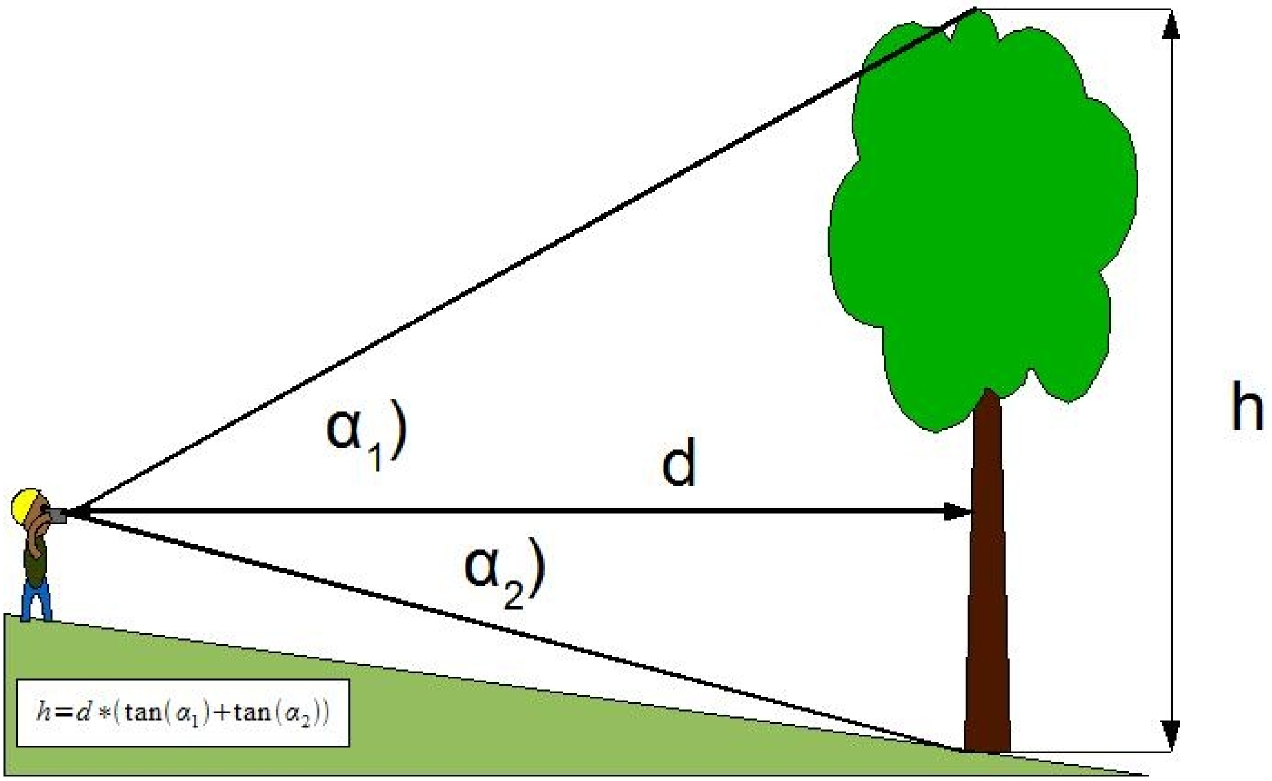


Fig. 25: Height measurement with distance measurement

3.4.3.3 Height measurement without distance measurement

The procedure of measurements are generally the same as above, but the distance measurement will be left, instead a third angle, to the reference height placed at the tree, will be measured. As **reference height** use your prepared survey stick *(p.94)*. Instead also interlocked ranging rods or a long levelling staff can be used as reference length. If necessary reference heights can be improvised in the field.
In the dense forests vegetation it is normally not practical to carry reference heights of more than 3 m length. This problem can be solved by just uplifting the survey stick to a certain height or the usage of telescoping, folding or pluggable survey sticks or levelling staff. It is recommended to use a length of at least 3 m. A practical solution would be the uncommon length of 3.3 m, by lifting the survey stick to breast height. Thus, the reference height of 3.3 m would be indicated. The observer has to find a good observing position.

It is recommended to go at least 10 m away from the tree but not more than 25 m[18].

The assistant places the reference height at the tree and has to hold it in a straight position. The observer has to take the readings in degree with the clinometer while he keeps his observing position. He proceeds bottom-up (bottom angle, reference height, log height, top height).The angles will be recorded in the particular columns in “backward sheet”.

It is most severe necessary that you take the angle readings of the bottom and the reference height with rigorous accuracy and record your applied reference height in the remarks column as well as any changes of the method used.

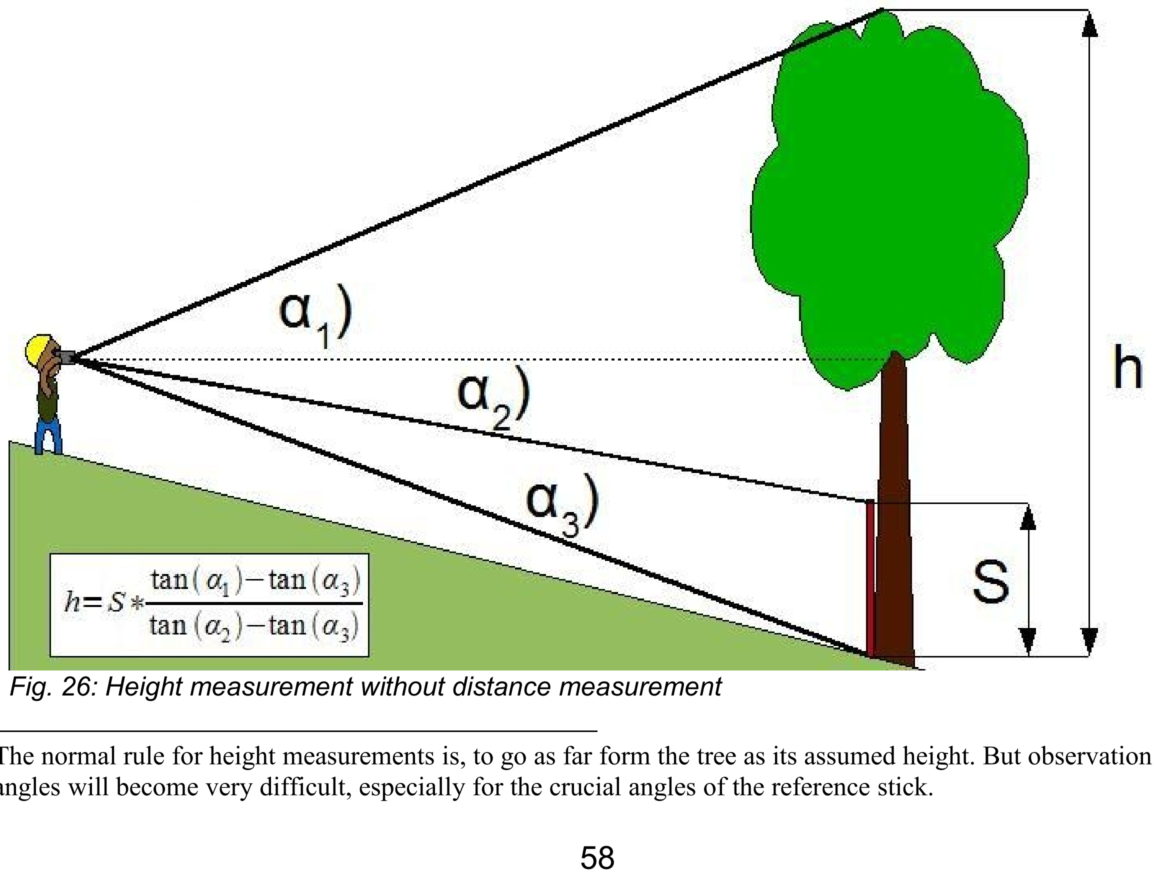


Fig. 26: Height measurement without distance measurement

[18] The normal rule for height measurements is, to go as far form the tree as its assumed height. But observation of angles will become very difficult, especially for the crucial angles of the reference stick.

3.4.3.4 Obstacles of height measurements

If you use interlocked ranging rods, or other fixed length reference heights and the bottom of the tree is not visible (because of e.g. grasses or other vegetation), just lift it above the disturbing vegetation, but keep it in a straight position. The procedure of reading out the clinometer remains the same but with the difference of measuring the bottom of the reference height instead of the bottom of the tree. The recorder has to write the reference heights bottom angle in the “bottom column” and **highlights the variant method** by writing the lifted height in the “remarks column”. This will be added in the calculation of the height later in Phase 3.

If you want to use the reference height of 3.3 m (2 m survey stick lifted to breast height), the stick have to be lifted more than 1.3 m. If it fits, you can lift the stick first to 0.7 m (opposite of the 1.3 m mark of the 2 m survey stick) and take the “bottom angle” reading. Then lift the stick up to 2 m. It will be recorded “+0.7 m” in remarks column.

If you use the distance to the tree as reference length, the survey stick also can be used to resemble the bottom of the tree. Just lift the stick up as in the example above, take the bottom angle reading and highlight the lifted height in “remarks column”

3.4.3.5 Sources of error of height measurements

Mistakes in height measurements can easily happen and cause a significant error for a lot of calculated figures. If these mistakes would be sighted first in the office during the analysis, it will be too late to correct and the data is useless. A lot of labour time and money would be lost. So the avoiding of errors is a top priority in keeping the monitoring program efficient and successful.

Total avoidance of errors might be impossible but the understanding of the sources of errors helps achieve conciseness for your capacities. The three main sources of errors are object-related errors, instrument-related errors and observer-related errors.

Object-related errors

In dense forests it is very difficult to define the top, e.g. some trees appear to have no distinct top, or it is aimed to a wrong place. If you have very spreading tree crowns the top has to be aimed through the crown, but this needs practice. Sometimes walking around the tree can help to identify the top, and the distance to the tree can be adapted. If a little wind blows, it helps some times to get a better spatial sense of the crown. If the lighting conditions and the visibility are bad and heavy winds blow, no height measurement should be undertaken. Also the lean of trees can cause bigger errors, if the tree is leaning towards the observer the height is over estimated, if the tree is leaning away it is under estimated. Therefore measure leaning trees perpendicular to the lean angle *(see Annex Height Correction of Leaning Trees p.110).*

Instrument-related errors

The accuracy and calibration of the instruments should be checked from time to time by measuring a known height of e.g. a building.

Observer-related errors

Wrong handling causes plenty errors, e.g. the clinometer is not held straight and the disk can not freely move or the scales are confused by reading the angle. Also the reference height could not be hold straight and the observer is rushing the measurement. Handling mistakes are normally noticed by others, rather than by self. If team members notice wrong handling, they should point to.

Also wrong sighting or bad vision of the observer can cause errors. Sighting errors normally even out if always the same person undertakes the reading.

3.4.3.6 Cross-checking of height measurements

Especially the observer-related errors on determined figures of the height measurement can be cross checked using control tables to easily provide the height of the inventoried tree in the field. The control tables display the formula used for the calculation. The height is cross checked by applying the bottom and the top angle to get the first interim result. Following the bottom and the stick angle are applied to the table to get the second interim result. Both interim results are now applied to the second table to get the tree height.

Pay attention that the control tables can only provide an estimation of the true height which averagely differs ≈ 4% [19] (if a reference height of 3.3 m was used) to ≈ 7% [19] if a reference height of only 2 m was used) from the calculated tree height.

The control tables are provided in Annex Height Control Tables p.106.

[19] These figures are the outcome of field observations where normal calculated height figures were compared to the results of the cross checking tables.

3.4.4 Lying deadwood survey (line intersect method)

The line intersect method is used to estimate the volume of lying deadwood or slash after logging or storms. It is a plot less sampling technique, i.e. it uses a line to assess the data, not a determined area. The theory behind is that sampled objects are selected with probability proportional to their seize[20], i.e. the diameter at crossing (DC) of the sampling line of random distributed lying logs can be related to their volume.

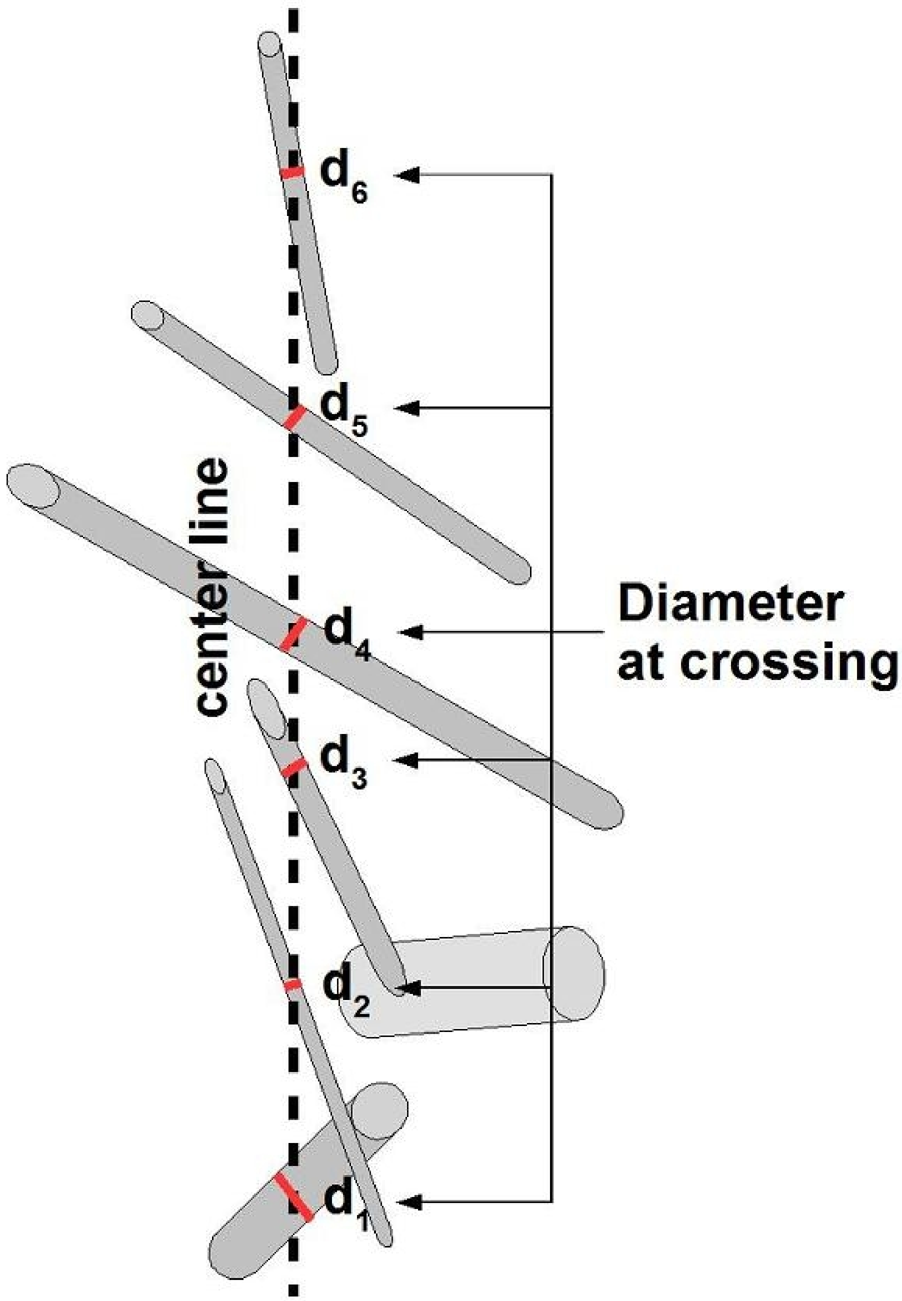


Fig. 27: Line intersect method for lying deadwood assessment

20 Shiver, B.D.; Borders, B.E. 1996

For the MAR Project, the center line section of every Sub-Plot (100 m) forms a measurement line for lying deadwood. The recording level for lying deadwood (DC) is the same as for standing trees. *(Tab. 3: Recording Levels p.33 and Fig. 28)*

Lying deadwood with lower DC is assessed within Sub-Units and Circular Plots. Within the CU the measurement line is the diameter of the CU parallel to the center line of the Sub-Plot. Very small lying deadwood, e.g. twigs, will be included in litter sampling of the Biomass Plot. *(Sub-Task 3f: Sampling of Biomass Plot (e.g. BU1) p.45)*

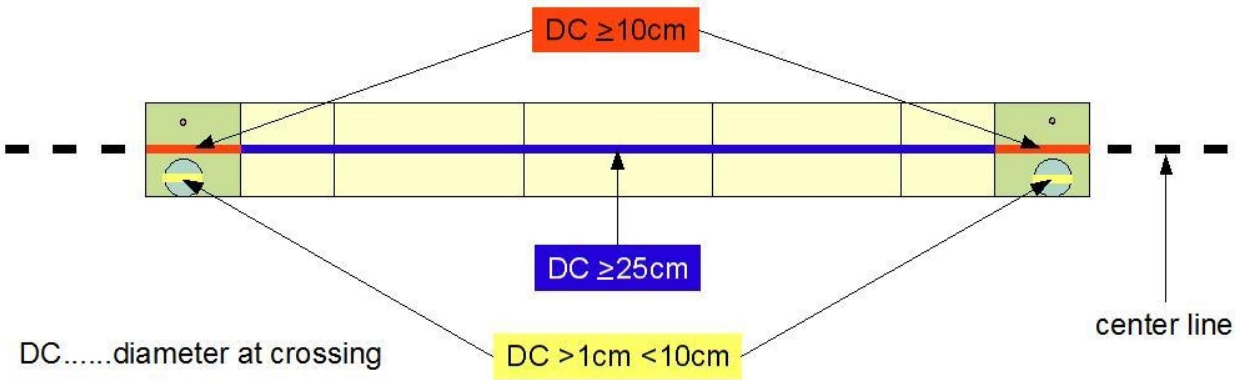


Fig. 28: Recording levels and Survey lines for Lying deadwood assessment

The DC is measured by the surveyor with a calliper (or diameter tape if it is possible to take it around the lying stem). The diameter is measured rectangular to the stem axis of the deadwood piece at the point where it crosses the sampling line *(Fig. 27)*.

If it is not possible to go around with the tape, and the diameter is bigger than the calliper scale, also the distance tape can be used to estimate the diameter. In that case the distance tape has to be hold in right angle position to the stem axis and placed optically in front of the trunk. The read length is then the DC.

Every Deadwood is categorized in one of the 3 decay classes, “sound”, “intermediate” and “rotten” and recorded next to the diameter in “remarks column” in the field form.

The Surveyor has to determine the decay class according to Tab. 6: Decomposition classification of lying deadwood *(p.46).*

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L'Océanie, le terreau de notre avenir.
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Monitoring, Assessment and Reporting for Sustainable Forest Management in Pacific Island Countries

Phase 3

Data processing

4 Data Processing (Phase 3)

For storage and processing of collected data a professional data base (e.g. OpenOffice Base, Microsoft ACCESS®, SPSS) is required. On a long term a centralized data base accessible for all participating countries would be a favourable option. However, as long as such a data base does not exit the relevant algorithms and procedures shall be introduced here for immediately analyses (for OpenOffice Calc or Microsoft EXCEL®) and for own data base development. General skills in applying database applications are required for understanding this chapter.

Most of the criteria to monitor (forest extend, ownership, functions, characteristics, disturbances *(Interviews p.29, Task 1: Site description p.47)* are descriptively assessed on the Unit level and just need to be totalled up for Plot related results. If you want to have hectare based results you have to use expansion factors *(Tab. 8 p.65)*. For country wide interpretation one Plot represents an area within the square calculated by the distance of 2 neighbouring Center Points *(Location and Calculation of Plot Quantum p.24 and example: 1 Plot represents 13.5 x 13.5 km = 182.25 km^2 or 18,250 ha).*

The criteria removals/benefits and biodiversity will partly end up with totalled up or listed results (e.g. list of endangered species) on the Sup-Plot or Plot level to expand on the desired scale. The other criteria (growing stock, carbon stock, biomass stock, biodiversity indices) need to be calculated on the base of different parameter (e.g. DBH, height, number of observations, weight) using specific algorithms.

All results should be checked for their credibility. Computation errors may be found by systematic checks which should be incorporated into any computation sheet. Especially dangerous and difficult to detect are errors committed in transcribing.

4.1 Expansion Factor

The expansion factor *(Formula 3)* is the ratio of the Plot area to one hectare (ha)[21]. Thus, hectare related figures have to be calculated with the expansion factor as e.g. Stem/ha (Stems per hectare), V_t/ha (total volume per hectare), etc..

Formula 3: Expansion factor

Expansion factor = 10,000 m² / observation area (m²)

Tab. 8: Expansion factor for hectare related figures

	Area	**Calculation**	**Expansion factor**
Sub-Plot	100 m * 10 m = 1000 m² 4 Sub-Plots * 1000 m² = 4,000 m²	10,000 m² / 4,000 m²	2.5
Sub-Unit	10 m * 10 m = 100 m² 8 Sub-Units * 100 m² = 800 m²	10,000 m² / 800 m²	12.5
Circular Plot	π * (2 m)² ≈ 12.57 m² 8 Circular Plots * 12.57 m² ≈ 100.56 m²	10,000 m² / 100.56 m²	≈ 99.471839
Biomass Plot	π * (0.3 m)² ≈ 0.283 m² 8 Biomass Plots * 0.283 m² ≈ 2.26 m²	10,000 m² / 2.26 m²	≈ 4420.970641

It is important that you calculate expansion factors ever with as much decimal places as possible in order to avoid bias. At best, type in the formula instead of applying the given expansion factors.

21 1 ha = 100 m * 100 m
= 10,000 m²
≈ 2.47 ac.

Example: Application of Expansion factor

You measured 54 trees (> 25 cm DBH) on one Plot with a log volume of 42 m³. Multiplied by the expansion factor for one Plot (2.5) you get:

Equation:	**Calculation in Excel:**
Stems per hectare: Stems per hectare [N/ha] = 54 trees * 2.5 = 135 N/ha	=A1*(10000/4000) *Instead of A1 choose the cell of the summed amount.*
Log Volume: V_{log} [m³/ha] = 42 m³ * 2.5 = 105 m³/ha	=A1*(10000/4000)

Example: Application of Wrong Expansion factor

You have summed 223 small trees (>1.3 m high <10 cm DBH) of the Circular Plots (Expansion factor ≈ 99.471839) of one Plot:

Stems per hectare [N/ha] = 223 trees * 99.47183943 ≈ 22,182 N/ha

with erroneously rounded expansion factor:
*Stems per hectare [N/ha] = 223 trees * 99 = 22,077 N/ha*

You see 105 trees less than with the correct expansion factor. Nevertheless the error is not so big, it could be exponentiated in national figures, but it can easily avoided.

4.2 Growing Stock

(See Annex Carbon stock p.88)

As mentioned under Field Measurements *(Tab. 2: Data to be collected p.32)* you need different parameter (DBH, height, form factor, number of trees/hectare) to calculate the growing stock.

To make a statement about the growing stock you have to calculate:

- Stems/ha
- total Volume/ha
- loggable Volume/ha
- proportion of trees species of growing stock (stems/ha for each species)

4.2.1 Volume calculation with form factor

The Volume of a tree is calculated in 3 steps:

1. The basal area of a tree or shrub needs to be calculated using the dbh measurement, for shrubs the basal diameter (BD) was measured and the equivalent diameter (EBD) will be calculated per individual.
2. A first and very rough estimation of the volume can be done by multiplying the basal area with the height of the tree *(Formula 6)*. The result will be a clear over-estimation of the volume due to the fact that the shape of a tree is not barrel-like but more or less conical.
3. Therefore the volume has to be reduced by using a form factor. The estimated real volume of a tree is calculated with the formula *Volume = basal area * height * form factor*

Equation:	**Calculation in Excel:**
$$Basal\ area(Trees)\ [m^2] = \frac{\pi}{4} * \left(\frac{DBH}{100}\right)^2$$ $$Basal\ area(Shrubs)\ [m^2] = \frac{\pi}{4} * \left(\frac{EBD}{100}\right)^2$$ *Formula 4: Basal area calculation*	=PI()/4*(DBH/**100**)^2 =PI()/4*(EBD/**100**)^2
$$EBD\ [cm] = \sqrt{BD_1^{\,2} + BD_2^{\,2} + ... + BD_n^{\,2}}$$ *Formula 5: Equivalent Basal Diameter calculation* EBD.....Equivalent diameter BD_n......Basal diameter of one stem	EBD =SQRT(SUMSQ(BD_1:BD_n)) *Instead of DBH, EBD and BD choose the particular cells.*
! Be aware that the DBH (BD) is normally recorded in cm and has to be converted into meter by dividing by 100. Otherwise, you will calculate the volume in cm³ but should be in m³. That can be easily integrated in the equation as shown above.	
Equation:	**Calculation in Excel:**
$$Volume\ [m^3] = basal\ area * height * form\ factor$$ $$V\ [m^3] = \frac{\pi}{4} * \left(\frac{DBH}{100}\right)^2 * h * f$$ *Formula 6: Volume calculation*	=PI()/4*(DBH/**100**)^2*h*f *Instead of DBH, h and f choose the particular cells.*

Form factors differs slightly between tree species but also between different hight classes tree ages etc. However, a suitable form factor is 0.5 for volume estimation of whole trees (including volume of branches > 7 cm) used together with the total height. The form factor of 0.7[22] shall be used for Volume estimation of usable log together with the Log Height. For plantation conifers (e.g. Caribbean Pine) use form factor 0.5 also for log Volume estimation.

For the time being the Volume of Coconut palms can be estimated with the form factor of 0.5, but the figures has to be handled like very rough estimations, until a proper form factor is investigated.

For shrubs, palm ferns and bamboo form factors have to be developed for volume calculations.

Example: Calculation of Total Volume (V_t) and Log Volume (V_{log})

DBH = 30 cm

Top height = 25 m   form factor = 0.5

Log height = 10 m   form factor = 0.7

Equation:	**Calculation in Excel:**
$Basal\ area\ [m^2] = \left(\frac{\pi}{4}\right) * \left(\frac{30cm}{100}\right)^2$ $Basal\ area\ [m^2] = \underline{0.071\ m^2}$	=PI()/4*(30/100)^2
Total Volume: $V_t\ [m^3] = \left(\frac{\pi}{4}\right) * \left(\frac{30cm}{100}\right)^2 * 25m * 0.5$ $V_t\ [m^3] = \underline{0.884\ m^3}$ **Log Volume:** $V_{\log}\ [m^3] = \left(\frac{\pi}{4}\right) * \left(\frac{30cm}{100}\right)^2 * 10m * 0.7$ $V_{\log}\ [m^3] = \underline{0.495\ m^3}$	=PI()/4*(30/100)^2*25***0.5** =PI()/4*(30/100)^2*10***0.7** *Instead of DBH, h and f choose the particular cells.*

[22] The method can be refined for broad leaved trees by applying different form factors depending on log height see Improvement of Volume Calculation with Form Factor *(p.111)*

4.2.2 Height calculation

4.2.2.1 Method with distance measurement

(see Height measurement with distance measurement p.57)

For this method you took at least three angles: to the top of the tree, the log height, the bottom and the distance to the tree.

Equation:	**Calculation in Excel:**
$h\,[m] = d * (\tan(\alpha_1) - \tan(\alpha_2))$ *Formula 7: height calculation with distance measurement*	=d*(TAN(α_1***PI()/180**)-TAN(α_2***PI()/180**)) *Instead of d, α_1 and α_2 choose the particular cells.*
d.....distance to the tree [m] α_1...angle to the tree Top α_2...angle to the tree Bottom *For calculation the Log height just replace the Top Height angle.*	***Excel uses the radian unit system for expressing angle values. That means you have to convert your taken angles form degree to radian. Otherwise you get a systematic error. To convert it, multiply the angles (°) by π/180. That can be easily integrated in the height formula, as shown above.***

Example: Top Height (h_{top}) calculation with distance measurement

You measured 12.5 m distance to the tree, Top angle(α_1) = 62°, Bottom angle(α_2) = -8°

Equation:	**Calculation in Excel:**
$h_{top}\,[m] = 12.5\text{m} * (\tan(62°) - \tan(-8°))$ $h_{top}\,[m] = 12.5\text{m} * (1.880726 - (-0.140541))$ $h_{top}\,[m] = 12.5\text{m} * 2.021267 \approx \underline{25.3\text{m}}$	=12.5*(TAN(62*PI()/180)-TAN(-8*PI()/180))

4.2.2.2 Method without distance measurement

(see Height measurement without distance measurement p.58)

For this method you took four angles: the Top height angle, the Log height angle, the reference angle and the Tree bottom angle. Also you know the fix length of your reference.

Equation:	**Calculation in Excel:**
$height = L \frac{\tan\alpha_1 - \tan\alpha_3}{\tan\alpha_2 - \tan\alpha_3}$ *Formula 8: height calculation without distance measurement*	=L*(TAN(α1***PI()/180**)-TAN(α3***PI()/180**))/ (TAN(α2***PI()/180**)-TAN(α3***PI()/180**)) *Instead of L, α_1, α_2 and α_3 choose the particular cells.*
α_1...Tree top angle α_2...Reference angle α_3...Tree bottom angle L.....Reference length *For calculation the Log height just replace the Top Height angle.*	***Excel uses the radian unit system for expressing angle values. That means you have to convert your taken angles form degree to radian. Otherwise you get a systematic error. To convert the angle multiply the angle (°) by π/180. That can be easily integrated in the height formula, as shown above.***

Example: Top Height (h_{top}) calculation without distance measurement

You measured :

Top angle(α_1) = 68° Reference angle(α_2) = 17° Bottom angle(α_3) = 1°

Reference length = 3.3 m

Equation:	**Calculation in Excel:**
$h_{top}[m] = 3.3\text{m}\frac{\tan(68°) - \tan(1°)}{\tan(17°) - \tan(1°)}$ $h_{top}[m] = 3.3\text{m}\frac{2.4751 - 0.1746}{0.3573 - 0.1746}$ $h_{top}[m] = 3.3\text{m}\frac{2.4576}{0.2883}$ $h_{top}[m] = 3.3\text{m} * 8.5253$ $h_{top}[m] \approx \underline{28.1\text{m}}$	=3.3*(TAN(68***PI()/180**)-TAN(1***PI()/180**))/ (TAN(17***PI()/180**)-TAN(1***PI()/180**)) *Instead of L, α_1, α_2 and α_3 choose the particular cells.*

4.3 Biomass Stock

4.3.1 Calculation of above ground tree biomass

Biomass equations relate DBH to biomass. Equations are established for individual species or groups of species, but currently no specific equations for pacific trees exist. For the time being, the following general tropical equations are suggested. However, in future better adapted equations should replace this suggestions[23].

When calculating biomass, the given maximum diameter for the equation should be carefully observed. Using equations for trees that exceed the maximum diameters can lead to substantial error.

The following Tab. 9 shows only a few examples. Choose a suitable biomass equation for your forest regarding to the annual rainfall. If you do not have a suitable biomass equation estimate the biomass by multiplying the volume (e.g. total tree volume) by density.

Tab. 9: General equations for tropical forests biomass calculation

General classification	**Equation**	**Source**	**Max DBH**
Dry (900 –1500 mm rainfall)	Biomass [kg] = 0.2035 x $DBH^{2.3196}$	Brown, S. (unpublished)	63 cm
	Calculation in Excel: =0.2035*DBH^2.3196		
Moist (1500–4000 mm rainfall)	Biomass [kg] = exp(-2.289+2.649 x lnDBH-0.021 x $lnDBH^2$)	Brown, S. 1997. (updated)	148 cm
	Calculation in Excel: =EXP(-2.289+2.649*LN(DBH)-0.021*LN(DBH^2)		
Wet (> 4000 mm rainfall)	Biomass [kg] = 21.297 – 6.953 x DBH + 0.740 x DBH^2	Brown, S. 1997.	112 cm
	Calculation in Excel: =21.297-6.953*DBH+0.740*DBH^2		

23 Before applying a biomass equation, consider its classification, because trees in a similar functional group can differ greatly in their growth form between geographic areas. For calculating Shrubs and Coconut (also other Palms, Tree ferns, Bamboo) no suitable equations were available. For this woody plants, it is recommended to create new and adapted equations. Coconut Biomass can be calculated with Formula 9 p.72.

Example: Biomass calculation for Trees

You measured a tree in wet tropical forest:

DBH = 65 cm

Biomass [kg] = 21.297 – 6.953 x DBH+ 0.740 x DBH^2

Equation:	**Calculation in Excel:**
Biomass [kg] = 21.297 – 6.953*65+0.740*65² = 21.297 – 451.945+3126.5 =2695.85 kg/1000 ≈ 2.7 t	=(21.297-6.953**65*+0.740**65*^2)/1000 *Instead of DBH choose the particular cell.*

Example: Biomass calculation for Coconut

You measured a Coconut Palm with a log volume of 0.756 m³

roughly averaged density of Coconut wood = 479 kg/m³

(De Silva, S. ed. 1990. Coconut Wood Utilization. Proceedings of the Workshop for Policy Makers. APCC – Asian Pacific Coconut Community. Zamboanga, Philippines.)

$$Biomass\,[kg] = Volume[m^3] * Density[\frac{kg}{m^3}]$$

Formula 9: Biomass calculation

Biomass [kg] = 0.756 m³ * 479 [kg/m³] = 362.1 kg = 0.362 t

4.3.2 Calculation of deadwood biomass

4.3.2.1 Standing deadwood biomass

Standing deadwood is classified in 3 decomposition classes (*Tab. 7: Decomposition classification of standing dead wood p.51)*. For decomposition class 1 estimate the biomass of the tree using an appropriate equation as for living trees. But subtract out the biomass of leaves (about 3 % of aboveground biomass for hardwood/broadleaved species and 6 % for softwood/conifer species)

For the other decomposition classes[24], where it is not clear what proportion of the original biomass has been lost, it is the conservative approach to estimate the biomass of just the bole (trunk) of the tree. Therefore use the normal volume function for log height. Using DBH and log height measurements and form factor 0.7. The biomass can be calculated by multiplying the density of the dead wood. That has to be done for each decay class for its own.

Example: Biomass calculation for Standing Deadwood
You measured a dead tree (decay class 1) in wet tropical forest:

DBH = 35cm   Substract 3% of Leave biomass by multiplying by 0.97

Biomass [kg] = (21.297 – 6.953 x DBH+ 0.740 x DBH^2)* **0.97**

Equation:	**Calculation in Excel:**
Biomass [kg] = (21.297 – 6.953*35+0.740*35²)***0.97** = (21.297 – 243.355+906.5)***0.97** = 684.442***0.97** <u>= 663.91 kg</u>	=(21.297-6.953*35+0.740*35^2)***0.97**/1000

[24] Density values for each decomposition classes should be investigated. They should be general established for particular vegetation types. Average the densities to get a single density value for each class. Take separate wood samples of the density classes and process these like the non tree biomass samples. Measure their seize and record it. Then the deadwood samples will be oven dried as the other samples. To calculate the density divide the dry mass by the volume.

$$Wood\ Density\left[\frac{kg}{m^3}\right]=\frac{dry\,mass[kg]}{fresh\,Volume[m^3]}$$

$$dry\,mass=the\,mass\,of\ the\,oven\,dried\ sample[kg]$$

$$Volume\,of\ the\ fresh\,sample[m^3]=\frac{\pi}{4}*(average\ diameter[m])^2*average\,width[m]$$

Formula 10: Wood density calculation

4.3.2.2 Lying deadwood biomass

For each recording level (regarding the different sample lines e.g. deadwood ≥ 25 cm diameter at crossing a 100 m line, ≥ 10 cm < 25 cm, two 10 m lines, etc.) the volume can be calculated. The results can be summed afterwards and multiplied by deadwood density [kg/m³] to get the biomass. It is recommended to calculate the volume separately for each decomposition class, for differentiated biomass calculation.

If no figures about deadwood density (for each decomposition class) are available they can be investigated or a conservative estimation is possible. Multiply the volume by an average deadwood density. Therefore no decomposition classification is needed. To get an average deadwood density, divide the average wood density by half.

Volume calculation:	**Calculation in Excel:**
$Volume\ [m^3/ha] = \frac{\pi^2 * (d_1{}^2 + d_2{}^2 + d_3{}^2 + d_4{}^2 ... + d_n{}^2)}{8 * L}$ *Formula 11: Volume calculation of lying deadwood* d_n^2...diameters of intersecting pieces of dead wood in cm L.....length of the line in m	*=PI()^2*SUMSQ(d_1:d_n)/(8*L)* *Instead of d_1, d_2,...,d_n choose the particular cells.*
Biomass calculation:	
Biomass [kg/ha] = Volume [m³/ha]* Deadwood density [kg/m³] *Formula 12: Biomass calculation of lying deadwood*	

Example: Volume calculation of lying deadwood without decomposition classification

You want to calculated total Volume of lying deadwood(≥ 25 cm Diameter at Crossing (DC)), measured on a whole Plot (four times a 100 m line for each Sub-Plot = 400 m) and got following diameters:

Number	**DC**	**Number**	**DC**	**Number**	**DC**
d_1	33 cm	d_7	31 cm	d_{13}	31 cm
d_2	25 cm	d_8	40 cm	d_{14}	56 cm
d_3	26 cm	d_9	29 cm	d_{15}	27 cm
d_4	32cm	d_{10}	25 cm		
d_5	45 cm	d_{11}	26 cm		
d_6	25 cm	d_{12}	33 cm		

Total Volume (V_t):

$$V_t[m^3/ha] = \frac{\pi^2 * (33^2+25^2+26^2+32^2+45^2+25^2+31^2+40^2+29^2+25^2+26^2+33^2+31^2+56^2+27^2)}{8*400}$$

$$V_t = \frac{\pi^2 * (1089+625+676+1024+2025+625+961+1600+841+625+676+1089+961+3136+729)}{3200}$$

$$V_t[m^3/ha] = \frac{9.86961*16682}{3200} = \underline{51.45\ m^3/ha}$$

Calculation in Excel:
=PI()^2*SUMSQ(33;25;26;32;45;25;31;40;29;25;26;33;31;56;27)/(8*400)

Example: Biomass calculation of Lying deadwood

Average Wood density = 595 kg/m³

Average Deadwood density = 595/2 = 297.5 kg/m³

total Volume of lying deadwood = 51.45 m³/ha

$Biomass_{total}$ [kg/ha] = 51.45* 297.5 = <u>15,306.4 kg/ha</u>

Example: Volume calculation of Lying deadwood per decay class
You want to calculated figures for lying deadwood ≥ 25 cm, measured on a whole Plot (four times a 100 m line for each Sub-Plot = 400 m) and got following diameters:

Decay class 1 "Sound"		**Decay class 2 "intermediate"**		**Decay class 3 "rotten"**	
d_1	33 cm	d_1	25 cm	d_1	33 cm
d_2	25 cm	d_2	31 cm	d_2	31 cm
d_3	26 cm	d_3	40 cm	d_3	56 cm
d_4	32cm	d_4	29 cm	d_4	27 cm
d_5	45 cm	d_5	25 cm		
		d_6	26 cm		

Calculate the volume for each decay class:

Decay class 1 "Sound":

$$V_{sound}\,[m^3/ha]=\frac{\pi^2*(33^2+25^2+26^2+32^2+45^2)}{8*400}$$

$$V_{sound}\,[m^3/ha]=\frac{\pi^2*(1089+625+676+1024+2025)}{3200}$$

$$V_{sound}\,[m^3/ha]=\frac{9.86961*5439}{3200}=\underline{16.78\ m^3/ha}$$

Calculation in Excel: =PI()^2*SUMSQ(33;25;26;32;45)/(8*400)

Decay class 2 "Intermediate":

$$V_{intermediate}\,[m^3/ha]=\frac{\pi^2*(25^2+31^2+40^2+29^2+25^2+26^2)}{8*400}$$

$$V_{intermediate}\,[m^3/ha]=\frac{\pi^2*(625+961+1600+841+625+676)}{3200}$$

$$V_{intermediate}\,[m^3/ha]=\frac{9.86961*5328}{3200}=\underline{16.43\,m^3/ha}$$

Calculation in Excel: =PI()^2*SUMSQ(25;31;40;29;25;26)/(8*400)

Decay class 3 "Rotten":

$$V_{rotten}\,[m^3/ha]=\frac{\pi^2*(33^2+31^2+56^2+27^2)}{8*400}$$

$$V_{rotten}\,[m^3/ha]=\frac{\pi^2*(1089+961+3136+729)}{3200}$$

$$V_{rotten}\,[m^3/ha]=\frac{9.86961*5915}{3200}=\underline{18.24\,m^3/ha}$$

Calculation in Excel: =PI()^2*SUMSQ(33;31;56;27)/(8*400)

Example: Biomass calculation of Lying deadwood per decay class

Volumes were taken from the example above.

Example densities[21]:

Sound 430 kg/m³	Intermediate 340 kg/m³	Rotten 190 kg/m³

$$Biomass_{sound}\ [kg/ha] = 16.78 * 430 = 7{,}215.4\ kg/ha$$

$$Biomass_{intermediate}\ [kg/ha] = 16.43 * 340 = 5{,}586.2\ kg/ha$$

$$Biomass_{rotten}\ [kg/ha] = 18.24 * 190 = 3{,}465.6\ kg/ha$$

$$Biomass_{total}\ [kg/ha] = 7{,}215.4 + 5{,}586.2 + 3{,}465.6 = \underline{16{,}120\ kg/ha}$$

4.3.3 Processing of samples and calculation of above ground non tree biomass

The collected samples will be weighed with a spring scale either just on the Plot or later in the laboratory (small Sub-Samples can also be weighed with laboratory scales). If you got a big sample, which does not fit in the plastic bag, weight and record first the total sample and remove than a well-mixed Sub-Sample (representative) for determination of dry-to-wet mass ratio. Weigh the Sub-Sample and record the weight, then oven-dry to a constant mass (usually at between ~ 70°C and ~105° for 12 hours or up to 24 hours). That depends on the shape and moisture content. Plants and litter will dry faster than the small dead wood, which can be sometimes a big part of the sample.

Fig. 30: Weighing of Sub-Sample with laboratory scale

Fig. 29: Laboratory oven for drying of Sub-Samples

Alternative: In case you do not have an laboratory oven available you can spread out the sample on a corrugated sheet iron for approx. 2 days in the sun. But you have to protect it from humidity (collect it during night and rainfall) and from wind (wire mesh or mosquito net over sample). The remaining moisture content of the air dry sample will be handled as measurement error of approx. 20 - 30%.

Record the weight of the sample after the drying process. Where a Sub-Sample was taken for determination of moisture content, calculate the biomass with following formula:

$$Biomass\ [kg] = \frac{Subsample\ dry\ weight\ [kg]}{Subsample\ fresh\ weight\ [kg]} * fresh\ weight\ of\ whole\ sample\ [kg]$$

Formula 13: Sample Biomass calculation form Sub-Sample

The biomass density (kg/hectare) is calculated by multiplying the dry mass by an expansion factor.

$$Biomass\ [kg/ha] = Sampled\ Biomass * Expansion\ factor$$

Formula 14: Biomass per ha calculation

Example: Calculation of Sample Biomass from Sub-Sample

Sub-Sample dry weight = 82.8 g
Sub-Sample fresh weight = 213.3 g
Fresh weight of whole sample = 921.5 g

$$Biomass = \frac{82.8}{213.3} * 921.5 = \underline{357.7g \approx 0.357\ kg}$$

Example:
You have 3.896 kg of oven dried biomass for one whole Plot:

$$Biomass_{total}[kg/ha] = 3.896 * 4420.97064 = 17{,}224.1\ kg/ha$$

4.3.4 Calculation of below ground root biomass of trees

Living Root biomass, either alive or dead, is an important carbon pool which amount of total carbon in tropical forest can vary from 10% to 40%[25]. However it is a important carbon pool, it is very time consuming and expensive to measure the root biomass.

For the MAR Program it was found feasible to undertake conservative estimations using a general equation for tropical trees[26]. The equation relates the aboveground biomass to below ground root biomass.

Equation:	Calculation in Excel:
$BGB\ [t/ha] = \exp(-1.0587 + 0.8836 * \ln AGB)$ *Formula 15: Below ground root biomass calculation* BGB [t/ha] =belowground biomass AGB [t/ha] =Aboveground biomass	=EXP(-1.0587+0.8836*LN(AGB))

Example: Below ground Root Biomass calculation

The calculated Aboveground biomass (AGB) is 256.7 t/ha.

$$BGB\ [t/ha] = \exp(-1.0587 + 0.8836 * \ln(256.7))$$

$$BGB\ [t/ha] = \exp(-1.0587 + 0.8836 * 5.548) = \exp(3.8435)$$

$$BGB\ [t/ha] = 46.69\ t/ha$$

25 MacDicken, K.G. 1997.

26 Due to not available equations for Shrubs, Coconut and other vegetation the formula shall be used until specific equations are developed.

4.4 Carbon Stock

It is common practice to convert biomass to carbon by dividing the dry biomass by 2 (Formula 16). However, if local values for the carbon content are available, use these instead. At best you sum all dry biomass figures for each category (e.g. all Deadwood biomass (lying and standing)) and just divide the sum by 2.

$$C = \frac{dry\ Biomass}{2}$$

Formula 16: Calculation of Carbon Content

4.5 Calculation of Biodiversity

Biodiversity can be expressed in many ways. For this program we want to determine biodiversity by lists of relevant indicator or rare species and by the diversity of the trees.

The diversity of trees can be expressed with the biodiversity indices "Shannon-index" together with the "Evenness-Index".

Biodiversity indices provide information on the current state and changes and also differences between managed and unmanaged forests. They are important for monitoring the trends in biodiversity and indicate the effectiveness of biodiversity management. These Indices can be compared with other results to make a statement of the biodiversity. However, they are difficult to interpret, especially when taken out of context. First there has to be regional investigation on how the certain figures are related to the different vegetation and management types (e.g. what are common figures for a secondary tropical rainforest in your country/region?). For interpretation of the indices please consult experts and special literature.

The Shannon index is one of several diversity indices used to measure diversity in categorical data. Simply, it relates the proportion of every species to the overall number of individuals, but takes into account the balance of the different species. The index is increased either by having additional unique species, or by having a greater balance of the species.

The Evenness-Index relates the maximum diversity of a stand with the actual diversity. That is essential for comparability of the diversity of stands with variable number of species.

4.5.1 The Shannon-Index

Equation:	**Calculation in Excel:**
$$H=-\sum_{i=1}^{n} p_i * \ln(p_i)$$ *Formula 17: Calculation of "Shannon-Index"* n..........Number of species p_i...............portion of species from total population $$p_i=\frac{n_i}{N}$$ n_i..............Number of individuals of certain Species N.........Total amount of individuals	=-(P1*LN(P1)+P2*LN(P2)+...+Pn*LN(Pn)) ***It can easily happen that you got a high amount of species e.g. in tropical rainforest sometimes 20 and above. The equation will become very long, therefore it is recommended to calculate interim results for p_i in a separated column.***

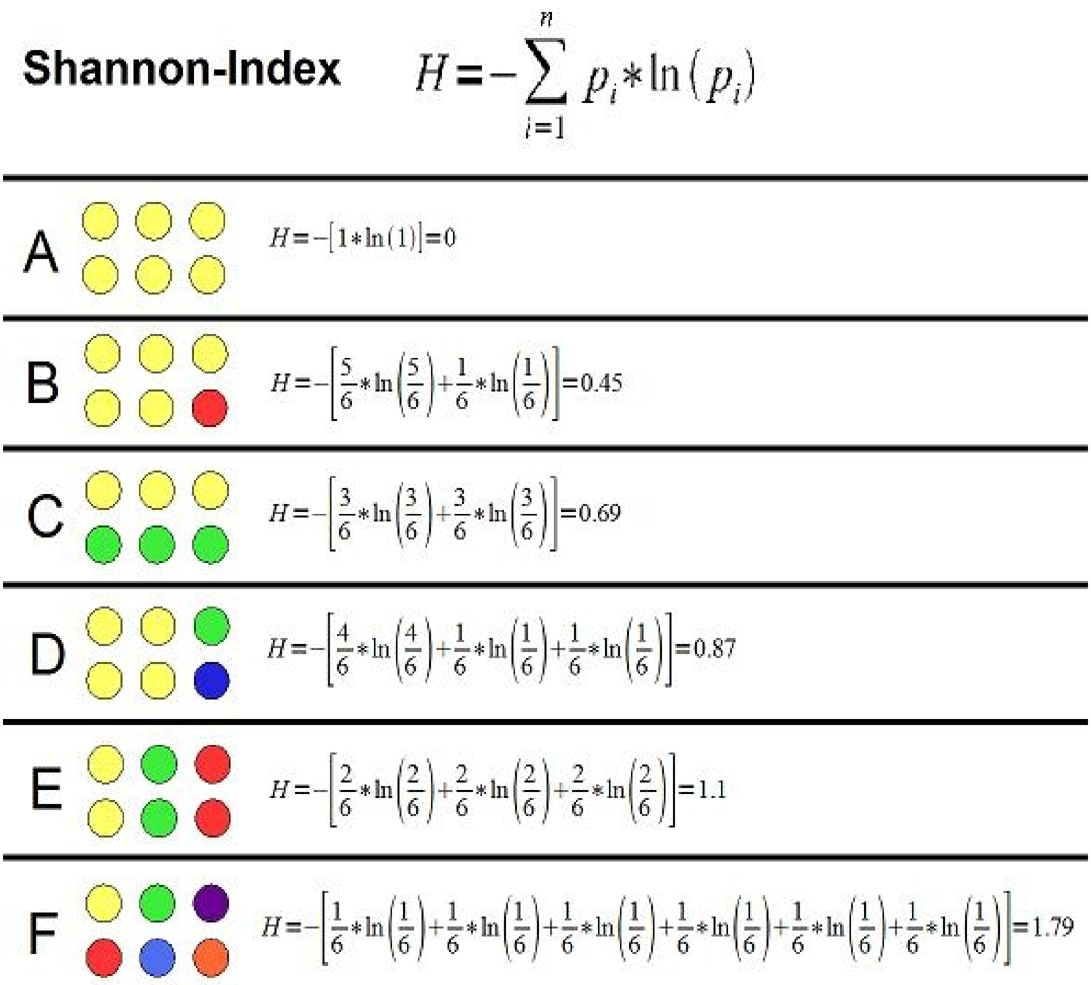


Fig. 31: Shannon-Index schematic examples

4.5.2 The Evenness-Index

Equation:	***Calculation in Excel:***
$E = \frac{H}{H_{max}}$ $H_{max} = \ln(n)$ *Formula 18: Calculation of "Evenness-Index"* n...........total of species H..........Shannon index H_{max}..........maximum diversity	*In Microsoft Excel® you can combine both equations, but in cases of very long and complex equations it is recommended to make it disconnectedly.* =(-(P1*LN(P1)+...+Pn*LN(Pn)))/LN(n) =H/LN(n)

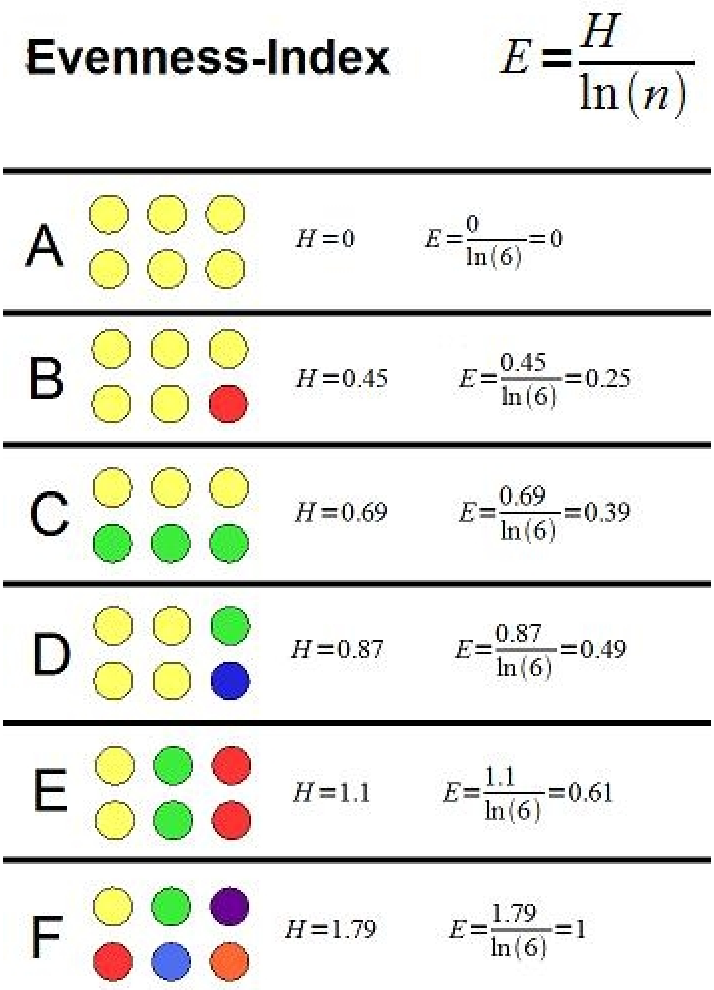


Fig. 32: Evenness-Index schematic examples

Example 1: Shannon- and Eveness-Index calculation

Total amount of species (n) = 8
Total amount of individuals (N) =80

Number of individuals n_i : *(as it can occur in a Fijian forest)*	Portion of species from total population p_i: $p_i = \frac{n_i}{N}$	Logarithm of portions of species $\ln(p_i)$	Interim result $p_i * \ln(p_i)$
Kaudamu 20	0,2500	-1.39	-0.348
Yasiyasi 15	0,1875	-1.67	-0.313
Rosarosa 10	0,1250	-2.08	-0.26
Sa 10	0,1250	-2.08	-0.26
Vutukana 10	0,1250	-2.08	-0.26
Bau 5	0,0625	-2.77	-0.173
Kauvula 5	0,0625	-2.77	-0.173
Laubu 5	0,0625	-2.77	-0.173

Shannon-Index:

$$H = -\sum_{i=1}^{n} p_i * \ln(p_i)$$

Calculation in Excel:
=-[0.25*(-1.39)+0.1875*(-1.67)+0.125*(-2.08)+0.125*(-2.08)
+0.125*(-2.08)+0.0625*(-2.77)+0.0625*(-2.77)+0.0625*(-2.77)]

Choose the particular cells of p_i and Ln(p_i).

H=1.96

The Shannon-Index in this example is 1.96.

Evenness-Index:

$$H_{max} = \ln(n)$$
$$H_{max} = 2.079$$
$$E = \frac{H}{H_{max}} = \frac{1.96}{2.079} = 0.94$$

The Eveness-Index in this example is 0.94.

Example 2: Shannon- and Evenness-Index calculation				
Total amount of species (n) = 32 Total amount of individuals (N) =132				
Number of individuals n_i : *(as it can occur in a Fijian forest)*		Portion of species from total population p_i: $p_i = \frac{n_i}{N}$	Logarithm of portions of species $\ln(p_i)$	Interim result $p_i * \ln(p_i)$
Ai Masi	4	0.0303	-3.4965	-0.1060
Balabala	8	0.0606	-2.8034	-0.1699
Balaka	4	0.0303	-3.4965	-0.1060
Bau	2	0.0152	-4.1897	-0.0635
Bo	4	0.0303	-3.4965	-0.1060
Bo Loa	2	0.0152	-4.1897	-0.0635
Boiboi Da Levu	1	0.0076	-4.8828	-0.0370
Damanu	1	0.0076	-4.8828	-0.0370
Diriniu	8	0.0606	-2.8034	-0.1699
Dulewa	2	0.0152	-4.1897	-0.0635
Kaudamu	18	0.1364	-1.9924	-0.2717
Kaukaro	4	0.0303	-3.4965	-0.1060
Kauloa	2	0.0152	-4.1897	-0.0635
Kaunigai	6	0.0455	-3.0910	-0.1405
Kauniuna	1	0.0076	-4.8828	-0.0370
Kautoa	2	0.0152	-4.1897	-0.0635
Laubu	2	0.0152	-4.1897	-0.0635
Lolo	4	0.0303	-3.4965	-0.1060
Losilosi	4	0.0303	-3.4965	-0.1060
Makita	8	0.0606	-2.8034	-0.1699
Mala	3	0.0227	-3.7842	-0.0860
Mana i Vanua	1	0.0076	-4.8828	-0.0370
Nunu	6	0.0455	-3.0910	-0.1405
Roro	1	0.0076	-4.8828	-0.0370
Rosarosa	1	0.0076	-4.8828	-0.0370
Sisisi	4	0.0303	-3.4965	-0.1060
Sole	2	0.0152	-4.1897	-0.0635

Example 2 continued:				
Sosoniura	14	0.1061	-2.2437	-0.2380
Tabuuna	2	0.0152	-4.1897	-0.0635
Vasa Veiku	1	0.0076	-4.8828	-0.0370
Yasileba	2	0.0152	-4.1897	-0.0635
Yasiyasi	8	0.0606	-2.8034	-0.1699

Shannon-Index:

$$H = -\sum_{i=1}^{n} p_i * \ln(p_i)$$

H = - [-0.1060 -0.1699 -0.1060 -0.0635 -0.1060 -0.0635 -0.037 -0.037 -0.1699 -0.0635 -0.2717 -0.106 -0.0635 -0.1405 -0.037 -0.0635 -0.0635 -0.106 -0.106 -0.1699 -0.086 -0.037 -0.1405 -0.037 -0.037 -0.106 -0.0635 -0.238 -0.0635 -0.037 -0.0635 -0.1699]

H = 3.13

The Shannon-Index in this example is 3.13.

$$H_{max} = \ln(n)$$
$$H_{max} = 3.466$$

$$E = \frac{H}{H_{max}} = \frac{3.1282}{3.4657} = 0.90$$

The Evenness-Index in this example is 0.90.

Example 3: Shannon- and Evenness-Index calculation

Total amount of species (n) = 3
Total amount of individuals (N) =190

Number of individuals n_i :	Part of species from total population p_i: $p_i = \frac{n_i}{N}$	Logarithm of portions of species $\ln(p_i)$	Interim result $p_i * \ln(p_i)$
Mahogany 129	0.6789	-0.3872	-0.2629
Pasiu (African Tulip Tree) 48	0.2526	-1.3758	-0.3475
Sole 13	0.0684	-2.6821	-0.1834

Shannon-Index:

$$H = -\sum_{i=1}^{n} p_i * \ln(p_i) = -[0.6789 * (-0.3872) + 0.2526 * (-1.3758) + 0.0684 * (-2.6821)]$$

$$H = -[-0.2629 - 0.3475 - 0.1834]$$

$$H = 0.79$$

The Shannon-Index in this example is 0.79.

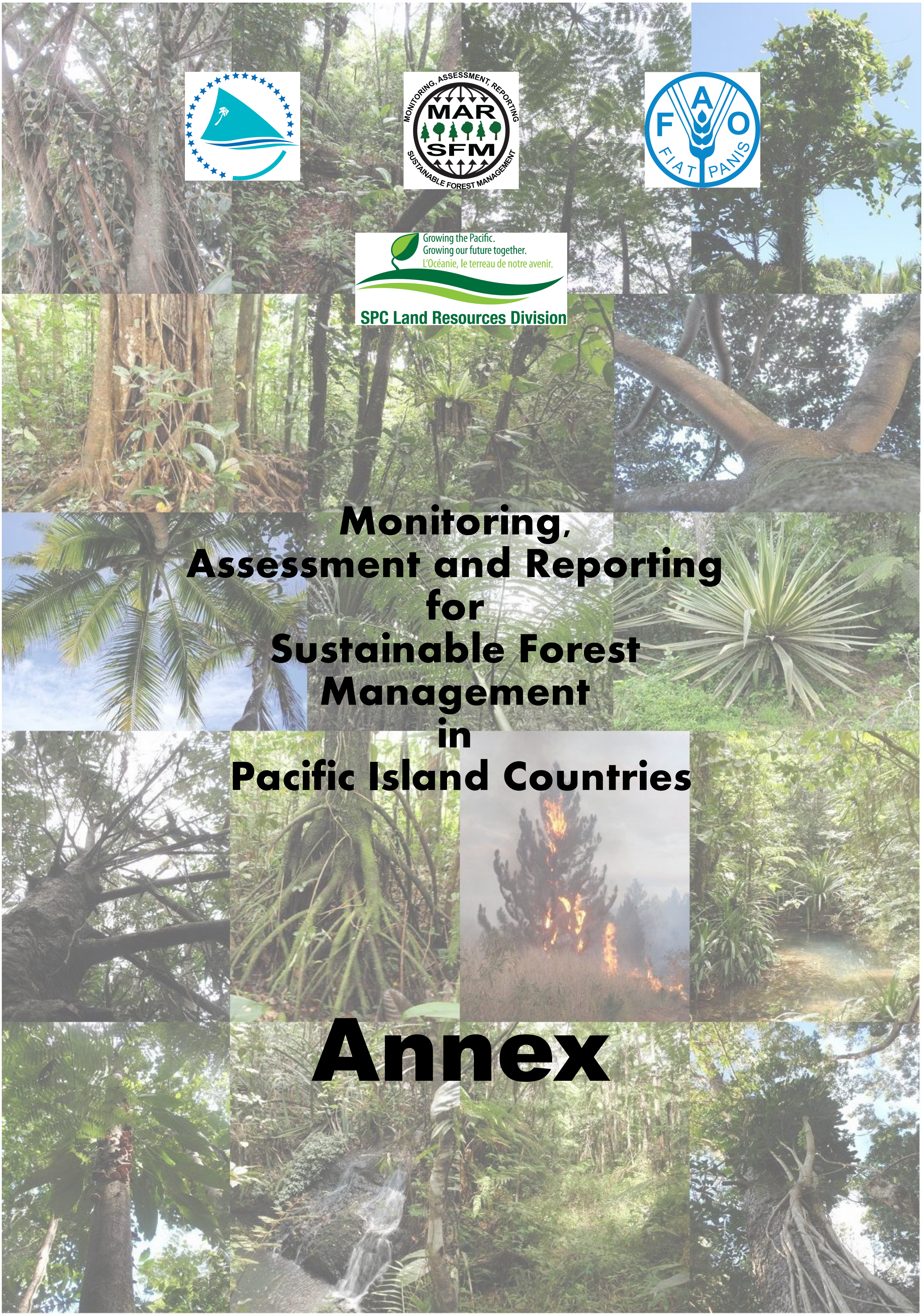
Evenness-Index:

$$H_{max} = \ln(n)$$

$$H_{max} = 1.1$$

$$E = \frac{H}{H_{max}} = \frac{0.79}{1.1} = 0.72$$

The Evenness-Index in this example is 0.72.



Monitoring, Assessment and Reporting for Sustainable Forest Management in Pacific Island Countries

Annex

5 Annex

5.1 Underlying Definitions for Data Collection

Taken from : **FAO. 2004.** Global Forest Resources Assessment Update 2005. Terms and Definitions (Final Version). Forest Resources Assessment Programme. Working Paper 83/ E. Rome. Italy.

5.1.1 Biomass

Organic material both above-ground and below-ground, and both living and dead, e.g., trees,crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above – and below - ground biomass.

Above ground Biomass
All living biomass above the soil including stem, stump, branches, bark, seeds and foliage.

Dead wood biomass
All non-living woody biomass not contained in the litter, either standing, lying on the ground,or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

Litter
Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country for lying dead (for example 10 cm), in various states of decomposition above the mineral or organic soil. This includes the litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.

5.1.2 Carbon stock

The quantity of carbon in a “pool”, meaning a reservoir or system which has the capacity to accumulate or release carbon.

Carbon in above-ground biomass
Carbon in all living biomass above the soil, including stem, stump, branches, bark, seeds, and foliage.

Carbon in dead wood biomass
Carbon in all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

Carbon in litter
Carbon in all non-living biomass with a diameter less than a minimum diameter chosen by the country in various states of decomposition above the mineral or organic soil. This includes the litter, fumic, and humic layers.

5.1.3 Designated functions (of forest and other wooded land)

For the purpose of FRA 2005 the designated function refers to the function or purpose assigned to a piece of land either by legal prescriptions or by decision of the land owner/manager. It applies to land classified as “Forest” and as “Other wooded land”.

Conservation of biodiversity
Forest/Other wooded land designated for conservation of biological diversity.

Multiple purpose
Forest/Other wooded land designated to any combination of: production of goods, protection of soil and water, conservation of biodiversity and provision of socio-cultural services and where none of these alone can be considered as being significantly more important than the others.

Production
Forest/Other wooded land designated for production and extraction of forest goods, including both wood and non-wood forest products.

Protection of soil and water
Forest/Other wooded land designated for protection of soil and water.

Social services
Forest/Other wooded land designated for the provision of social services.

Unknown function
Forest/Other wooded land for which a specific function has not been designated or where the designated function is unknown.

5.1.4 Disturbances (affecting forest health and vitality)

A disturbance is defined as *an environmental fluctuation and destructive event that disturb forest health, structure, and/or change resources or physical environment at any given spatial or temporal scale.* Disturbances that affect health and vitality include biotic agents such as insects and diseases and abiotic agents such as fire, pollution and extreme weather conditions.

Disturbance by diseases
Disturbance caused by diseases attributable to pathogens, such as a bacteria, fungi, phytoplasma or virus.

Disturbance by fire
Disturbance caused by wildfire, regardless of whether it broke out inside or outside the Forest/Other wooded land.

Disturbance by insects
Disturbance caused by insect pests that are detrimental to tree health.

Other disturbance
Disturbance caused by factors other than fire, insects or diseases.

5.1.5 Forest and other wooded land

Forest
Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use.

Other wooded land
Land not classified as Forest, spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds *in situ*; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.

Other land
All land that is not classified as Forest or Other wooded land.

Other land with tree cover
Land classified as Other land, spanning more than 0.5 hectares with a canopy cover of more than 10 percent of trees able to reach a height of 5 meters at maturity.

Tree
A woody perennial with a single main stem, or in the case of coppice with several stems,
having a more or less definite crown.

Trees outside forests
Trees outside forests include all trees found outside forests and outside other wooded lands:

- stands smaller than 0.5 ha;
- tree cover in agricultural land, e.g. agroforestry systems, homegardens, orchards;
- trees in urban environments;
- along roads and scattered in the landscape.

5.1.6 Forest characteristics

Modified natural forest/other wooded land
Forest/Other wooded land of naturally regenerated native species where there are clearly visible indications of human activities.

Primary forest/other wooded land
Forest/Other wooded land of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.

Secondary forest
Forest regenerated largely through natural processes after significant human or natural disturbance of the original forest vegetation.

Semi-natural forest/other wooded land
Forest/Other wooded land of native species, established through planting, seeding or assisted natural regeneration.

Productive plantation (in Forest/Other wooded land)
Forest/Other wooded land of introduced species and in some cases native species, established through planting or seeding mainly for production of wood or non wood goods.

Protective plantation (in Forest/Other wooded land)
Forest/Other wooded land of native or introduced species, established through planting or seeding mainly for provision of services.

5.1.7 Growing stock

Volume over bark of all living trees more than X cm in diameter at breast height. Includes the stem from ground level or stump height up to a top diameter of Y cm, and may also include branches to a minimum diameter of W cm.

Commercial growing stock
The part of the growing stock that is considered as commercial or potentially commercial under current market conditions (and with a diameter at breast height of Z cm or more)

Growing stock composition
The composition of the Growing stock in Forest and Other wooded land by (each inventoried) forest tree species.

5.1.8 Ownership

Other ownership
Land that is not classified either as Public ownership or as Private ownership.

Private ownership
Land owned by individuals, families, private co-operatives, corporations, industries, private religious and educational institutions, pension or investment funds, and other private institutions.

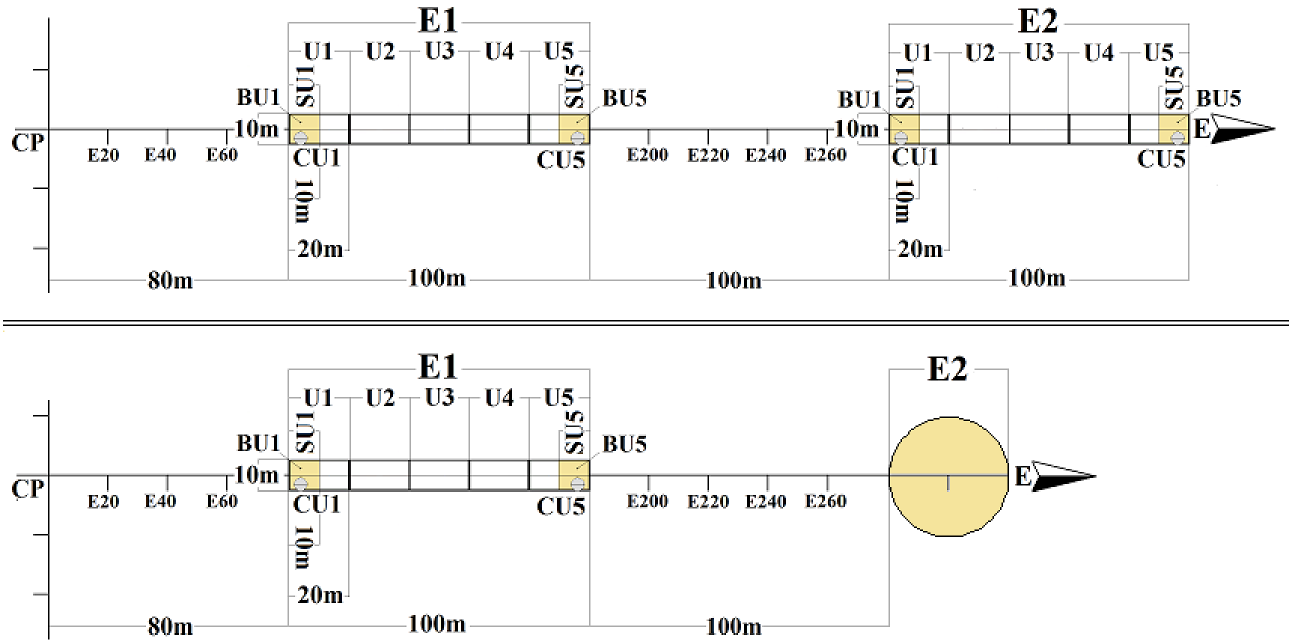
Public ownership
Land owned by the State (national, state and regional governments) or government-owned institutions or corporations or other public bodies including cities, municipalities and villages.

5.1.9 Biodiversity

It's the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

5.2 Additional Sub-Plots

The establishment of more Sub-plots in one Plot could be easily realized through extending the center lines and establishing additional Sub-plots in 100 m distance to the end of the existing Sub-plots. On demand, also other shaped Sub-plots (e.g. circular plots) might be added.



CP..........Center Point	SU1.........Sub-Unit
E1...........Sub-Plot	BU1.........Biomass Plot
E2...........Additional Sub-Plot	CU1.........Circular Plot
U1...........Unit	E220........220m distance east of CP

Fig. 33: Additional Sub-Plots

5.3 Materials

A **diameter tape** is normally made from steel or fibre glass and is calibrated with 2 scales. On one side is a normal distance scale and on the other side is the diameter scale. Here all Units are multiplied by π (pi≈3.14), which is the ratio of the circumference to its diameter, i.e. one centimetre on the diameter scale is approx. 3.14 cm long. Thus direct diameter measurements are possible. Diameter tapes measure always an average diameter corresponding to the girth of the tree.

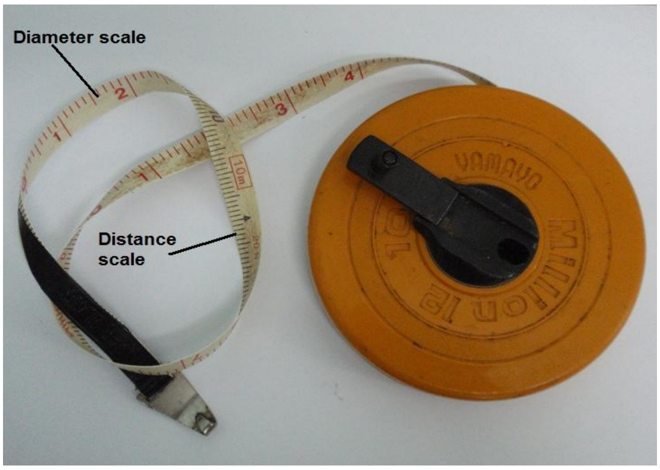


Fig. 34: diameter tape

A **calliper** consist of a graduated bar with two parallel arms at right angle, one is fixed and the other one can slide on it. The tree will be clamped between the two arms to indicate the diameter. Callipers measure only one diameter of the cross-section of the stem. The form of the cross-section of the stem will have normally little irregularities in shape, therefore normally two measurements in right angle will be done and averaged.

Fig. 35: Calliper

A handheld **survey compass** consists of a strong housing made from light metal. A liquid dampened disk protected by the housing, serves as magnetic needle with a calibrated degree unit scale on it. All models provide a sight glass for precise scale readings, a thread for tripod and a lanyard holder. The sight glass is adjustable for different visual acuity. Some models have also a back bearing scale and a declination adjusting system, to instantly correct readings to geographic north.

Fig. 36: handheld survey compass

Fig. 37: handheld survey compass rough readout

A handheld **survey clinometer** consists of a strong housing made from light metal. A liquid dampened disk protected by the housing, serves to express inclination with a calibrated degree and percentage scale on it. All models provide a sight glass for precise scale readings, a thread for tripod and a lanyard holder. The sight glass is adjustable for different visual acuity. Some models are specially made for tree height measurements and provide optical distance measure, but have the disadvantages of only supporting the fixed distances. Thus, it is very difficult to find a good observing point in dense forests.

Fig. 38: handheld survey clinometer

Fig. 39: handheld survey clinometer rough readout

The **survey stick** is a simple but very useful tool for the assessment. It will be used for determination of breast height, as reference length for height measurement and reference height for slope measurement, as tool for in and out judgement, for lying deadwood measurement and could also be used as walking support in difficult and slippery terrain. It can be a 2 m long ranging rod or self made stick from strong and straight but light wood, light metal or plastic tube. It should be signal coloured, marked (at 0.3 m, 1 m, 1.3 m) and extensible by another 2 m e.g. another survey stick. A preferable option would be a plug connection or lockable folding clamp (Fig. 40 below). It can also be improvised in the field.

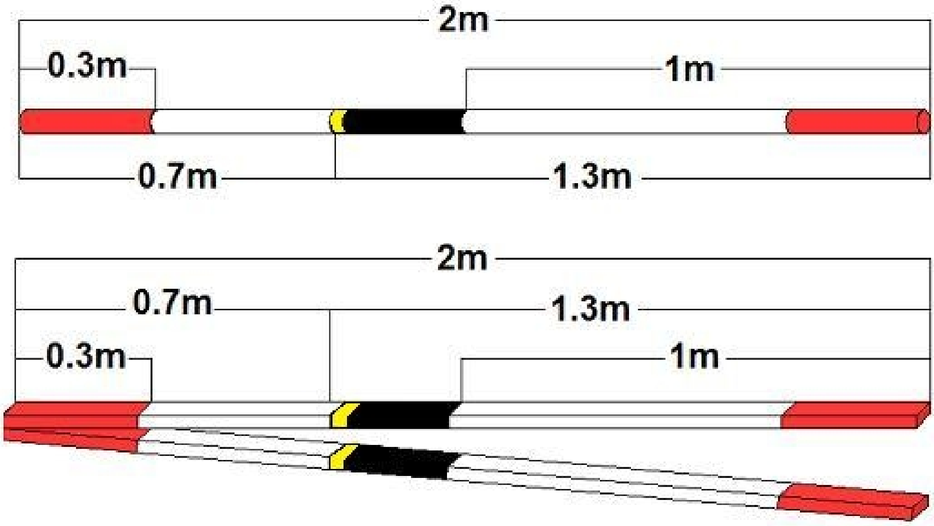


Fig. 40: Survey Stick

5.3.1 The compass

It is common practice in forestry to use handheld compasses as e.g. SUUNTU® for field measurements. They are easy to use and provide reliable measures. *(Fig. 36: handheld survey compass p.94)*

Compasses use commonly the 360° scale to describe the bearing of an object. The bearing is the horizontal angle clockwise from due north 0° (0° = 360°) to 359°. Where north is 0°/360°, east 90°, south 180° and west 270°.

A measurement precision of 1° can be achieved by reading the scale from above *(Fig. 37: handheld survey compass rough readout p.94)* and 0,5° by using the sight glass and precise scale.

There are different kinds of handheld survey compasses on the market with a unit price of approximately 140 to 300 US-$.

5.3.1.1 Compass usage for field work

To find roughly a given direction as e.g. for clearing a center line of a sub-plot, the compass will be held on the flat hand in a horizontal position to make sure the disk can run freely. The observer has to wait until the disk stops moving and reads out the bearing angle with the rough scale from above. Then the viewing direction will be equalized to the achieved direction.

For precise measurement as e.g. for aligning a 20 m section on the Sub-Plot center line the compass will be held with both hands in a horizontal position at eye level. The observer keeps both eyes open and looks with one eye through the sight glass and with the other one he is aiming at the object (e.g. the post) in order to align. The views of both eyes overlap and so the cross hair, the scale and the post are simultaneously in view. The cross hair has to be congruent to the post and also the disk have to stand still when the reading is made.

Fig. 41: Compass precision readout

The cross hair, the scale and the object in order to determine its bearing overlap in the moment of undertaking the reading. The desired bearing shall be in the center of the post.

5.3.1.2 Causes of errors

Generally, causes of errors can be wrong handling,of the instrument (e.g. the compass is not held in a horizontal position so the disk can not freely move or the cross hair is not properly correlated with the object), incorrect readings, ignorance of local attraction and declination.

Declination

Compasses point always to magnetic north pole but maps are normally orientated to geographic north pole. The angle formed between magnetic north and geographic north is called magnetic declination or short declination. The quantity of declination depends on the region and is changing in time and also periodically. So up to date declination correction values must be added or subtracted by any measurement.

Local attraction

Compass needles are not only attracted by earth magnetic field but also unlikely by all close by magnetism, electricity and iron things. The ability to influence the compass needle by these things is called local attraction. In fieldwork this so called local attraction can be caused by e.g. iron tools (bush knife etc.), metal fences, power lines, transmitter masts, cars and so on. To avoid errors all iron things has to removed from the observer when measurements are made. In case of big attracting objects the observer has to take a security distance from the object. As bigger the object and therefore the local attraction is, as longer the distance has to be. As rule of thumb stay away about 10 m form a car and about 50 m from a power line post.

Checks

To check your measured bearings so called back sights or back bearings can be made when establishing a straight line (e.g. center line of sub-plot).

The difference between the back bearing of a measured bearing is always 180°. The back bearing can be calculated by using formula 19. To check the bearing of a post e.g. on a center line, it will moved on to the next post and the back bearing is measured and compared to the calculated back bearing.

Measured bearing is between 0° to 180°	Back bearing = Bearing +180°
Measured bearing is between 180° to 360°	Back bearing = Bearing – 180°

Formula 19: Calculation of back bearing

5.3.2 The clinometer

For field measurements of slopes and angles for height determination a handheld survey clinometer as e.g. SUUNTU® is used *(Fig. 38: handheld survey clinometer95p.)*. They are easy to use for describing the slope of an aimed object and provide reliable measures commonly in degree and/or in percent.

The handheld clinometer can be used as a spirit level to determine e.g. the leaning of a ranging rod, by placing the clinometer at the object and reading through the window at the side. But no slope readings should be made, in order of being unable of precise readings from that scale. *(Fig. 39: handheld survey clinometer rough readout p.95)* If applying the precise scale through the sight glass, readings with a precision of 0,5° can be achieved.

There are different kinds of handheld survey clinometer on the market with a unit price of approximately 140 to 300 US-$.

5.3.2.1 Clinometer usage for field work

For slope measurements either the percentage scale (on the right) or the degree scale (on the left) will be used, but the degree scale is recommended for angle measurements for height determination.

For precise measurement as e.g. for height measurements the clinometer will be held with both hands in a vertical position at eye level. Make sure the disk can freely move. The observer keeps both eyes open and looks with one eye through the sight glass and with the other one he is aiming at the object (e.g. reference height) in order to determine the angle off. The views of both eyes overlap and so the cross hair, the scale and reference height are simultaneously in view. The cross hair has to be congruent to the top of the reference height and also the disk have to stand still when the reading is made.

Fig. 42: Clinometer precise readout

The cross hair, the scale and object in order to determine its angle (e.g. reference height) overlap in the moment of undertaking the reading.

5.3.2.2 Causes of errors

Nevertheless, slope readings with handheld survey clinometers are not difficult but need exercise and practise to achieve conciseness.

Some common mistakes in applying clinometers are unfortunately also the most crucial ones. It is most severe necessary to take readings not in a rush and concentrate on error avoiding.

Common mistakes made:

- the scales are confused (if readings are taken with a different scale than commonly used, it have to be highlighted in “remarks column” on the field form)
- the scales are not readout correctly (not all calibration units are numbered, above zero you have to count upwards (e.g. 4 lines below + 20° will be read as 16°), below downwards (e.g. 2 lines below -20° will be read as -22°)
- aiming at the wrong target (for slope measurements always aim at a point of equal height as your eye height)
- see also Sources of error of height measurements *(p.59)*

5.4 Horizontal Distance Measurement and Slope Correction

All Plot dimensions *(Sampling Layout p.16)* are seen as horizontal distances. In the field it is most likely that you do not have level surface. Therefore it is recommended to undertake horizontal distance measurements by keeping the spanned distance tape in horizontal position. In case of steep slopes step-wise measurements of suitable distances shall be done *(Fig. 43)*.

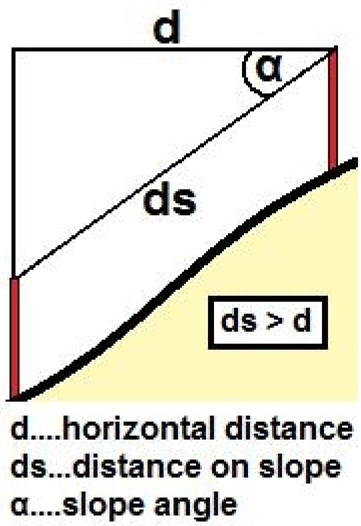


Fig. 44: Slope correction

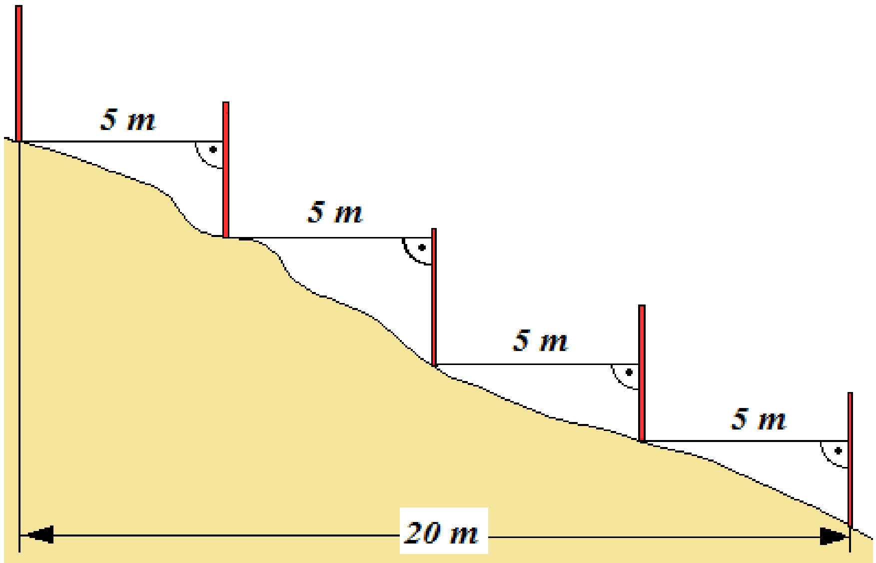


Fig. 43: Step-wise horizontal measurements

Fig. 45: horizontal distance measurement in the field

Nevertheless, it is also likely situations occur where horizontal distance measurement is not applicable or too difficult and time consuming. In these cases, the slope will be measured with the clinometer either in degree or percent and a slope correction factor is applied. Slope corrections will be necessary from slopes bigger or equal 15 % (9°). The corrected distance can be taken from the slope correction table[27] below.

Tab. 10: Slope correction table

Slope	**Degree**	**Factor**	**Horizontal distances**								**Slope**
%	**°**	**f_s**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**%**
15	9	1.0112	5.1	10.1	15.2	20.2	25.3	30.3	40.4	50.6	**15**
20	11	1.0198	5.1	10.2	15.3	20.4	25.5	30.6	40.8	51.0	**20**
25	14	1.0308	5.2	10.3	15.5	20.6	25.8	30.9	41.2	51.5	**25**
30	17	1.0440	5.2	10.4	15.7	20.9	26.1	31.3	41.8	52.2	**30**
35	19	1.0595	5.3	10.6	15.9	21.2	26.5	31.8	42.4	53.0	**35**
40	22	1.0770	5.4	10.8	16.2	21.5	26.9	32.3	43.1	53.9	**40**
45	24	1.0966	5.5	11.0	16.4	21.9	27.4	32.9	43.9	54.8	**45**
50	27	1.1180	5.6	11.2	16.8	22.4	28.0	33.5	44.7	55.9	**50**
60	31	1.1662	5.8	11.7	17.5	23.3	29.2	35.0	46.6	58.3	**60**
70	35	1.2207	6.1	12.2	18.3	24.4	30.5	36.6	48.8	61.0	**70**
80	39	1.2806	6.4	12.8	19.2	25.6	32.0	38.4	51.2	64.0	**80**
90	42	1.3454	6.7	13.5	20.2	26.9	33.6	40.4	53.8	67.3	**90**
100	45	1.4142	7.1	14.1	21.2	28.3	35.4	42.4	56.6	70.7	**100**
110	48	1.4866	7.4	14.9	22.3	29.7	37.2	44.6	59.5	74.3	**110**
120	50	1.5620	7.8	15.6	23.4	31.2	39.1	46.9	62.5	78.1	**120**
130	52	1.6401	8.2	16.4	24.6	32.8	41.0	49.2	65.6	82.0	**130**
140	54	1.7205	8.6	17.2	25.8	34.4	43.0	51.6	68.8	86.0	**140**
150	56	1.8028	9.0	18.0	27.0	36.1	45.1	54.1	72.1	90.1	**150**

*For other horizontal distances, not included in the table, it is possible to get a corrected distance by multiplying the horizontal distance by the slope correction factor scf. For instance, on a terrain with a 25 % slope, the aim is to find the horizontal distance of 7.5 meter, it is necessary to carry out the following operation: 7.5 * 1.0308 = 7.73 meters.*

[27] FAO. 2008; modified

5.5 Indicators for Site Description

For categorization of the site, you can use indicators to simplify the decision. The provided indicators tables shall be seen as an inspiration to develop own, more detailed and adapted indicator lists for your particular situations.

Furthermore it is recommended to use the exclusion principle *(Fig. 46: Example for exclusion principle from forest characteristics estimation p.103)*. While going through the Unit in order to categorize, ask you some simple but systematic questions as shown in the example below.

Indicators are not evidence! Not all indicators are exclusive. Some indicators can be fit to different categories. They have to be seen in a greater context together with collected information from Pre-Phase.

Example: Indicators are not evidence

- The Sub-Plot lies between two Skid tracks. Form the observers point of view no signs of harvesting can be seen, but because of interviews with locals, it is known that there was a wood harvest 10 years ago. Therefore the forest cannot be primary any more.
- The Area is under protection because of a rare bird living there. But the forest is a left plantation. So the protection status is not an exclusive indicator for primary forests.

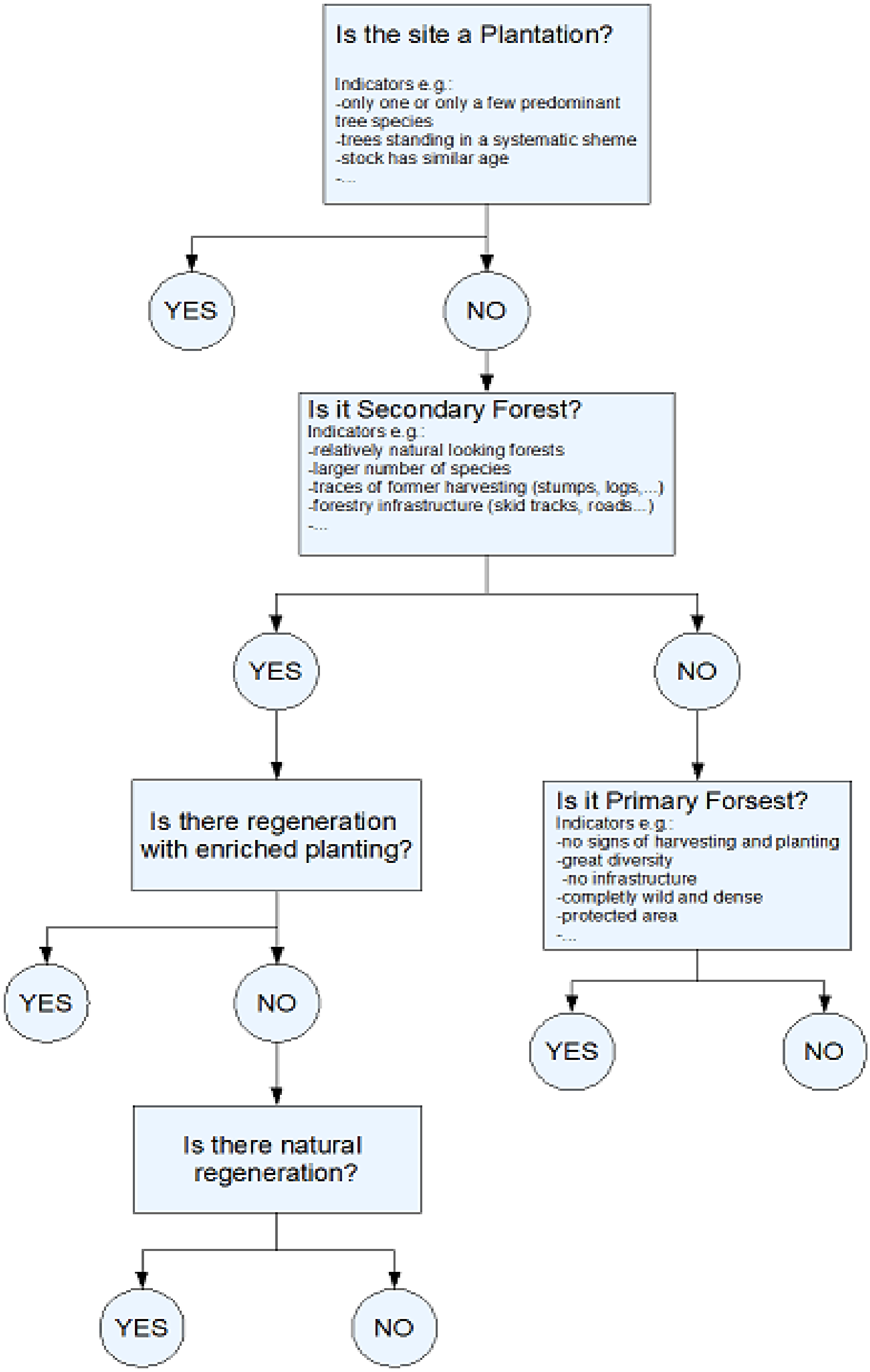


Fig. 46: Example for exclusion principle from forest characteristics estimation

Tab. 11: Indicators for forest categories

Categories of "Forest Characteristics"	**Indicators**
Plantation	• only one (or only a few) predominant tree species • trees standing in a systematic system (they have all more or less the same distance to their next neighbouring trees) • stock has similar age (all trees have same height, DBH, etc.) • barely regeneration • etc.
Secondary Forest	• relatively natural looking forest • plenty climbers and stranglers • different age classes of Trees (wide ranging DBH and height) • larger number of species • inhabited area (hunting area, wood harvesting) • traces of former harvesting as e.g. stumps, logs etc. • forestry infrastructure (skid tracks, roads) • etc.
Primary Forest	• no signs of harvesting and planting • great diversity • no infrastructure • completely wild and dense • protection status? • etc.

Tab. 12: Indicators for designated functions

Categories of "Designated Functions" (forest and other wooded land)	**Indicators**
Production	• plantation (trees, Coconuts, etc.) • agricultural land use (crops, grazing, agroforestry etc.) • logging/harvesting • etc.
Protection of Soil and Water	• tough slope e.g. 25% gradient (danger of erosion, landslides etc.) • site includes or is close by a river, stream, creek • mangroves (almost ever protection of soil and water) • etc.
Conservation of biodiversity	• primary forest (almost ever conservation of biodiversity) • any conservation or protection status • rare vegetation type /biotope • etc.
Social and cultural services	• water sources • bathing areas • touristic infrastructure (hiking tracks, viewpoints, bird watching etc.) • pick nick areas • cemetery • religious sites • etc.
Multiple purpose: more than one category fits, write down as "key point" which categories go together in "remarks column"	

Tab. 13: Indicators for disturbances

Categories of "Disturbances":	**Indicators:**
Disturbance by cyclones	• obvious damage as broken trees • high amount of relative fresh lying deadwood • plenty green leaves and broken twigs lying on the ground • etc.
Disturbance by fire	• charred stems, deadwood etc. • brownish needles/leaves of lower branches • died off regeneration, grass and bush vegetation • ash covers the ground • etc.
Disturbance by insects	• exhaustive leave damage • large scale crown damage • disengage of big parts of the bark • many relative fresh standing dead trees • etc.
Disturbance by invasive species	• sightings of invasive species or traces of them, according to the prepared list • etc.
Other	• grazing in forests • infrastructure and buildings, power lines • flooding • illegal junk yards, waste disposals • landslides • volcanic eruptions • etc.

5.6 Height Control Tables

As mentioned under Sources of error of height measurements *(p.59)*, crucial errors can come up by applying the easy but fault-prone height measurement with the clinometer. The Control Tables are useful tools for filling the gap and keep the height measurements reliable.

The tables *(Fig. 47: Height Control Table 1, Fig. 48: Height Control Table 2, Fig. 49: Additional Result Tables)* are provided on the next pages.

For control purpose it was found feasible to round the tree heights of the result tables to full meters. If you need more precise figures you can use the general result table as basis for construction of new tables.

Control Tables for trigonometric height measurement with reference height

Undertake the three angle readings, to the top of the tree, the reference height and the bottom of the tree. To check your measured figures to their credibility proceed as follows:

1. Go to table 1 and find your measured top angle (light purple) and bottom angle (light blue).
   The given number indicates the row number of the result table.
2. Go to table 2 and find your measured reference angle (light green) and again the bottom angle (light blue).
   The given letter indicates the column of the result table.
3. Keep the row number and column letter in mind and please turn over to table 3 (the result table).
   Find your row and column and you get the tree hight in m.
4. Compare your result with your estimated tree height. If you end up in a blank cell your tree height would be more than 45 m or less than your reference height.

1 — Bottom angle *(range: -20° to 5°)*

Top angle *(range: 30° to 70°)*						
70°	5°…0°	-1°…-5°	-6°…-11°	-12°…-16°	-17°…-20°	
	5	4	3	2	1	
69°	5°…4°	3°…-2°	-3°…-8°	-9°…-13°	-14°…-19°	-20°
	7	6	5	4	3	2
68°	5°…2°	1°…-4°	-5°…-9°	-10°…-15°	-16°…-20°	
	8	7	6	5	4	
67°	5°…1°	0°…-5°	-6°…-10°	-11°…-16°	-17°…-20°	
	9	8	7	6	5	
66°	5°…0°	-1°…-5°	-6°…-11°	-12°…-16°	-17°…-20°	
	10	9	8	7	6	
65°	5°…0°	-1°…-6°	-7°…-11°	-12°…-16°	-17°…-20°	
	11	10	9	8	7	
64°	5°…1°	0°…-5°	-6°…-11°	-12°…-16°	-17°…-20°	
	12	11	10	9	8	
63°	5°…1°	0°…-4°	-5°…-10°	-11°…-16°	-17°…-20°	
	13	12	11	10	9	
62°	5°…2°	1°…-3°	-4°…-9°	-10°…-15°	-16°-20°	
	14	13	12	11	10	
61°	5°…4°	3°…-2°	-3°…-8°	-9°…-13°	-14°…-19°	-20°
	15	14	13	12	11	10
60°	5°	4°…-1°	-2°…-6°	-7°…-12°	-13°…-17°	-18°…-20°
	16	15	14	13	12	11
59°	5°…1°	0°…-4°	-5°…-10°	-11°…-15°	-16°…-20°	
	16	15	14	13	12	
58°	5°…3°	2°…-2°	-3°…-8°	-9°…-14°	-15°…-19°	-20°
	17	16	15	14	13	12
57°	5°…0°	-1°…-6°	-7°…-11°	-12°…-17°	-18°…-20°	
	17	16	15	14	13	
56°	5°…2°	1°…-3°	-4°…-9°	-10°…-14°	-15°…-20°	
	18	17	16	15	14	
55°	5°	4°…-1°	-2°…-6°	-7°…-12°	-13°…-17°	-18°…-20°
	19	18	17	16	15	14
54°	5°…2°	1°…-4°	-5°…-9°	-10°…-15°	-16°…-20°	
	19	18	17	16	15	
53°	5°	4°…-1°	-2°…-7°	-8°…-12°	-13°…-17°	-18°…-20°
	20	19	18	17	16	15
52°	5°…2°	1°…-4°	-5°…-9°	-10°…-15°	-16°…-20°	
	20	19	18	17	16	
51°	5°	4°…0°	-1°…-6°	-7°…-12°	-13°…-17°	-18°…-20°
	21	20	19	18	17	16
50°	5°…3°	2°…-3°	-4°…-8°	-9°…-14°	-15°…-19°	-20°
	21	20	19	18	17	16
49°	5°…1°	0°…-5°	-6°…-11°	-12°…-16°	-17°…-20°	
	21	20	19	18	17	
48°	5°…4°	3°…-2°	-3°…-7°	-8°…-13°	-14°…-18°	-19°…-20°
	22	21	20	19	18	17
47°	5°…2°	1°…-4°	-5°…-10°	-11°…-15°	-16°…-20°	
	22	21	20	19	18	
46°	5°	4°…0°	-1°…-6°	-7°…-12°	-13°…-17°	-18°…-20°
	23	22	21	20	19	18
45°	5°…3°	2°…-2°	-3°…-8°	-9°…-14°	-15°…-19°	-20°
	23	22	21	20	19	18
44°	5°…1°	0°…-4°	-5°…-10°	-11°…-15°	-16°…-20°	
	23	22	21	20	19	
43°	5°	4°…-1°	-2°…-6°	-7°…-12°	-13°…-17°	-18°…-20°
	24	23	22	21	20	19
42°	5°…3°	2°…-2°	-3°…-8°	-9°…-14°	-1°…-19°	-20°
	24	23	22	21	20	19
41°	5°…2°	1°…-4°	-5°…-10°	-11°…-15°	-16°…-20°	
	24	23	22	21	20	
40°	5°…0°	-1°…-6°	-7°…-11°	-12°…-17°	-18°…-20°	
	24	23	22	21	20	
39°	5°…4°	3°…-2°	-3°…-7°	-8°…-13°	-14°…-18°	-19°…-20°
	25	24	23	22	21	20
38°	5°…2°	1°…-3°	-4°…-9°	-10°…-15°	-16°…-20°	
	25	24	23	22	21	
37°	5°…1°	0°…-5°	-6°…-11°	-12°…-16°	-17°…-20°	
	25	24	23	22	21	
36°	5°	4°…-1°	-2°…-7°	-8°…-12°	-13°…-17°	-18°…-20°
	26	25	24	23	22	21
35°	5°…3°	2°…-2°	-3°…-8°	-9°…-14°	-15°…-19°	-20°
	26	25	24	23	22	21
34°	5°…2°	1°…-4°	-5°…-9°	-10°…-15°	-16°…-20°	
	26	25	24	23	22	
33°	5°…0°	-1°…-5°	-6°…-11°	-12°…-16°	-17°…-20°	
	26	25	24	23	22	
32°	5°	4°…-1°	-2°…-7°	-8°…-12°	-13°…-18°	-19°…-20°
	27	26	25	24	23	22
31°	5°…3°	2°…-2°	-3°…-8°	-9°…-13°	-14°…-19°	-20°
	27	26	25	24	23	22
30°	5°…2°	1°…-4°	-5°…-9°	-10°…-15°	-16°…-20°	
	27	26	25	24	23	

2 — Bottom angle *(range: -20° to 5°)*

Reference angle *(range: -5° to 30°)*										
30°	5°…3°	2°…1°	0°…-2°	-3°…-5°	-6°…-8°	-9°…-11°	-12°…-14°	-15°…-16°	-17°…-19°	-20°
	J	K	L	M	N	O	P	Q	R	S
29°	5°	4°…2°	1°…-1°	-2°…-4°	-5°…-6°	-7°…-9°	-10°…-12°	-13°…-15°	-16°…-17°	-18°…-20°
	I	J	K	L	M	N	O	P	Q	R
28°	5°…4°	3°…1°	0°…-2°	-3°…-5°	-6°…-8°	-9°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
	I	J	K	L	M	N	O	P	Q	R
27°	5°	4°…2°	1°…0°	-1°…-3°	-4°…-6°	-7°…-9°	-10°…-12°	-13°…-14°	-15°…-17°	-18°…-20°
	H	I	J	K	L	M	N	O	P	Q
26°	5°…4°	3°…1°	0°…-2°	-3°…-4°	-5°…-7°	-8°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
	H	I	J	K	L	M	N	O	P	Q
25°	5°…3°	2°…0°	-1°…-3°	-4°…-6°	-7°…-9°	-10°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
	H	I	J	K	L	M	N	O	P	Q
24°	5°	4°…2°	1°…-1°	-2°…-4°	-5°…-7°	-8°…-10°	-11°…-12°	-13°…-15°	-16°…-18°	-19°…-20°
	G	H	I	J	K	L	M	N	O	P
23°	5°…3°	2°…0°	-1°…-2°	-3°…-5°	-6°…-8°	-9°…-11°	-12°…-14°	-15°…-16°	-17°…-19°	-20°
	G	H	I	J	K	L	M	N	O	P
22°	5°	4°…2°	1°…-1°	-2°…-4°	-5°…-6°	-7°…-9°	-10°…-12°	-13°…-15°	-16°…-17°	-18°…-20°
	F	G	H	I	J	K	L	M	N	O
21°	5°…4°	3°…1°	0°…-2°	-3°…-5°	-6°…-8°	-9°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
	F	G	H	I	J	K	L	M	N	O
20°	5°…3°	2°…0°	-1°…-3°	-4°…-5°	-6°…-9°	-10°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
	F	G	H	I	J	K	L	M	N	O
19°	5°…4°	3°…2°	1°…-1°	-2°…-4°	-5°…-7°	-8°…-10°	-11°…-12°	-13°…-15°	-16°…-18°	-19°…-20°
	E	F	G	H	I	J	K	L	M	N
18°	5°…3°	2°…0°	-1°…-2°	-3°…-5°	-6°…-8°	-9°…-11°	-12°…-14°	-15°…-16°	-17°…-19°	-20°
	E	F	G	H	I	J	K	L	M	N
17°	5°	4°…2°	1°…-1°	-2°…-3°	-4°…-6°	-7°…-9°	-10°…-12°	-13°…-15°	-16°…-17°	-18°…-20°
	D	E	F	G	H	I	J	K	L	M
16°	5°…4°	3°…1°	0°…-2°	-3°…-5°	-6°…-7°	-8°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
	D	E	F	G	H	I	J	K	L	M
15°	5°…3°	2°…0°	-1°…-3°	-4°…-6°	-7°…-8°	-9°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
	D	E	F	G	H	I	J	K	L	M
14°	5°	4°…2°	1°…-1°	-2°…-4°	-5°…-7°	-8°…-9°	-10°…-12°	-13°…-15°	-16°…-18°	-19°…-20°
	C	D	E	F	G	H	I	J	K	L
13°	5°…4°	3°…1°	0°…-2°	-3°…-5°	-6°…-8°	-9°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
	C	D	E	F	G	H	I	J	K	L
12°	5°…3°	2°…0°	-1°…-3°	-4°…-6°	-7°…-9°	-10°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
	C	D	E	F	G	H	I	J	K	L
11°	5°…4°	3°…2°	1°…-1°	-2°…-4°	-5°…-7°	-8°…-10°	-11°…-12°	-13°…-15°	-16°…-18°	-19°…-20°
	B	C	D	E	F	G	H	I	J	K
10°	5°…3°	2°…1°	0°…-2°	-3°…-5°	-6°…-8°	-9°…-11°	-12°…-13°	-14°…-16°	-17°…-19°	-20°
	B	C	D	E	F	G	H	I	J	K
9°	5°	4°…2°	1°…0°	-1°…-3°	-4°…-6°	-7°…-9°	-10°…-12°	-13°…-14°	-15°…-17°	-18°…-20°
	A	B	C	D	E	F	G	H	I	J
8°	5°…4°	3°…1°	0°…-1°	-2°…-4°	-5°…-7°	-8°…-10°	-11°…-13°	-14°…-15°	-16°…-18°	-19°…-20°
	A	B	C	D	E	F	G	H	I	J
7°	5°…3°	2°…0°	-1°…-2°	-3°…-5°	-6°…-8°	-9°…-11°	-12°…-14°	-15°…-16°	-17°…-19°	-20°
	A	B	C	D	E	F	G	H	I	J
6°		4°…2°	1°…-1°	-2°…-3°	-4°…-6°	-7°…-9°	-10°…-12°	-13°…-15°	-16°…-17°	-18°…-20°
		A	B	C	D	E	F	G	H	I
5°		3°…1°	0°…-2°	-3°…-5°	-6°…-7°	-8°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
		A	B	C	D	E	F	G	H	I
4°		2°…0°	-1°…-3°	-4°…-5°	-6°…-8°	-9°…-11°	-12°…-14°	-15°…-16°	-17°…-19°	-20°
		A	B	C	D	E	F	G	H	I
3°			1°…-1°	-2°…-4°	-5°…-6°	-7°…-9°	-10°…-12°	-13°…-15°	-16°…-17°	-18°…-20°
			A	B	C	D	E	F	G	H
2°			0°…-2°	-3°…-5°	-6°…-7°	-8°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
			A	B	C	D	E	F	G	H
1°			-1°…-3°	-4°…-6°	-7°…-8°	-9°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
			A	B	C	D	E	F	G	H
0°				-2°…-4°	-5°…-7°	-8°…-9°	-10°…-12°	-13°…-15°	-16°…-18°	-19°…-20°
				A	B	C	D	E	F	G
-1°				-3°…-5°	-6°…-8°	-9°…-10°	-11°…-13°	-14°…-16°	-17°…-18°	-19°…-20°
				A	B	C	D	E	F	G
-2°				-4°…-6°	-7°…-9°	-10°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
				A	B	C	D	E	F	G
-3°					-5°…-7°	-8°…-10°	-11°…-12°	-13°…-15°	-16°…-18°	-19°…-20°
					A	B	C	D	E	F
-4°					-6°…-8°	-9°…-11°	-12°…-13°	-14°…-16°	-17°…-19°	-20°
					A	B	C	D	E	F
-5°					-7°…-9°	-10°…-11°	-12°…-14°	-15°…-17°	-18°…-19°	-20°
					A	B	C	D	E	F

Result table for reference height of 3.3 m

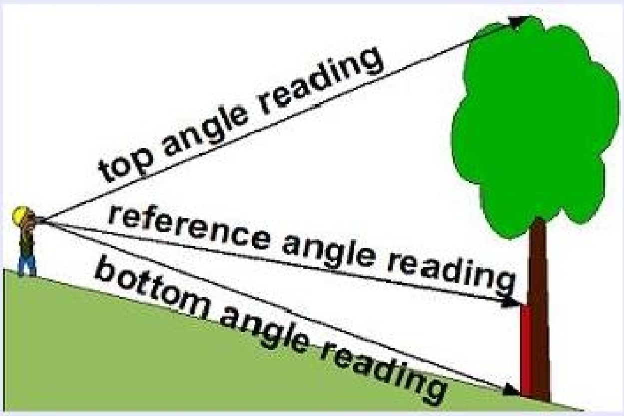
(rounded tree height in m)

3	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1						34	29	26	23	20	19	17	16	15	14	13	12	11	11
2					40	33	28	25	22	20	18	17	15	14	13	12	12	11	10
3					38	32	27	24	21	19	17	16	15	14	13	12	11	11	10
4					37	31	26	23	21	18	17	15	14	13	12	12	11	10	10
5					36	30	25	22	20	18	16	15	14	13	12	11	10	10	9
6					34	29	25	21	19	17	16	14	13	12	11	11	10	10	9
7					33	28	24	21	18	17	15	14	13	12	11	10	10	9	9
8				40	32	26	23	20	18	16	14	13	12	11	11	10	9	9	8
9				38	30	25	22	19	17	15	14	13	12	11	10	9	9	8	8
10				36	29	24	21	18	16	15	13	12	11	10	10	9	9	8	8
11				35	28	23	20	17	15	14	13	12	11	10	9	9	8	8	7
12				33	26	22	19	17	15	13	12	11	10	9	9	8	8	7	7
13				31	25	21	18	16	14	13	11	10	10	9	8	8	7	7	7
14			40	30	24	20	17	15	13	12	11	10	9	8	8	7	7	7	6
15			37	28	22	19	16	14	12	11	10	9	9	8	7	7	7	6	6
16			35	26	21	18	15	13	12	11	10	9	8	8	7	7	6	6	6
17			33	25	20	17	14	12	11	10	9	8	8	7	7	6	6	6	5
18			31	23	18	15	13	12	10	9	8	8	7	7	6	6	5	5	5
19			29	21	17	14	12	11	10	9	8	7	7	6	6	5	5	5	5
20		40	26	20	16	13	11	10	9	8	7	7	6	6	5	5	5	4	4
21		36	24	18	15	12	10	9	8	7	7	6	6	5	5	5	4	4	4
22		33	22	17	13	11	9	8	7	7	6	5	5	5	4	4	4	4	
23		30	20	15	12	10	8	7	7	6	5	5	5	4	4	4			
24		26	18	13	11	9	8	7	6	5	5	4	4	4	4				
25		23	15	12	9	8	7	6	5	5	4	4	4						
26	40	20	13	10	8	7	6	5	4	4	4								
27	33	16	11	8	7	5	5	4	4										

Example : **Top angle 60°, Reference angle 3°, Bottom angle -15° results in Column F and row 12, which again results in 22 m tree height.**

Results from table differ averagely ≈ 4% from calculated tree height. (e.g. sample trees between 10 to 35 m had have an averagely absolute height difference of 0.7 m.) Singular differences can be higher or less.

Trigonometric height measurement



As reference height use your prepared survey stick as described in the Manual.
The observer has to find a good observing position, fitting the following rules:

- Go at least 10 m away from the tree but not more than 25 m.
- Clearly look at the top and the bottom of the tree is given.
- Observers eyes are above the base of the tree.
- Keep your exact position for all angle measurements.
- If the tree is leaning, stand in a plane perpendicular to the lean angle.

Do not rush and take the angle readings conscientiously.

Fig. 48: Height Control Table 2

Additional Tables

General result table																			
to get the tree height [m] multiply the value with your reference length [m]																			
3	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**
1	62.0	31.0	20.7	15.5	12.4	10.3	8.9	7.8	6.9	6.2	5.6	5.2	4.8	4.4	4.1	3.9	3.6	3.4	3.3
2	60.0	30.0	20.0	15.0	12.0	10.0	8.6	7.5	6.7	6.0	5.5	5.0	4.6	4.3	4.0	3.8	3.5	3.3	3.2
3	58.0	29.0	19.3	14.5	11.6	9.7	8.3	7.3	6.4	5.8	5.3	4.8	4.5	4.1	3.9	3.6	3.4	3.2	3.1
4	56.0	28.0	18.7	14.0	11.2	9.3	8.0	7.0	6.2	5.6	5.1	4.7	4.3	4.0	3.7	3.5	3.3	3.1	2.9
5	54.0	27.0	18.0	13.5	10.8	9.0	7.7	6.8	6.0	5.4	4.9	4.5	4.2	3.9	3.6	3.4	3.2	3.0	2.8
6	52.0	26.0	17.3	13.0	10.4	8.7	7.4	6.5	5.8	5.2	4.7	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7
7	50.0	25.0	16.7	12.5	10.0	8.3	7.1	6.3	5.6	5.0	4.5	4.2	3.8	3.6	3.3	3.1	2.9	2.8	2.6
8	48.0	24.0	16.0	12.0	9.6	8.0	6.9	6.0	5.3	4.8	4.4	4.0	3.7	3.4	3.2	3.0	2.8	2.7	2.5
9	46.0	23.0	15.3	11.5	9.2	7.7	6.6	5.8	5.1	4.6	4.2	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4
10	44.0	22.0	14.7	11.0	8.8	7.3	6.3	5.5	4.9	4.4	4.0	3.7	3.4	3.1	2.9	2.8	2.6	2.4	2.3
11	42.0	21.0	14.0	10.5	8.4	7.0	6.0	5.3	4.7	4.2	3.8	3.5	3.2	3.0	2.8	2.6	2.5	2.3	2.2
12	40.0	20.0	13.3	10.0	8.0	6.7	5.7	5.0	4.4	4.0	3.6	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1
13	38.0	19.0	12.7	9.5	7.6	6.3	5.4	4.8	4.2	3.8	3.5	3.2	2.9	2.7	2.5	2.4	2.2	2.1	2.0
14	36.0	18.0	12.0	9.0	7.2	6.0	5.1	4.5	4.0	3.6	3.3	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9
15	34.0	17.0	11.3	8.5	6.8	5.7	4.9	4.3	3.8	3.4	3.1	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8
16	32.0	16.0	10.7	8.0	6.4	5.3	4.6	4.0	3.6	3.2	2.9	2.7	2.5	2.3	2.1	2.0	1.9	1.8	1.7
17	30.0	15.0	10.0	7.5	6.0	5.0	4.3	3.8	3.3	3.0	2.7	2.5	2.3	2.1	2.0	1.9	1.8	1.7	1.6
18	28.0	14.0	9.3	7.0	5.6	4.7	4.0	3.5	3.1	2.8	2.5	2.3	2.2	2.0	1.9	1.8	1.6	1.6	1.5
19	26.0	13.0	8.7	6.5	5.2	4.3	3.7	3.3	2.9	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.4
20	24.0	12.0	8.0	6.0	4.8	4.0	3.4	3.0	2.7	2.4	2.2	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3
21	22.0	11.0	7.3	5.5	4.4	3.7	3.1	2.8	2.4	2.2	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2
22	20.0	10.0	6.7	5.0	4.0	3.3	2.9	2.5	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.3	1.2	1.1	1.1
23	18.0	9.0	6.0	4.5	3.6	3.0	2.6	2.3	2.0	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.9
24	16.0	8.0	5.3	4.0	3.2	2.7	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8
25	14.0	7.0	4.7	3.5	2.8	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.9	0.9	0.8	0.8	0.7
26	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.6
27	10.0	5.0	3.3	2.5	2.0	1.7	1.4	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5

The general result table serves also as basis for creating new result tables for certain common reference heights.

Result table for reference height of 4 m																			
(rounded tree height in m)																			
4	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**
1							35	31	28	25	23	21	19	18	17	16	15	14	13
2						40	34	30	27	24	22	20	18	17	16	15	14	13	13
3						39	33	29	26	23	21	19	18	17	15	15	14	13	12
4						37	32	28	25	22	20	19	17	16	15	14	13	12	12
5						36	31	27	24	22	20	18	17	15	14	14	13	12	11
6						35	30	26	23	21	19	17	16	15	14	13	12	12	11
7					40	33	29	25	22	20	18	17	15	14	13	13	12	11	11
8					38	32	27	24	21	19	17	16	15	14	13	12	11	11	10
9					37	31	26	23	20	18	17	15	14	13	12	12	11	10	10
10					35	29	25	22	20	18	16	15	14	13	12	11	10	10	9
11					34	28	24	21	19	17	15	14	13	12	11	11	10	9	9
12				40	32	27	23	20	18	16	15	13	12	11	11	10	9	9	8
13				38	30	25	22	19	17	15	14	13	12	11	10	10	9	8	8
14				36	29	24	21	18	16	14	13	12	11	10	10	9	8	8	8
15				34	27	23	19	17	15	14	12	11	10	10	9	9	8	8	7
16				32	26	21	18	16	14	13	12	11	10	9	9	8	8	7	7
17			40	30	24	20	17	15	13	12	11	10	9	9	8	8	7	7	6
18			37	28	22	19	16	14	12	11	10	9	9	8	7	7	7	6	6
19			35	26	21	17	15	13	12	10	9	9	8	7	7	7	6	6	5
20			32	24	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5
21			29	22	18	15	13	11	10	9	8	7	7	6	6	6	5	5	5
22		40	27	20	16	13	11	10	9	8	7	7	6	6	5	5	5		
23		36	24	18	14	12	10	9	8	7	7	6	6	5	5				
24		32	21	16	13	11	9	8	7	6	6	5	5	5					
25		28	19	14	11	9	8	7	6	6	5	5							
26		24	16	12	10	8	7	6	5	5									
27	40	20	13	10	8	7	6	5											

Fig. 49: Additional Result Tables

5.7 Height Correction of Leaning Trees

If a tree is leaning, its height differs from its stem length, obviously it would cause an error in volume calculation if the measured height is treated as the bole length.

But, taking into account that height measurements are never totally correct the error caused by the lean have to exceed the accuracy of the height measurement method. For example: The presume accuracy of trigonometric height measurement is only to the nearest 0.5 m and the measured trees are about 30 to 40 m high, the lean has to be more than 9° to produce relevant errors. So, in most cases lean of trees can be ignored.

If a tree height shall be corrected by its lean, the observers point has to be in a plane perpendicular to the lean angle. Then normal procedures of trigonometric height measurement can be applied. Also the lean angle have to be measured by placing the clinometer on the stem. This has to be recorded in the remarks column.

For trees lower than 20 m and slant more than 3 m of vertical axis from tree base the error can be eliminated by holding the reference stick in the same altitude than the tree.[28]

To calculate the lean corrected height the following formula will be used:

$$h' = h / \cos(\alpha_L)$$

Formula 20: Height correction of leaning trees

h'.....corrected height
h......measured height
α_L....lean angle

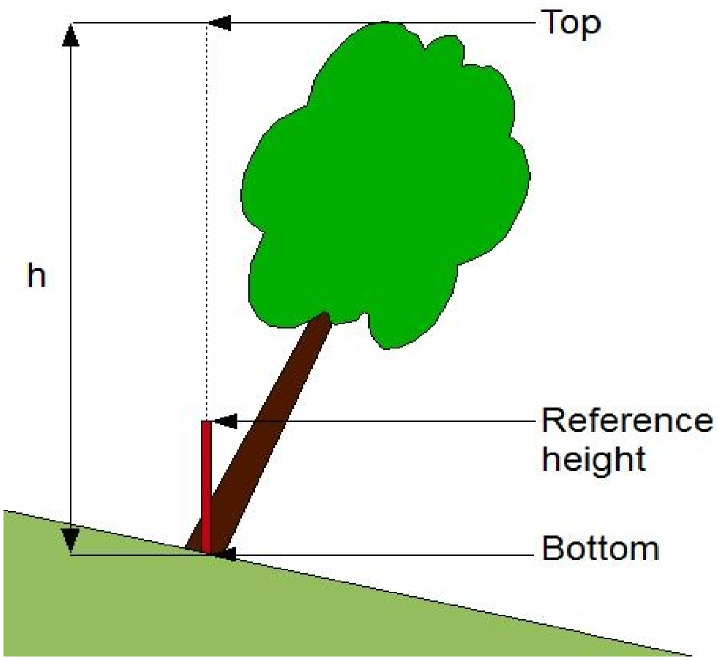


Fig. 50: observers view on leaning tree

[28] Loetsch, F.; Zöhrer, F.; Haller, K.E. 1973

5.8 Improvement of Volume Calculation with Form Factor

To refine the volume calculation more detailed from factors can be taken from following table[29].

Tab. 14: Form factors for various diameter classes and log length

DBH (cm)					LOG LENGTH (m)									
					6 7	8 9	10 11	12 13	14 15	16 17	18 19	20 21	22 23	24 25
35	36	37	38	39	.8	.75	.7	.7	.65	.6	.6	.6	.6	.6
40	41	42	43	44	.8	.75	.75	.7	.65	.6	.6	.6	.6	.6
45	46	47	48	49	.8	.8	.75	.7	.65	.6	.6	.6	.6	.6
50	51	52	53	54	.8	.8	.75	.7	.65	.65	.6	.6	.6	.6
55	56	57	58	59	.8	.8	.75	.7	.7	.65	.6	.6	.6	.6
60	61	62	63	64	.8	.8	.75	.75	.7	.65	.6	.6	.6	.6
65	66	67	68	69	.8	.8	.75	.75	.7	.65	.6	.6	.6	.6
70	71	72	73	74	.8	.8	.8	.75	.7	.65	.65	.6	.6	.6
75	76	77	78	79	.8	.8	.8	.75	.7	.65	.65	.6	.6	.6
80	81	82	83	84	.8	.8	.8	.75	.7	.65	.65	.6	.6	.6
85	88	87	88	89	.8	.8	.8	.75	.7	.7	.65	.6	.6	.6
90	91	92	93	94	.8	.8	.8	.75	.7	.7	.65	.6	.6	.6
95	96	97	98	99	.8	.8	.8	.75	.7	.7	.65	.6	.6	.6
100	101	102	103	104	.8	.8	.8	.75	.7	.7	.65	.6	.6	.6
105	106	107	108	109	.8	.8	.8	.75	.7	.7	.65	.65	.6	.6
110	111	112	113	114	.8	.8	.8	.75	.7	.7	.65	.65	.6	.6
115	116	117	118	119	.8	.8	.8	.75	.7	.7	.65	.65	.6	.6
120	121	122	123	124	.8	.8	.8	.75	.7	.7	.65	.65	.6	.6
125	126	127	128	129	.8	.8	.8	.75	.75	.7	.65	.65	.6	.6
130	131	132	133	134	.8	.8	.8	.75	.75	.7	.65	.65	.6	.6
135	136	137	138	139	.8	.8	.8	.75	.75	.7	.65	.65	.6	.6

29 The table was an outcome of observations from Fiji. (Mussong, M. 1992) Country specific tables should be established.

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