Course 4

Text-only version

Introduction to fieldwork

The interactive version of this lesson is available free of charge at https://elearning.fao.org/

In this course

This course lays down the considerations for fieldwork and discusses plot-level variables as well as tree-level measurements.

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Who is this course for?

The course is targeted mainly for those who engage in planning for fieldwork, and fieldwork in general, but can be taken by anyone with an interest in the subject. Specifically, this course targets:

1. Forest technicians responsible for implementing their country's NFIs
2. National forest monitoring teams
3. Students and researchers, as curriculum material in forestry schools and academic courses
4. Youth and new generations of foresters

Course structure

There are four lessons in this course.

Lesson 1: Preparing for fieldwork	This lesson looks at the general considerations for fieldwork, the types of expertise that NFIs typically require and the suggested composition and skillsets of field teams. It also explains the key elementsof preparing for security and personal safety while in the field.
Lesson 2: Fieldwork training	This lesson describes how to prepare field crews for data collection and about the aspects of data quality and training that they should keep in mind.
Lesson 3: Plot and sub-plot level measurements	This lesson focuses on the typical workflow of field procedures. It also addresses the topic of typical plot level variables.
Lesson 4: Tree-level measurements	This lesson explains key measurements on single trees and focuses on some of the core variables and measurements that are typically assessed in NFIs.

About the series

This course is the fourth in a series of eight self-paced courses covering various aspects of an NFI.

Here's a look at the complete series

Course	You will learn about
Course 1: Why a national forest inventory?	Goals and purpose of an NFI, and how NFIs inform policy- and decision-making in the forest sector.
Course 2: Preparing for a national forest inventory	The planning and work required to set up an efficient NFI or a National Forest Monitoring System (NFMS).
Course 3: Introduction to sampling	General aspects of sampling in forest inventories.
☞ **Course 4: Introduction to fieldwork**	**(You are currently studying this course)**
Course 5: Data management in a national forest inventory	Information gathering and data management for NFIs.
Course 6: Quality assurance and quality control in a national forest inventory	QA and QC procedures in forest inventory data collection and management.
Course 7: Elements in data analysis	Typical approaches/calculations in data analyses and related topics.
Course 8: National forest inventory results: Reporting and dissemination	NFI reporting and the importance of reporting in the context of REDD+ actions.

Lesson 1: Preparing for fieldwork

Lesson introduction

In this lesson, we will look at the general considerations for fieldwork, the types of expertise that NFIs typically require and the suggested composition and skillsets of field teams.

We will also understand the key elements of preparing for security and personal safety while in the field.

Learning objectives

At the end of this lesson, you will be able to:

- Appreciate the importance of planning before a field mission.
- Examine the composition of field teams and address issues of available capacity.
- Describe the safety measures that need to be in place for field work.

The importance of planning in fieldwork

You are probably aware that a lot of planning is necessary before we can start collecting data in the field. Generally speaking, the three broad domains of a forest inventory, **planning and preparation, implementing** (fieldwork) and **analysis and reporting** require about the same time period to complete (while the number of person-months may be largest in fieldwork).

It is therefore essential to **allocate adequate time for planning** in order to have a successful field campaign.

Elements of planning

Developing an efficient and sustainable inventory design requires a lot of preliminary work (such as institutional arrangements, developing field protocols, analysis of existing remotely-sensed products, a pilot field study on the sampling design or first phase sample), all of which must be settled before fieldwork begins. What's more, fieldwork itself requires careful planning, including (among others):

1. identifying roles and responsibilities;
2. tendering and recruiting suitably qualified personnel;

3. training and capacity development;
4. planning finance and logistics;
5. acquiring tools and devices;
6. preparing printed and digital materials (such as maps, software for mobile devices); and
7. finalizing sampling strategy and related methodological guidance.

For a large area forest inventory such as an NFI, it might take a year or more for planning until actual fieldwork begins.

Note

The importance of the **field manual** is discussed as part of **Course 2: Preparing for an NFI**. The field manual contains a general introduction, description, and justification of the design elements and describes every single variable and its measurement—**the importance of this document cannot be stressed enough**.

Fieldwork: Who does it?

Assuming that all the required sampling planning—plot and estimation design, variable definition, detailed field manuals, data collection, management and analysis protocols—are prepared and aligned with the desired reporting, the next question is who will do the fieldwork.

At this point, various approaches are feasible, and t**he general character and funding sources for the inventory**—as well as **the institutions involved in it**—will **influence the nature of the fieldwork**. In the following part of this lesson, we assume a 'project character' of the NFI, with time-bound financing, in which field crews are contracted directly by the project or by the implementing institution.

Some countries have a clearly defined NFI strategy, which is a component of a multi-disciplinary and long- term endeavor with a 'programme-character'. As part of this, responsible institutions might conduct the inventory themselves or tender the field assessments to suitable companies responding to a corresponding call. In the case of such outsourcing, a very clear definition of expected results and well-defined Terms of Reference (TORs) and contract agreements are necessary. For these longer-term scenarios, sustained budgets and staffing are provided by government institutions. The NFI implementation becomes a permanent activity embedded into broader forest sector policies and procedures—and requires institutionalization.

Getting a field team ready

Field crews play a crucial role in an NFI, because they determine the quality of the data collected. However, they also have the most physically demanding and dangerous job in an NFI. For these reasons, having a motivated field crew is crucial—both for their own well-being, as well as for the overall goal of the NFI to collect high-quality field data.

What are some ways to motivate the field team? Let's find out!

There are several ways of keeping motivation of field teams high:

- Emphasizing the importance of their role in the inventory process;
- Equipping them with state-of-the-art equipment and devices;
- Facilitating interaction among crews;
- Providing appropriate pay and additional bonus incentives for teams with higher quality performance;
- Organizing regular meetings of all field teams to allow for a constructive exchange of experiences;
- Providing health insurance (e.g. in case of snake bites);
- Providing them with adequate opportunities of rest; and
- Scheduling a visit to the field at appropriate intervals (e.g. when the field team moves to new field sites or administrative districts).

Moreover, **targeted capacity development is a prerequisite for motivated field teams**. When the team is motivated and proud to contribute to an endeavor of a national scale, they will be ready to honestly report on challenges and issues encountered. All NFIs face unexpected challenges during fieldwork— alert and committed field teams can report these on a timely basis to the organizers.

Quick tips!

The importance of accurate measurements

It is important to make the field teams aware about the character of a "representative" sample and emphasize the importance of accurate measurements. Samples observe a very tiny proportion of the total area. In an NFI context, the sampling intensity is usually far below 0.01 percent of the total area.

Related to the total forest area in a country with millions of hectares of forest and billions of trees above the minimum diameter, a single tree measurement might represent measurements for hundreds of thousands of trees. Therefore, every single measurement should be done with the highest possible care, avoiding systematic errors in the first place, but also keeping random errors small!

Field team composition

The composition of field teams depends on a number of factors:

1. complexity of the assessment;
2. availability of transport and access to forest areas; and
3. means of emergency communication.

What should the size of field teams be?

From a practical, logistical and economic perspective, **a core field team should be as small as possible in the given circumstances**. Smaller teams allow for improved coordination, greater ease of transport and increased efficiency of the fieldwork.

The Forest Inventory and Analysis (FIA) Program of the US Forest Service is known to operate with single- member teams, aided by excellent communication means for emergencies.

In **countries with temperate forests**, plot assessments typically benefit from good road infrastructure inside forests and a relatively low complexity of forest structure. Hence, fieldwork can be accomplished by two-person teams.

However, **tropical countries** (with more complex forests) **might require greater logistical efforts**, including the use of more people, especially if teams stay inside the forest for longer periods (e.g. in a flying camp)—in such cases, field logistics might justify teams of five or more people.

How are field teams organized?

Field teams are organized like usual working teams: in that a **clear assignment of roles and responsibilities fosters smooth workflows**. Usually, a clear hierarchy helps as well.

While the basics of this division of labour may be defined in general (possibly described in the field manual), a process of adjustment and individual agreement on how a specific field team optimally organizes itself is expected. While some teams prefer a fixed division of duties, others are happier shuffling duties among the team. Frequently, after some days of working together, a consensus emerges on what is most optimal.

Field team composition and responsibilities

While all team members should have a clear understanding of the different measurements and the definitions in the field manual, the division of labour might be as follows:

- **Team leader**

One person should take over the responsibility to organize the daily work, to observe (together with all team members) the security situation and to secure communication with the base camp and possibly other field teams. He/she makes all decisions, is responsible for the data quality and supervises the work of others. He/she might also record the data, if no other team member is qualified for this task, and care for daily backup of data, functionalityof equipment and transfer of data to the central database for archiving.

- **Enumerator**

One or more persons should feel responsible for the measurements on single trees and plot characteristics. These roles can change within the team to keep the motivation high. They should be familiar with the specific instruments and devices used.

Depending on the level of knowledge and skills, also locally recruited temporary assistants can be included and can provide valuable local knowledge on accessibility, tree species identification, usage of forests and forest products, wildlife and more.

- **Botanist**

In forests with relatively high species diversity, a trained botanist or expert may be required for species identification —if the inventory can afford to hire such specialist.

The importance of this expert depends on the target variables of the inventory. If species richness is used as an indicator for biodiversity, an unequivocal identification of all tree species is necessary.

In such cases, expert knowledge is critical. However, species identification might not be possible directly in the field. Then, samples need to be taken, stored and preserved. Also, transport to the herbarium for identification needs tobe organized in time intervals as short as possible to avoid the quick degradation of samples of botanical specimens.

In the best case, a suitable enumerator can take over the responsibility of taking samples, preparing them for the herbarium and storing them accordingly (usually pressed between newspaper pages).

- **Assistants of the team leader**

Depending on forest conditions, additional assistants might be required to support measurements and logistics. Contracting local helpers may also be recommended because they have good local knowledge, can streamline moving around in the field and finding the plot locations. They may also share their experiences on forest utilization in these particular areas and serve as a “liaison” person to the local communities, as well as help in tree species identification. They are often the key persons for a smooth implementation of the field work. Depending on the mode of transportation (truck, car, motorcycle, etc.) a driver is part of a field team.

Note

Additional expertise that may be needed, depending on the nature/focus of the NFI, might be on wildlife, rangeland, soil, peat, etc. possibly to be employed as "accompanying research studies" in selected plots. All described tasks can be accomplished by men and women equally.

An effort should be made to encourage participation of female foresters and youth (students and young forestry officers), as there is hardly any better opportunity to learn about the forests of a country, their conditions and usage than participating in the field work of a national forest inventory.

Security in the field

In planning and implementing fieldwork especially in transport to the field and plot assessments onsite, **the security and personal safety of all team members must have highest priority**. For example, in war-torn regions both during the design and implementation phases, plots located in conflict areas are to be avoided at all costs. Risk assessment and work safety measures are a part of a proper Quality Assurance system and preparations before going out into the field.

Risks associated with fieldwork should be prepared for in advance. For these risks, instructions should be prepared on how to act in the case of an emergency.

Apart from looking out for the motivation and safety of fieldwork teams, organizers also need to consider some general security measures. Some questions to consider include the following:

1. Do the field team members have appropriate health insurance that covers costs in case of work accidents (if available in the country)?
2. Did the teams receive a first aid training and are they aware of the nearest hospitals? Does every field team have a well-equipped first aid kit? Are they trained to respond to medical emergencies?
3. How will the home base and field teams communicate? Is the mobile network coverage sufficient, or are field radios or satellite telephones required?
4. Should team members be responsible for their own personal safety equipment and proper

clothing, or should it be organized centrally?

5. Should team members provide a health certificate or record of vaccinations for fieldwork?
6. How can an emergency situation (chain of survival) be organized, and which central and local institutions should be contacted?
7. Which local institutions should be informed about ongoing inventories and how (media)?
8. Have all safety issues regarding car transport and accommodations been considered adequately?
9. Who is deciding whether a plot can be safely accessed or not? Not reaching a selected plot means a case of non-response—but safety comes first!

Risk mitigation measures

All members of a field team should be aware about the possible risks and the appropriate modes of behaviour to reduce any risk as far as possible. Every team member should feel responsible to constantly check his/her personal safety. Each team member must be aware that an accident in the field is a serious danger for the whole team and that irresponsible behavior of single individuals is not acceptable. If there is a potential risk due to this behavior, the team leader should inform the base camp or his contact person in the office immediately. Some important measures that should be considered in order to reduce risks are:

Proper planning of fieldwork - Proper planning of fieldwork is one important measure to reduce risk. Therefore, all decisions about planned fieldwork should be made with enough time and should be communicated to all team members. Avoid spontaneous changes in implementing fieldwork, whenever possible. If you have a time-bound schedule, remember to be flexible and stop fieldwork before it gets dark (or consider 6-hour tide cycles when working in mangroves). Inform the base camp and/or other teams about your daily working locations. Sometimes networking with major agencies can provide support on avoiding risks.

Orientation - All members of a field team should know where they are working and should be able to describe their actual position whenever necessary. Regularly check the cellular phone network coverage and possibly mark a waypoint for the last connection on the GPS receiver. Track the way to a sampling location in difficult terrain in order to be more flexible on the way back. Take the safest way to a sampling location, not the shortest. It is a good practice to find the (best) possible tracks in advance before going into the field and always check the update information of the situation (e.g. the tidal cycle in mangrove or thunderstorms in the mountains).

Equipment - Completeness and functionality of equipment should be checked before going out to the field. This includes the charging status of batteries for field radios or mobile phones and carrying supplementary batteries. A first aid set is always a default part of the equipment. Personal safety equipment, proper shoes and clothing are a must.

Information and communication - If working in areas under sensitive political situations, it is good practice to have an information handout that describes the background of the mission in simple words. Local people and communities might be very critical about strangers working with surveying equipment on their land as they might not have legal land titles and are afraid that surveyors might prepare to kick them out; this may lead to extremely severe problems. If possible, establish contact with these groups before going into the field and explain the scientific character of the inventory study in clear, understandable terms. It may also be advisable to invite or contract locals to accompany the field teams during their work. They know the area, they speak the local language and their presence will reduce suspicions in the local community about your work. It is important to inform to the land holders or local communities before and after the field work and let them know your time schedule if you still need to visit again.

Accompanying research studies

A lot of additional research studies might be integrated into fieldwork. However, remember that such studies are accompanying assessments that may not be relevant in each repetition of a permanent NFI or on every single plot. Usually, the goal of such studies is to:

- collect additional data for model building or for specific analyses
- answer general scientific questions related to forests; or to
- optimize the inventory design.

The integration of these studies needs to be planned and, if necessary, integrated into the default inventory work; alternatively, independent workflows for data collection and data management of these scientific studies need to be prepared. Typical examples are:

Soil sampling	If soil sampling is done to derive soil maps over larger areas, the relatively sparse sampling intensity of an NFI is not very suitable. However, there might be synergies during fieldwork. Some soil characteristics will only change over very long periods and soil mapping is therefore not necessarily included in each cycle of an NFI. An exception is if soil organic carbon or belowground biomass should be estimated for international reporting. For this purpose, a field manual on how to collect, store and analyze the samples must be available.
Tree age and increment analysis by core borings	In those climatic zones where trees develop annual rings, sometimes core samples are taken to determine the age of trees or the increment over the last few years. This information is used to construct growth models. Such growth models are needed to predict the increment per age class and to determine a sustainable yield potential or the development of forest biomass in general. Usually, a subset of trees from different canopy layers is selected for this special investigation.
Socioeconomic data	In some NFIs, household surveys are carried out in parallel to the collection of biophysical data. The intention is to document forest conditions and socioeconomic variables affecting forest owners or nearby communities. These surveys typically focus on the use of forest products. The allocation of resources (and funding) for collecting such data needs a clear justification and a meaningful vision for how they will be used and analyzed. Moreover, a sampling frame based on the human population (and not biophysical properties such as land use/land cover) should be considered if interested in drawing nationally representative conclusions on the population at large. While this may actually be an additional research study, it is useful as an integral part of NFIs with the goal to learn more about the use of the forests. It is then important to: • have experienced interviewers in the team (women are usually better

	in that, and better accepted); and • make sure that the interviews are related to the plot locations of the biophysical assessments– otherwise it will be difficult to establish links.

Before we conclude this lesson, let's have a look at a video from Papua New Guinea's flrst Multi-Purpose National Forestry Inventory. The NFI included in-depth data collection on soil as well as plant and animal biodiversity, and is an excellent example of including research questions within an NFI.

Video resource

Watch the video

A Day at a National Forest Inventory Camp in Papua New Guinea (Long version)

Summary

Before we conclude, here are the key learning points of this lesson.

- A lot of planning is necessary before data collection in the field can begin.
- The field crew has the most dangerous and physically demanding job in an NFI and also determines the quality of collected data. For this reason, having a motivated field crew is crucial.
- From a practical, logistical and economic perspective, a field team should be as small as possible in the given circumstances.
- Field teams are organized like usual working teams: a clear assignment of roles and responsibilities fosters smooth workflows.
- Risks associated with fieldwork should be prepared for in advance. All members of a field team should be aware about the possible risks and the appropriate modes of behavior to reduce any risk as far as possible.

Lesson 2: Fieldwork training

Lesson introduction

In this lesson, we will learn how to prepare field crews for data collection and about the aspects of data quality and training that they should keep in mind. Remember that sufficient training and preparation for all field routines must be completed before the teams are sent out for fieldwork.

Learning objectives

At the end of this lesson, you will be able to:

1. At the end of this lesson, you will be able to:
2. Explain how to organize training for field crews.
3. Identify the typical themes for training field crews.
4. Describe what happens after the training of field crews.
5. Understand the importance of a clear field manual.

Training the field teams

Since a large inventory project (such as an NFI) usually aims to collect data at prescribed points in time, such a mission can only be accomplished with a number of field teams that work in parallel. And these field teams need to collect data in exactly the same manner following the same field assessment protocol (field manual). Assuming that several thousand cluster plots need to be assessed in a relatively short period of time, how can we ensure that every field team is applying the same protocol for measurements and observation in order to guarantee optimum consistency?

The only solution is proper training, based on a complete field protocol!

Getting started with a training for all

There are different ways to organize field crew training. However**, it is common to start with a joint training for all teams together**, which provides a basic understanding about the methodology (sampling and plot design) and communicates the general goals of the inventory to all team members.

These trainings are also very important to develop team spirit and a strong sense of belonging. Apart from keeping teams motivated, this also leads to higher efficiency and lesser delays. Team members that are friends will be able to deal better with problematic situations than team members that barely know each other. This should not be underestimated.

After this general training, different target groups need diverse training input, based on the roles they will play in their teams (field- or office-based).

Such initial training may also be seen as the final proof of concept of the field protocol; a training session evaluating practical experiences using the field protocol may identify where adjustments are needed.

Quick tips!

It is important to set the right expectations with training. Team members responsible for collecting field data don't need to become experts in statistics and analysis, however, they should at least know about the analysis workflow and the importance of sound, consistent and comparable data. Likewise, data managers and analysts responsible for data cleansing and compiling don't need to know how to use equipment (e.g. a Laser clinometer)—it is sufficient if they have a clear understanding on how the data is generated.

Typical training themes

Training on various aspects of a field inventory can be done according to the sequence of fieldwork. However, it might also make sense to have a more generic training session to address overarching topics such as forest mensuration, surveying techniques, mobile data collection and so on. The following section presents important training topics ordered according to a typical field work sequence.

Navigation in the field

Global Navigation Satellite System (GNSS) receivers are used for many purposes: navigating to plot locations and marking of way points, working with mobile GIS apps, using different background layers, tracking routes and settings (e.g. Coordinate Reference System (CRS)) and taking long-term measurements for plot locations.

For planners who are responsible for uploading spatial data and plot locations, a basic training in GIS (e.g. QGis) and data exchange between mobile devices might be required.

If highly accurate position measurements are required, for example when linking field plots to remote sensing imagery, the use of a differential RTK (Real Time Kinematics) GNSS receiver, together with a regional or local reference base station may be indicated. These devices allow to achieve much higher accuracy than standard receivers as they use correction signals, either real time directly in the field or later when processing the position data. Of course, the use of such receivers requires extra and specific training. Planners should also undergo training in basic communications according to the devices they will use.

Mobile data collection (or paper field forms)

Once the team has reached the plot location, data needs to be recorded. This can be done with mobile applications or simple paper forms. In case that a mobile data collection app (such as pen Foris Collect Mobile) is used, a specific training is needed on how to enter the data. This includes a clear understanding of real time validation rules and error messages.

Experts for this task should also have a basic knowledge about the layout of the definition used and understand the interdependencies between different entries. The training should include data backup and data transfer to the database. A test of importing data into the database can help prevent any problems that might arise. In the case that paper field forms are used, the logic and entries of codes should be discussed and trained.

Establishing the plot

NFI plots (or subplots) should be marked invisible. If permanent, they should be marked in a way that guarantees their visibility only for inventory teams, using iron cores that are put below ground.

Tree numbers or any other marks should be temporary, and no evidence should be found once the team leaves the plot. A clear description of the plot location (including important reference points) will help to relocate the position for later assessments.

Navigating to the target position will never lead us to the exact position due to locating interference, such as those caused by canopy cover. To determine the position as accurately as possible, it is very important to measure the flnal plot position with a precise, long-term coordinate measurement.

An example of a typical plot enumeration workflow by a crew can be found in **Liberia National Forest Inventory Manual 2018-29, Pages 16-18.**

Assessment of plot and landscape/terrain variables

At first, the field teams need to be clear about the plot design used and the respective reference area for plot observations. Usually, a whole set of variables (e.g. forest type, landscape/terrain characteristics), or other assessments of site conditions (e.g. crown coverage or degradation status) can be used to describe plot conditions. A lot of these categorical variables need clear criteria and descriptions for correct interpretation of the ground situation.

Measurements of metric variables (e.g. slope angle) need training. Training is also required for the use of apps or devices such as those that estimate crown coverage. The variables that need expert interpretation need a dedicated training with all fleld teams together to ensure consistency of data.

Assessment of single tree variables (forest mensuration basics)

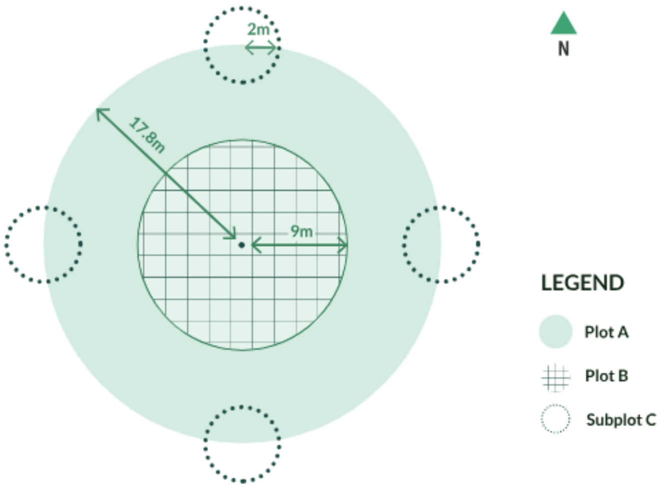
After plot variables are recorded, a typical workflow would be to assess single tree variables. The training topics in this domain are mainly focused on forest mensuration techniques and the use of measurement devices.

This includes measurement of dbh and tree heights, identification of tree species, measurement of distances and angles, assignment of trees to defined canopy layers, and many more.

To make the workflow on the plot efficient, it is important to develop a suitable sequential order in which trees are measured and numbered and a sequence in which data are measured (matching to the sequence of data recording). It is recommended to mark the recorded trees by using temporary markers (such as chalk) so that they will not be counted twice and no missing trees are left behind. Ideally, these temporary marks should all be made located on the stems that they can be seen from the center point of the plot.

Assessment of regeneration

Regeneration plots are usually nested within a plot, and ideally placed far away from the plot centre to avoid disturbance. They should already be marked before assessment commences to avoid trampling and can be assessed before or after measuring the standing trees.



Regeneration plots are usually very small and might have different area sizes for seedlings and saplings. Since the dispersion of regeneration typically shows a high spatial variability (changes in local density), these small plots might follow a cluster design (multiple subplots). Usually density (plants per unit area) in different diameter or height classes is the main focus of the assessment.

Deadwood and other assessment

Depending on whether flxed area plots or line transects are used to assess lying deadwood, the required measurements call for training.

Another variable, classification of decay status, is often determined with a knife. If a stump inventory is included, it may be a challenge to determine the species and the point in time of cutting.

Accompanying assessments for research studies

Fieldwork procedures might include assessments for accompanying research studies (soil sampling, core borings, other special data collection) and can warrant additional training.

There are some NFIs in which these samples are taken as a standard to estimate SOC (soil organic carbon) or the age of trees (borings).

This bring us to the end of the discussion on typical training themes. In the next section of this lesson, we will look at what happens after the training is complete.

Phases of training

After an introduction and training on basic concepts, field teams should be exposed to real situations in different forest types and conditions. If such different conditions cannot be found in close proximity, it might make sense to organize smaller workshops in different parts of the country. Once the single measurements and interpretations are understood, the teams should practice measurements on whole plots/clusters.

While a trainer might be present for giving feedback and corrections at the beginning, all teams should practice working independently on a few sample plots.

It is instructive to send all field teams one after the other to the same plots. The data coming from these repeatedly measured field plots can then be compared and analyzed as part of the training. Errors/deviations and differences in measurements should then be discussed in the training.

Control measurements

Control measurements of field sample plots are an integral component of all field inventories, even though there are no generally accepted standards—either on their implementation or their analyses and consequences.

It is recommended to control-measure between 5 percent and 15 percent of the field plots in order to check for compliance with the field protocol and quality standards. Such control measurements should be carried out by a supervisory team (Quality Control/ Quality Assurance team) that is entirely independent of all field teams and reports directly to the inventory managers.

Training and quality control are continuous processes

Training and quality control are not only important at the beginning of fieldwork but also throughout the process. Optimally, training or supervision should be repeated on a regular basis because quality control checks may also be used during the analysis phases to test possible biases.

Trainers should visit the field teams and be available for questions. You will find more details about controlling field measurements in **Course 6: Quality assurance and quality control in an NFI**.

Note

Consequences of weak assessments

It should be clear to the field teams that their work is constantly cross-checked and that a low quality of measurements will lead to consequences. If errors become obvious early enough, repeated training of certain teams is indicated. In case of repeated or severe errors, the teams should re-measure the plot. For contracted consultants, low data quality even after re-training may be an argument to cancel the contract.

Importance of clear field manuals

The field manual, describing the standard procedures and measurements, is an essential basis for the training and implementation of fieldwork. All descriptions need to be comprehensive and should include advice, especially on special cases (e.g. plot establishment on a slope, the definition measurement height of dbh, upper diameters in case of deformations, stilt roots or buttresses, etc.).

For every variable, it is necessary to find a short justification (purpose of measurement, or the analyses it will be used in) and a detailed description of the measurement procedure (including the devices that should be used). Additionally, the unit of measurement, the accuracy of recorded values and the special case when it is relevant or required, should all be included. There is no one-size-flts-all solution for field procedures, but there are good (and bad) examples of guidelines.

Examples of NFI field manuals

The links below provide examples of field manuals. You can go through these to observe the general structure, especially regarding the:

1. Grouping of variables according to “entities” or objects they describe (plot variables, tree variables, and so on);

2. Provided code lists and guidance for interpretation of categorical variables;
3. The use of graphs to illustrate different classes for categorical variables; and
4. Suggested workflow of field assessments.

Summary

Before we conclude, here are the key learning points of this lesson.

- There are different ways to organize field crew training. However, it is common to start with a joint training for all teams together.
- After a training on basic concepts, field teams should be exposed to real situations in different forest types and conditions.
- The field manual, describing the standard procedures and measurements, is an essential basis for the training and implementation of field work.

Lesson 3: Plot and sub-plot level measurement

Lesson introduction

In the previous lesson you learned how to organize training and prepare field teams.

We are now moving to the implementation phase and will focus on the typical workf1ow of field procedures.

We will first address some examples of typical plot level variables—and in the next and final lesson, will look at measurements on single trees.

Learning objectives

At the end of this lesson, you will be able to:

1. Explain variables at plot level and the ways in which they can be recorded.
2. Describe the importance of clear definitions for categorical variables.
3. Distinguish between core variables and accompanying research studies.

Beginning plot assessment

While there is a natural sequence that is always relevant for some steps, detailed field procedures for additional observations might vary according to the identified information needs and defined variables in the field manual. As you have already studied in previous lessons, we assume that planning and preparation steps are comprehensively settled before the teams are sent out to the field. This means that by this time:

1. Field teams have been trained and are aware of field procedures;
2. Field plot locations are known by coordinates (sampling design) and preliminary information for each plot is available, e.g. obtained from visual interpretation of high-resolution imagery and from topographical maps;
3. Local authorities and/or communities are informed, and the security situation is clear;
4. Field teams are equipped with all necessary materials and tools; and
5. Detailed maps (also high-resolution imagery, if available) for each plot are available and

maps of plot locations, including route scenarios, are prepared (as hardcopy or as layers in a mobile GIS application). Note that for repeat inventories, plot maps are printed (or available on- screen on the tablets), showing the position of the sample trees on each sample plot: this supports finding the plot center and facilitates making repeat measurements of clearly identified sample trees.

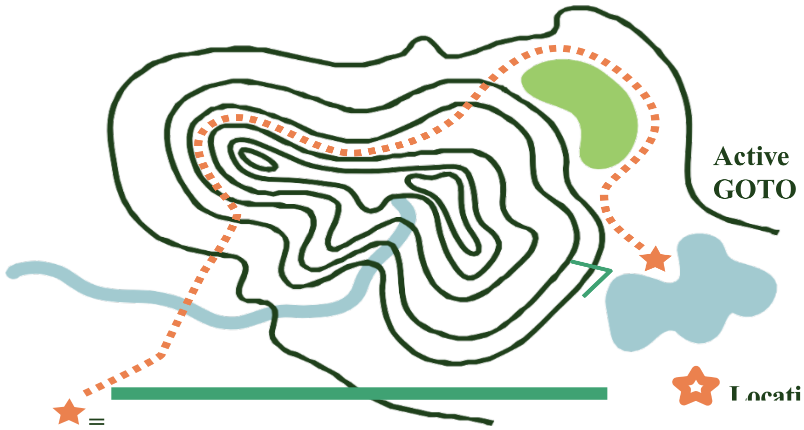
Once all these points are clear, field teams will start their work. **Usually, the enumerations of the first plots take much more time compared to later ones**, since teams first need to identify an optimal workflow. During this phase, it is imperative that data coming in from the field is checked as soon as possible in order to give direct feedback on errors.

Accessing sample units

Navigation to plot

An initial task for the field teams is to locate the selected plot coordinates in the field that serve as reference or center point of the corresponding sample plot. For navigation purposes, a common Global Navigation Satellite Systems (GNSS) receiver—sometimes called GPS—is usually sufficient. However, for a highly accurate measurement of the plot location, a so-called differential GNSS should be used, which uses correction information to eliminate some of the position errors.

In case the plot is located far away from the closest road, **it is recommended to record the access route in order to track the same (or a better) way back**. A simple drawing (such as shown below) with some relevant reference points can be helpful to relocate the plot (in case of permanent plots, or for the QA/QC team) and should be part of the documentation (e.g. as a photo of this drawing in the database). It is also recommended to check the mobile network coverage (if available) from time to time. In case of an emergency, it can be very important to know the last point of mobile coverage.



Sample of a hand-drawn location of a plot with some relevant reference points

Once the team is near the intended plot location, a more precise measurement with a suitable differential GNSS receiver may start. It is hardly possible to reach the very exact position in the field. This is not a problem, as long as the final coordinates of the marked plot location are measured (preferably with a long-term measurement during plot assessment) and recorded. GNSS receivers allow to take a long-term measurement in which coordinates are averaged over a longer time interval (e.g. over 10 min a position determination every 10 seconds). The longer you measure, the better the coordinates.

Quick tips!

Working with spatial data

There are many different possibilities to project the earth surface onto a map plane, and many different coordinate systems. Depending on the coordinate systems used, one and the same point in the field can have very different coordinates. If the coordinate system that was used is not known, it is impossible to find these coordinates in the field.

In the settings of a GNSS receiver, such coordinate systems must be correctly set. The correct settings and/or documentation of the current projection and map datum (reference ellipsoid) are always important. Reporting or long-term storage of position data should always contain this important information, otherwise it is not useful.

The importance of accurate position measurements

If remote sensing data is used as an ancillary data source in the planning or estimation phase of an inventory, the importance of accurate and precise coordinate measurements of plot locations cannot be overrated. To make full use of possible correlations between remote sensing information and ground observations, both data sources need to be co-registered (e.g. spatially matched) as accurately as possible. Co-registration errors due to low quality position measurements will compromise the quality of the statistical models and will affect the overall precision of estimation.

Recent developments of GNSS and respective differential and two-phase satellite receivers, make it possible to reduce position errors considerably. However, under a dense forest canopy and even if regional or local correction data are available, position errors of several meters can still be expected. In case of relatively small sample plots and the use of high- resolution remote sensing data, a wrong selection of pixel values can result, which do not coincide with the respective ground observation. The prices for modern RTK (Real Time Kinematics) receivers, using GPS+GALILEO+GLONASS (the US, European and Russian GNSS, respectively) and allowing for more accurate positioning, are reducing every day and a suitable base station and reference station can be obtained for a reasonable price. Also, depending on the area, lower-priced, modern devices receiving GPS+GLONASS+GALILEO or Beidou (the Chinese GNSS) can provide sufficient accuracy.

Quick tips!

The relevance of position errors

Any deviation between the sample plot in the field and the assumed coordinate used for spatial matching (co-registration) of field observations and remote sensing data sources, will compromise the quality of the relationships (models). Accurate and precise measurements of plot coordinates are very important and, in case of model-based or model-assisted inference, have a direct influence on the quality of estimates!

When not modelling with remote sensing, the accurate positioning of the plots is not much of an issue, as long as subjective factors (that influence the positioning) are avoided. For purely field plot-based estimation, it is not so important that the sample point is being determined to the millimeter.

Plot/subplot establishment: Possible work sequence in the field.

Every data collection process in the field starts with the selected sampling position in the forest and with marking of the plot or subplot position.

In some cases, it might be better to start with the assessment of regeneration—as well as samples of soil and litter, if they are within the plots—to avoid damage from trampling by the field teams, and sometimes it is done after assessing standing trees. In mangroves, where field teams might use deadwood pieces as stepping stones, it makes sense to assess them first. On the other hand, in temperate forests where inventories are carried out in winter, locating the deadwood pieces under snow cover is easier after or while other tree assessments take place. The following sequence of measurements and observations on plot and tree variables can be different depending on forest type and team size:

1. Identify and mark plot location with differential GNSS and permanent marking of this position in the field (usually by an iron core sunk to the ground);
2. Start a long-term coordinate measurement (>10 min) of the plot location;
3. Start data collection with plot variables and variables referring to the plot surroundings (forest type, terrain conditions, etc.);
4. Start single tree measurements of dbh, height and other variables in a clockwise direction (according to azimuth). Mark trees with temporary numbers or marker;
5. Measure a subset (or all) of sample tree heights (according to selection rules);
6. Assess regeneration and deadwood sample; and
7. Complement plot assessment with other remaining variables (Non-wood forest products (NWFP), such as bamboo or rattan, other vegetation, soil samples, etc.)

Did you know?

How much time does plot assessment take?

Subplot design is often planned such that it does not take more than an hour on average. The team then moves to the next subplot and completes the whole cluster plot step by step. Except in cases where very large plots are planned, another measure of good planning is to ensure that assessment allows for the completion of a minimum of one cluster/day.

Plot/subplot marking

Long-term monitoring programs are based on continuously repeated measurements on the same plots. Therefore, plots (and single trees) need to be re-identified after a relatively long period (e.g. 5 or 10 years). An efficient marking of the plot centre (or several points with rectangular plots) and accurate measurements of tree positions (distance and azimuth) are essential to clearly identifying the plot centres and the tree positions at later points in time. If available, a number of reference objects in the surroundings (rocks, large trees, terrain) are identified and distance and azimuth are measured towards the plot location. A hand drawing is useful and can later be stored as a photo in the database.

Quick tips!

Visible marking of plots (e.g. by permanent colour, numbers on trees or by visible poles) is not recommended because we aim to hide the sample plots from forest users and forest managers! The nature of an observational study is to observe typical conditions, including human induced changes, and to avoid these areas may be treated differently from others, which might lead to biased observations in repeat inventories.

A typical way of marking plots invisibly is to use iron or aluminium tubes, 30-50 cm in length, that are completely hidden into the ground at the plot center. These marks can be found using a metal detector once one is close enough. Also, triangulations (distance and azimuth) to specific reference features in the surrounding area may be taken as additional plot information.

Photos as additional information

Photos can be taken from different positions and might help to get an overview about local forest conditions. The acquisition of photos is mainly driven by modern mobile data collection in the field since they can be stored together with the collected data on the same device. They can be useful in reconstructing the situation (e.g. in case of questions during data cleansing), but they are rarely analyzed.

Note

Modern mobile data collection apps make it very easy and simple to take photos and directly store them in a database. Remember that every photo will blow up the file size of backups and might even compromise the local storing capacity of a mobile device. Especially if data need to be transferred and sent to headquarters, backup files should be small and easy to handle.

Also pay attention to which photos are taken and how to store and reference them. Photos could be coded as follows: 'Three/Four-digit Sampling Unit number' + '-' + 'plot number' + '.' + 'running photo number within plot' (e.g. 3rd reference photo taken in the 2nd plot of SU number 028 = 028-2.3).

Plot level data

There is a lot of important information referring to the plot area or the surroundings of the plot. Plot information is gathered through a characterization of the plot area by basic variables, such as slope angle, forest type, accessibility, disturbance status and more. We begin this section by looking at some variables and their specific purpose. How these variables are implemented in the observation design might differ.

➲ Conservation and sustainability

Indicator variables contributing to qualitative or quantitative information on the conservation value or conservation status, for example:

- ✓ Degradation/disturbance status (defined by some observable indicator variables, like signs of illegal logging, land conversion, excessive grazing, and so on).
- ✓ Habitat characteristics (e.g. presence/absence of different habitat elements for different species, such as nesting sites or specific elements like stone walls, ponds, caves, etc.).
- ✓ Soil erosion, assessed in different classes of severity.
- ✓ Livestock management (e.g. there can be communal grazing taking place in forest lands). Existence of endangered or red list species (such as IUCN Red List species).
- ✓ Relevant aspects of forest structure (even aged low structure forest vs. high structured forest).
- ✓ Canopy or shrub cover percentage.

➲ Forest utilization

Information on the use and management of the area for different purposes.

- ✓ Products harvested in the forest, both commercial and non-commercial.
- ✓ Existence and amount of NWFPs such as mushrooms, berries, rattan, bamboo and more.
- ✓ Ownership, user rights and forest management regime,
- ✓ Logging technology used or to be used, if known.
- ✓ Existence of rare biotopes and species.
- ✓ Social use of the forest.

➲ Forest composition and development

NFI-derived information cannot be used for stand-level management purposes (the NFI is not the right data source for these small area analyses), but only for a wider regional context.

However, it can be important information for the formulation of national or regional forest management programs and political decisions regarding utilization or conservation of forest resources. The following categories can yield valuable information:

- ✓ Layering, into number of different canopy layers.
- ✓ Forest development stage, such as regeneration phase, young forest/regrowth, mature, old-growth.
- ✓ Area proportions of species groups (proportions of basal area) or age classes (if not derived from the single tree data).
- ✓ Stocking density (according to a yield table or a maximum stocking capacity).

Quick tips!

Additional observations 'outside' the sample

Field teams spend a lot of time in the forest, and can make a lot of observations outside the selected plots. And even though the statistical framework cannot produce estimates from such observations—because the absence of a sampling and plot design does not allow for deriving any selection or inclusion probabilities—these observations can be very relevant for other purposes, such as model building or as training and validation points for remote sensing classification or for wildlife monitoring. It therefore makes a lot of sense to include these in the NFI workflow.

Field teams could potentially record ground points for different forest types, land use and land cover classes, based on a hierarchical land use and landcover classification scheme, along the way to the plots. Such classifications are not time consuming and storing the coordinates is fast and easy.

Example of categorical variables

At the plot level, the measurements taken include slope angle, accessibility and land use/land cover type. Most of the variables are categorical variables that need very clear definitions and decision rules for interpretation. In some cases, example photographs for the different categories may help. Possible examples might include information on 'Disturbance' or 'Degradation status' which are often inaccurate and need clear indicators with definitions.

The following example shows a definition of the variable Disturbance according to a NFI field manual template provided by FAO.

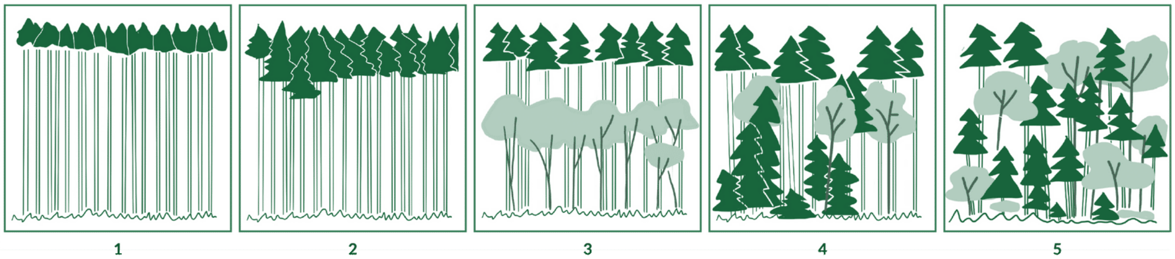
Option / Label	Description / definition	Code
Not disturbed	Protected areas, all resources conserved	0
Slightly disturbed	Exploitation of goods and services is carried out according to management plans	1
Moderately disturbed	Many products collected without conforming to management plans, notion of sustainability not respected	2
Heavily disturbed	Removal of products at rates higher than Mean Annual Increment (MAI), biodiversity degradation due to high pressure on selected species, encroachment of agriculture leading to high rate of deforestation.	3

Note

Even with detailed descriptions, it might still be difficult for the field teams to arrive at a conclusion. Discussions in the field (about correct assignments) and possible group-individual interpretations of definitions are a strong indication that the descriptions in the field manual are not sufficient!

'Forest structure' is another example of a categorical variable that requires a clear definition. The vertical structure describes the variability of tree heights and the layering of a stand. Structure can be observed by visual estimation of mean conditions on the plot and on the direct plot surroundings. This variable is also of interest for remote sensing integration, as it influences the correlation and saturation of ground-based estimates and remotely sensed metrics. Figures or drawings can support the final decision and should be used wherever possible and meaningful.

Option/Label	Description/Definition	Code
Single layer, same heights	Typical single layer age-class forest where all trees are of same height	1
Single layer, variable heights	A single layer forest, but differentiation in tree heights	2
Multiple clear layers	A clear separation into different layers (usually of same age)	3
Variable structure in gaps	Gap structures with local variability of tree heights	4
Complete variable structure	A typical natural forest or planter forest in which all age- and height classes are mixed	5



Vertical stand structure (adapted from Otto, 1994)

Note

Interpretation of 'fuzzy' variables

Even with very clear definitions, some variables will remain fuzzy. When field teams are confronted with real situations in different forest types, it is essential that these variables are understood and interpreted consistently.

The main problem usually is with categorical variables that are not measured but classified according to visual interpretation and a classification key. Categorical variables can include the classification of forest types, the interpretation of the degradation status or the structure of the forest edge; or for single trees: the classification of layers and sociological position (between dominant to suppressed) or tree vitality or stem quality. For some of these variables, a set of example pictures/schematic graphs/photographs may help. Comparable observations from multiple teams can only be expected if all members are trained together or at least by the same trainers! A very obvious example is forest types in tropical countries, with many species sharing space. Training on this is particularly arduous and potentially expensive. Hence for some of these variables, sometimes it might be better to redefine forest types and go through a thorough QA/QC during the analysis phase.

Data collection on subplots

Besides standing trees, there is usually interest in other tree-related objects and variables, including forest regeneration and on deadwood or NWFPs that are collected in (nested) subplots. The compliance of diameter thresholds to international reporting standards (e.g. IPCC Guidelines) should be checked during the definition of the variables.

Forest regeneration informs about the density, quality and species mixture of the next forest generation and could provide an outlook on the potential for natural regeneration.

Regeneration assessment

Tree regeneration provides important information about the potential future forest composition. Tree regeneration often refers to all those trees that have dbh below the minimum diameter for tree assessments (for example 10 cm). In some cases, however, 'regeneration' and 'established regeneration' are distinguished and very small seedlings (for example less than 25 cm in height) are ignored. This is all a matter of clear definitions and terminology. Regeneration trees are usually recorded on relatively small sub-plots as their density can be very high, particularly in natural forests with a wide variability of dbh.

Seedlings and saplings are recorded in nested plots with 1-2 m radii; while sub-plots for the small regeneration trees are usually placed some meters away from the plot centre to avoid these plants from being trampled on by the field team members or cut by a machete when helpers clear the path for the field team to smoothly move forward. Regeneration is typically recorded by species and count per area.

Quick tips!

Regeneration subplots (or micro-plots) need to be shifted away from the plot center. Some times they are defined outside the larger subplot and field teams can become nervous about that. But it does not matter whether the regeneration micro-plot is embedded in the higher-level subplot or outside. It is just a matter of clearly following the measurement instructions.

Deadwood assessment

Deadwood in forests includes all deadwood parts that are not earmarked to be brought to the sawmill or for other uses. Deadwood can be assessed on fixed area plots (which are usually relatively small, typically < 100 m^2), or based on Line Intersect Sampling (LIS) along transect lines. LIS is mainly for downed woody debris—while stumps and standing dead trees (broken or not) are recorded on the plot area just like healthy trees. Similar to regeneration, the occurrence of deadwood shows a high spatial variability (a lot in some places, but many places without any deadwood).

With LIS one option is to count the intersections of a sampling line (transect) of defined length with deadwood pieces and observe the diameter class of these pieces at the point of intersection. Based on statistical estimators for LIS, it is possible to derive an estimate of the total length of deadwood pieces per diameter class, from which we can then also derive the volume. Deadwood is one of the five default carbon pools on which countries need to report changes to the climate convention. Over the long run, all deadwood will decay and feed their carbon into the atmosphere, but changes in deadwood stocks can alter the role of forests as a net source or sink of carbon. For this distinction, the decay status is assessed in different classes, including sound, intermediate and rotten.
Deadwood can include:

1. **Standing dead trees** (variables of interest for observation commonly include species, dbh, height, broken or not, reason for mortality);
2. **Stumps** (variables of interest for observation commonly include species, stump diameter, stump height, decay status, age/year of felling/mortality);

3. **Down coarse woody debris** (variables of interest for observation commonly include number of pieces, diameters, lengths, decay status—the goal is to estimate the carbon content); and
4. **Smaller down woody debris** (variables of interest for observation commonly include number of pieces, diameters, lengths, decay status—the goal is to estimate the carbon content).

Note

Deadwood according to the **United Nations Framework Convention on Climate Change (UNFCCC)** comprises categories 1-3, while category 4 is within the carbon pool litter. The threshold between deadwood and litter is defined in IPCC at a diameter of 10 cm.

Soil sampling

An NFI can be the basis for reporting to international conventions, such as the UNFCCC. In this case, carbon stocks need to be estimated separately for the different carbon pools. Apart from deadwood that you just studied about, the other carbon pools are aboveground and belowground biomass, litter and soil organic matter. For the latter, soil samples can be collected for lab analysis. Sampling procedures and logistics need a clear protocol, since samples must reach the lab within a few days. However, because soil samples are rapidly taken (and tedious to transport), it is important to establish a clear analysis workflow for the process. This includes securing lab space and factoring in time and cost expenditures. The field manual below provides a soil sampling protocol.

Other assessments

In many NFIs, additional assessments on other components are integrated. An example is making estimations on the amount and use of NWFPs. This might be an expert guess in defined classes, or a real assessment with measurements on suitable (nested) subplots.

Also, the ground vegetation, shrubs and herbaceous layer might be of interest (e.g. for information on biodiversity). Instead of detailed measurements, usually an expert guess of coverage in a defined reference area is recorded. There are textbooks for the sampling of herbaceous vegetation (often used in rangeland monitoring) which are beyond the scope of this course.

Summary

Before we conclude, here are the key learning points of this lesson.

- For an accurate measurement of plot location, it is recommended to use a differential GNSS that uses correction information.
- Accurate and precise coordinate measures of plot locations are crucial if remote sensing data is to be used as a data source in the planning and estimation phases of an NFI.
- Visible marking of plots (e.g. by permanent colour, numbers on trees or by visible poles) is not recommended because it is good to keep the sample plots hidden.
- A typical way of marking plots invisibly is to use iron or aluminium tubes, 30-50 cm in length, that are completely hidden into the ground.
- Plot information is gathered through a characterization of the plot area by basic variables, such as slope angle, forest type, accessibility, disturbance status and more.
- Besides standing trees, information on forest regeneration and on deadwood or NWFPs that is collected in (nested) subplots is also of importance for carbon pool reporting.

Lesson 4: Three-level measurements

Lesson introduction

In this lesson, we will learn about key measurements on single trees. We will also focus on some of the core variables and measurements that are typically assessed in NFIs.

While the set of variables assessed on each sample plot in an NFI may exceed 100-150 in number, each with very specific definitions, this lesson will concentrate on typical tree measurements and observations, like tree diameters and heights.

Learning objectives

At the end of this lesson, you will be able to:

- Describe the basic measurement principles of some of the tree-related core variables of an
- NFI.
- Explain how to measure dbh.
- Identify how principles of trigonometry help in tree height measurement.
- Enumerate the categorical variables of single trees that are of an interest in an NFI.

Some common measurements on single trees

Many variables of interest that we assess on a sample plot (or subplots) are aggregate values over measured or modelled single tree characteristics. Once the plot position is located in the field, the plot design determines which trees are to be included as sample trees and need to be measured.

Remember that nested plots, with different plot sizes for different diameter classes of trees, are the common standard.

For permanent inventory systems in which the same plots are measured repeatedly, it is recommended to map the tree position by recording the azimuth and distance from the sample plot centre to the tree. Measurements on single trees should be done in a fixed sequence according to increasing azimuth (in a clockwise direction).

Video resource

A **series of video tutorials addressing different plot assessments and standard forest mensuration techniques** are available from the Chair of Forest Inventory and Remote Sensing at the University of Göttingen and are a useful resource for this lesson. You can watch these videos in parallel to the specific topics or after completing the course. For your convenience, direct links to specific videos have also been made available within the content where relevant.

Measurements of tree diameters

What is "measured" in a forest inventory?

Before we proceed, let's look at the elements that are measured in a forest inventory. A measurement is characterized by a single source of error (or variability), which is the **measurement error**. Remember that there are only two kinds of direct measurements in a forest inventory: **lengths** and **angles**. The dbh of a tree, for example, can be derived from the measurement of the length of the stem circumference (by using a tape) or as distance between the left and the right side of the trunk (using a caliper).

Diameter at breast height (dbh)

The most common and also the most important measurement made in a forest inventory is that of the diameter of the stem. Most commonly, the diameter measurement is carried out for stems of standing trees, and on some occasions, on stumps or dead standing trees. Diameters are usually measured above bark so that a reduction needs to be applied if merchantable volume is of interest. The standard height for a diameter measurement is 1.3 m, also called 'breast height', leading to the acronym dbh = diameter at breast height.

Dbh is a core variable in forest inventory and analysis because in most cases, is it easily and directly measured, and diameter distribution in a forest gives a good insight into the forest structure and development stages. It is also useful to remember here that **basal area—**a crucial variable of NFIs, and related to other core variables such as volume, biomass, and carbon, is derived from dbh—

always under the assumption that the tree has a perfectly circular cross- section.

Moreover, since basal area (the cross-sectional area in 1.3 m height) of a tree is highly correlated to the tree´s volume, biomass and carbon, the **diameter at breast height (dbh) is a standard variable assessed in practically all cases**.

In addition, tree height is important information, though sometimes more difficult to measure in the field, depending on forest type and density. Tree heights are usually measured on a subsample of trees. From this set of height measurements a relationship between dbh and height, a height curve can be derived by regression analysis that allows to predict tree height from dbh measured.

Further, the height of the trees where height was not measured are predicted from these models. In a few species, such as palms, height is generally more important than dbh, at least if one aims to estimate its biomass. There should be a clear selection rule for subsampling those trees on which height is to be measured on a plot.

Where to measure dbh

The standard position for diameter measurements of standing trees is at breast height, defined at the height of 1.3 m in most countries. But there are still various countries where dbh is or has been measured at different heights (e.g. 4.5 or 1.2 m).

While today, 1.3 m should be the standard height for dbh measurements, one must always check how dbh was defined in previous inventory data. It may also be that existing volume models or biomass models require input of dbh measured at 4.5 ft instead of 1.3 m—this needs to be checked during analyses.

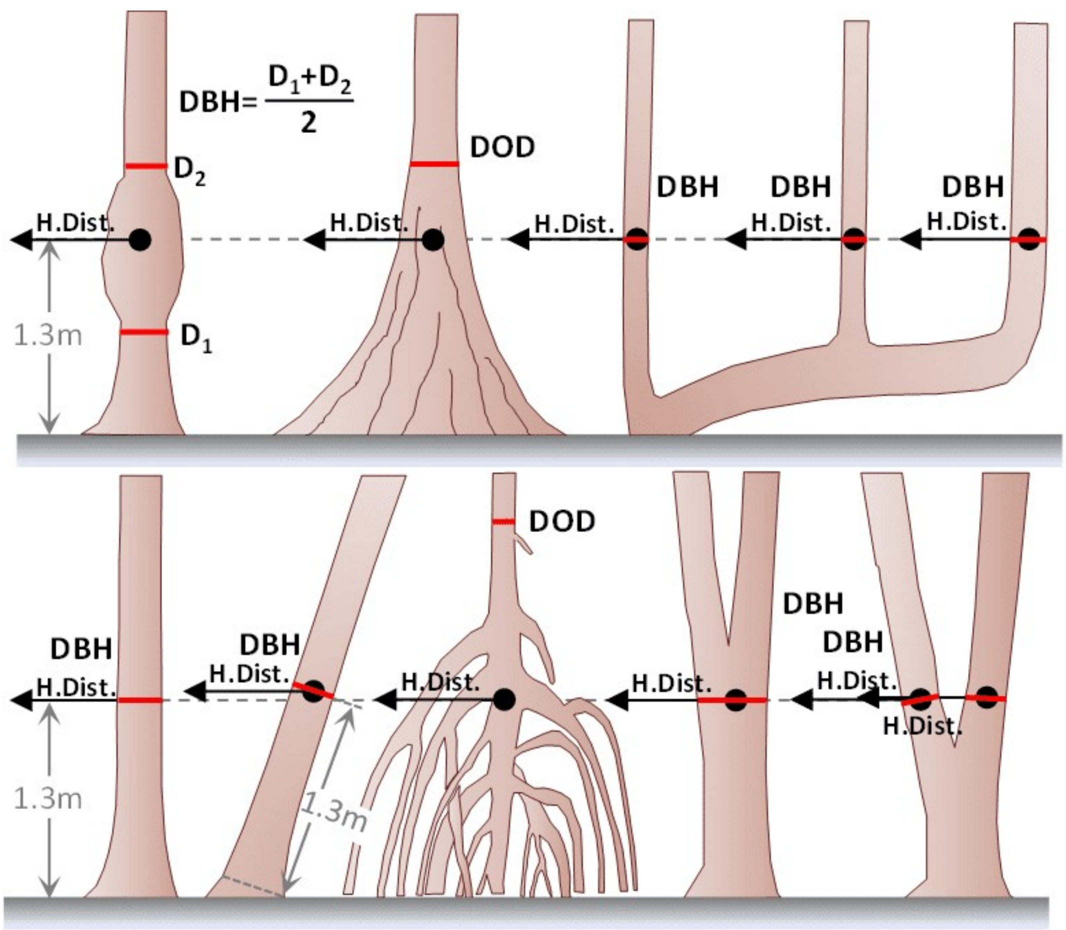
Therefore, it is always good to agree on where dbh is measured before engaging in data collection and analysis. Keep in mind that measurements should be consistent over time to avoid systematic errors and changes that are not due to real changes but to different measurement approaches.

How to measure tree diameters and dbh

Video resource

Watch the video: Lesson 1: **About the measurements of tree diameters and dbh with a caliper and a diameter tape**.(https://www.youtube.com/watch?v=17NPkVXteiI&t=3s)

In general, the diameter is measured perpendicular to the stem axis. A more detailed definition of measurement positions for special cases (see figure below) should be part of the field manual. In sloped terrain, the measurement height is taken from the upper side of the slope in most countries, but sometimes also at the "middle-slope" is defined measured from the side.



Example of a detailed definition of measurement positions of diameter over deformation (DOD) and horizontal distance (H. dist) from an inventory in a peat swamp forest in Kalimantan, Indonesia

Note

Special cases of measuring dbh

There are more special cases, such as coppice stems where 1.3 m is recorded up from the 'seeding point level'. The Papua New Guinea NFI followed this rule in case of aerial roots—diameter was measured 30 cm above the upper root. Among genus *Ficus,* there are some species of trees which often contain prop roots above 1.3 m from the ground. Some upper roots are well established in the soil, while others have just started forming, or are formed from within the canopy. Therefore, only roots originating from the central stem and touching the soil are considered when pointing out the 'upper root'.

Why measure at 'breast height'

The reason why breast height developed to be a standard measure probably has to do with the ease and convenience of measurement. This position at the stem can be reached easily and is usually above larger root bulges in the lower stem section for most trees.

However, measuring at an absolute height also means that the dbh height is in different relative positions for trees of different heights: for a huge tree it may be within the section where the roots and stem base influence the stem shape—while for small trees, 1.3 m is usually in a stem section where the stem is very regularly formed. A measurement position in fixed relative height (e.g. 5 percent of the total tree height) would be more meaningful and better related to other tree characteristics, but difficult for field work. Further, a common, defined measurement height is important since the dbh is input to models (e.g. volume or biomass) that are only valid if we stick to a certain definition.

How to measure dbh

There are three ways to measure dbh—through a tape measure, through a caliper, and remotely. Let's consider the advantages and disadvantages of using a tape measure and a caliper.

TAPE: With a tape we measure the "length of the convex hull around the irregular cross-sectional area". From that perimeter length, we derive the diameter of the cross-section where we assume that the cross-section has a perfect circular shape. Then the diameter can be derived by dividing circumference by π (3.1416). A diameter tape has a "π" scale where length is divided by π, o that the diameter can be read directly

CALIPER: A caliper measures the distance from the left to the right side of the stem. Irregular cross-sections of the stem result in different readings from different measurement directions. A typical rule might be that the arm of the caliper should always point to the center of a circular sample plot. Usually, a second measurement, perpendicular to the first one, is taken for larger trees and dbh is derived as average from both measurements.

Quick tips!

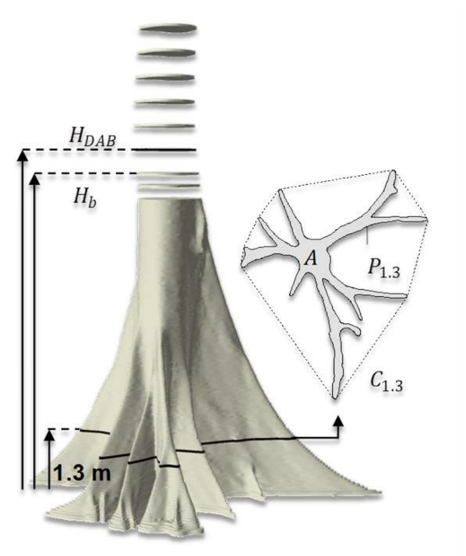
Tape vs. caliper—which tool to use in an NFI?

Comparing both instruments, it is obvious that a caliper is not a handy instrument: if we expect to find larger trees, we will need a very big caliper. Field teams would prefer to carry a diameter tape. But there are also other reasons why a tape is the better choice: a tape reading is much more precise (less variation if repeated many times), while with a caliper we obtain a different reading whenever we measure from a different direction (in the usual case of a non-circular stem cross section). This is especially critical if the interest is in estimating changes from multiple measurements at different points in time. Exceptions are diameter measurements on lying deadwood or on thorny trunks, here a caliper is handier than a tape.

The special case of buttress trees

Buttress roots are found in many botanical families, but among those represented in tropical forests, some have a much greater tendency to produce these tabular roots than others. In many cases, these are the largest trees in a forest and contribute the major share of total volume or biomass.

The very irregular cross-sectional area of the stem, at 1.3 m height, makes any measurement of a diameter impossible or meaningless. Instead, a diameter above the buttress roots (dab in the figure) is often used. This position (depending on tree dimension it can be at 7-9 m height) may not be within reach, requiring indirect measurement of upper diameters. Stilt roots of mangroves are similarly unhandy examples.



Cross section through a buttress tree at 1.3 m height and position for a measurement of a diameter above buttresses (dab)

Measurement of upper diameters

There are different situations in which a direct measurement of dbh is not possible (e.g. for a diameter above buttresses or above stilt roots on mangroves). Different techniques are available for indirect measurements from a distance.

Typical devices for such measurements are a Mirror Relascope, or more modern alternatives like the Criterion RD1000 (Laser Technology, Inc). With such instruments, a fixed relation between the width and distance of an object can be used to visually determine diameters in any height of the stem.

While the Relascope (or Telerelascope) provides scales with fixed relations, more modern devices allow users to visually determine the width of a stem and measure the distance to this position. The actual diameter can be calculated from both measurements.

Video resource

The following video explains how to use a Mirror Relascope to measure tree diameters in different heights.

Measuring upper tree diameters with a Mirror Relascope

[https://www.youtube.com/watch?v=W88BzlC715o&t=1s]

Measurement of tree heights

Tree height is defined as the maximum vertical distance between the lowest point (stem foot) and the top of the tree. Tree height is therefore not the same as stem or tree length: height and length are identical for perfectly upright trees, but different for leaning trees!

Direct measurement of tree heights is possible only for very small trees, like for small tree regeneration (respective telescope poles can be extended to 7-10 m). Usually, tree height is calculated from measurements of angles (to the top and to the base) and a horizontal distance to the tree. Depending on the actual situation in the forest, different measurement techniques are available. Field teams should be trained to use all of them and be able to decide about the most suitable approach.

The following video explains the basics of tree height measurement based on geometric and trigonometric principles.

Basic principles of tree height measurement

Should we always measure heights just because it's a standard?

Height measurements are time consuming, and therefore expensive. In many countries, information on tree heights is required as input to models (e.g. biomass or volume models). However, the need for height information might be different under different country conditions.

For example, in cases where all trees have similar heights, as in an African Miombo forest, there is no point in measuring many tree heights. This also applies in cases of very complex forest canopy structures, such as in mixed tropical forests, where height measurements are a huge effort and quite error-prone, and volume and biomass models are sometimes based on dbh alone. In this case it might be difficult to find enough justification for the time-consuming height measurements.

Palms are regarded as trees in the data collecting phase but distinguished in the data analysis phase. Because palms typically do not have clear dbh-height relationships, it is recommended to record all palms' heights in the plot. Often the height of the palm is measured from the base to the top of the stem.

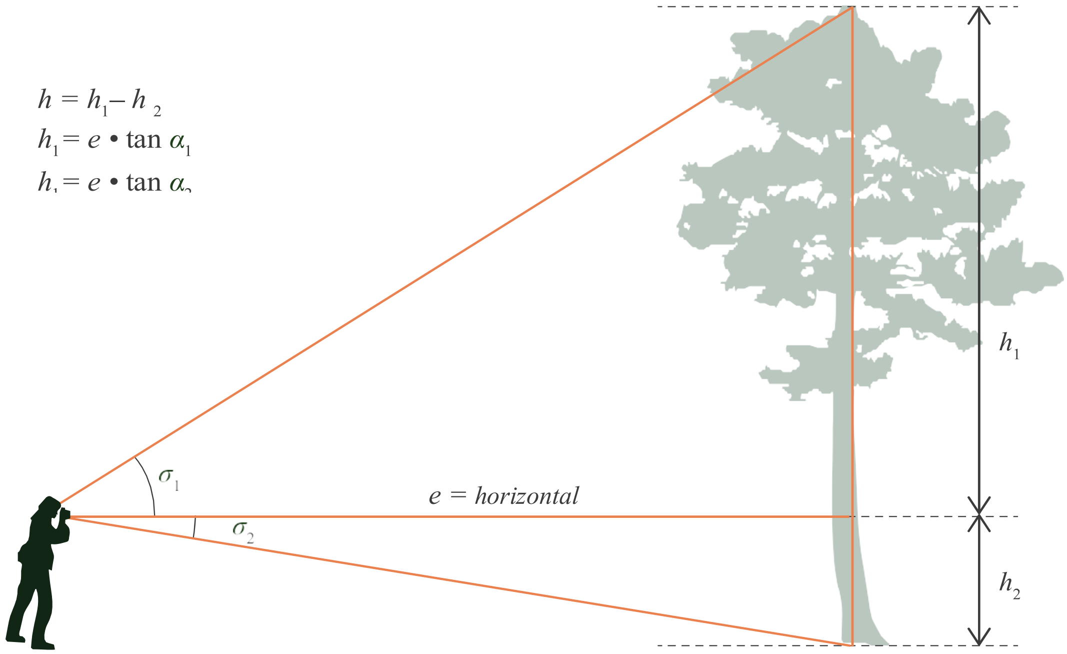
Tree height measurement based on trigonometric principles

Trigonometry is the common basis to determine tree heights with modern, as well as rather historical devices. The calculation of the total height of a tree is based on the measurement of a horizontal distance and vertical angles to the tree top and the base of the stem.

Because the calculation of tree height requires various measurements, the measurement errors in each variable propagate to the total error in the tree height, volume or biomass estimates. As a consequence, the relative error in height is usually considerably larger than the relative error in measuring dbh.

The Tangent method

The underlying principle of nearly all measurement devices—from a modern laser instrument to the old mechanical hypsometers—the tangent method assumes that two right-angle triangles can be constructed (sharing a common adjacent side), for which the opposite sides are calculated based on measured horizontal distance and angles. A total tree height can be calculated by height to top–height to base. Measuring in flat terrain, the height to stem base is usually negative, but there might be cases where the observer stands slightly below the level of the stem base.



Calculating tree height using the Tangent method in flat terrain. Note that h_2 is usually negative if the observer stands above the stem foot.

Video resource

The following video describes how to measure tree heights with simple devices following the tangent method.

Measuring tree height with Blume-Leiss and Suunto clinometer

[https://www.youtube.com/watch?v=EahhlAazK1Y]

Alternatively, the tangent method can also be extended to work without a distance measurement, using a reference pole of known height at the tree. An additional angle measurement can then substitute the distance measurement.

Potential error sources

A potential misinterpretation of the actual treetop can easily happen if the distance to the tree is not sufficient or visibility difficult. A distance of at least 1-1.5 times the tree length is recommended for convenient visibility, especially for large and wide crowns. Also, a shorter distance also means that we need to measure a steeper angle to the top. Even small errors in this angle measurement will have a huge effect on tree height.

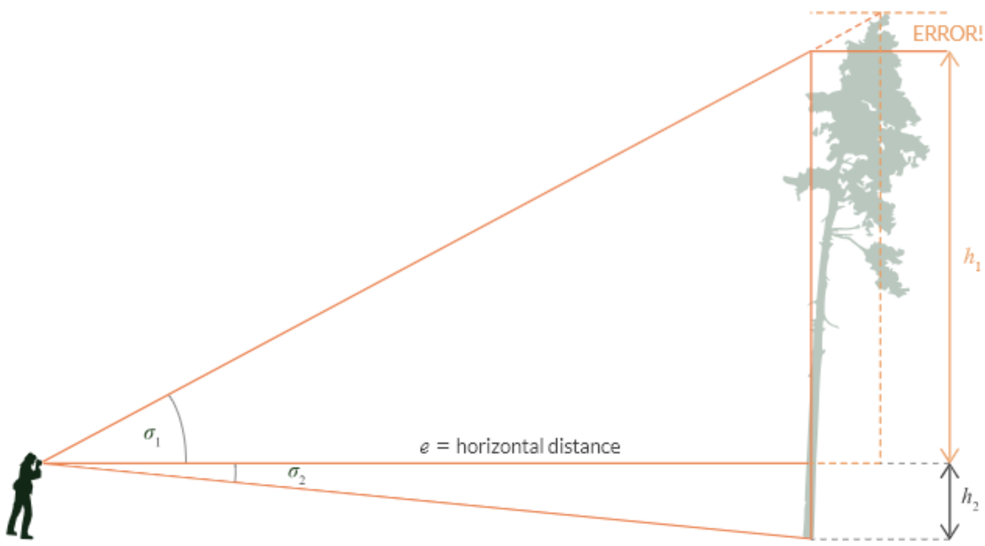
For trees on a slope, a position on the upper slope, above the tree position, is more suitable for measuring height than from below. A correct calibration of the device (tilt sensor of a laser instrument or transponder distance for vertex) will be assumed here.

Let's now look at some typical errors in the tangent method of measuring tree heights.

➲ Incocrect baseline distance

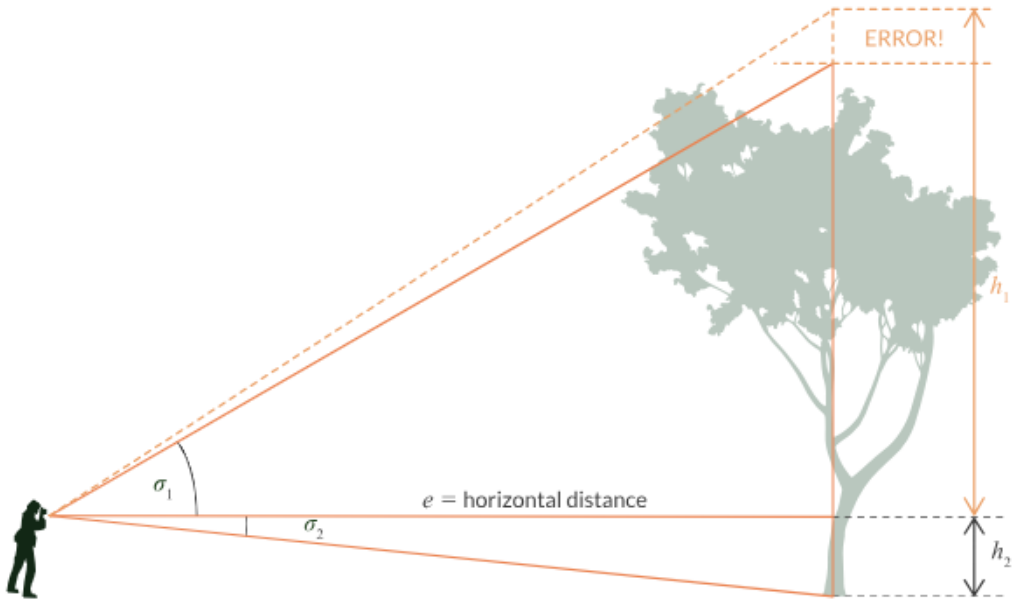
If the tree is leaning away or towards the observer, the measured horizontal distance is not the correct triangle side! Ignoring this can introduce errors. Two solutions are available to address this:

1. find a position perpendicular to the direction in which the tree is leaning (easier), or
2. locate the vertical projection point of the treetop on the ground (more difficult) and measure distance and angle to this point.



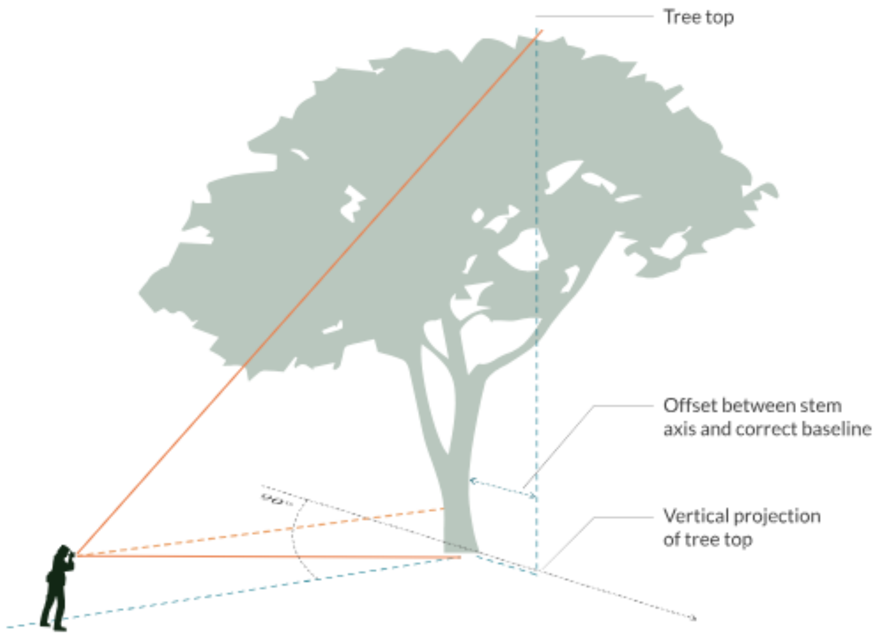
➲ Misinterpretation of tree top

The correct identification of the highest point of the crown of a tree is difficult, especially for large broadleaved trees with large crown dimensions. Even from a large distance we are still looking only from below and need to imagine a point directly vertically above the stem (to which the distance is measured).



➲ Offset to stem position

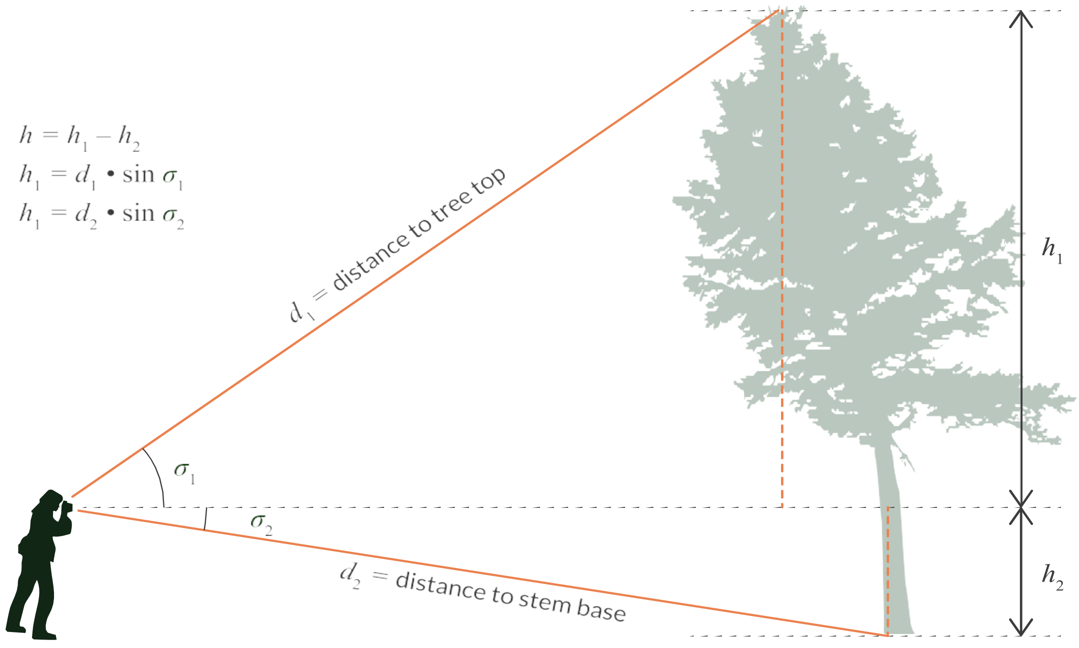
Similar to leaning trees, savannah trees with wide crowns can have a huge offset between the stem position and the horizontal projection of the highest point. To avoid errors, apply the same solutions as for leaning trees.



The Sine method

Another trigonometric approach can be applied exclusively when using a laser rangefinder. With such a device, it is possible to measure the oblique distance to the treetop (from a position with sufficient distance to the tree). Whether such a distant measurement to the top branch is possible depends almost entirely on the crown shape.

If, at the same time, the inclination angle is measured, and a second similar measurement is possible to the base of the stem (distance + inclination angle), these single partial heights can be calculated by multiplying the oblique distance, with the sine of the respective inclination angles. Modern devices include both functions and can take both measurements at the same time.



Sometimes, for leaning trees, or cases of an offset between the treetop and stem position, the Sine method can help avoid errors of the Tangent method, such as wrong baseline distance.

However, there is a distinct disadvantage as well. Whereas the Tangent method is based on angle measurements to both points, which are also possible without a completely free view, this method of measurement requires a free view to the base of the stem and treetop because a correct laser-based distance measurement is required and for the light-based laser, a free sighting to the target object is required. In forests with dense understory, the second height measurement to the base turns usually out to be very difficult if not impossible.

Special cases: direct measurement of vertical distances

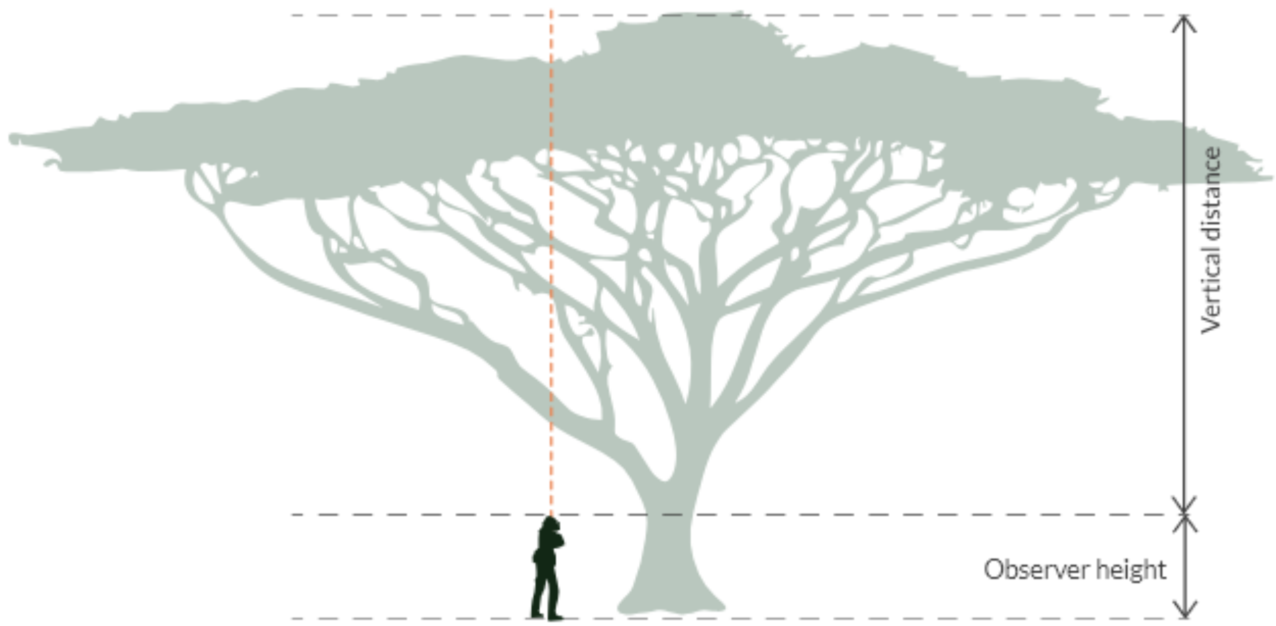
Most textbooks on forest mensuration were written long ago, and modern devices such as laser rangefinders were not available at that time. This is perhaps the reason why sometimes obvious and simple alternatives to measure tree heights are not discussed. We will now look at two special cases of vertical distance measurement.

Scattered crowns

In cases of conifers or large trees with scattered crowns, as often found in tropical forests, we can measure a vertical distance directly with a laser instrument. Measurements of angles are obsolete in this case.

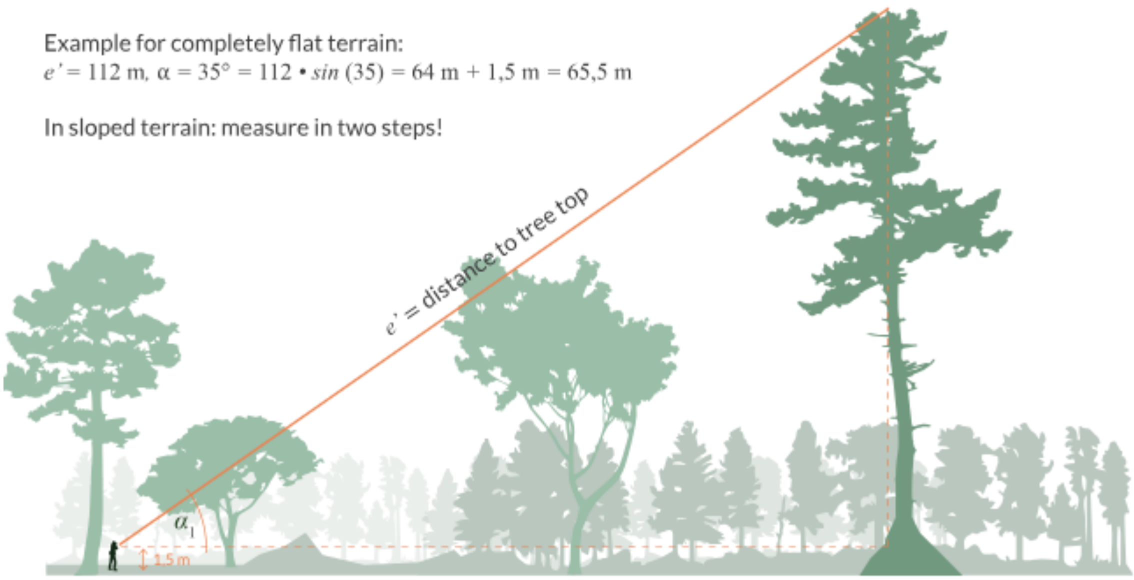
For such a measurement, modern laser rangefinders allow switching to a "last pulse priority" mode, which measures the distance to the farthest object instead of the closest object that was hit.

This technique, however, should only be used in special cases in which no other suitable measurement position can be found. It also works only for trees in the upper canopy with no other tree crowns in the vertical background. Don't forget to add the height of the observer (that is: of the measurement device in the observer´s hand) to this measurement.



Emerging trees

In tropical forests with emerging trees and heights of sometimes more than 60 m, it is often impossible to find a position (and measure its distance) from which the tree can be seen completely. It might, however, be possible to find gaps in the crown layer that open a line of sight to the top. In this case, and if no other option is available, it is possible to use the sine method to get a height between the top and the horizontal line of sight by measuring distance and angle to the top. We then need to add the height of the observer. This, however, is only correct in completely fiat terrain.



Did you know?

What about airborne LiDAR tree height measurements?

Modern NFI designs sometimes include sample-based airborne LiDAR scanning from an airplane. In case the forest structure allows for a sufficient number of ground returns in canopy gaps to be obtained, and if a good quality terrain model (DTM) can be derived over these last pulse returns, a high-resolution canopy height model (CHM) can be derived by subtracting the terrain height from the absolute surface height (DSM = Digital Surface Model). In complex forest structures such as tropical forests, but also in simple structures, such LiDAR based height measurements are usually considerably more accurate than field measured tree heights!

However, using such data to construct tree height models would require:

1. a single-tree segmentation of tree crowns,

2. matching the dbh measurements from the ground with the respective tree crowns, which is not easily done and prone to co-registration errors,
3. LiDAR imagery is available with an appropriate point density, and a sufficient number of ground returns, and
4. experts who are able to analyze LiDAR point clouds (and respective software licenses).

Further, this technique will only work for trees in the upper canopy.

Typical devices for measuring tree height

Decisions on the equipment for an NFI are part of the planning phase. Although the prices for equipment vary and there is a wide range of prices to consider, here is a non-exhaustive overview of some typical devices (or categories of tools)—categorized into mechanical and electronic devices.

Disclaimer: The prices given here are average price classes on the European market (for 2021).

Mechanical devices

Mechanical devices don’t need batteries and are usually very robust. Devices in this group can usually only measure inclination angles. A disadvantage is that the direct reading of a tree height requires a fixed horizontal distance, which limits the choice of positions. Also, slope correction is required when working on a slope. They usually contain scales, on which tree height can be read if the observer stands in the correct horizontal distance to the tree.

Determining this distance can be done with a measuring tape, holding it horizontally. Some instruments (like Blume-Leiss, Haga, Silva clinomaster, Mirror Relascope and some Suunto clinometers) are equipped with an additional scale or prism to determine a specific distance visually. This, however, requires a free line of sight and only works in relatively open forest structures. The prices (as of 2021) vary between ~170 EUR (Suunto clinometer) to ~600 EUR (Blume-Leiss) or ~2 200 EUR (Relascope).

Note

Slope correction

Trigonometric principles are based on a measurement of a horizontal distance. Working on a slope with mechanical devices therefore requires a correction of the measured height depending on the slope angle. If distance was measured as slope distance, the corresponding horizontal distance is shorter by the factor cosine (inclination angle). **Example**: on a slope with 16° slope angle, a measurement distance of 20 m was used with one of the above mechanical devices. Tree height was read (from the 20 m scale) to be 18 m. However, the actual horizontal distance is less than the slope distance of 20m (20*cos(16°) = 19.2 m). That means we are actually closer to the tree than expected and need to correct the measured height by this cosine factor, such the actual height is now (18*cos(16°) = 17.3 m).

Electronic devices

The group of modern electronical devices includes different laser rangefinder and clinometers as well as the vertex instrument (Haglöf), which is a common tool in forest inventories. All of these tools can measure inclination angles (by an electronic tilt sensor) and distances.

While laser-based devices use a laser beam to measure distances, the vertex measures distance based on a ultrasonic sound signal that can easily penetrate even dense vegetation. The drawback is a limited range (30-50 m maximum distance) and sensitivity to other interfering sounds (such as sounds of cicadas, rain, car traffic, etc.).

Video resource

The following video explains how to measure tree height with the Haglöf Vertex IV + Transponder.

[Measuring tree height with Vertex IV](https://www.youtube.com/watch?v=OrGh-4Giyq0&t=2s) [https://www.youtube.com/watch?v=OrGh-4Giyq0&t=2s]

The drawback of a laser instrument is that a free line of sight to the object is required, which is difficult to find in very dense tropical forests. Prices (as of 2021) range from ~500 EUR (Nikon Forestry Pro) to ~1 800 EUR (Vertex IV) and ~2 000 EUR (TruPulse 360).

Video resource

Before we conclude this section, let's look at the following video that explains the basics about measurement of tree heights with laser rangefinder and clinometer.

[Measuring tree height with a laser rangefinder and clinometer](https://www.youtube.com/watch?v=eXdl94HclyE&t=1s)

[https://www.youtube.com/watch?v=eXdl94HclyE&t=1s]

Measurement of other tree level variables

In addition to tree dbh and height, there are many other variables of interest that we may measure or observe on single trees. Most of these are categorical variables that classify trees into different categories, which later allow for production of the desired results.

Which variables are to be observed and how they are defined depends largely on the stakeholders and user groups that are expected to use the results of an NFI. In any case, the inventory protocol must contain a complete and workable definition and description of the assessment approach.

NGOs or government institutions working in nature conservation will have different information needs than, for example, the wood industry, or companies that work in ecotourism. In the following section, we address some groups of variables that are commonly assessed in the NFI context.

Tree species

The identification of tree species is among the most important variables assessed on single trees; it is a nominal variable as it is defined by names (*nomen* is a Latin word meaning name). Species identification is relevant for the assessment of species diversity and also for the choice of biomass models. The challenge of tree species identification varies depending on forest type and biome. While it is not an issue in areas with low species diversity, it is critical in species rich tropical forests or some dry forest ecosystems, where sometimes 1 000 or more tree species can be found in an inventory region and more than 100 even per hectare.

It is hardly possible to find full-blown botanists, who are able to determine the correct scientific species name and are willing to join the field team over months, and it would be very costly, since such experts are rare and expensive.

Trained foresters with academic backgrounds might be able to distinguish a relatively high number of species, but often, in particular when local people are contracted to accompany the field teams, mostly local names of commercial species are well known.

Moreover, local names may not translated one-to-one into a scientific name, and the other way round: one and the same local name may include more than one scientific names. And there may be more than one local names for one and the same scientific names.

The challenges become even greater if regional or local foresters are used to local names that might even vary between different regions in a country.

Quick tips!

Preparing a useful and complete taxonomic backbone (species list) with translations between local names and botanical species is a huge long-term effort and should start early during the planning phase of an inventory.

Wherever possible, each field crew should be composed of field foresters adept at species identification. Additionally, local guides with botanical knowledge should be sought and compensated to ensure accurate species identification. The future is likely to witness apps for tree species identification where pictures of bark, leaves, fruits etc. are taken to support tree species identification.

FAO is working on a tool to quality-check and validate backbone species lists.

The problem of unknown species in biodiversity assessments

In species-rich tropical forests, but also dry forests with high diversity, a certain proportion of trees cannot be identified during field work, even by skilled botanists. If such trees are classified as unknown without further information, it will lead to problems during the estimation of species richness as an indicator for biodiversity.

The challenge here is that it remains unclear whether all unknown trees belong to only one single species, or whether there are multiple or even many different species. Commonly there are few species with relatively high abundance and many species with low abundance. The unknown ones are usually the less common and predominantly those that are not commercial (at least when we resort to field helpers that have experience in forest operations).

Therefore, even if the identification on the species level is not possible with reasonable effort, it would be important to at least find out how many different unknown species were found in an inventory. The subset of unknown trees can then be subsequently classified into "unknown_1, 2, 3…." This requires taking samples or useful photos that allow for a clear distinction afterwards. Only then it is possible to calculate diversity indices based on species abundance or to apply species richness estimators predicting the total number of species from the number of observed species in an inventory region.

Variables on commercial aspects

An NFI does not deliver useful data for forest management planning on smaller areas, but it might deliver relevant data on commercial aspects on a larger scale. Such information is sometimes required to evaluate the market potential and sustainable use of forest products or to justify larger investments in the wood production industry. Typical variables related to commercial features that can be assessed on single trees are:

- commercial stem height
- stem form
- wood quality
- damages

The definition of these variables will depend on the common standards of commercial wood in a country; they cannot be defined in general or on global level. Since many of these variables are assessed by a visual interpretation, it is very important to train the field teams in using a common standard. The different category items need a very clear definition and description.

Examples and pictures help to keep the data quality high and consistent comparable between different field teams.

Examples of the definition of other categorical variables

In order to have a closer look at the definition of a categorical tree variable, let's take stem quality as an example. Usually, a quality assessment only makes sense for larger trees, and the variable is relevant only if a certain minimum dbh (e.g. >30 cm) is exceeded, which applies to commercial wood.

The stem shape can be described in multiple ways. A stem can be straight, curved in one direction, or curved in multiple directions. These would be the different possible expressions of the variable 'stem curvature'. Further, a stem might be twisted, or show a bifurcation at a low height, or bifurcation at a high height. These are all expressions of the variable 'stem shape'.

Also, 'stem damages' have an impact on wood quality and can range from felling damage, skidding damage, fungi, broken crown, and to many other classes. Finally, it is possible to categorize stem sections into different country-specific quality classes or assortments. Based on

such classifications, it is later possible to derive estimates of mean wood volume, for example, in these different classes.

Definitions of variables that only distinguish among different levels, such as low, medium and high (e.g. applied to degradation or complexity of forest structure) are difficult and may lead to a tendency of the field teams to interpret everything as “medium.” So, it is better to avoid using these types of categories.

Summary

Before we conclude, here are the key learning points of this lesson.

- Once the plot position is located in the field, the plot design determines which trees are included in the sample and need to be measured.

- There are only two kinds of direct measurements in a forest inventory: lengths and angles.
- Dbh is a core variable in forest inventory and analysis because in most cases, it is easily and directly measured. Basal area is directly derived from it which is closely related to volume, biomass or carbon. Also, the diameter distribution in a forest gives a good insight into the forest structure and development stages.
- The standard position for diameter measurements of standing trees is at breast height, defined at the height of 1.3m in most countries.
- Regardless of whether modern or historical devices are used, the basis of tree height measurement is always trigonometry.
- Besides tree dbh and height, there are many other variables of interest that we can measure or observe on single trees, including tree species, stem height, stem damages, stem shape and so on.