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Definition of a minimum standard for forest management inventories on KPH level

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Definition of a minimum standard for forest management inventories on KPH level

FORCLIME

Forests and Climate Change Programme

Content

Abbreviations

BAF	Basal area factor (*faktor bidang dasar*)
DBH	Diameter at breast height
DSS	Double sampling for stratification *(pengambilan contoh berganda untuk stratifikasi*)
EF	Expansion factor (*faktor ekspansi*)
FAO	Food and Agricultural Organization of the United Nations
FMI	Forest management inventory
FORCLIME	Forests and Climate Change Programme
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global positioning system
HHBK	Hasil Hutan Bukan Kayu *(Non timber forest product)*
IPSDH	Direktorat *Inventarisasi* Dan *Pemantauan* Sumber Daya Hutan *(Directorate of Forest Resources Inventory and Monitoring)*
KAK	Kerangka Acuan Kerja *(Terms of References)*
KPH	Kesatuan Pengelolaan Hutan *(Forest Managemet Unit)*
KPHL	Kesatuan Pengelolaan Hutan Lindung *(Protection Forest Managemet Unit*)
KPHP	Kesatuan Pengelolaan Hutan Produksi *(Production Forest Managemet Unit)*
LAPAN	Lembaga Penerbangan dan Antariksa Nasional *(National Institute of Aeronautics and Space)*
MoEF	Ministry of Environment and Forestry
NDVI	Normalized Differenced Vegetation Index
NFI	National Forest Inventory (*Inventarisasi Hutan Nasional*)
NTFP	Non-timber forest products *(here synonymous to NWFP= Non-wood forest products)*
QA	Quality assurance (*jaminan kualitas*)
QC	Quality control (*kontrol kualitas*)
SIG	Sistem informasi geografis *(Geographic Information System GIS)*
UNFCCC	United Nations Framework Convention on Climate Change

Preface

The Forestry Law, Law No. 41/1999, mandates the management of forests to be implemented at the provincial level through establishing Forest Management Units/ Kesatuan Pengelolaan Hutan (FMUs/ KPHs) as institution under the Forestry Service (Dinas Kehutanan) that can manage the forest area efficiently and sustainably according to its function and purpose. The establishment of FMUs aims at fostering a more sustainable use of forest resources on local level and facilitating forest planning as foreseen in the Forestry Regulation No P6/Menhut-II/2010 on forest use planning and the development of forest management plans. As of 2016, 529 production (KPHP) and protection (KPHL) FMUs have already been established. Additionally there are 98 conservation FMUs (KPHK).

The application of sound and efficient forest inventory methods at FMU level is a precondition for the formulation of 10-year as well as annual management plans of FMUs and therefore of high importance to the forest sector reform of the Indonesian Government. Specific inventories need to be conducted at regular intervals at FMU, resort and compartment level to provide the basis for forest management by determining the potential of forest and non-timber forest products.

In this context, technical guidelines for forest inventories were developed by the Ministry of Forestry Directorate of Area Management and Preparation of Forest Area Utilization in 2012. The now merged Ministry of Environment and Forestry in cooperation with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, FORCLIME Forests and Climate Change Programme, has initiated a review and revision process of these guidelines in 2014 based on scientific considerations, specific FMU inventory needs and current field realities.

The document at hand is the result of the extensive review process which took place over the course of two years, involving international as well as national forest monitoring and inventory experts from various institutions and agencies. It is a set of recommendations and options for improvement which have been gratefully considered to revise the previous technical guidelines for forest inventories on FMU level (No. P.67/2006).

The Director General of Forestry Planning and Environmental Governance has decided to additionally commission FORCLIME to publish a reference document on minimum standard for KPH inventories in order to provide key stakeholders of forest inventories and FMU management with the complete multifaceted recommendations.

We would like to express our sincere thanks to everyone who has contributed to the compilation of this standard document and hope that this book will be a guiding document in the process of implementing forest management inventories at FMU level.

Director General of Forestry Planning and Environmental Governance

Prof. Dr. Ir. San Afri Awang, MSc.

Preface

A Forest Management Unit (FMU/ KPH) is a provincial organisation and serves as a public service provider under national and subnational governments, a permanent management entity and an operational unit of a defined forest area. Oversight over planning and management processes within its jurisdiction is an integral part of the responsibilities implemented by the FMU. Additionally, FMUs fulfil monitoring, advisory and controlling functions within their designated forest management area. Particularly in terms of FMUs managing state forest areas (so called "wilayah tertentu", constituting for non-licensed production and protection forests), which are not given to third parties (e.g. concession companies), appropriate forest management inventories are required as fundamental basis for Sustainable Forest Management (SFM).

This document summarizes the recommendations for the planning of forest inventories in context of forest use planning and development of forest management plans in Protection Forest Management Units (KPHL) and Production Forest Management Units (KPHP). The review of the existing technical guidelines and the discussion on proposed methods based on scientific and practical considerations were first steps towards the overall goal which is to revise the existing guidelines. Throughout the compilation of this document in 2015 – 2016, several workshops and trainings were conducted. The results of these workshops were considered during the further planning of design elements for management inventories and are included in this final version. This document is composed of two main parts:

(1) An Inventory Protocol that describes background, context and justification of forest management inventories in Indonesia; this protocol elaborates on the technical details of the inventory design elements; and
(2) A field manual that translates the inventory protocol into technical instructions and definitions of variables and that serves as a binding guideline for the field teams when implementing field work.

It should be noted here that the active involvement of local KPH staff in the further planning of inventories is a key requisite for successful KPH planning processes. Local information needs and restrictions for planning and implementation of inventories on the KPH level need to be considered and can only be formulated together with KPH managers who rely on the information from inventories for their management purposes..

The minimum standard document provides a sound basis for FMU managers and other personnel concerned with the topic to make forest management inventories an operational reality in the field.

FORCLIME Principal Advisor

Georg Buchholz

Part

I

Planning inventories on the KPH level

1 Background - Management inventories on KPH level

The formation of 120 forest management units as of 2014 is one of the key performance indicators (KPI) in the Strategic Plan of the Ministry of Forestry (Permenhut No. P.51/Menhutll/ 2010 dated 31 December 2010). The establishment of KPHs has the goal to foster a more sustainable use of forest resources at local level and facilitate forest planning as foreseen in the Forestry Regulation No P6/Menhut-II/2010 on forest use planning and the development of forest management plans. In this context technical guidelines for forest inventories should be developed that describe the scope and goals of forest inventories and define minimum requirements for the different design elements, like sampling-, plot- and estimation design for sample based inventories that should be applied for inventories on the KPH level (KPHP, KPHL).

The main purpose for management inventories in the different areas of a KPH is to generate a sound basis for sustainable management of the respective resources. At least two kinds of information are needed whenever a sustainable management is planned: The actual extent or amount of the resource per unit area and the expected change or future growth rate. While the first one can be estimated based on statistically planned inventories, the latter requires growth models. Such models can be created from permanent inventories or repeated assessments of the resources under study to monitor the development over time.

KPHs are highly heterogeneous in regard to their composition, the environmental circumstances, forest types, the production- or management goals, their area size and the available expertise and human capacity to carry out forest inventories. It is therefore not practical to define a fixed standard for forest management inventories that should be applied under all these very different conditions. A practical standard must be very flexible and easy to adapt to local conditions, the actual information needs and management goals of different KPHs. Therefore, a useful standard contains recommendations how to adapt the very general design elements of forest inventories that are sampling-, plot- and estimation design to the actual environmental conditions and expected future information needs. In the following some general criteria and design options are presented together with simple instructions on adapting the proposed general sampling and plot design for special purposes.

1.1 General planning criteria for forest inventories

The starting point for all forest inventory strategy development is the information needs by the respective decision makers. Forest inventories are never an end in itself but they respond to explicit or implicit information needs and have the goal to satisfy these needs to the extent that is technically and economically possible.

The guiding principles of planning forest inventories on the KPH level are a result of the general aim of sustainable and planned management of resources. The inventories should provide the necessary information as basis for a planned and sustainable management, rehabilitation or conservation of available resources, depending on the actual management goals. The main guiding principles for planning management inventories can be summarized as follows:

1. Permanence (to a certain extend) and repeated in adequate time intervals
   - Contrary to “one-shot” inventories that give a picture of the actual state of a resource, management inventories should be planned as permanent inventories that are able to monitor the change of respective target variables and that are consistent over time. Change information is the core information to retrospectively assess the success of forest management in the past planning period and the core information for forest management planning for the next planning period. Changes can best be estimated from repeated inventories, which are then called “permanent” inventories. That means that the same sampling locations are visited again, and observations are taken on the same plots and from the same trees in all cycles of the inventory.
2. Statistically soundness (on the KPH or stratum level, not necessarily on compartment level)
   - Estimates from forest inventories are credible only if the inventory design does follow methodically sound and scientifically defendable approaches. At the end, one may look at a forest inventory as a complex empirical scientific study that needs to be planned accordingly. This is why inventory experts with a sound background in sampling statistics and statistical modeling shall be integrated in the development of the inventory design. Methodological soundness implies that a detailed inventory methodology is documented that makes the planning and implementation of all inventory steps transparent and understandable also for those who were not involved in to the study. Only adhering to the methodological principles of statistical sampling will allow producing sound estimates, including statistical precision and confidence intervals, for the target variables. A high precision is desirable for estimates on strata level (e.g. different forest types). A lower precision can be accepted on the level of single compartments.

3. Overall efficiency
    - Inventories should be planned essentially just like any other empirical study: the defined goals shall be best achieved with the resources available in terms of money and human resources as the goals are usually defined in terms of precision of estimation for core target variables for specific units of reporting (KPH area, larger forest blocks or strata). The efficiency considerations do always refer to a joint optimization of the technical design elements and the allocation of resources: the inventory design must achieve the defined precision, and must at the same time be technically and economically feasible.
4. Consideration of the heterogeneous level of inventory expertise inside the KPHs
    - All design elements of a minimum standard should be planned as easy as possible and only as complex as necessary. It cannot be expected that KPH staff has in depth knowledge about statistical sampling or remote sensing analysis.
5. Remote sensing integration
    - Considering large and sometimes difficult to access areas, the integration of remotely sensed data is a means to increase the efficiency of inventories. Stratification or double sampling for stratification (DSS) are potential methods to be applied. However, also here simple to apply methods that can be reproduced by local staff should be used.
6. Adaptability to special needs and environmental conditions
    - In order to be flexible, the minimum standard should define some general design options (e.g. a basic plot design) and a practical set of options on how to adapt a basic design to local needs or environmental conditions.
7. Integration with other inventories
    - Inventories on the KPH level should be aligned to the national-wide grid of the National Forest Inventory (NFI). By that the sampling grid in each KPH is referenced to the NFI grid. In order to reduce costs, forest inventories should be combined with other assessments (e.g. soil sampling campaigns or biodiversity monitoring) as much as possible. For common variables that are also assessed in the NFI, the same categories and definitions should be used.
8. Comparability between KPHs
    - Even if the sampling and plot design might be adapted to the actual local conditions, forest types and information needs, the results of inventories should be comparable between KPHs.

These guiding principles have been considered while planning basic sampling- and plot design options.

1.2 Objectives and spatial scale of management inventories

The scope of forest management inventories (FMI) is to give a picture about the extent of natural resources (timber, NTFPs, ...) and their use in those forest areas of the KPH that are under active management. The term management is here not restricted to wood production, but includes also other goals, like conservation. The collected data are used for KPH wide mid-term planning of sustainable yields, as basis for management plans or as basis for decisions about conservation or rehabilitation. Forest management inventories are permanent inventories that are carried out in fixed time intervals to derive information about state and changes of resources on the whole KPH level or on the level of larger strata, like e.g. forest types or management zones. Permanence here refers to an inventory design, where most of the plots are revisited and observations are taken exactly at the same points. These “dependent” observations from two points in time are able to deliver more accurate estimates of changes than “independent” inventories, in which other plots are visited during a repetition.

Because of their spatial resolution, forest management inventories are not suitable to deliver detailed information on single forest stands, smaller blocks or individual compartments! Therefore, forest management inventories are not producing data as basis for small scale on site planning. Usually statistically planned inventories on the KPH level are therefore combined with non-statistical surveys or taxation methods on the lowest level of management compartments. These stand or compartment surveys are thereby a means to allocate a KPH-wide sustainable harvesting rate (of timber or NTFPs) to spatially explicit management units. Compartment inventories are not planned as statistical sampling studies but are rather based on non-statistical surveys of the areas. They give room to collect site specific information that does not require a statistical confidence interval (because no statistical sampling procedure is applied) and that aims at describing single forest stands. Usually also other aspects, like biotope mapping or general information is collected by means of such surveys or taxations. It is obvious that a delineation of the forest area in single management blocks or compartments is required in order to describe each one of them individually.

Methods for such stand surveys are not discussed in this document, but they should be developed parallel to the management inventories.

1.3 Information needs on KPH level

The typical information needs that drive a FMI are the information needs of the KPH or forest enterprise. While this may vary to some extent and priorities (e.g. districts with a high population pressure will be different from those with lesser population pressure) there is always a core set of information that any KPH or forest enterprise needs. And this refers to the information about all elements of the growing stock (so to say: the "production capital") which includes all marketable forest functions (e.g. wood production, NTFP production) and about their changes (production and productivity). Depending on the specific goals of a forest district and possibly also on legal regulations about forest management, other functions need also to be taken into account which may refer to functions like biodiversity conservation, soil protection, water protection, and recreation / tourism.

Further, the information that is needed as basis for management plans on KPH level is not static but will probably change over time. This is due to the fact that management targets might change according to the actual market situation or the changing extent and status of available resources inside the KPH. **Therefore it is recommended to plan forest management inventories in such a way that they are also able to satisfy expected future information needs**. Forest resources for timber production are actually widely degraded in many of the newly established KPHs. Therefore the actual mid-term management (and business-) plan will rather focus on other resources, like Non-Timber Forest Products (NTFPs) at the beginning. However, in case of a successful management of the degraded forest areas, it can be expected that the management target might change back to sustainable timber production once the respective forest stands are rehabilitated. In order to have sufficient information about the past development of timber resources at hand, it is therefore highly recommended to collect a basic set of forest variables from the beginning on. This is also necessary to monitor the rehabilitation success or the success of conservation activities. As exact yield tables and growth models are lacking for many tropical tree species, such historical data about the stand development are also a valuable basis for growth information and by that for sustainable management of timber resources.

It is therefore recommended to separate between the information need for actual and mid-term management targets and a general information need to satisfy expected or planned future long-term utilization of forest resources. Therefore, it is a minimum requirement to collect a core set of variables providing the most common standard information for any forest management.

The actual information need emerging from the relevant regulations on the establishment of management inventories on the KPH level is not defined very clearly yet and is sometimes very vague. In general information should be provided on multiple and very different aspects, such as:

- NTFPs
- Illegal logging
- Ownership
- Biodiversity of flora and fauna (priority areas)
- Timber resources (in some areas)
- Rehabilitation status (rehabilitation concessions)
- Socio-economic information about communities

It is hardly possible to integrate all of these different and very general information needs into a forest management inventory and it is therefore highly recommended to separate information that can realistically be generated from sample based inventories from other information that rather requires additional or other techniques, e.g. interviews with local communities or remote sensing analysis. The following suggestions for a minimum standard for forest inventories concentrate on such indicators that can realistically be integrated in sample based inventories and that can be observed in the field.

1.3.1 Translation of information needs to indicators

The translation of the general information needs into indicators (variables) that can be measured or observed in the field is a key aspect of planning an inventory. Besides a defined set of minimum requirements that will focus on standard variables usually assessed in context of forest inventories, there are changing additional information needs for each single KPH. It is in the responsibility of the actual KPH management to define and integrate further variables that need to be observed for their individual and specific planning purposes. If additional variables should be included, it is obligatory to define each of them very clearly. Introducing additional variables that should be measured or observed in the field requires (i) a clear description on their measurement (in case of metric variables) or a definition of classes (in case of categorical variables), and (ii) the precision of the measurement or the number and descriptions of classes that can be assigned. These additional variables should be included in an extended field manual. For each newly introduced variables it should be explained how this indicator should be used to generate the required information and how they will be used during data analysis. It is also highly recommended to plan how these additional variables should be observed and how the observation can be integrated in the proposed plot design. Further, the additional costs (in terms of additional time and assessment effort) should be considered carefully.

Many variables can directly be observed, like “tree species” or “tree diameter” – but for other variables more or less complex indicator systems need to be developed. Examples are “biodiversity” or “degradation status” which cannot directly be observed but they need to be based on the observation of a set of easily observable indicator variables. The development of such indicator systems is usually a matter of discussion and research and finally agreement among the national experts.

The definition of variables that are included in the forest management inventories for Indonesia has been guided by some general efficiency considerations:

In general

1. The set of variables is restricted to those variables that are not available more easily or more economically from other sources;
2. Each variable needs an individual justification why it is observed. To record data for which there is no analysis plan is usually meaningless, unless there is the suspicion that these variables may become relevant in the future in the context of “emerging issues”.
3. The set of variables for the FMI has been defined along the needs as expressed by the counterparts and along the standard variables of FMIs. Of course, there are limits when it comes to variables that require specialized skills or knowledge or that are very time consuming or that are logistically too demanding.

In what refers to information needs, it appears important to stress that mapping needs are commonly not part of forest management inventories. FMIs are sample based and serve to produce statistical estimations for a defined set of target variables. For the implementation of the FMI, maps need to be readily available, and, of course, the quality of the maps can be validated when implementing a FMI. The repeatedly expressed expectation that FMIs may also produce biotope maps, habitat maps, site quality maps, … is definitely mistaken. However, a FMI may give some input to such mapping processes, in particular when the FMI field data are used as training data for remote sensing based mapping exercises.

2 Methods

In the following a core set of methods for forest inventories are described. **The different design elements of sampling studies that need to be planned are the sampling-, plot- and estimation design**. The proposed methods assume a certain amount of prior information that is obligatory basis for planning an inventory and that should be available in each KPH. For planning purposes it is for example necessary, to have information about the KPH boundaries (preferably in form of vector data in a GIS) or a zoning according to different forest uses. Further, a core set of remote sensing products should be available. Some of the required data can be provided by national agencies, like e.g. LAPAN or IPSDH, other data are freely available (like e.g. multitemporal Landsat imagery or standard products derived from this data) and can be acquired by each KPH.

2.1 Definition of target areas for inventories

In sample based forest inventories the population is defined as the total area under study. Sampling locations are selected from this population. For pure management inventories that should produce data for management purposes, it is efficient to restrict the sampling frame (the areas in which field observations are collected) to those areas that are under management or are expected to be managed in near future. Management here refers to any kind of planned activity that should be monitored and is not restricted to timber production. Conservation or NTFP utilization are also forms of management. Therefore, **not necessarily the whole forest area of a KPH should be inventoried.** Sampling should be restricted to those areas where data for management planning are needed and not yet available from other sources. These are usually not the most inaccessible areas. As KPHs are usually composed of different forest areas (concession areas, community forests, conservation / rehabilitation areas, …),

the first step in planning is therefore to identify and prioritize those areas inside the KPH in which the KPH management is obliged to plan and implement inventories. These are usually “public forests” in which a planned and sustainable management is lacking. Areas that are already covered by permanent inventories (like e.g. concession areas) can be excluded from further planning. For the identification of target areas available official maps and the actual land register should be used to identify and delineate the target areas for inventories (sampling frame).

On top of the actual information need for planning purposes, it might be that other information is needed for the total forest area inside the KPH. If, for example, an inventory of carbon stocks should be integrated into the management inventory, then the total forest area is relevant. This information need, however, should be satisfied by complementary studies that can partly also be integrated in management inventories. As the main purpose and most urgent need for information arises in context of planning for sustainable management, this goal should be addressed with a higher priority.

In order to clearly define the sampling frame it is recommended to carry out a zoning of the KPH area, if not yet done. Such a zoning will inform about the different information needs on different areas and helps to restrict inventories in the different zones to the collection of necessary data. A proper distinction of different zones as well as their monitoring priority is hardly possible without information from field visits. It might therefore be necessary to carry out basic surveys of the forest areas in order to collect basic information about the management priority, the actual use of products, the rehabilitation status or biodiversity. This survey is not intended to be a statistical inventory, but a collection of basic information about different sites by the KPH staff that help to get an overview about the area. In context of this zoning a preferably complete GIS with relevant information should be build up (if not yet existent). This GIS should also be used to plan forest inventories in the different KPH areas.

2.1.1 Integration of sample based inventories and forest zonation

The zoning of the forest area in areas of different forest use, conservation priorities or NTFP utilization potential can in principle be combined with the sample based inventories. In this case the assessment of sample plots at pre-determined locations (defined by the sampling design) would need to be combined with a non-statistical field survey with the intention to distinguish and delineate different zones. As the areas of different zones are then not known a priori, but determined during the field campaign, it is not clear from the outset how many plots will be in which zone. Further, as the field teams that carry out the sample based management inventory will move from one plot to the next, they will not get a complete overview about the area and a clear delineation of zones in the field might be difficult and not very efficient. However, the collection of information for a zonation could be integrated by taking relevant observations on the way from one plot to the next. As teams will not always be able to navigate in a straight line (because of terrain conditions and access), this information cannot be used for a statistical analysis, but it is important information that can be used for mapping the zones later. Together with the information from sample plots (from the systematic grid), terrain conditions (a digital terrain model) and other information, like infrastructure (roads, rivers), a first draft delineation of zones could be done. This, however, should be revised and validated later, for example in context of a repetition of the inventory after a certain time period.

The collection of relevant (non-statistical) information that is assessed during the walking time is not described in detail in this guideline document. Usually a field book is used to write down relevant information or GPS coordinates (or tracks), like intersections of the walking line with rivers, special biotopes, observations of rare species, relevant terrain conditions (e.g. rocks, caves, …). The resulting data inform about the presence of these objects in the area, but will not allow estimating their total number. In order to allow field teams to mark and draw special features in the field, respective field maps, in the best case from higher resolution satellite imagery, should be prepared. More details on field maps are given in 2.3.1.

If field teams are able to navigate from one plot to the next in a straight line, then the situation is different and a statistical estimation of the total number of objects is possible following the concept of transect sampling (see 2.5.6).

2.2 Set of variables

The minimum standard proposes a core set of indicators and variables that are measured or observed in all KPHs in whole Indonesia. As the actual management goals of KPHs, the environmental and topographic conditions (forest types, terrain) and the existing resources and capacity to carry out forest inventories are very heterogeneous, a core set of variables to be assessed is a minimum requirement that should be extended by further useful indicators and variables for the actual management goals on the individual KPH level.

In order to ensure consistency of variable definitions between management inventories on the KPH level and the existing concept for a NFI, it would be most useful to adopt those variables (and their definition and classes) that are expected to be useful for management planning from the NFI guidelines. This does not mean that all variables measured in the NFI should be adopted for management inventories, but only those that are relevant and useful for planning! General categorical variables, like forest types, tree species groups, damage classes, etc. should be comparable to existing information or NFI data in order to avoid confusion and misinterpretation between different data sources.

Variables can be grouped in different ways, either according to their purpose as indicators or according to the entity that they are describing. For planning the set of variables that should be observed it is useful to consider both aspects. As example: a subject matter grouping of variables would mean to form “information groups”, like “biodiversity”, or “NTFP management”. Variables that are used as indicators can be summarized in these groups. One variable in the group “biodiversity” might be the total number of tree species, or the vertical structure of the forest (layering). This grouping is useful to explain the meaning, purpose and priority of each variable.

A comprehensive set of variables has been defined below that can be broken down according to different criteria, among them the sub-division of variables in two groups:

1. According to the object / topic on which the observation took place, for example tree, stand, topography, surroundings, soil, vegetation, …
2. According to their role in analyses. Some variables are used to characterize the forest found at the sample point (basal area, stand strata, growing stock, presence of habitat trees, ...), some serve as classifiers (forest type/species composition, slope, distance to roads,…), and some do support inventory planning, implementation and optimization (time observations, tree positions, coordinates, …).

For data management (and as basis for a database structure) it is, however, more straightforward and meaningful to organize the variables according to the “entity” that they describe or the observation unit and spatial scale on which they are assessed. An example for an entity is a “sample plot” or “sample sub-plot”.

Many different variables can be defined that describe the plot area itself (e.g. its topography by slope, elevation, aspect, …). On a sample plot there are usually trees which are also entities that can be described by variables like DBH or height or damages.

Each variable is described and defined in the “Field Manual” which is an extra section in this document. Description and definition refers to the general meaning of a variable and the measurement/observation procedure to be applied to collect the data, including the measurement devices to be applied for metric variables and complete lists of categories for categorical variables. It is important that these definitions and measurement prescriptions be strictly adhered to by all field teams.

A core set of variables (minimum requirement) and possible additional variables are summarized in Table 1.

Table 1. Grouping of indicator variables according to their scale of observation (categorial, measurement), the respective entity and information category. For each variable its meaning as indicator for different purposes is given.

Scale of observation / Entity	Variables		Remote sensing / GIS integration	Information category / management goal				Minimum requirement
	Categorial	Measurement		Wood products/ timber	NTFP	Biodiv. / Conservation	Ecosyst. Services / Carbon	
Point	Accessability class			Utilization potential	Utilization potential	Disturbance risk	Vulnerability	YES
Point		Time from path			Utilization potential	Disturbance risk		YES
Point		Coordinates	Co-registration					YES
Point		GPS Error	Co-registration					YES
Point	Landscape context					Isolation / fragmentation		YES
Point	Protection status			Restrictions	Restrictions	Importance / priority		YES
Point			Eco-zone					YES
Point			Catchment area				Water provision / beneficiary	YES
Point		Elevation				Conservation priority		YES
Point			Distance to settlement			Disturbance risk		
Point			Distance to road			Disturbance risk		
Compartment	Origine (planted/natural)							YES
Compartment	Prior management					Rehabilitation status	Loss/gain	
Compartment	Last logging					Rehabilitation status		

Table 1. (Continued)

Scale of observation / Entity	Variables		Remote sensing / GIS integration	Information category / management goal				Minimum requirement
	Categorial	Measurement		Wood products/ timber	NTFP	Biodiv. / Conservation	Ecosyst. Services / Carbon	
Compartment	Mixture/ Diversity class			Potential	Potential	Importance	Stability	YES
Compartment	Layering					Vertical structure / heterogenity	Stability	YES
Compartment	Rare species			Restrictions	Restrictions	Zoning / Priority areas	Priority areas	
Compartment	Special habitats biotopes			Restrictions	Restrictions	Zoning / Priority areas	Priority areas	YES
Compartment	Utilization			Products	Products	Pressure	Beneficiary	YES
Compartment	Illegal exploitation (traps, ..)				Restrictions / sustainability	Pressure	Beneficiary	
Compartment	Orangutan (nest sites)			Restrictions	Restrictions	Zoning / Priority areas		
Compartment	Evidence of intense animal use (salt licks, …)			Restrictions	Restrictions	Zoning / Priority areas		
Plot	Forest type		Training data for classification	Potential	Potential	Zoning / Priority areas		YES
Plot	Forest sub-type							
Plot	Development class			Potential	Potential			YES
Plot		Slope	Training data for classification	Restrictions		Zoning / protected areas	Protection function	YES
Plot	Terrain form		Training data for classification					YES
Plot	Aspect		Training data for classification					YES

Table 1. (Continued)

Scale of observation / Entity	Variables		Remote sensing / GIS integration	Information category / management goal				Minimum requirement
	Categorial	Measurement		Wood products/ timber	NTFP	Biodiv. / Conservation	Ecosyst. Services / Carbon	
Plot		Crown Closure	Training data for classification			Degradation	Protection function	YES
Plot	Ground vegetation					Diversity and disturbance indicator		YES
Plot		coverage of ground veg.						YES
Plot	Disturbance species					Disturbance		
Plot	Soil erosion			Restrictions		Degradation	Risk/Loss	
Plot	Humus layer							
Plot		Basal area		Potential		Conservation value	Carbon density	YES
Plot	Soil texture			Site-Species matching		site conditions	Soil sensitivity	
Plot	Soil color			Site-Species matching		site conditions	Soil sensitivity	
Plot	Soil humidity			Site-Species matching		site conditions	Soil sensitivity	
Plot	Fire occurence		Training data for classification	Quality	Extend / area	Biodiv. Loss	Carbon loss	
Plot	Fire cause					Pressure		
Plot	Time since fire		Training data for classification			Rehabilitation		
Plot	Peat depth			Restrictions		Conservation priority	Carbon stocks	
Plot	Utilization			Products	Products	Pressure	Beneficiary	YES

Table 1. (Continued)

Scale of observation / Entity	Variables		Remote sensing / GIS integration	Information category / management goal				Minimum requirement
	Categorial	Measurement		Wood products/ timber	NTFP	Biodiv. / Conservation	Ecosyst. Services / Carbon	
Plot	D-class of stumps			legal/illegal logging	legal/illegal extraction	Pressure/ conservation priority		
Plot		# of stumps		Extracted volume	Extracted volume			
Regeneration sub -plot	Regenaration height class	# of individuals		Future timber species	Future NTFP species	Regrowth / rehabilitation / species composition	disturbance / site potential	YES
Regeneration sub-plot	Browsing damage			Sustainability	Sustainability	Pressure	Loss	
NTFP sub-plot		# of bamboo culms			NTFP potential	Disturbance		
NTFP sub-plot	NTFP category				NTFP potential			
Dead wood sub-plot	Dead wood category			Natural or (legal/illegal) logging		Illegal logging	Biomass / Carbon	
Dead wood sub-plot		Diameter				Dead wood volume	Biomass / Carbon	
Dead wood sub-plot		Length				Dead wood volume	Biomass / Carbon	
Tree		Azimuth		Growth of single tree	Change	Species loss		YES
Tree		Distance		Growth of single tree	Change	Species loss		YES

Table 1. (Continued)

Scale of observation / Entity	Variables		Remote sensing / GIS integration	Information category / management goal				Minimum requirement
	Categorial	Measurement		Wood products/ timber	NTFP	Biodiv. / Conservation	Ecosyst. Services / Carbon	
Tree	Species			Commercial species	NTFP species	Diversity / Relation between commercial and pioneer	Wood density	YES
						commercial and pioneer		
Tree		DBH		Standing stock (Vol)			Biomass / Carbon	YES
Tree		DOB						YES
Tree		Buttress height		Bole volume		# of buttress trees	Biomass / Carbon	YES
Tree		Height (sub-sample)		Height curve; Standing stock (Vol)		Vertical structure (Variability)	Biomass / Carbon	YES
Tree		Commercial height (sub-sample)		Commercial volume				
Tree	Stem form			Products/ assortment				
Tree	Damage			Wood quality		Degradation		YES
Tree	Habitat					Conservation value		YES
Tree	Commercial class			Products/ assortment				
Tree	Crown class							
Tree	NTFP species				NTFP potential			

2.2.1 *Organizing variables for data management*

Contrary to the subject matter grouping of variables described above, the data should be subdivided into different groups according to their reference scale and/or the respective target object for the data management. This grouping is much more suitable to construct a suitable database structure and to analyze the data. Every variable is explicitly defined in terms of scale of measurement/ observation, the possible values or classes (in case of ordinary or Boolean scale) and their precision.

- **Sample information [SAMPLE_]:** General information on the sample, e.g. date of assessment, field team, etc.
- **Sample point [POINT_]:**All variables describing the sampling location (dimensionless point), e.g. coordinates, height above sea level, etc.
- **Compartment [COMP_]:** Characteristics of the forest stand or management compartment in which the sample point is located. This information refers to the conditions in the surrounding of the plot. Some variables could also be assessed on the way to the plot.
- **Plot [PLOT_]:** Variables describing the conditions on the defined sample plot. These variables describe characteristics that are directly affecting the trees growing in the plot area and that could be correlated to remote sensing data covering the plot area and direct surrounding.
- **Single tree [TREE_]:** Variables measured or observed on the individual trees in the plot.
- **Dead wood [DEAD_]:** All variables observedon standing and lying dead wood, if information on deadwood is needed.
- **Regeneration [REG_]:** Variables assessed on the regeneration sub-plot describing the status of regeneration.
- **NTFP [NTFP_]:** Variables assessed on the NTFP sub-plot referring to Non Timber Forest Products.

The naming of each variable (in the database, not necessarily in the field forms) should follow this standard in order to allow a consistent data management. Following this concept the diameter of a tree (dbh measured in 1.3m height) would be named TREE_DBH as it is an attribute of the entity "TREE".

All these variables will be further defined in the following chapters.

2.3 Integration of remote sensing

Management inventories should only be implemented where management (planned utilization of resources or conservation) is planned; however, for some reasons there is also interest to get information on the total forest area. Remote sensing can play an important role in this regard. In principle there are two options to integrate remote sensing data into forest inventories: 1) in the design phase of inventories, where remote sensing can help to increase the efficiency of the sampling- and plot design for field samples, or 2) in the estimation stage. In case that target variables are correlated to indicators derived from remote sensing (a typical example is NDVI or texture indices). Remote sensing data can increase the efficiency of the estimation process if correlations to field observations can be found.

Some examples on how to integrate remote sensing data in the design phase are given in context of the described sampling designs, while remote sensing integration in the estimation phase is briefly discussed in the chapter on estimation design.

2.3.1 Collection of training data for remote sensing classification

Beside the use of remote sensing data during the planning and estimation stage of forest inventories, it is also meaningful to integrate the collection of training data for remote sensing classification into the field work. This is not part of the actual inventory work, but a complementary study that can be integrated in the field work. The collection of such training data (sometimes referred to as “ground truth”) has no direct influence on the sample based estimation of target variables from field plots, but it is important information that can be used as basis for remote sensing analysis later. Training data are needed to “train” a classification algorithm during remote sensing analysis. They provide information on the actual land cover (or forest typ and structure) for a specific set of pixel values from a satellite image.

Standard plot designs of management inventories are usually relatively small and therefore not very suitable to deliver enough information for remote sensing classification. Therefore, in order to integrate a meaningful collection of training data, larger areas should be considered. These areas are not intended to take any measurements, but just to assign a land cover- or forest type.

The following methodology was proven to be efficient and easy to integrate into sample based inventories: based on the satellite imagery that should be used for a supervised classification, maps of the area in suitable resolution should be produced. In order to highlight the difference of land cover, it is useful to derive a principle component analysis of spectral bands to increase the contrast between different classes as much as possible. If the distinction of different classes is possible in the imagery, it is also possible to derive a segmentation, which is a grouping of pixels into segments according to their spectral characteristics. If field teams are equipped with such maps, they can describe the actual land cover or forest type for each segment that they are passing on the way and assign the respective class (land cover code) on the map. A more statistical way to collect ground truth would be to restrict this assessment to an area around the locations of sample plots (e.g. a map window of 100*100 m). In order to allow a later classification, the respective forest- or land cover types should be determined before going to the field.

2.4 Sampling design

“Sampling design” refers (1) to the way how samples are selected and (2) to sample size (=the number of samples).

Out of the two basic sampling designs – simple random sampling and systematic sampling – it is clearly systematic sampling which is most frequently used in forest monitoring. Given the same number of plots, systematic sampling produces commonly much more precise estimates than simple random sampling. That means: a given targeted precision can be obtained with a smaller sample size with systematic sampling. This is why systematic samplings is always the first choice for forest inventories and there is no FMI that these authors are aware of that utilizes simple random sampling. Commonly, FMIs employ systematic sampling on square grids which show close to optimal properties regarding precision of estimation.

The planning of a suitable sampling design depends very much on the available a priori information about the KPH area. Considering the very different conditions in KPHs all over Indonesia, three different general design alternatives are proposed here: a) **unstratified systematic sampling**, b) **stratified systematic sampling** and c) **double sampling for stratification (two phase sampling)**. All of them are briefly described in the following.

The different sampling designs could also be implemented in a stepwise approach, starting with a systematic grid over the whole area in the first cycle of the inventory and implementing more advanced techniques in a next cycle (repetition) when more data are available.

2.4.1 *Systematic sampling (not stratified)*

With this sampling design a fixed systematic (usually quadratic) grid is superimposed over the forest area inside the KPH (or the defined sampling frame for inventories). The grid should be aligned to the base grid of the NFI that is, depending on location in Indonesia either 20x20 km, 10x10 km or 5x5 km. The sampling grid should therefore be planned in the same map projection and a NFI sampling location should be used as starting point for the KPH grid. In order to align the grid width to the NFI, the point distance should be planned as a multiple of the NFI grid distance. Based on the estimated required sample size (see 2.4.5) the closest integer grid width should be identified as a multiple of the NFI base grid. The alignment of grids with the NFI grid should ensure that the single sampling studies on individual KPH areas could in principle be combined and aggregated over multiple KPHs. Planning and implementation of the sampling grid should be done in a GIS. After defining the grid, all grid coordinates should be computed and can be uploaded to GPS receivers for field work.

With unstratified sampling, the same sampling intensity (plots per area) and the same plot design is used for all different forest types in the total area of the sampling frame.

2.4.2 *Stratified systematic sampling*

Whenever suitable data are available that allows subdividing the total forest area in more homogeneous subpopulations (called strata), stratification of the population can increase the efficiency of inventories. Stratified sampling is efficient especially in those cases where the variability inside the strata is low and the differences of means between the strata are large. In this case a higher precision can be achieved with the same sample size. Beside statistical issues there are further practical arguments for stratification, like e.g. the organization of field work.

We can distinguish two general approaches for stratification, the so called pre-stratification in which strata are formed before the sampling study starts, and the post-stratification, where strata are distinguished in course of the sampling or even afterwards based on the data. In the first case the strata must be defined and - in case of geographical strata - delineated to define the sampling frame.

The precondition for a meaningful partitioning of a population in non-overlapping strata is the availability of prior information that can be used as stratification criteria. In forest inventories this information might be available in form of forest management- or GIS-data or can be derived from remote sensing data like aerial photos or satellite imagery.

Most efficient from a statistical point of view, is the stratification of a population proportional to the target value of the inventory. As this target value is typically not known before the inventory, forest variables that are correlated to this value are used as stratification criteria. In large managed forest areas age classes or forest types might be good stratification criteria if the estimation of volume per ha is targeted. The statistical estimation in stratified sampling derives an independent estimate for the single strata that is then combined to a weighted estimate of the total over all strata. The weighting factors applied are derived based on the stratum areas.

As stratified sampling assumes that the strata are independent sub-populations, it is possible to adapt the sample size (also sampling intensity) and the plot design to the respective stratum conditions. With this design it is therefore possible, to adapt the plot design to the actual conditions of a specific forest type. Further, it is possible to adapt the sampling intensity to the actual information need.

As it cannot be expected that profound remote sensing analysis capacity is available in each single KPH, remote sensing based stratification criteria should build on simple approaches or even better use readily available information that does not require any additional computing or analysis. Therefore, simple indicators, like e.g. the spatial distribution of NDVI (Normalized Difference Vegetation Index) can be used to differentiate the total forest area into strata of more homogeneous expected volume or biomass. The NDVI is, to a certain extent, related to the amount of green vegetation and therefore also to volume, biomass and carbon stocks and biodiversity. Readily available multi temporal NDVI products based on Landsat imagery can be obtained freely, e.g. via the Google Earth Engine. Every KPH should be motivated to use these products and further data provided by LAPAN, IPSDH or other national and regional agencies for their own planning purposes. In case that higher resolution imagery is available, stratification can be done by delineating different forest types visually. For some KPHs high resolution imagery can be found in virtual globes, like Google Earth or Bing. If a separation of forest types is possible, the strata can be delineated and mapped.

2.4.3 Double sampling for stratification (two phase sampling)

Stratified sampling as explained above requires knowledge about the actual stratum area and a complete delineation of the stratathat is not always available. If the stratification is based on a classification of satellite imagery according to remote sensing based stratification criteria (like NDVI) it is possible to derive the respective area (even though this estimate is affected by classification errors). However, if other criteria are used for stratification, like e.g. forest types, the actual area of strata is usually not known. In such cases, double sampling for stratification (DSS) is an efficient approach. This technique is a two phase sampling approach, in which a relatively large first phase sample is taken. In this first phase sample, easy to observe variables are used to classify a high number of points into different strata. In practice it is implemented by a relatively dense sampling grid over the expected forest areas. All points in this grid are observed in remote sensing imagery with sufficient resolution. The data used in this first phase of sampling might differ between KPHs. In some areas virtual globes like Google earth or Microsoft bing already offer high resolution imagery that can be used as basis for visual interpretations. In other KPHs where free imagery is not available in sufficient resolution and actuality, high resolution satellite imagery provided by LAPAN (e.g. Spot data) or medium resolution like Landsat might be used. Each point is classified according to the stratification criterion, e.g. forest type or crown density in high resolution imagery or NDVI or texture indices from Landsat imagery (in the second case visual interpretation is not possible or necessary). This first phase sample already allows estimating the total area of strata. In the second phase of sampling, a subset of all points per stratum is selected randomly for field measurements. The size of this second phase sample should be calculated based on the required sample size that is necessary to meet a defined precision level. Therefore, preliminary information about the variability of target variables from the different strata must be available.

In order to reduce the number of points that need to be classified in the first phase of sampling, remote sensing can be integrated in a half automatic way. If wall to wall satellite imagery is available (e.g. Landsat) or the NDVI product derived from it, all points below a defined threshold that are expected to be non-forest with a high probability, can be excluded from further classification. Then, only the remaining points that have a high probability to be forest needs to be interpreted visually. In contrast to stratified sampling that is usually based on spatially coherent strata, DSS might lead to spatially incoherent strata as each point is classified individually.

Another advantage of DSS is that a pilot study can be directly integrated in the second phase sample. Therefore a sufficient number of points per stratum (a recommendation based on statistical considerations is around 20-30 plots) are randomly selected as pilot plots from the first phase samples. After assessing the plots data are analyzed to estimate the variance of target variable (usually basal area). This information is then used to determine the total required sample size (as explained in 2.4.5). The pilot plots are then complemented by the remaining number of required plots.

2.4.4 *Using available prior information*

All existing prior information on the actual forest areas should be utilized during the choice of a design alternative and the further planning of inventories. Useful information are (actual) maps (geo-data) of the forest areas, but also estimates derived from prior inventories in these areas. In case of existing geo-data (shape files of boundaries, ...) the quality should be checked before. To derive information about the expected variability of different target variables (e.g. basal area, diameter distribution, number of tree species, ...) inside the different forest types, it might be useful to analyze plots of the NFI from these forest types or to ask the central agencies for respective results. It might be necessary to include also regional plots from neighboring KPHs. Analyzing the NFI plots, however, should not be based on a whole cluster plot. The NFI cluster plots are much larger than efficient inventory plots of a forest management inventory and therefore estimates from these plots would show a much smaller variability as can be expected on the KPH level. It would be an option to analyze single sub-plots from each NFI cluster to get a more reliable estimate of the target variables and their variability.

In case that no prior information about the target variables in different forest types or strata is available, it is recommended to plan for pilot inventories. These inventories can be integrated in the pilot phase of the management inventories.

2.4.5 Determination of required sample size

The sample size is the number of samples (plots)selected in a defined area based on a certain sampling design. The determination of sample size is an important requirement in forest inventory as it directly affects the costs of the sampling exercise as well as the confidence interval for the derived estimations. It is important to note, that the sample size is an absolute value (it refers to the number of samples) while the sampling intensity is a relative value. Sampling intensity refers to the proportion of the area that was observed. Sampling intensity has no direct influence on the precision of estimates and is not helpful during the planning of inventories. For example: the same sampling intensity of, let's say 2%, could be achieved with some very big plots, or many smaller plots. The latter solution will be much more precise, because the sample size is larger.

After pilot studies in the respective KPH area or based on estimates from comparable neighboring or regional KPHs, basic information about mean conditions in comparable forest types can be derived and can serve as basis to estimate the required sample size for a pre-determined precision for the specific information. There are two guiding questions in this context:

1. Which variable should serve as target variable to estimate the sample size?

The sampling and plot design can only be optimized towards one single target variable. In many cases the basal area per hectare is selected as key variable for this optimization, as it is closely related to volume and biomass. However, a sampling study optimized towards basal area estimates might not deliver the best results for other target variables, like e.g. the number of tree species (biodiversity) at the same time.

2. What is the required precision of information that is targeted?

Sample size can only be calculated (on statistical criteria) if a target precision for the estimate is determined before. The required sample size to meet this precision requirement can then be estimated based on information of the expected variability of the target variable. If one defines the desired width of the confidence interval to be A and the desired error probability to be α, then one can calculate the sample size which is required to reach that precision (this holds for simple random sampling only!):

$$A = t_{\alpha,v}\ s_{\bar{y}}$$

$$A = t_{\alpha,v}\ \frac{s}{\sqrt{n}} \rightarrow n = \frac{t^2 s^2}{A^2}$$

Where t is the value from the student-t distribution (for a given α-error) and S^2 is the variance of the target variable estimated from prior data or a pilot study.

However, in practice it is more usual that the available resources in terms of time and budget are restricted and by that determining the maximum number of field plots that can be visited. In this case the sample size is limited by other arguments and the aim is to get the best possible precision with the available resources.

For the time being, the limited capacity for the implementation of inventories on the KPH level will rather follow the second option. Therefore, information on the average required time for the measurement of one plot is helpful and allows calculating how many plots can realistically be implemented in total with the given resources. The precision of estimates can then only be influenced by the plot and estimation design.

It is important to note that the calculation of sample size in stratified sampling includes different allocation options that help to further optimize the distribution of sample size to different strata. There are 3 major criteria when allocating the samples to the strata:

1. stratum size N_h: the larger the stratum the more samples are allocated to it;
2. the variance σ_h^2 within the strata: the more homogeneous a stratum is, the less samples will be taken; and
3. Cost k_h : the higher the cost per sample plot, the less samples will be allocated in a stratum.

The respective allocation strategies are called proportional allocation, Neyman allocation and optimal allocation (For the notation used please refer to the chapter estimation design!).

Proportional allocation: $n_h = n \frac{N_h}{\sum_{h=1}^{L} N_h} = n \frac{N_h}{N}$

Neyman allocation: $n_h = n \frac{N_h \sigma_h}{\sum_{h=1}^{L} N_h \sigma_h}$

Optimal allocation: $n_h = n \frac{\frac{N_h \sigma_h}{\sqrt{k_h}}}{\sum_{h=1}^{L} \frac{N_h \sigma_h}{\sqrt{k_h}}}$

The required total sample size can be calculated by: $n = \frac{t^2 \sum_{h=1}^{L} \frac{N_h^2 s_h^2}{c_h}}{N^2 A^2}$

2.4.6 *Calculation of grid width*

Once the required sample size $n$is estimated based on precision requirements or determined by available resources, the width *d*of a quadratic grid can be calculated as:

$$d = \sqrt{\frac{Area(m^2)}{n}}$$

The area here refers to the total area of the sampling frame or stratum in which plots should be placed. In order to align the grid to the base grid of the NFI, the result of this calculation should be rounded to the closest integer multiple of the NFI grid width (example: if d=615m, it should be rounded to 625m, which is an integer multiple of 5000m).

In case that double sampling for stratification is applied, the grid with is already defined in the first phase of sampling (independent of the above calculations) and the second phase samples are selected as random subset of the first phase. The sample size in the first phase (and the resulting grid width) is here planned on other criteria: the sample should be possibly large and is only limited by the available resources for the visual interpretation of points. In practical terms a dense grid of 500x500m over all forest areas, or even denser, should be targeted. This might lead to some thousands of points (depending on the area size) that need to be interpreted. However, this desktop work is relatively cheap compared to field assessments and can usually be accomplished within reasonable time. Technical solutions to facilitate this are available and should be used. One option in this context is provided with the open source toolbox Open Foris by FAO. The Open Foris Earth collect is a tool that is especially designed for such kind of two phase sampling approaches and is easy to use and to configure for special needs.

2.4.7 Non-Response

In statistical sampling, non-response refers to those locations that cannot be observed because of special reasons. It might be that sample points fall in extremely steep slopes and cannot be reached or they are on private properties. In such cases the points should be marked (on the field form) as non-response. **Points falling on an area without trees inside the forest are not defined as non-response. They yield valid observations even if they are 0 in this case! A predefined sampling location should not be shifted to another place in any case!** Non response might also occur in remote sensing imagery, for example because of cloud cover or haze.

2.5 Plot design

“Plot design” refers to the “approach and actions” taken regarding observations once a sample point has been reached. “Plot design”, therefore, refers to the rules how sample trees are included around the sample point and to the measurement prescriptions for the variables to be observed.

The basic guiding principles for plot design definition in FMIs - including Indonesia- are as follows:

1. The plot design shall allow making observations of all variables that were identified necessary either as directly relevant variables or as indicator variables to establish complex variables. Commonly in FMIs, nested circular sample plots are established.

2. Regarding recording of sample trees, it is recommended that per sample plot (or sub-plot) there should be 15-20 trees observed. This has been mentioned as a guideline for an efficient definition of a plot size.
3. The plot design shall make provisions that as much variability as possible is captured per plot. This is frequently not well understood and confused with the explicit goal in experimental design to have homogeneous plots: inventories are not experimental but observational studies and highest precision is, in fact, achieved if one captures as much variability per plot as possible. As a consequence that means that variability between plots is kept low and this leads to a higher precision of estimation. Plot design optimization is a typical research issue and can best investigated when inventory data are collected in such way that the questions can be worked on and analyzed. It can be an important aspect of pilot inventories to systematically improve the corresponding information base and to make one step further in finding an appropriate plot design for the different KPHs or forest types in Indonesia.
4. The implementation of the plot design shall be logistically, financially and technically feasible within the resources and capacities available and the overall conditions given. Depending on the grid size and the available road infrastructure, the movement from one sample plot to the next will either be on foot or by car. In any case, walking times will be often long; and careful planning is required to minimize the "unproductive" walking time when no inventory measurements are taken.

In regard to the plot- (or observation-) design that is implemented at each sampling location, a minimum standard for whole Indonesia can only suggest basic design aspects. Considering the many very different forest types, various topographies, different information needs and management targets of KPHs, it will be necessary to adapt a basic plot design to local conditions in order to make it more efficient for the respective target variable. Forest types in Indonesia are highly variable, ranging from mangrove forests over lowland rainforest, peatswamp forest, to many other forest types. It cannot be expected that one single fixed design will be efficient for all these different conditions.

In general only unbiased estimators should be used. Fixed area Plots, nested plots, line transects of defined width, Relascope (Bitterlich-) sampling (depending on goals and purpose), or a combination of several designs are suitable design options. A minimum standard should further be easy to implement and to explain. The final plot design (e.g. the radius of nested plots) can then be adapted per forest type.

However, whenever possible the basic diameter thresholds, like e.g. the minimum diameter of included trees, should be similar and comparable between KPHs. In the following the proposed basic plot designs are presented.

In context of management inventories that have the goal to describe the actual state of resources but also their change over time, the plots should be planned as permanent plots. This means, the plot locations (a base grid) are fixed and exactly the same plots are measured during the next cycle of the inventory. The repetition cycle (temporal intervals) of inventories depends very much on the expected changes. A re-measurement of sample plots should not be done after very short intervals. Usually the changes in diameter and height of trees are hardly "detectible" after time intervals less than 5 years. This is because the measurement errors are exceeding the actual increment and no statistically significant change could be found. The repetition cycle is also limited by the restricted personnel capacity in each KPH and should therefore not be shorter than 5 years. This, however, refers to the plot measurements only. As basis for yearly management plans, it might be necessary to carry out surveys of the area also in shorter intervals.

2.5.1 Nested fixed area sample plots

In natural forests but also in degraded secondary forests the density of small trees is usually much higher than that of big trees. A single plot would therefore include a high number of smaller trees and only few big trees. Therefore, nested plot designs where trees of different diameter classes are assessed on plots with different radius are usually more efficient from a statistical point of view, at least if the target variable is volume, biomass or carbon (its lesser clear if the target variable is "biodiversity" with the number of species being the indicator).

From a practical point of view circular plots are usually easier to install and can also be better re-identified after a certain time period. However, if field crews are used to establish rectangular or quadratic plots or the available devices for an efficient implementation of circular plots are not available, such forms are also an option. In this case, however, slope correction and re-identification can become a critical issue. The basic plot design proposed here is therefore a nested circular plot design as shown in

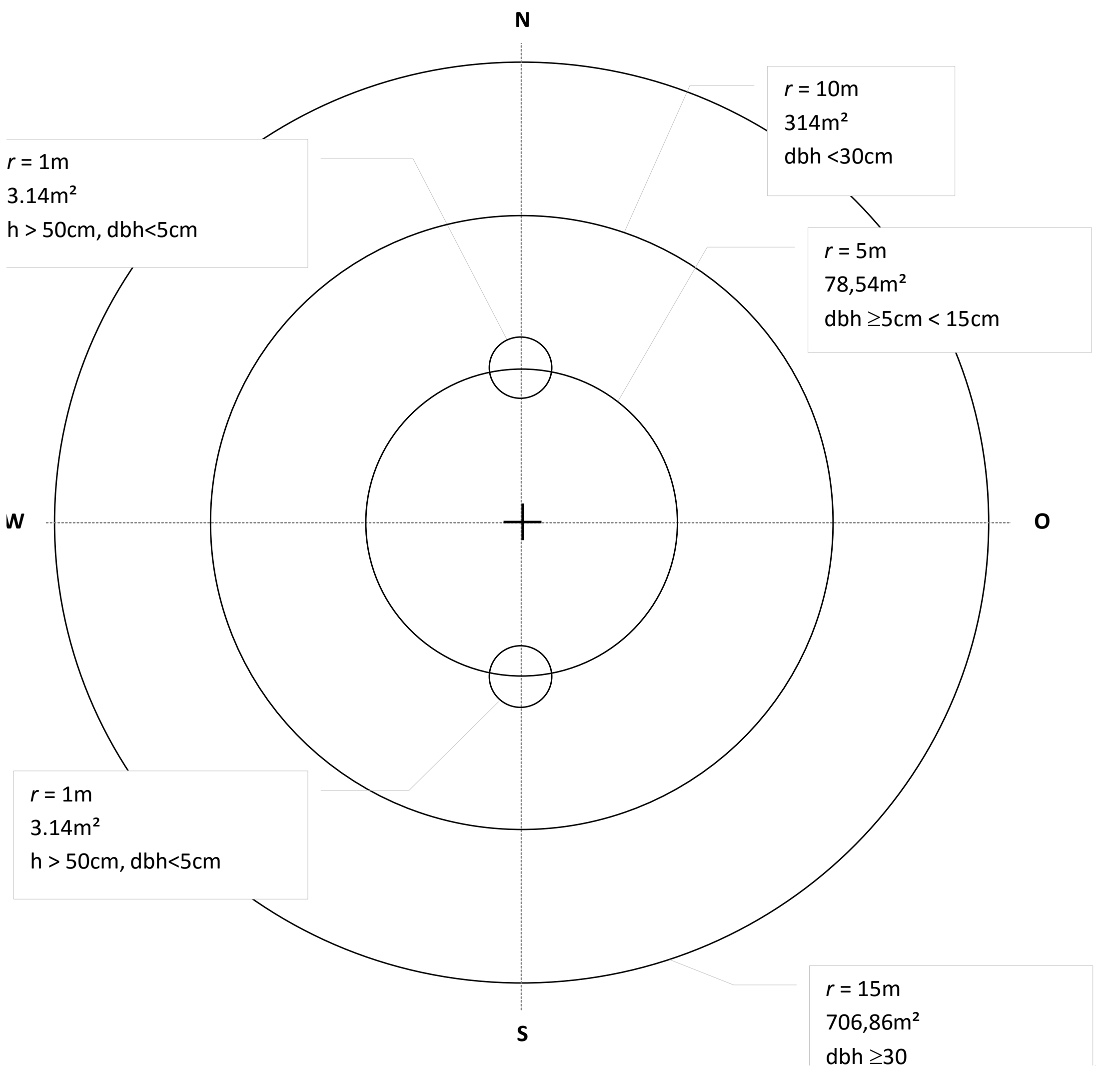

Figure 1. . Example of a nested circular plot design.

These different sub-plot sizes contribute considerably to streamlining field work and they optimize the estimation of stand characteristics: large trees, that contribute much more to basal area (and therefore also to the core variables volume, biomass and carbon), are included as sample trees with a much higher inclusion probability than smaller trees.

For analyses, then, these differences of inclusion probabilities must be taken into account by using different expansion factors per sub-plot when extrapolating the per-plot observations to the corresponding per-hectare "observation". The expansion factors EF are calculated from EF = (10000m²/sub-plot area) and are as follows:

- R=5m => EF5m = 127.32
- R=10m => EF10m = 31.38
- R=15m => EF15m = 14.15

It is important to realize that each one of these nested sub-plots is a full circular plot. It is NOT so that only rings are observed as some times mistakenly assumed!

The diameter thresholds and radii in the depicted figure **are an example and not necessarily optimal for all forest types**! Therefore a comprehensive guidance on how to adapt this basic design is given in 2.5.10.

The characteristics of the proposed plot design are the following: plots with three different radii are centered at the sampling location. In addition to that a cluster of two micro-plots are placed North and South of the sample point to assess small regeneration or ground vegetation. For a common minimum diameter of tree resources 5 cm are suggested (everything smaller is regarded as regeneration). The assessment of trees follows the simple rule (referring to the above example): trees with dbh smaller 15 cm are included up to a distance of 5m, trees ≥15 cm and <30 cm are included up to 10m distance and all trees ≥30 cm are measured up to a distance of 15m.

Even if trees are included in different plots, the data can be written in one table and the 3 plots can be assessed in one turn (not treating the plots individually). For the implementation only the center point needs to be fixed (contrary to rectangular plots where all corner points need to be located).

2.5.2 Regeneration sub-plots

Presence and composition (in terms of species and height classes) of tree regeneration is an important information for silvicultural planning as the future stands are recruited from this regeneration. Damages to regeneration (for example by cattle, goat, sheep or game browsing) may indicate the necessity for counter-actions.

Presence of regeneration depends on the overall development stage of the stand but very much also on micro-site conditions like light on the ground. The spatial pattern of regeneration is, therefore, diverse. There may be parts of the stand where there is no regeneration while regeneration is very dense elsewhere.

Regeneration is, therefore, commonly recorded on relatively small regeneration sub-plots (sometimes also referred to as “micro-plots”).

Here, we suggest to record regeneration on two regeneration sub-plots per sample point of R=1,5m each which are placed 5m to the North and to the South from the plot center. Regeneration sub-plots are commonly not placed directly around the plot center because there at the plot center, movements of field teams would possibly damage the regeneration by trampling.

Regeneration plants are counted and classified according to species and height classes.

The following three height classes h are distinguished:

Seedlings: 25cm < h ≤ 50cm

Saplings: 50cm < h ≤ 150cm

Established regeneration: h > 150cm and DBH < 5cm

Each one of the two regeneration sub-plots has an area of 7.07m². For estimation per plot, therefore, the two regeneration sub-plots cover 14.14m² which corresponds to a "regeneration expansion factor" of EFreg=707.4. That means, the observed number of regeneration plants in a specific height class for a particular species will be multiplied with EFreg=707.4 to extrapolate the per plot observation to the per hectare observation at this particular sample point.

2.5.3 Deadwood sub-plots

Deadwood is an important indicator for biodiversity and it is also one out of five carbon pools that need to be considered in UN-FCCC reporting. Deadwood is not necessarily a variable of immediate interest for forest management per se. However, if forest management is planned also with a focus towards conservation management, the dead wood stocks may be an important indicator for biodiversity and thus included into the forest management inventory, as well.

If there is specific interest in the forest district to also produce data on all carbon stocks relevant for UN-FCCC, the assessment of dead wood should be integrated into the FMI, because it constitutes one out of 5 carbon pools relevant for UN-FCCC reporting. While the assessment of deadwood is standard in modern national forest inventories, it requires a strategic decision of the KPH management whether to include dead wood also in the FMI or not. This may even be different for different forest districts, depending on the role that the recording of biodiversity / carbon data play.

Here, in this inventory protocol, the approach to data recording for dead wood is covered:

Down deadwood will be recorded on the R=5m sub-plot and on the R=10m, depending on its size class; these sub-plots constitute the "dead-wood sub-plots". Standing dead trees and stumps are recorded on the nested circular sub-plots together with the life trees in the corresponding diameter classes. Down dead wood refers to all stems and branches lying on the ground and have their thicker end within the deadwood sub-plot, and that refers also to uprooted trees.

Only dead wood is recorded that has a minimum diameter of 10cm; below 10cm, dead wood is considered “litter” according to the UN-FCCC definitions. If national definitions are different, this needs to be adjusted here.

For crown deadwood, every branch with the target diameter and bigger is considered an extra piece of deadwood and is recorded separately (if the thicker end is within the deadwood plot and has a minimum diameter of 10cm).

Pieces of deadwood that do not have their thicker end in the dead-wood sub-plots will not be counted even if part of them are covering the dead-wood sub-plots.

Freshly cut trees that will be extracted are not counted as dead wood. Old felled timber, however, that will not be extracted but will remain in the forest decaying are considered deadwood. If there are piles of such left wood, each piece is considered extra, along the conditions defined above.

For all counted lying deadwood parts, the length and diameter at both ends are measured so that the Smalian formula can be applied. A piece of deadwood according to the definition in this FMI ends where the diameter goes below 10cm.

2.5.4 Bitterlich (relascope) sampling

Bitterlich (or relascope-) sampling is a form of unequal probability sampling that is particularly efficient for the estimation of basal area per ha. It is a very fast and efficient technique that can be implemented by means of any device that defines a certain fixed opening angle (e.g. Relascope or Dendrometer). Bitterlich plots have no fixed boundary. Trees are included in the sample if their dbh optically appears wider than the critical width given by the device. An estimate of basal area is calculated by multiplying the counted number of included trees by a basal area factor that is specific to the defined angle defining the critical width.

With Bitterlich sampling the estimate of basal area can also be derived for different classes of trees, like e.g. commercial and non-commercial species. From these separated estimates the share of both classes on the total basal area can be derived. This relation might also be an indicator for the rehabilitation status of secondary forest.

Bitterlich sampling requires a relatively good visibility inside the forest and might be difficult if the understory is very dense.

2.5.5 Cluster plots

Cluster plots are a special form of fixed area plots that are composed of spatially dispersed subplots. Cluster plots can be integrated with other plot designs. In Figure 1 a cluster plot for the assessment of regeneration is combined with nested circular plots. Cluster plots have the advantage that more of the small scale variability of regeneration can be captured inside the plot compared to a single plot.

2.5.6 Transects of defined width

If an area left and right of a line is observed, the resulting observation unit is a long narrow rectangle. Such transects can cover large areas and might be a suitable design to assess NTFPs or other objects that occur in low density. However, it should be planned very carefully how much observation effort is put in such transects. Because of the large area the observations should be easy and fast to obtain.

2.5.7 Observation units for the assessment of NTFPs

The sustainable management of Non Timber Forest Products (NTFPs) is an essential part of the business plan for many KPHs. This is due to the fact that timber resources are degraded on large areas and need to be rehabilitated over a longer period before a sustainable management is possible. NTFPs usually occur in low density (amount per area) and are spatially dispersed over the forest areas. This makes it very difficult to estimate the amount based on relatively small forest inventory plots that are optimized towards tree resources. It is therefore recommended to combine different plot design in order to capture enough information on NTFPs in the field. For some rare NTFPs it is recommended to include interviews with local users in order to get information on harvesting rates and the actual amount.

In order to find efficient plot designs for these resources it is crucial to define the resources of interest first and to consider their occurrence in the planning of suitable observation designs. A suitable design will include, in average, enough NTFP resources per plot to derive sufficiently precise estimates of density and characteristics over the whole area, but will not lead to huge efforts in the field. It is hardly possible to advice a fixed design for all different NTFPs that are used in different KPHs all over Indonesia. Therefore, several options on how to include NTFPs in the proposed plot designs or by a combination with other observation designs are given.

2.5.7.1 NTFP use of tree species

Several tree species are of interest for NTFP use. Usually such trees occur in very low density and are scattered over the forest area. The same holds for rare species that are of interest in context of biodiversity conservation and a zonation of forest areas. Relatively small sample plots will rarely contain such a tree and are not a good basis to estimate the total amount or characteristics like diameter distributions. For such “rare events” very large plots are needed. One option for their assessment is to use the way that field teams walk from one plot to the next to take observations on the occurrence and diameter class of such trees (or other rare species and indicators, like Orangutan nests). In case that a straight transect line as connection between neighboring sample points can be installed, there are two options to define an observation design: Outgoing from the transect line, NTFP trees or other objects are observed up to a fixed distance (e.g. 15m to the left and to the right). This design would be equal to a long rectangular fixed area plot. The length of plots along the transect needs to be planned according to the expected average density of trees for the whole study area (not necessarily the total distance between plots needs to be observed). A second option is to record all individuals of the respective target species that can be seen from the transect line and to measure the horizontal distance to these trees perpendicular to the transect. Such an assessment would require a model based estimator where the detection probability of target objects depending on their distance to the transect needs to be modeled. This second approach requires profound knowledge on statistical estimation and modeling that might not be available in each KPH. However, standard software for distance sampling is freely available and can be used to plan and analyze respective samples (e.g. www.distancesampling.org). If the required capacity inside the KPH is not available, it is recommended to apply transects with fixed width.

One crucial point in establishing transects along the way from one plot to the next is that teams will not follow a planned systematic order of plots. For practical reasons the teams will choose the most efficient way to reach the next plot. Therefore it is hardly possible to ensure that the estimates from such transects are statistically unbiased. However, in order to get an overview about the existing resources and also for the purpose of a zonation, this might be accepted. Here the interest is more on presence/absence than on an estimation of the total number.

Figure 2 shows how a transect could be established along the way between two plots (here in West-East direction).The transect does not need to cover the whole disntance between two neighboring plots (this might be very long) but can be limited to shorter distances. In this case all transects should have the same length.

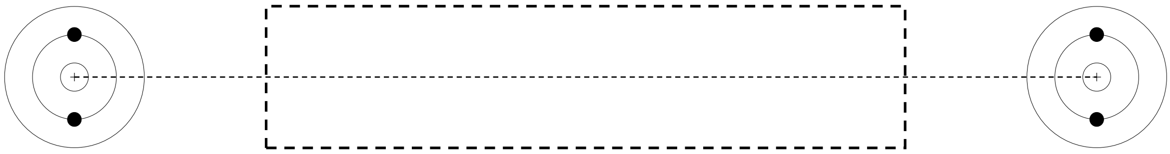

Figure 2. Establishing a transect for NTFP assessments (rectangular sample plot) along the way from one plot to the next.

2.5.8 *Slope correction*

The results of forest inventories refer to the horizontal map-projected area (like e.g. number of stems/ha or volume /ha). If sample plots are installed in sloped terrain, the horizontally projected area is smaller and not constant anymore. Therefore a slope correction needs to be considered. In practice there are two options to account for slope: 1) all distances on the plot are measured as horizontal distances, or 2) the size of plots on a slope is corrected such that the horizontally projected area of the plot equals the intended plot size.

The first option (measurement of horizontal distances) is practicable if measurement devices are used that automatically calculate the horizontal distance from the measured slope distance. Modern laser rangefinders or standard instruments like Vertex are useful in this context. However, it is not expected that such devices are available in each KPH and that inventories are probably implemented with basic equipment like tapes. In this case the radii of plots should be enlarged according to the slope angle. Therefore the respective new plot radius on the slope needs to be calculated such that the defined fixed plot area $F_p = \pi r^2$ remains constant in its horizontal projection. This corrected radius r_{slope} is then used to lay out the plots.

$$r_{Slope} = \frac{r}{\sqrt{\cos \alpha}}$$

For the calculation of the corrected plot radius the slope angle needs to be measured first. This angle should be measured as mean slope angle over the plot area, from the lower plot boundary to the upper side of the plot. The corrected slope radii are also written in the field form.

When applying Bitterlich sampling in sloped terrain the slope needs to be taken into account too; either by using an instrument that does the correction automatically (like a relascope), or by introducing the correction factor into the analysis if the slope is not automatically corrected (which is the case for simpler devices). The slope correction is then to be applied from slopes of 10% and more.

The correction factor is $\frac{1}{\cos\alpha}$ so that the basal area per hectare observation from one Bitterlich sample point is $G_i = k \cdot N_i \frac{1}{\cos\alpha_i}$, where G_i = corrected basal area (m2/ha) at the i^{th} sampling point, N_i = number of trees tallied at the sampling point and

α_i = angle of slope at the i^{th} sampling point.

2.5.9 Plots at the forest boundary

If a plot installed in the field intersects the forest boundary and is partly outside the forest, a correction is necessary. Therefore, a clear definition of the forest boundary is necessary, which is not always possible in the field. The correction is only necessary if a part of the plot is outside the defined sampling frame that is the forest area. It is not necessary in case of gaps without trees inside the defined forest area. Figure3 illustrate the mirage method that should be applied in such cases.

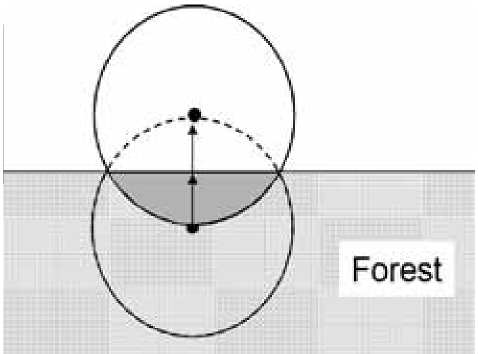

Figure 3. Mirage method to correct plots overlapping the forest boundary.

The center of the plot is mirrored at the forest edge outside the forest. From that new point, again a circular plot is laid out and all trees in the forest area tallied again which fall into it; these trees are observed twice (the gray area in the figure). As the respective trees are already recorded on the field form, they don't need to be measured again, the entries are just copied and recorded twice.

2.5.10 Adaption of plot size to local conditions

Plot design can be optimized for a given local forest condition if previous information about the area of interest is available. An efficient plot design will gather the necessary information at each sampling point with a reasonable effort. Plot design can only be optimized towards a single variable of interest (i.e. volume, biomass, biodiversity, etc.).

Therefore, there is not a unique optimum plot design which satisfies the requirements for all variables of interest. The following overview on optimizing the size of inventor plots refers to tree resources exclusively and addresses the above mentioned plot designs 1) fixed-area plots, 2) nested fixed-area plots, and 3) Bitterlich plots.

Adaption of fixed-area plots.

In fixed area plots, all trees above a given diameter at breast height (DBH) are measured within the plot area. These plots have two main design elements: 1) the minimum DBH for a tree to be measured, and 2) the size (area) of the plot. The minimum DBH is set based on the objectives of the inventory. Thus, if the inventory is mainly focused in commercial volume stock the minimum DBH can be larger than in the case where tree regeneration is also a variable of interest. A standard proposed here is 5 cm. The plot size should be calculated based on the desired number of selected trees within the plot ($T_{DESIRED}$). Because tradeoffs between data quality and efficiency, it is generally recommended to measure on average 18-20 trees per plot in average. Therefore, if the number of trees per hectare of interest ($N_{INTEREST}$, in this case those above the minimum DBH) was estimated by means of a pilot inventory, the plot size can be approximated with the Equation [1], where A (m^2) is the plot size and $T_{DESIRED}$ is the desired average number of trees per plot larger than the minimum DBH. Example 3 deals with the plot size optimization for fixed area plots.

$$A = T_{DESIRED} \cdot \frac{10000}{N_{INTEREST}} \qquad [1]$$

<u>Nested fixed-area plots</u>: Nested fixed-area plots are a specific case of fixed-fixed area plots, where trees of different dimension classes are measured in different fixed-area plots. These plots are known to be more efficient than fixed-area plots in natural forests, where it is a common situation to have many more trees of small diameter classes than on large diameter classes. Under such circumstances, fixed-area plot holds mainly small trees but only few large trees. This situation is usually not efficient for basal area and biomass estimation, as the large tree DBH classes are those contributing more to the total value of basal area or biomass per hectare. There are three design elements in nested fixed-area plots: 1) the number of nested plots, 2) the DBH thresholds (minimum and maximum) of the trees to be included in each nested plot, and 3) the size of each nested plot. There is no general recommendation on the number of nested plots, but the most common situation are designs with two or three nested plots. The DBH threshold for the trees to be measured in each nested plot are usually set based on commercial DBH classes, but they can also be optimized for a given variable of interest (see Example 4).

The size of each nested pot is related with the tree dimensions in a direct way: the larger the tree dimensions the larger the plot. The determination of the optimum size of each nested plot requires first setting the total number of trees to be measured in each nested design. It is generally recommended to measure a total number of trees per plot across all nested plots between 18 and 20 trees in average. The size of each nested plot can be optimized by using the Equation [1], where $N_{INTEREST}$ is now the number of trees per hectare of the trees to be measured within the correspondent nested plot, and $T_{DESIRED}$ is the number of trees to be measured on average on that nested plot. The Example 5 deals with the optimization of the plot area in nested fixed-area nested design.

<u>Bitterlich plots</u>: Bitterlich (or angle-count) plots select trees proportionally to their basal area, and therefore this technique is very efficient in the estimation of this variable. There is only one design element in this plot design, which is the basal area factor (BAF) to be used. It is usually recommended to select the BAF which selects at least 8 trees per sampling point in average. Therefore, if the basal area is known, the optimum BAF (BAF_{OPT}) can be determined with the Equation [2], where G is the estimation of the basal area ($m^2 \cdot ha^{-1}$) and $T_{DESIRED}$ is the desired average number of selected trees per sampling point. The Example 6 deals with the optimization of the BAF selection.

$$BAF_{OPT} = \frac{G}{T_{DESIRED}} \qquad [2]$$

Nevertheless, there is also a very important consideration in the selection of the optimum BAF, which is the visibility in the study area. To avoid biased estimations, it must be ensured that the selected trees are in the visibility range of the observer. In tropical forests with relatively low visibility and large trees, BAF is usually 4 or higher.

Conducting a pilot inventory

Plot design can be optimized if previous information about the study area is available. This type of information is gathered by means of a <u>pilot inventory</u>, which is a sampling study of similar characteristics than the forest inventory, but with the objective of collect enough information for optimizing both plot design ad sampling design. That supposes that some of the requirements for a sample based forest inventory are ignored (like the statistically sound selection of the sampling points). The aim of the pilot inventory is to test a plot design in all typical conditions, including extreme cases (e.g. very high and very low density). In the best case these different cases are selected proportional to their proportion on the total area.

As already stated above, the basic information for plot design optimization is the diameter distribution, which is the number of trees per hectare in each DBH class. In forest inventory, it is usual to consider DBH classes of 5 or 10 cm bin. Thus, if the minimum DBH to be measured is 5 cm, the fist diameter class would be 5≤DBH<10 for DBH for DBH classes of 5 cm bin, or 5≤DBH<15 for DBH classes of 10 cm bin. Even though the diameter distribution can be computed for each plot, for KPH management purposes we are interested in the mean diameter distribution across all plots. This diameter distribution is obtained by summing up all the trees measured in a given diameter class across all plots and dividing by the total number of plots. In plot design optimization, it is also important to calculate the total value of the variable of interest (i.e. basal area, biomass, etc.) per DBH class.

In computing the DBH distribution it is important to consider the plot design which was used in the pilot inventory, as it affects the way of expanding the per-plot values to per-hectare values. In fixed area plots, all DBH classes have the same expansion factor. Therefore, the average number of trees per plot multiplied by the expansion factor is the number of trees per hectare in such DBH class. But in nested fixed-area plots there are as many expansion factors as nested plots. The computation of the DBH distribution out of the mean records across all plots for fixed area plots and nested fixed-area plots is shown in Examples 1 and 2. For simplicity reasons in the expansion of the per-plot to the per-hectarevalues in nested fixed-area plots, it is recommended to set the DBH thresholds for the trees to be measured in each nested design to multiples of 5.

Example 1: Determination of the DBH distribution from a pilot inventory with fixed-area plots show the average records per diameter class collected in a pilot inventory with circular fixed area plots of 8 m radius. This data corresponds to a real forest inventory implemented in peat-swamp forest in the Sebangau National Park (Central Kalimantan, Borneo). *DC* is the center of each DBH class (i.e. 7.5 is the center of the DBH class 5≤DBH<10), *Np* is the number of trees per plot, *Gp* is the basal area (m^2/plot) and *Wp* is the aboveground biomass (Mg/plot) in each DBH class. It can be seen that 54.2 trees were measured on average on each plot, which demonstrates that the plot design implemented was not efficient. As all the trees were measured in the same fixed area plot, the per-hectare values can be calculated multiplying the same expansion factor (*EF*) for all DBH classes. *EF* is calculated with the Equation [3], where *A* is the plot size (201.06 m^2 in this case).

The columns N, G and W show the per-hectare values of the stand density, the basal area and the aboveground biomass, respectively.

$$EF = \frac{10000}{A} \quad [3]$$

Table 2. Diameter distribution (Np, trees·plot^{-1} or N trees·ha^{-1}) and values of basal area (Gp, m^2·plot^{-1} or G ·ha^{-1}) and aboveground biomass (Wp, Mg·plot^{-1} or W, Mg·ha^{-1}) for DBH classes (DC) of 5 cm. Data from Peat Swamp Forests In Sebangau National Park (Central Kalimantan).

DC	Per-plot			per-hectare		
	Np	***Gp***	***Wp***	***N***	***G***	***W***
7.5	31.277	0.127	0.897	1555.6	6.3	44.6
12.5	13.787	0.159	1.410	685.7	7.9	70.1
17.5	4.766	0.108	1.072	237.0	5.4	53.3
22.5	2.000	0.078	0.843	99.5	3.9	41.9
27.5	1.468	0.085	0.927	73.0	4.2	46.1
32.5	0.503	0.041	0.467	25.0	2.0	23.2
37.5	0.194	0.021	0.229	9.7	1.0	11.4
42.5	0.122	0.017	0.181	6.1	0.8	9.0
47.5	0.037	0.006	0.068	1.9	0.3	3.4
52.5	0.032	0.007	0.059	1.6	0.3	2.9
57.5	0.008	0.002	0.014	0.4	0.1	0.7
62.5	0.013	0.004	0.035	0.7	0.2	1.8
67.5	0.000	0.000	0.000	0.0	0.0	0.0
72.5	0.003	0.001	0.014	0.1	0.1	0.7
77.5	0.003	0.001	0.013	0.1	0.1	0.6
82.5	0.003	0.001	0.009	0.1	0.1	0.4
87.5	0.003	0.002	0.011	0.1	0.1	0.6
All	54.219	0.66	6.249	2696.6	32.8	310.7

Example 2: Determination of the DBH distribution from a pilot inventory with nested fixed-area plots

show the average records per diameter class collected in a pilot inventory with nested fixed area plots. This data corresponds to a real forest inventory implemented in secondary forest in the Harapan Rainforest (Jambi, Sumatra). The plot design consisted in three nested plots of: 15x15m (small), 30x30m (medium) and 30x50m (large). The threshold DBH for the trees to be measured in each nested design are: 5≤DBH<20 for the small sized plot, 20≤DBH<30 for the medium sized plot and DBH≥30 for the large sized plot. 43.4 trees were measured on average on each plot, which demonstrates that the plot design implemented was not efficient.

In the determination of the values per hectare with nested design it must be considered that not all the trees were measured in the same nested plot (see also 2.6.1).

Each nested plot has its own expansion factor (*EF*), and all the DBH classes being measured in the same nested plot must be expanded with the same *EF*. In this example, for instance, the *DC* 7.5, 12.5 and 17.5 share the same *EF*, which is 44.44 (see Equation [3]). The graphical representation of the diameter distributions in Figure4 shows the differences between the two study areas.

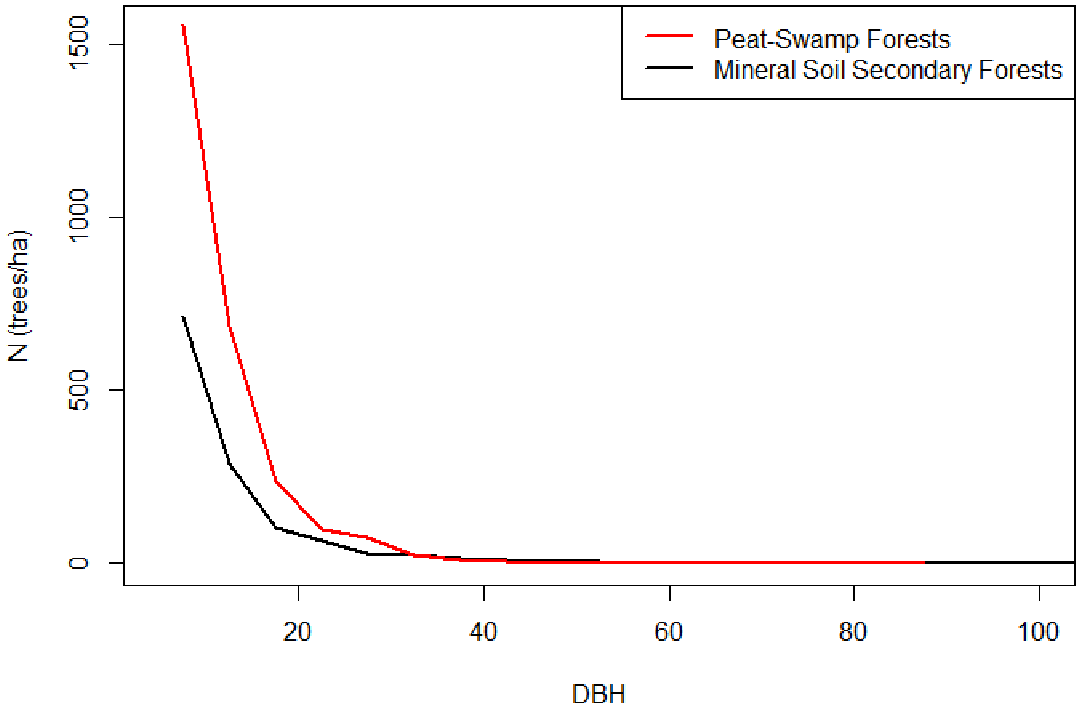

Figure 4. Diameter distribution for the Example 1 (red) and Example 2 (black).

Example 3: Determination of the optimum plot size for fixed area plots

Even though a nested plot design is superior in both cases, the general procedure of adapting size of a single fixed area plot is explained first. Supposing that the target number of trees per hectare to be measured in each plot is 20, the optimum plot size can be calculated based on the estimate of the total number of trees per hectare, information that can be extracted from the pilot inventory. Thus, the estimated stand density is 2697 trees·ha^{-1} for the Example 1 and 1265 trees·ha^{-1} for the Example 2. The plot size can be determined by using the Equation [1], which yields an optimum plot size of 74.2 m^2 for the Example 1 and 158.1 m^2 for the Example 2. By knowing the plot size, the plot dimensions can be determined for a given plot shape. In case of circular fixed area plots this would lead to a radius of only 4.85 m for the peat-swamp forest and 7.1 m for the lowland secondary forest. These plots are very small because of the high number of small trees. Single fixed area plots are therefore not optimal for such conditions and will lead to extreme values if a big tree or no tree can be found in such a plot.

Table 3. Diameter distribution (Np, trees·plot^{-1} or N trees·ha^{-1}) and values of basal area (Gp, m^2·plot^{-1} or G ·ha^{-1}) and aboveground biomass (Wp, Mg·plot^{-1} or W, Mg·ha^{-1}) for DBH classes (DC) of 5 cm. Data from Secondary Forests In Jambi (Sumatra, Indonesia).

DC	per-plot			per-hectare		
	Np	***Gp***	***Wp***	***N***	***G***	***W***
7.5	16.119	0.065	0.181	716.4	2.9	8
12.5	6.448	0.073	0.270	286.6	3.3	12
17.5	2.284	0.052	0.237	101.5	2.3	10.5
22.5	5.910	0.233	1.235	65.7	2.6	13.7
27.5	2.418	0.143	0.856	26.9	1.6	9.5
32.5	3.403	0.279	1.834	22.7	1.9	12.2
37.5	2.328	0.252	1.795	15.5	1.7	12.0
42.5	1.231	0.171	1.313	8.2	1.1	8.8
47.5	1.075	0.19	1.571	7.2	1.3	10.5
52.5	0.560	0.12	1.048	3.7	0.8	7.0
57.5	0.358	0.093	0.859	2.4	0.6	5.7
62.5	0.403	0.122	1.181	2.7	0.8	7.9
67.5	0.291	0.103	1.045	1.9	0.7	7.0
72.5	0.112	0.046	0.485	0.7	0.3	3.2
77.5	0.134	0.063	0.695	0.9	0.4	4.6
82.5	0.045	0.023	0.257	0.3	0.2	1.7
87.5	0.067	0.04	0.465	0.4	0.3	3.1
92.5	0.090	0.06	0.729	0.6	0.4	4.9
97.5	0.000	0.000	0.000	0.0	0.0	0.0
102.5	0.045	0.037	0.473	0.3	0.2	3.2
...	0.000	0.000	0.000	0.0	0.0	0.0
132.5	0.000	0.000	0.000	0.0	0.0	0.0
137.5	0.022	0.033	0.511	0.1	0.2	3.4
...	0.000	0.000	0.000	0.0	0.0	0.0
267.5	0.022	0.125	2.848	0.1	0.8	19
All	43.365	2.323	19.888	1264.8	24.4	167.9

Example 4: Determination of the DBH thresholds for each nested plot in nested fixed-area plots

As stated above, the DBH thresholds for each nested design in nested plots are usually set based on commercial dimensions. Nevertheless, these thresholds can be optimized for a given variable of interest. Even though there is not a unique way of optimizing the DBH thresholds, here we present a methodology, which can be used when the variable of interest can be expressed per diameter class.

In the two study areas considered in the present technical note, the basal area (G) and the aboveground biomass (W) was calculated per diameter class. Thus, the shows the non-cumulative values of N, G and W in the per-hectare basis. These values can also be expressed in cumulative way, which show the accumulated value of the variable of interest at each DBH class. A relative proportion is calculated by dividing the cumulative value by the total amount of the variable of interest across all diameter classes and multiplying by 100.

Figure 5 shows the cumulative values for the stand density (*N*, black lines), basal area (*G*, red lines) and biomass (*W*, green lines) as the percentage of the total value per hectare for the two study areas.

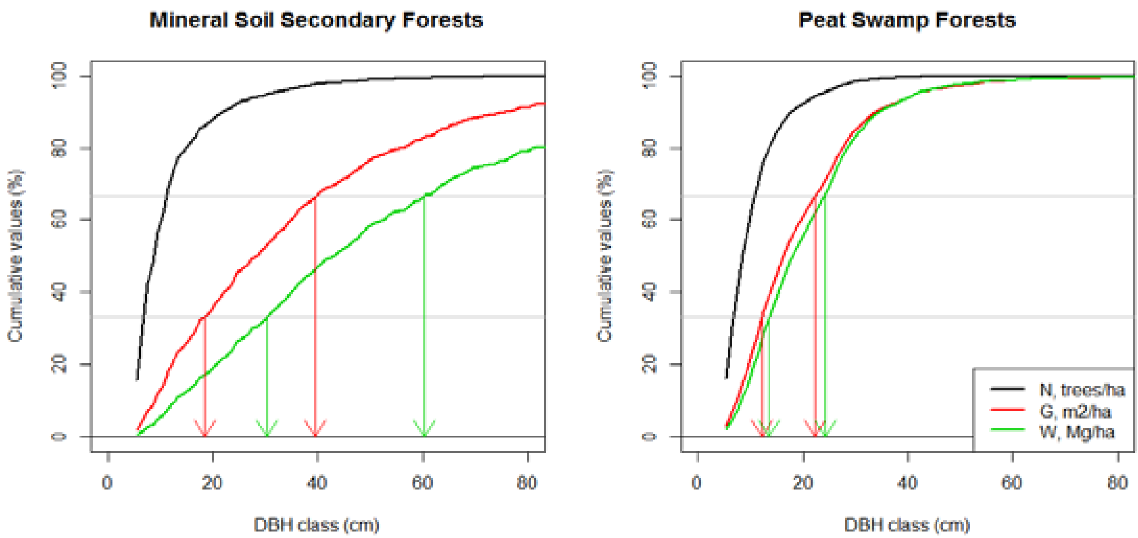

Figure 5. Cumulative values in percentage for the stand density (*N*, black lines), basal area (*G*, red lines) and aboveground biomass (*W*, green lines). The horizontal grey lines display 1/3 and 2/3 of the total value per hectare, and the arrows show the DBH thresholds which held <1/3, 1/3-2/3 and >2/3 for each variable of interest.

One way of optimizing is to adjust the DBH thresholds such that in each nested plot the same share of the total value of the variable of interest is assessed. For example, if three nested plots are used and the main variable of interest is basal area, it makes sense to find those DBH values that have the cumulative values of 1/3 and 2/3 of the total basal area. These thresholds would be optimum for the estimation of basal area, as each nested plot measure 1/3 of the total value per hectare.

Figure 2 shows the DBH thresholds calculated by using this approach for two different forest types and for two variables of interest (*G* and *W*). The figure show how different the optimum DBH thresholds can be for different forest types, even by using the same optimization criteria and variable of interest. The threshold DBH obtained with this approach for mineral soil secondary forests were 18.5 cm and 39.5 cm for basal area, and 30.3 cm and 60.2 cm for aboveground biomass, and for peat swamp forests were 12.2 cm and 22.2 cm for basal area, and 13.6 cm and 24.3 cm for aboveground biomass.

Example 5: Determination of the nested plot size in nested fixed-area plots

The determination of the nested plot size is the last step in the plot optimization process.

The formula to be used in this step is the Equation [1], and the calculus process was already described in the Example 3. As an example, we use the same design (number of nested plots and DBH thresholds) than described in Example 4 for mineral soil secondary forests when the variable of interest is basal area.

Thus, the number of nested plots is 3, and the DBH thresholds are 18.5 cm and 39.5 cm. The first consideration to be made here is that it is recommended to round the DBH thresholds accordingly to the desired DBH classes to avoid errors from the field crews in the plot implementation. Thus, it is recommended to round the DBH thresholds to 20 cm and 40 cm.

The next step is to decide on how many trees to measure in each nested plot. In this case, as we know that each nested plot will represent the same share of the total value of the variable of interest per hectare, it makes sense to design the plots to measure on average the same number of trees in each nested plot. Thus, in this case, we decide to measure 7 trees per nested plot (altogether 21 trees per plot in average).

By reading the **Table 3.** we can see that: the number of trees per hectare with DBH<20 is 1104.5 trees, the number of trees per hectare with 20≤DBH<40 is 130.7 trees, and the number of trees per hectare with DBH≥40 is 29.6. By using these numbers and the Equation [1], we came up with the plot areas of 63.4 m^2 (4.5 m) for the small sized nested plot, 535.6 m^2 (13 m) for the medium sized nested plot and 2364.9 m^2 (27.4 m) for the large sized nested plot.

Example 6: Determination of the BAF in Bitterlich sampling

When the basal area is the variable of interest, and the approximate value of the variable of interest is known by means of a pilot inventory, the BAF can be optimized for a desired number of selected trees. For the two case studies presented here, the estimation of basal area from the pilot inventory are: 24.4 $m^2 \cdot ha^{-1}$ for peat swamp forest and 32.8 $m^2 \cdot ha^{-1}$ for mineral soil secondary forests. By using the Equation [2], and assuming that our goal is to select on average 8 trees per sampling point, the optimum BAFs are 3.05 and 4.1. As not all devices allow using decimal BAFs, the values must be rounded to the closest BAF of the device to be used in the inventory.

In the rounding process, it must be considered that small BAFs select more trees, but far away from the observer, and large BAFs select less trees but close to the observer. As previously mentioned, the visibility in the study area must be considered to avoid estimation bias because uncounted trees, and therefore the selection of the BAF must take into account the visibility conditions of the study area.

2.6 Estimation design

The estimation design defines how the statistical estimates are derived from the defined sampling design and plot design. The estimators (formulae) need to comply with these two design elements. Only sampling and plot designs shall be employed for which estimators are known. This is, for example, not the case, when plot designs are subjectively adapted in the field according to specific situations encountered, like shifting the plot position or enlarging the plot size.

Results of forest inventories are commonly reported as per-hectare values, and the estimation design defines how these values are calculated in a statistically sound manner. This refers both to the so-called point-estimates (including mean values and totals) and to the so-called interval estimates (including standard error and confidence intervals). It is an important feature of reporting of forest inventory results that all estimates are accompanied by precision statements; these precision statements inform the data user about the “statistical reliability” of the results. Further, information about precision of estimation is an important basis for the optimization of sampling design and plot design and may lead to considerable increase in cost-efficiency of an inventory system.

It is important to realize that all results derived from sampling studies are estimates. Therefore, when reporting results it is correct to write, for example “the growing stock is estimated to be xxxm^3/ha” and not “the growing stock is xxxm^3/ha”.

2.6.1 Calculation of plot values

Target of the estimation is to describe the mean conditions of variables in different classes or areas. Therefore it is necessary to first calculate the “observations” per plot. If a nested plot design is used, where trees of different diameters are measured in plots of different radius, a common reference area needs to be adopted in order to “upscale” the different plots to one common basis. This common basis is 1 ha. All per-plot observations need, therefore, to be converted by extrapolation to per-hectare values resulting in, among others, results for basal area/ha, number of trees/ha, or volume/ha.

In the database or spreadsheet where all single tree measurements are recorded, the respective expansion factor (EF) for trees of different diameters needs to be considered. The expansion factor is the relation between 1 ha (10,000m^2) and the respective plot areas on which trees in a certain diameter class were measured.

The expansion factors for the nested circular sub-plots, for example, are calculated from the individual sub-plot radii r from:

$$EF = \frac{10.000}{\pi r^2}$$

Taking the plot design depicted in Figure 1 as example, trees smaller 15 cm are measured up to 5m distance, while trees ≥15 cm and <30 cm are included up to 10m distance. Trees ≥ 30 cm are measured up to a distance of 15m. The respective expansion factors are then:

For trees <15cm: 10,000m²/Pi*5m^2 = 10,000m²/78.54m² = 127.32
For trees ≥15cm and <30cm: 10,000m²/Pi*10m^2 = 10,000m²/314.16m² = 31.83
For trees ≥30 cm: 10,000m²/Pi*15m^2 = 10,000m²/706.86m² = 14.14

All area related values of single trees need to be multiplied with the respective expansion factor in order to derive the observation/ha (e.g. the volume of a tree or the basal area of a tree). For the number of trees/ha the expansion factor itself can be used. These up scaled single tree values can then be aggregated per plot. The total number of trees/ha would be the sum of all expanded single tree values (imagine we found only one tree per diameter class, the result for the given example would be 127.32+31.83+14.14=173.29 trees/ha).

All further estimation of means and totals for area related variables (derived from single trees) will be based on these aggregated plot observations (per ha values).

2.6.2 Estimation of means, totals and variance

In the following the statistical estimators for systematic sampling, stratified systematic sampling and double sampling for stratification are presented. For a full coverage of the basics of design based sampling and for more detailed elaborations on estimation and estimators, textbooks in statistical sampling or on sampling for forest inventory should be consulted.

In context of management planning on KPH level, it is questionable whether all information is required as statistical estimate with a confidence interval. In context of actual short term planning, the responsible KPH might be satisfied with a reliable estimate of means and total, maybe combined with expert opinions on the actual situation. Nevertheless, it is important to consider that the selected estimators must fit to the applied sampling- and plot design, otherwise results might be biased or wrong. In the following a set of estimators for the proposed design alternatives are presented.

2.6.3 *Estimators for simple random sampling (to be applied for systematic sampling)*

Simple random sampling is rarely (if ever) applied for forest inventory and monitoring, because there are more efficient sampling designs. However, simple random sampling estimators are frequently applied to systematic sampling design: in the absence of an unbiased statistical variance estimator for systematic sampling, the estimator for simple random sampling is commonly used as one option to approximate the estimated variance in systematic sampling. This estimator is known to be upwards biased to an unknown extent if applied to systematic sampling. In practice this means, he true variance is assumed to be lower than the estimated variance in practically all cases. This also means that the estimate of precision is a so-called conservative estimate and the true standard error of estimates is assumed to be lower; in many cases it is much lower, but it is always unknown how much lower.

Mean: $$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$$

Variance: $$s^2 = \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}$$

Standard deviation: $$s = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}}$$

Standard error: $$s_{\bar{y}} = \frac{s_y}{\sqrt{n}}$$

Where,

N	=	number of sampling elements in the population (= population size);
n	=	number of sampling elements in the sample (= sample size);
y_i	=	observed value of *i*-th sampling element;
μ	=	parametric mean of the population;
$\bar{y}$	=	estimated mean;
σ	=	standard deviation in the population;
s	=	estimated standard deviation in the population;
σ^2	=	parametric variance in the population;
s^2	=	estimated variance in the population;
$\sigma_{\bar{y}}$	=	parametric standard error of the mean;
$s_{\bar{y}}$	=	estimated standard error of the mean.

Most relevant for any reporting from forest inventories is the mean value (point estimate) and the standard error (interval estimate) where the latter is usually reported in a standardized manner as relative standard error in order to allow for comparisons also for variables that have markedly different mean values.

2.6.4 Estimators for stratified sampling

Stratification means "subdivision of the population into sub-populations" and these sub-populations are called strata. In each stratum an independent sampling study is carried out. Notation must carefully be observed then in order to avoid confusions.

We use the following notation which is common in large parts of the sampling textbooks:

L Number of strata, where $h = 1,\ldots, L$;

N Total population size;

N_h Size of stratum h, thus $N = \sum_{h=1}^{L} N_h$;

y_{ih} Value of the variable Y measured on the ith sampling unit in the hth stratum;

$\bar{y}$ Estimated mean of the entire population;

$\bar{y}_h$ Estimated mean for stratum h;

n Total sample size;

n_h Sample size in stratum h, thus $n = \sum_{h=1}^{L} n_h$;

s_h^2 Estimated variance in stratum h;

$\hat{\tau}$ Estimated total of the entire population;

$\hat{\tau}_h$ Estimated total in stratum h, where $\hat{\tau}_h = N_h \bar{y}_h$;

c_h Relative size of stratum h or weight of stratum h, where $c_h = \frac{N_h}{N}$;

$\hat{\text{var}}(\bar{y})$ Estimated error variance of the estimated population mean;

$\hat{\text{var}}(\hat{\tau})$ Estimated error variance of the estimated population total.

The estimated mean in stratum h is

$$\bar{y}_h = \frac{\sum_{i=1}^{n} y_{ih}}{n_h} \text{ and}$$

The estimated population mean, i.e. the mean value for the entire population is

$$\bar{y} = \sum_{h=1}^{L} c_h \bar{y}_h = \sum_{h=1}^{L} \frac{N_h}{N} \bar{y}_h = \frac{1}{N} \sum_{h=1}^{L} N_h \bar{y}_h \,.$$

The estimated total population value, i.e. the total for the entire population is

$$\hat{\tau} = N\bar{y} = \sum_{h=1}^{L} \frac{N_h}{N} \hat{\tau}_h = \sum_{h=1}^{L} N_h \bar{y}_h$$

The estimated error variance of the estimated population mean is

$$\hat{\text{var}}(\bar{y}) = \sum_{h=1}^{L} \left[\left(\frac{N_h}{N} \right)^2 \hat{\text{var}}(\bar{y}_h) \right] = \frac{1}{N^2} \sum_{h=1}^{L} \left(\frac{N_h^{\,2} s_h^2}{n_h} \frac{N_h - n_h}{N_h} \right)$$

The estimated error variance of the estimated total population value follows then as

$$\hat{\text{var}}(\hat{\tau}) = \hat{\text{var}}(N\bar{y}) = N^2 \, \hat{\text{var}}(\bar{y})$$

2.6.5 *Estimators for double sampling for stratification*

Notation in double sampling for stratification is similar to stratified sampling, only that we distinguish between the two phases:

L Number of strata;

n' Total number of samples in the first phase;

n'_h Number of samples in *h* stratum in the first phase;

w'_h Weight of stratum *h*;

$\bar{y}_h$ Estimated mean of target variable *Y* in stratum *h;*

$\bar{y}$ Estimated mean of the target variable *Y* for entire area of interest;

s_h^2 Estimated variance of the target variable *Y* within h^{th} stratum.

The relative size of stratum *h* = the stratum weight as estimated from the first phase, is $w'_h = \frac{n'_h}{n'}$ and then the estimated mean of the target variable *Y* for entire area of interest $\bar{y} = \sum_{h=1}^{L} w'_h \bar{y}_h$.

This estimator corresponds to the estimator in stratified random sampling, only that strata weights are also random variables here that are estimated, which affects the variance estimate.

The estimated error variance is then $\hat{\text{var}}(\bar{y}) = \sum_{h=1}^{L} \left(w_h'^{\,2} \frac{s_h'^{\,2}}{n'_h} + w'_h \frac{\bar{y}_h - \bar{y}^{\;2}}{n'} \right)$

2.6.6 *Estimating areas*

Estimation of areas is not necessarily at the core of FMIs (contrary to NFIs). However, estimation of the area of defined strata over the entire KPH is usually of interest. Other criteria of breaking down the total forest area may be of interest, including classes such as "forest area under legal protection" or "forest area out of management" or "forest area that suffers from severe degradation", to name just a few.

Areas are frequently determined by remote sensing analysis where also maps can be produced; accuracy assessments are commonly done to characterize the quality of these maps. However, areas can also be estimated by field sampling where precision statements can be given and confidence intervals estimated. Of course, maps cannot be produced from field observations alone, but area statistics only.

A typical approach is that the dimensionless sample points (the sample plot centers) are taken as observation unit and the characteristic of the sample point is recorded at each sample point, for example degraded/non-degraded. Degraded forest/non-degraded forest is a dichotomous variable that can take on only two values, which are converted for analysis in the numeric values 1="degraded forest" and 0="non-degraded forest". The cover proportion of a particular condition class is estimated from the fraction of points that hit the target class. If, for a sample of size n a number of n_f points fall into degraded forest and $n_{nf} = n - n_f$ in non-degraded forest the proportion of degraded forest in the inventory region is estimated from

$$\hat{p} = \frac{n_f}{n}.$$

This estimator corresponds exactly to the mean estimator $\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$ for simple random sampling as described before, when admitting only the two values 0 and 1 as observations y_i.

And, with q=1-p, the error variance of the estimated forest proportion $\hat{p}$ is estimated from

$$\hat{\mathrm{var}}(\hat{p}) = \frac{\hat{p}\hat{q}}{n-1},$$

which is valid for large populations. Confidence intervals can then be constructed in the usual manner.

These estimators are unbiased for simple random sampling. Applied to systematic sampling, as for the FMIs, the same considerations hold as elaborated before:

Application of the estimators for simple random sampling will be unbiased for the mean but upwards biased for the estimation of the error variance, thus producing a conservative estimate.

2.7 Data management and analysis

The proper management and analysis of inventory data is a key element in the inventory process and ensures that the information collected in the field can be used for planning purposes. A suitable strategy to analyze the data and to produce the required information as basis for management plans should be planned from the outset of the study. The presented estimators need to be applied correctly and data should be kept in a database that is maintained permanently to allow access to the data for all relevant stakeholders. As data management, analysis and the generation of reports and outputs requires expert knowledge, it is recommended not to leave this important part in the responsibility of the single KPHs, but to establish experts on regional or provincial level to support database management and data analysis.

Instead of developing an own data management and analysis framework, it is recommended to apply existing solutions, like the Open Foris toolbox provided by FAO. Open Foris collect is a survey designer that is a recursive database engineering tool that allows constructing a relational database according to a schema that is defined by the user.

This schema needs to be build up in accordance with the hierarchical structure of the underlying sampling design and requires a clear sampling protocol. Open Foris Calc is a robust tool for data analysis and results calculation. The input data and metadata come from Open Foris Collect and Calc provides a flexible way to produce aggregated results which can be analyzed and visualized through the open source software Saiku. Calc allows expert users to write custom R modules to perform calculations working with a variety of sampling designs. Once the schema is published Calc creates a PotgreSQL database. Access to this data base is also possible with the pgAdmin III (PostgreSQL administration and management tools). Further, the database could also be accessed via R, a powerful free software for statistical computing, which is an interesting option for data analysis and reporting.

2.8 Accompanying research

FMIs are specific empirical studies that have largely scientific character; they need to be planned, implemented and analyzed accordingly. Many FMI specifications can be defined on the basis of existing information and existing knowledge.

However, for a number of issues, specific research is required to obtain optimal / appropriate solutions.

These studies are not part of the regular inventory project but may be carried out in collaboration with the inventory project, implemented either by independent research institutes (e.g. national universities or international collaborations) or by the inventory unit in the National Forest Agency. In any case, these research studies offer great opportunities for (1) research collaborations, (b) for the advancement of forest science in the country and (c) for capacity development for interested students and scientists.

Many research issues do commonly occur during planning and implementation of FMIs. Not all can timely be worked on and not for all will there be an operational solution yet during the specific FMI project. However, any study that starts during implementation of the first FMIs in Indonesia will contribute to building up forestry knowledge in the country; and other forest inventories will benefit from the results, at the latest when the next phase of the inventory is implemented.

In the following, some research issues are addressed that may typically occur in the context of FMIs, with special reference to the conditions in Indonesia. It is likely that more research issues will come up during implementation of the first FMIs; it is important then, that it is clear to which unit these tasks / requests can be assigned to.

2.8.1 Volume and biomass models

Volume and biomass models are important “tools” for the determination of individual tree and stand biomass, as the variables “biomass” and “volume” cannot directly be measured, but need to be modelled from easier to measure variables. These “easier to measure” variables are typically *DBH* in stand-wise inventories and in forest management inventories that refer to relatively small units of reporting where relatively stable relationships *DBH*/height may be assumed and relatively stable form factors. For large area inventories, like national forest inventories, however, much more variability will be present, and typically more variables are measured to model volume and biomass: in addition to *DBH,* the tree height is also included to capture the variable relationship between *DBH* and *height* and an *upper diameter* (sometimes in fixed height, sometimes in relative height) to capture variability in stem form factor.

If volume and biomass models are not available, they must either be constructed or models from neighboring regions are used whose suitability must be checked first. Both activities (building new models and checking the suitability of existing models) are typical research tasks and typical examples for accompanying research.

Such studies are not a generic part of the inventory work, but data collection for such purposes may easily be integrated into the FMI field work. Also needs and specifications of models may better be defined and the quality of models better be tested when seizing the experiences of FMIs.

For the estimation of removals, volume models are needed that allow **predicting tree volume from stump measurements**, if not existing already. Such model development can most easily be integrated into a forest inventory by measuring at a subset of trees not only the *DBH* but also the *diameter at stump height:* from these pairs of observations, a simple model can be built that allows predicting the *DBH* from the stump diameter; then, standard *DBH* based models may be applied, possibly using a mean tree height for the predicted *DBH*.

When producing new volume and biomass models, these must be documented in a comprehensive manner, best together with all sample tree data used. Only with a transparent and complete documentation it will be possible to use this information later for a potential enhancement of the models.

2.8.2 Remote sensing models

Remote sensing based regionalization may be tested for the provision of localized information, if suitable regionalization approaches can be developed. Field plot observations serve then as training data and remote sensing data as carrier data. With an appropriate model, forest characteristics may be predicted for each pixel. As with all modelling approaches, the quality of such stand-wise prediction is exclusively a function of the relationship that can be established between field observations and the remotely sensed data. Terrain conditions and forest types in Indonesia are such that the development/identification of suitable models is a generic research work and not a standard task in FMI implementation.

The type quality of stand-wise information that can possibly be produced in that way cannot be predicted. It is likely, however, that it will be limited to categorizations; for example “high”, “medium” or “low” growing stock; or “degradation” and “no degradation” or alike classes regarding species composition. Another application of remote sensing may be relevant for non-response: it may happen in FMIs that some field sample locations cannot be searched in the field with reasonable efforts.

Then, a prediction for this sample location may be produced by remote sensing by applying the MSN technique (= most similar neighbor technique): the spectrally most similar sample plot is identified and its values are transferred to the non-response plot.

2.8.3 Installing demonstration areas

The implementation of the FMI offers an excellent opportunity to install permanent observation and demonstration plots in the KPHs that have more an experimental character. The goal is to learn more about the long-term effect of different forest management or other intervention schemes. The FMI may serve here to identify stands that exhibit suitable conditions in terms of site conditions, forest structure and management. These demonstration areas must not be identical with the sample plot positions, but may be nearby. They must be larger and should be maintained and monitored by the forest research unit of the Ministry. Such research sites will then contribute to systematically generate knowledge on the effect of forest management for each forest type.

2.9 QA/QC (Quality assurance and quality control) in forest inventories

2.9.1 General considerations regarding QA/QC in forest inventories

Quality assurance is an important element in forest inventories: at the end, it is the quality of the produced data and the quality of the derived information that generates credibility for the whole of the inventory study. Any avoidable quality flaw may impair the whole inventory study and make that the results are not accepted nor used for decision making. This is relevant for all inventories, but in particular when it may be expected that the inventories possibly produce unexpected or undesired results.

Quality considerations are accompanying all steps in inventory studies: in planning, in implementation and in analyses and reporting.

Quality assurance aims

1 at avoiding crude errors (= the true mistakes where something has been done wrongly) and

2 at reducing random errors (= the residual variability that is present in all empirical studies).

The methodological soundness of the statistical inventory design is also part of quality assurance; it is entirely in the responsibility of the inventory planners.

2.9.2 Preparation of field teams as measure of quality assurance

Regarding field work, the probably most important actions in inventory planning and implementation regarding quality assurance are *training* and *motivation*. Field teams must be comprehensively trained and skilled to carry out the technical measurements – but they must also understand well their important role within the inventory process.

All field team members – including those with the least paid role - must understand their responsibility within the inventory system: the quality of field observations is among the most important elements in overall inventory quality and contributes a lot to making a good and high quality inventory.

Crude errors are best avoided when measurement devices are calibrated at frequent intervals and when each measurement/observation is cross-checked by another field team member, either through checking for plausibility of measured values or through checking for agreement regarding categorical or nominal variables. Random errors are best reduced by taking the time to carefully use the measurement devices.

Only well motivated field teams will have the ambition to do high quality measurements. Motivation is generated by good guidance and leadership and by actively building a corporate identity among field teams which means that at regular time intervals meetings of all field teams may be organized for an exchange of experiences. There are many more points that contribute to keep motivation high: offering an adequate and fair payment, defining a well doable daily and weekly workload, and taking seriously into account, to the extent possible, concerns of the field team members when planning the field campaigns. Field teams should also be equipped with modern measurement devices and receive appropriate training to use these devices. Training, however, should not only focus on the (certainly most important) technical side of measurements but also on the set of definitions used and the general background of the inventory.

2.9.3 Control measurements

Control measurements are an integral component of all field inventories, even though there are no generally accepted standards, neither regarding their implementation nor regarding their analyses and consequences. It is generally recommended to measure between 5% and 15% of the field plots again in order to check for compliance with the field protocol and the quality standards. Such control measurements (sometimes also referred to as "check cruising") need to be carried out by a supervisory team that is entirely independent of all field teams and that reports exclusively to the inventory managers.

They need to know all details of the field protocol and the background of the ongoing inventory and monitoring study and have at the best participated as instructors at the training of the field teams.

The ultimate and only **goal of the control measurement is quality assurance**. The mere knowledge that any field plot might independently be controlled may contribute to positive motivation and ambition of the field teams. One may also consider paying an extra premium to the field team(s) that achieves the highest data quality.

But also, one may impose re-measurements of some or all plots to field teams where severe mistakes were identified that may invalidate the inventory; or one may even terminate the contracts with field teams as a result of these quality checks. All these measures and conditions should be explicitly formulated upfront in the contracts/working agreements with the field teams.

Control measurements of field work are generally implemented along two strategies:

1 The supervising team accompanies the regular field team on a normal field work day and observes and comments, where necessary, on the work procedures. Such control is sometimes referred to as “hot control”. These “control measurements” have very much the character on “on-the-job-training” and may contribute to motivation of field teams in particular when it turns out that the job is well done. In fact, “hot checks” are not truly independent controls as it is quite obvious that field teams´ acting may be different when accompanied by a supervision team. Therefore, only a minor part of the control measurements shall be implemented as “hot checks”, maybe 20% of all controlled sample points.

2 The supervision teams go independently out to measure again field plots that had already been recorded by the regular field teams. Such independent control is sometimes referred to as “cold control”. The supervision team carries with them all data and documents of the regular field team and checks all recorded data for their validity and quality.Here, of course, it is of very high relevance that the field plot position can straightforwardly be found. If the plots cannot be found by the supervision team with the documentation provided, such a plot would be a lost plot for a permanent inventory.

  Table 4 gives an overview of different categories of variables to be checked. For a specific inventory, error limits need to be defined for all variables in order to build an evaluation system that allows to objectively identify serious issues that need to be tackled in order to maintain inventory quality high.

Commonly, quality of measurements and observations are categorized into three classes:

- “Good” – that is: the observation is within “normal” ranges of variability and this variability is not expected to have an impact on the results.
- “Acceptable” – that is: the observation is slightly beyond the “normal” ranges of variability but one would not expect a major impact of this deviation on the results.

- "Not acceptable" – that is: the observation is so widely beyond the "normal" ranges of variability that one may expect a serious impact of this deviation on the inventory results.

It is the decision of the responsible inventory planners to devise an evaluation system from this classification of measurements/observation. Again: there are no established standards.

Table 4. Main categories of variables to be checked during control measurements (cold checks)

Identification of sample point (location of iron tube)	For a "good quality" the point should rapidly be found with the documentation prepared by the regular field team. If the plot center cannot be found within a reasonable time frame, this one of the most sever errors because it means that this plot location is lost for future inventories. Either the supervision team will establish a new plot and produce a better documentation – or the regular field team – that produced this error - is mandated to correct this error.
Sub-plot positions	Same as for sample point – where one may commonly assume that the sub-plot positions can straightforwardly be found once the sample point position has been identified.
Plot- and sub-plot sizes	Incorrect application of plot sizes means that too many or too few trees are recorded. This has a severe impact on extrapolation of the plot measurements to per-hectare values as incorrect plot sizes make that the expansion factors do not correctly apply. Slope correction is a potentially important source for this error and plot size checking must always take into account the slope angle measurement.
Metric variables	For all metric variables the ranges of "good" measurements and of "acceptable" measurements need to be defined. For *DBH* these ranges may be given in absolute terms (mm) or in % - and may vary for trees with a rough bark and a smooth bark or the special case of buttressed trees. For height measurements, a distinction may be made between different tree dimensions.
Categorical variables	By far the most variables in an inventory are categorical variables, and their immediate relevance for the inventory varies. For categorical variables that follow an order (= ordinal variables such as "damage class") one may define ranges for good and acceptable observations. For most of the truly categorical variables where the observations are "categories without an order" (e.g. management type) and for nominal variables (e.g. tree species) there is only "right" or "wrong" so that the 3 quality classes cannot be reasonably constructed for individual variables. However, three classes may be applied to a *set of categorical variables* per plot, if, for example, a certain percentage of incorrectly classified categorical variables exceeded.

The **selection of field plots for "hot" and "cold" control** is done by the inventory planners in an entirely independent manner. Any influence by field teams or prior information of field teams must be avoided because this would impair the value of the control measurements. Control measurements must cover *all* field teams and per field team a high variety of field conditions; that means that also difficult field plots must have a fair chance to be controlled.

In order to properly implement both cold and hot checks, the inventory planners must be constantly informed about the work progress and the work plan of all field teams so that the work plan of the supervision team can efficiently be planned for both cold and hot checks.

While cold checks can be implemented at any time after the regular field measurements by the field teams, hot checks need to be carefully coordinated with the field teams. These hot checks shall not cause interruption or delays in fieldwork implementation for the regular field teams. The checks should be announced some days in advance; however, without the option that the field team "adjusts" the fieldwork schedule at short notice.

Usually, the results of the control measurements are reported together with the detail results of the inventory. They are part of the inventory´s quality information, together with the information, for example, about the standard error. Results of the control measurements are commonly *not* used for a "calibration" or "adjustment" of the collected data.

2.10 FIM process – suggested workflow

This chapter describes the implementation steps for a FIM. It focuses on the technical steps while the institutional setup and the need to accompany this process by intensive capacity development and research studies is addressed only briefly.

It is assumed here that an "inventory unit" under the responsible Ministry is in place which coordinates, supervises and guides FMI implementation in the KPHs and is staffed with a sufficient number of experts who either can directly supervise, guide and support the implementation of measures of all FMI related activities (planning, implementation, analysis, reporting) or have the expertise to contract and supervise external experts.

It is also assumed that there is an appropriate legal basis that defines the need and format of FMIs and their implementation.

This is not only important for the technical implementation of FMIs but a prerequisite at the same time for the long-term functioning of this inventory unit. Of course, such inventory technical unit can also be supporting other types of forest inventories, including the national forest inventory and specific inventory type of activities that might be necessary in the future (e.g. forest health monitoring or forest site mapping or forest biotope mapping).

The main elements of the workflow as described below need to be coordinated just like in any other larger project. A clear assignment of responsibilities and clear definition of deadlines is part of this coordination. A graphical overview is in Figure6.

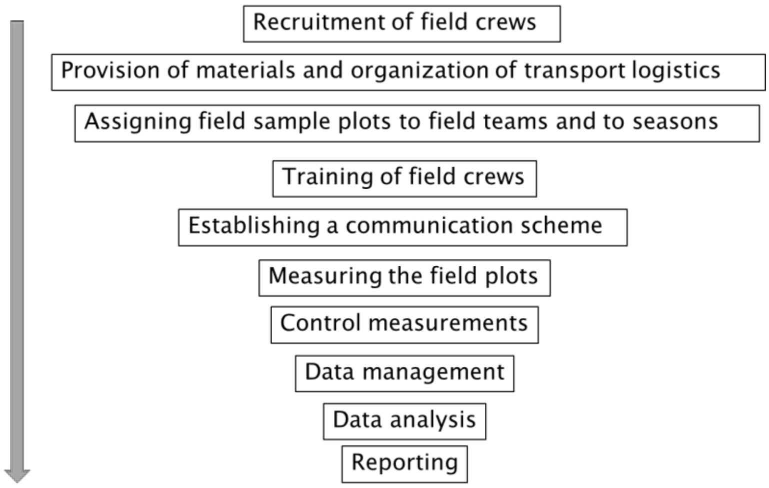

Figure 6. Overview of the main steps of the FMI implementation workflow

There are many different ways of adjusting or modifying this workflow. The major goal and guiding principle is always to aim at highest possible data quality within the limits of the given resources.

Important is here **that methodological soundness must never be compromised for seemingly easier or just more rapid approaches**. Eventually, it is the methodological rigor that makes the credibility forest management inventories - as for any other forest inventory.

2.10.1 Recruitment of field crews

In an early stage, field teams should be recruited that will be available when training and field work starts.

It is among the goals (1) to use also FMIs as an extensive capacity development measure and (2) to implement the fieldwork within a defined period.

That means that a suitable number of field teams need to be deployed simultaneously, depending on the specific number of sample points in the particular KPH.

2.10.2 Provision of materials and organization of transport logistics

Parallel to recruiting field teams, the provisioning of measurement devices needs to be done. It will depend on the type of contract that is being made with the field teams to what extent the provisioning of measurement devices is to be done by the responsible inventory unit.

It may be advisable to leave it to the contracted field teams (consultants) to provide for their own measurement devices; the service contracts need then to be formulated accordingly, also in terms of remuneration and fair compensation for devices. Such an approach guarantees that the field teams treat their equipment well and it considerably reduces the organizational work-load for the coordinating team, because the field teams will also be responsible for spare devices, replacement and repairs in case of failure.

The same should be done for transport logistics to the extent possible: consultants contracted as field team leaders should use their own vehicles, and be compensated for that in a fair manner. This reduces organizational burden for the coordinating unit.

An important point is also the preparation of maps and the preparation of prints of remote sensing imagery. These materials need to be made available to the field teams ahead of time through the coordinating unit.

2.10.3 Assigning field sample plots to field teams

Once the field sample points are categorized, and if more than one field team will be deployed, the sample points need to be assigned to the field teams.

Assignment of sample points to field teams should be balanced regarding the overall workload, and that is mainly with respect to the number of “easy” and “difficult” sample points.

2.10.4 Training of field crews

Field crews working in forest inventories need to be trained specifically according to the inventory protocol and the field manual. Depending on their role during the inventory work (taking plot measurements, managing the data, and analyzing the data) not all parts of this manual are relevant for each team member. However, it is important and sometimes helpful that people who are responsible for data management know how the data were generated; and it is also important that those who are doing measurements in the field have a certain understanding about the structure of the database.

Therefore, reading and understanding the field manual is mandatory for all who are participating in the inventories.

The major goals of the training measures are:

1 To familiarize all field team members with all details of the field manual and with the major overall goals of the inventory.
2 To motivate the field teams to do high quality measurements and to express ideas and suggestions how to possibly improve the field procedures.
3 In case that more than one team is active: to get the field teams into mutual contact and to foster exchange in case of problems.

Training should start with a theoretical description of the sampling and plot design followed by an introduction to all measurement devices and measurement principles. Later the practical implementation of inventory plots should be trained. After introduction, each team should implement at least two training plots and fill out the corresponding field forms. After the measurements, a discussion on the plot can help to answer remaining questions. Re-measurements of trees (selected randomly from the field forms) and a second interpretation of other variables should be done to control consistency and quality of data.

Data management and data analysis should be trained in parallel and can give important feedback to the field teams (e.g. wrong entries in field forms).

Important elements of training for **all field team members without exception** is also

1 the training of the proper use of the means of communication, including trouble shooting, and
2 a first aid training. This should best be organized as **"outdoor first aid training";** which exhibits quite some relevant differences to the regular first aid training.

A complete training of all relevant steps (excluding first aid training which should be separate) will probably need about 3 days and should include at least two complete field plots to be measured per field team. The organization of the training is up to the responsible inventory unit.

2.10.5 Establishing a communication scheme

Field teams should maintain contact among themselves (whenever more than one team is working) and to the inventory unit who has a supervision function.

This communication refers to exchange of topics regarding challenges in fieldwork implementation – but also with reference the safety situation: by all means it must be

avoided that field teams come into dangerous situations where they cannot call for help. Therefore, it should be considered to equip all field teams with radio devices or satellite telephones which do also work outside the coverage of normal mobile telephones. In any case, however, the field teams need to follow the common rules that are in place regarding safety at work.

All field teams need to inform the district forest office (or any other unit responsible for fieldwork coordination, for example the contracted consulting company) about the concrete work program and about all modifications that are met; also at very short notice. The coordinating inventory unit needs to be permanently updated, where the field teams are working and which access paths they are pursuing.

For cases of emergencies, the coordination unit needs to have developed an emergency/rescue protocol that is immediately to be followed in the (hopefully never materializing) case of need; this protocol may follow the ones that are in place also for other fieldwork.

2.10.6 Measuring the field plots

All field teams have a list of sample points (field sample plots) to work on. The field manual defines which variables are to be recorded for which plot design element at a given sample point.

The sequence of the sample points and the day-to-day organization of their work is up to the field team leader and must be organized such that all assigned field plots are covered. It is not admissible to start with the easy sample points and then leave at the end the more difficult ones possibly undone. To avoid that, the work plan needs to be discussed and coordinated with the responsible coordination unit and eventually approved by them.

2.10.7 Control measurements

It is elaborated in 2.9 that control measurements are an integral part of the quality assurance strategy for any forest inventory and also for the FMIs.

In general, between 5% and 15% of all field sample locations are visited by a control team who carries out all measurements again and checks for correctness and validity and compliance with the standards defined in the field manual.

For the FMIs, it is suggested that a minimum subsample of n_c=20 sample plots is always being control measured. Out of these, about 2/3 shall be implemented as “cold controls” (that is: searching the sample points independently and doing all measurements again) and about 1/3 as “hot controls” (that is: accompanying the field teams and observing/evaluating their field work organization and implementation). Assuming an average total number of n=300 sample plots, this corresponds a portion of about 6.7%, which is at the lower end of what is commonly employed.

It is important to make sure that the control measurements are absolutely independently organized and implemented and that all field teams are covered by about the same number of cold and hot controls.

2.10.8 Data analysis

Data analysis is being done along the estimators described above. It is a follow-up to the inventory implementation and not part of the inventory protocol. It is only briefly addressed here.

The data analyses shall produce all results required for reporting and to satisfy the information needs of the KPH – and it offers options for research oriented analyses; therefore, collaboration with a research institute may be indicated to make full use of the huge data set gathered.

2.10.9 Reporting

Reporting is done along the data analyses as addressed above. The inventory reports are among the most important products of the FMI for the targeted decision makers. Reporting is actually not part of the inventory protocol and is addressed here only briefly in a cursory manner.

The report produced from the FMI is giving all estimates (together with their standard errors), broken down into defined strata (e.g. forest types, tree species, accessibility, degradation status…). The reports are primarily to inform district forest offices and the supervising units in the regional forest offices and the Ministry. They are for an expert audience and should give details and can be written in technical language.

As the inventory data should serve as basis for the management plans of KPHs, their documentation and analysis should follow the regulations for the preparation of management plans.

Part

II

Field manual

3 Planning of field work

Forest management inventories are implemented to collect basic data on resources that are under management or are expected to be managed for different purposes in future. Therefore, field work should be restricted to respective areas where information is needed and should exclude completely inaccessible or protected areas.

3.1 Security in the field

Security and own safety of all team members during practical field work, transport to the field sites and plot location has the highest priority It is in the own interest of a KPH manager or responsible planner to take care of suitable equipment and the behavior of field team members. This also includes checking whether members of the field team have a proper health insurance.

All members of a field team should be aware of the possible risks and the appropriate mode of behavior to reduce any risk as much as possible. Every team member is self-responsible to constantly check his/her personal safety. **Every team member is free to stop field work whenever he/she feels uncomfortable or unsecure about a situation**. 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. A proper health insurance for workers, the availability of communication devices and suitable clothing of team members should be checked.

The most important measures that should be considered in order to reduce risk are:

- **Proper planning of field work, including transport to the field:** Proper planning of field work is one important measure to reduce risk. Therefore all decisions about planned field work should be taken with enough time and should be communicated to all team members. Avoid spontaneous changes in planning if possible. Always consider that time planning might be obsolete and be flexible to stop field work before ifit gets dark. Inform the base camp or the other team about your daily working locations.

- **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 coverage of cellular phone network; eventually mark a waypoint for 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!**
- **Communication:** In case that no phone network is available, field teams should be equipped with field radios to communicate among teams (if multiple), with the driver (if waiting at the road) or any other foreseen station or base camp that is informed about field work and is able to send help to the respective location. For this reason it is recommended to leave a copy of the field map, maybe with a network of defined emergency points, with the base camp. The base camp should be aware where the teams are working every day.
- **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. A complete and sufficient first aid set is a mandatory part of the equipment. In areas with special risks (e.g. dangerous snakes, tigers, ...), a proper evacuation should be planned before (where is the next hospital). In case that field teams need to build flying camps and stay in the forest for longer periods, a water filter is recommended.
- **Information:** When working in areas of sensible political situation it is recommended to have an information handout that describes the background of the mission in simple words. Land owners or local communities might be very critical if strangers working on their land without proper explanation (for good reason)! If possible, establish contact to these groups **BEFORE** teams actually go to the field and explain about the character of the inventory study in understandable terms. It may also be indicated to invite local people to accompany the field teams during their work and to help them to navigate to the plots in difficult terrain.

3.2 Equipment and materials

Every field team is equipped with the following items:

Devices / Materials	Number	Check / Comment
Back pack for devices	1	
GPS Receiver / Field GIS	1	Check batteries and whether all necessary data are uploaded on the receiver
Compass (360°) e.g. Suunto	1	Check declination for study area
Vertex III + Transponder + 360° mirror + mounting pole	(1)	If available. Check batteries. Calibrate regularly!
Clinometer (either: Suunto, Silva Clinomaster, Blume-Leiss, Vertex, Nikon Forestry, or similar)	1	If applicable: take backup batteries! For Vertex: calibrate daily before work starts
Relascope or other device for Bitterlich sampling (dendrometer or prism).	1	If no suitable device is available, calibrate own device as explained.
Diameter tape (Pi band)	2	One professional with hook (3 or 5 meter)
Measuring tape (50m)	1	
Overview map / Roadmap / topographic map	(1)	If available otherwise print from GIS with Google/bing imagery
Detail map of stand and plot location or high resolution satellite imagery		Print the necessary sector in advance
Field forms + pencils	10	Depending on number of plots
Marking pole 50 cm	10	A bamboo stick with red mark
Regeneration stick	1	With string for determination of regeneration plot radius
Folding rule	1	For deadwood and regeneration assessment
Calculator	1	
Chalk / paint	3	Chalk / paint to temporarily mark/number the trees
Replacement batteries	4	New batteries for GPS, Vertex or others
Field manual and overview tables	1	
Short manual for complicated devices		GPS, Vertex, TruPulse 360, Nikon Forestry laser, etc.
First aid kit	1	Check for completeness and add specific stand-by medicine (e.g. antivenom for snakes) if necessary!

3.3 Organization of field teams

For efficient field work and for safety reasons a field team should be composed of at least 3 persons (2 of the inventory team, one local guide). However, in difficult terrain a larger team of up to 5 persons is recommended. Each person has a specific role and responsibility during plot location and measurements. The roles of team members could be changed from time to time to make fieldwork less tiring.

The **roles in a team** are according to the different tasks to be covered and include the following (where different roles are taken over by the same field team member!):

Head of field team: Carries the overall responsibility of field work implementation.

- Plans the field work ahead of time
- Checks weather forecast and decides when the announced whether may be dangerous for fieldwork (for example heavy rains and thunderstorms announced when working in steep and partly open terrain)
- Supervises all fieldwork and makes sure that no measurement is forgotten. Given the physically very demanding fieldwork and the often times long workdays, this is one of the most important tasks: going back to the same field sample point to complete some measurements that had not been taken is extremely inefficient
- Takes on any other function during field measurement to ensure smooth implementation
- Engages actively in plausibility checks and checking for completeness and correctness of filling the field form
- Constantly motivates the field team to do high quality work and strives to optimize division of labors and work procedures

Navigator: handles the GPS receiver and navigates to the sample point

- Tracks the way from the closest road or former plot to the next sample point
- Looks for the most easy and safe way to the sampling location

Writer: stands at the plot center and records the reported values

- Visual inspection and plausibility check of stand- and plot variables together with measurer
- Record all measurements reported by the measurer in field forms
- Measuring Azimuth to each tree from the plot center
- Visual interpretation of tree competition status together with measurer
- Assists in dead wood and regeneration assessment

Measurer: goes from tree to tree (clockwise) and takes tree measurements

- Announcing tree number (and mark tree number with chalk)
- Measuring and reporting of horizontal angle, horizontal distance from tree to plot center and DBH
- Visual inspection and plausibility check of stand- and plot variables together with writer
- Visual inspection and plausibility check of tree competition status together with writer
- Dead wood and regeneration assessment

Second measurer (if available)

- Assists the measurer or takes own tree measurements
- Prepares the regeneration plots
- Conducts a Relascope sample
- Measures tree heights
- Dead wood and regeneration assessment

3.4 Locating sample points in the field

Sampling locations are defined by the stipulated sampling design and stored as waypoint list (or shape file if a field GIS is available) on the GPS receiver. **Field teams should carefully decide from which direction the plot location can be reached most easily**. In mountainous terrain with steep slopes, it is recommended to approach the sampling location from below or parallel to the slope, as walking downhill might be a higher risk because of limited visibility and dangerous escarpments. Therefore, it is also recommended to take a suitable map with contour lines if available. In difficult terrain, the way from the car / nearest road should be tracked (GPS receiver is on)! In difficult terrain and unknown field conditions it is recommended to contact and consult local people to help with locating plots.

3.4.1 Navigating with GPS

To start the navigation to the sampling location, the waypoint is selected from a waypoint list. Depending on the GPS signal and the accuracy of positions, the team can navigate close to the sampling location by GPS alone. A long term measurement (~2-3 min, depending on signal reception) is taken at a fixed position in the direct surrounding of the sampling location. The remaining horizontal distance and direction angle to the target are used to locate the sampling point with compass and rangefinder (or tape). **It is not recommended to locate the final position by walking around with the GPS receiver!** A GPS receiver constantly calculates the mean position from signals received over a certain time interval. Therefore, walking around in different directions will not allow getting a more accurate position.

If the canopy at the location is too dense to get a sufficient GPS signal and/or accuracy, a long term GPS measurement is taken at a nearby location with better reception (e.g. in a canopy gap). Distance and direction angle to the target can be read from the GPS receiver and are used for ground based navigation with compass, sighting rod and rangefinder or tape. It is important to measure **horizontal distances** in this case or to use a rangefinder that calculates horizontal distances! In case of limited visibility or large distances, the total distance is subdivided in segments of appropriate length. For navigation with compass it is recommended to approach the target uphill because of better visibility.

3.4.2 Marking the plot center

Once the sampling location is determined with sufficient accuracy, it is marked temporarily with a marking pole. Additionally the closest tree to the plot center is marked with a red marker tape. All marks on the plot area are only temporary as field plots should not be visible in order to ensure that they are not managed different from other areas.

3.5 Workflow

All assessments on the plot should be done in a defined sequence. Taking the measurements in the same order and manner in each plot prevents from forgetting variables and is more efficient. After marking the plot center the subsequent workflow is as follows:

1. Record Start time,
2. Start a long-term GPS measurement at the sample point. Even if a GPS measurement was used to locate the sample plot, the coordinates of the marked position might still change. It is important to get an accurate position in order to reduce co-registration errors during later integration of remote sensing imagery. While the measurement is in progress other work steps can go on,
3. Measure and record of POINT_ and SAMPLE_ variables,
4. Visual interpretations on STAND_ variables on the plot area and plot surrounding,
5. Measurement of slope angle and aspect and visual interpretation of other PLOT_ variables,
6. Start single tree measurements on TREE_ variables (start in north direction in clockwise sequence). Tree heights and height to crown base are measured separately after all other single tree data are recorded,
7. Implement the regeneration subplots and observe on RE_ variables,
8. Dead wood assessment
9. Record End time.

3.6 Variables

The variables that are observed at every sampling location are subdivided into different categories according to their reference scale and/or the respective target object. Every variable is explicitly defined in terms of scale of measurement/observation, possible values (in case of ordinary or Boolean scale) and their precision. The variables proposed in this minimum standard should be complemented by further variables of interest that need a clear definition.

- **Sample information [SAMPLE_]:** General information on the sample, e.g. date of assessment, field team, etc.
- **Sample point [POINT_]:**All variables describing the sampling location (dimensionless point), e.g. coordinates, height above sea level, etc.
- **Compartment [COMP_]:** Characteristics of the forest stand or management compartment in which the sample point is located. This information refers to the conditions in the surrounding of the plot. Some variables could also be assessed on the way to the plot.
- **Plot [PLOT_]:** Variables describing the conditions on the defined sample plot. These variables describe characteristics that are directly affecting the trees growing in the plot area and that could be correlated to remote sensing data covering the plot area and direct surrounding.
- **Single tree [TREE_]:** Variables measured or observed on the individual trees in the plot.
- **Dead wood [DEAD_]:** All variables observedon standing and lying dead wood, if information on deadwood is needed.
- **Regeneration [REG_]:** Variables assessed on the regeneration sub-plot describing the status of regeneration.
- **NTFP [NTFP_]:** Variables assessed on the NTFP sub-plot referring to Non Timber Forest Products.

3.6.1 SAMPLE_Variables

General information referring to the actual sample.

SAMPLE_TEAM

Name of the responsible team leader or writer. In case of any questions regarding the inter-pretation of recordings during data entering the writer could be asked for help.

SAMPLE_DATE

Date of plot assessment recorded as dd.mm.yy.

SAMPLE_TSTART

Start time of assessments (after the sample plot is located and marked) as hh:mm.

SAMPLE_TEND

End time of assessments (before leaving the plot) as hh:mm. Time recordings are important information that can be used for the optimization of plot designs. They can be correlated to terrain conditions and can be considered for the planning and allocation of sample size for different strata.

SAMPLE_ACCESS

Accessibility class describing whether the sampling location is easy or difficult to access.

0: relative easy access
1: difficult conditions, but accessible
2: hardly accessible
3: not accessible (sample was not taken)

SAMPLE_ACCESSTIME

If the sampling location was located outgoing from a path, trail or track the duration is recorded (hh:mm). As teams will sometimes access the sampling location from another direction (not the closest path, but from another sampling location), this recording might be corrected if a faster access is found on the way back.

3.6.2 POINT_Variables

POINT_X

X-coordinate (easting) of the sample point location as generated for the base grid in UTM (WGS84) coordinates. Base grid coordinates are generated as integer values!

POINT_Y

Y-coordinate (northing) of the sample point location as generated for the base grid in UTM (WGS84) coordinates. Base grid coordinates are generated as integer values!

POINT_XGPS

GPS measurement of the X-coordinate (easting) of the marked sample point location (WGS84) with dm precision.

POINT_YGPS

GPS measurement of the Y-coordinate (northing) of the marked sample point location (WGS84) with dm precision. Deviations from the planned target coordinate are important for later co-registration of remote sensing data! Put the GPS receiver on the marked sample point and record the coordinates after 5-10 min (or until they are stable).

POINT_GPSERROR

PDOP value or GPS error reading from GPS device.

POINT_HSL

Height above sea level at the sample point measured with GPS.

POINT_LANDSCAPE

Describes the landscape context of the area (e.g. whether the location is in a closed forest or an isolated forest patch).

0: large closed forest area
1: forest area with larger gaps
2: fragmented landscape, mainly forest
3: fragmented landscape, mainly non-forest
4: larger isolated forest patch
5: small isolated forest patch

POINT_PROTSTAT

Protection status (protected area or not). Can probably be derived from available GIS data.

0: no protection status
1: protected area

POINT_ECOZONE

If a classification in eco-zones is available it should be used here.Can probably be derived from available GIS data.

POINT_CATCHMENT

If a delineation of different water catchment areas is available. Can probably be derived from available GIS data.

POINT_DISTSETTLE

Distance to settlements as indicator for pressure on or use of resources. Can probably be derived from available GIS data.

POINT_DISTROAD

Distance to road as indicator for accessibility. Can probably be derived from available GIS data.

3.6.3 COMP_Variables

These variables are observed in the management compartment in which the sample point falls. Not the whole compartment area is of interest here. The variables should be correlated to single tree variables or used in context of remote sensing integration. Therefore, they should be observed in the surrounding of the plot. If a delineation of compartments or sub-compartments is not yet done, it is not a problem.

COMP_ORIG

Describes the origin of the main stand. In a multi-layer stand, the main stand is formed of the species of main commercial interest. Look for any evidence of planting or enrichment planting like tree rows or systematic patterns.

0: natural regeneration
1: planted/plantation or seeded
2: both (enrichment planting)

COMP_HIST

Describes the prior management (or utilization) of the area (or management history). Evidence for a prior management (e.g. timber extraction) might be stumps or logging trials. Evidence for former NTFP use might be abandoned rubber trees or clusters of fruit trees (old house gardens).

0: Natural forest, never managed before
1: Overlogged forest (e.g. former concession)
2: shifting cultivation (logged or burned)
3: Abandoned farm land / pastures / fields
4: NTFP use

COMP_LASTLOG

If there is evidence for past timber management, estimate how long ago the last logging took place. Evidence is the estimated age of bigger stumps or the age of logging trails.

0: last logging less than 10 years ago
1: last logging 20-30 years ago
2: last logging > 30 years ago

COMP_MIX

Tree species mixture (diversity class) of the stand or plot surrounding by estimating the number of different species. This variable can be e.g. correlated to basal area and biomass or remote sensing data in context of an exploratory data analysis.

0: pure (like plantation)

1: mixed (2-7 species)

2: diverse (>7 species)

3: very diverse (>15 species)

COMP_VERSTR

The vertical structure describes the variability of tree heights and the layering of a stand. Structure is observed by visual estimation of mean conditions on the plot and the direct plot surrounding. This variable is also of interest for remote sensing integration, as it influences the correlation and saturation of ground-based estimates and RS based predictions.

1: single layer, same heights
2: single layer, variable heights
3: multiple clear layers
4: variable structure in gaps
5: complete variable structure

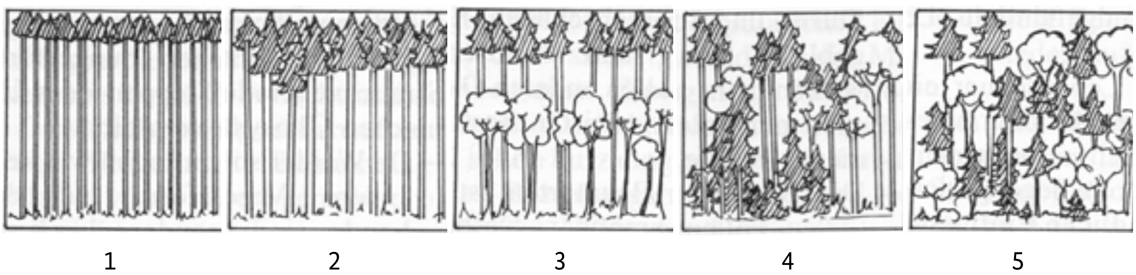

Figure 7. Vertical stand structure (adapted from Otto, 1994)

COMP_RARE

Presence of rare or endangered species. This variable needs to be specified in more detail according to the local conditions.

COMP_MANAG

Describes actual evidence for management activities or utilization (e.g. stumps, NTFP use). Also conservation is a form of management.

0: no evidence of management activities
1: NTFP use *3: timber extraction*
2: hunting *4: firewood extraction*

COMP_NTFPUSE

This variable specifies the NTFP utilization. It is a list of existing NTFP species that are utilized in the area around the sampling location. A compilation of all relevant NTFP species and products is given in the PERATURAN MENTERI KEHUTANANNOMOR : P.35 / Menhut-II/2007.

COMP_EXPLOIT

Evidence for (legal/illegal) exploitation

0: no evidence

1: bird-traps (nets or others)

2: snares

3: plants, flowers, orchid extraction

COMP_BA

Basal area (m^2/ha) is estimated by means of a Bitterlich (relascope) sample. A basal area factor k of 2 or 4 can be chosen depending on stand density and diameter distribution of the stand. In general, a lower basal area factor should be used if less than 8 trees are tallied at a sampling location and the relascope sample should be repeated with a smaller factor.

COMP_BAF

Basal area factor used for Bitterlich sampling. See also STAND_BA.

3.6.4 PLOT_Variables

Plot variables are measured or observed on the plot area. In some cases, it might be necessary to consider the direct plot surrounding for correct interpretation. However, the reference area for this observation is the plot only.

PLOT_SLOPE

Slope angle (gradient angle) of sample plot area measured in mean slope direction between two opposite points along the sample plot radius in degrees.

PLOT_ASP

Aspect of the sample plot area if slope angle is >5°. Aspect is the Azimuth along the slope direction measured with compass in degree. In case that there is no slope, assign 9.

1: North
2: North-East
3: East
4: South-East
5: South
6: South-West
7: West
8: North-West
9: flat

PLOT_TERR

Terrain form within the radius of the sample plot. Eventually it is necessary to include the direct surrounding of the plot.

1: very concave ∪
2: concave ⌣
3: flat ----
4: convex ⌢
5: very convex ∩

PLOT_FTYPE

Forest type on the plot area or direct surrounding. This variable is used to validate the forest management information in which forest types are assigned on larger scale. For later remote sensing integration the actual forest type on the plot area (or the direct surrounding) is relevant (also for possible post stratification).

The classification of forest types should follow the same classification scheme as defined for the NFI.

PLOT_CRCLOSE

Crown closure on the sample plot area assigned by visual estimation of mean condition on the plot area.

1: dense (crowns are overlapping)
2: close (crowns are touching)
3: loose (gaps are smaller than mean crown diameter)
4: open (gaps are larger than mean crown diameter)

PLOT_GROUNDVEG

Describes the type of ground vegetation. PLOT_GROUNDCOV describes the coverage of the vegetation. Both variables are estimated in the smaller plot only.

0: no vegetation, bare soil or humus
1: no vegetation, sand stones
2: herbaceous plants
3: grasses
4: fern
5: ginger

PLOT_GROUNDCOV

Coverage of the ground vegetation estimated in the smaller circular plot.

0: <25%
1: 25-50%
2: 50-75%
3: 75-100%

PLOT_GROUNDCOV

Describes the erosion status on the plot area. A classification guidewith photos should be prepared for correct interpretation.

1: no obvious erosion, vegetation and top soil is undisturbed
2: slightly eroded, ground vegetation or top soil is partly lost
3: serious erosion, ground vegetation or top soil is lost
4: heavy erosion, bare soil is affected by water or wind erosion, land slides

PLOT_FIRE

Describes whether the location was affected by fire.

0: no fire evidence

1: recent fire, ground vegetation burned

2: older fire, traces on trees

3.7 TREE_Variables

Tree variables are measured or observed on individual trees that are included at the sampling location based on the applied plot design.

TREE_ID

Unique id number of each tree per plot. The tree number is temporary marked with chalk to allow later identification of included trees, e.g. for tree height measurements.

TREE_STEMID

In case of multiple stems for one tree, every stem gets a unique ID.

TREE_AZIM

Azimuth measured in degree from plot center to the stem axis (at 1.3m height) of the tree. Azimuth is measured by the writer who is standing at the plot center with Suunto compass or TruPulse 360. The writer thereby sights the stem axis over the sampling location that is marked with the telescope pole of the Vertex transponder.

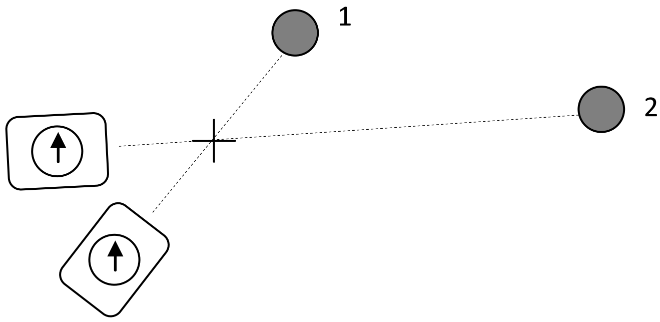

Figure 8. Measurement of Azimuth over the sampling location.

TREE_HDIST

Horizontal distance between each tree and the sample point. This distance can be measured in different ways:

1 By using a laser device it can be measured from the sample point to the tree. This is only recommended in stands with free visibility to the stem.

2 By using the Vertex this measurement is taken outgoing from the stem axis to the sample point. If the Vertex was used to measure the slope angle before, the device automatically calculates the horizontal distance. In this case the measurer is taking the decision whether the tree is included or not.

3 By using a tape. In this case it is not possible to measure the horizontal distance in sloped terrain. Therefore, in this case the inclination angle to the tree position should be measured.

TREE_VANGL

Vertical angle to tree position. This measurement is only necessary if the distance to the tree is measured as slope distance (by tape). The angle is measured parallel to the ground and recorded as signed integer from the sample point to the tree. That means if the angle is measured outgoing from the tree to the point, the sign has to be changed!

TREE_SPCODE

Code for the tree species. If a matching code is available no other recordings for TREE_SPEC and TREE_SPLOC are necessary. If a species cannot be identified assign n.i. (not identified). A tree species list with codes for each species is required.

TREE_FAM

Botanical family in case that further species identification is not possible.

TREE_SPEC

Botanical name of the tree species (in case it is known but no code is available).

TREE_SPLOC

Local name of the tree species (only in case that no species code is available and the botanical name is not known).

TREE_DIAM

Diameter at breast height measured perpendicular to the stem axis at 1.3m above ground with diameter tape with precision of 1mm. If measurement in 1.3m is not possible (e.g. buttresses), a diameter 20 cm above buttresses is measured. In this case a deviating height of the measurement should be recorded as TREE_DHDEV.

TREE_DHDEV

Deviating height of diameter measurement (in case that irregularities of the stem makes it impossible to measure the DBH at 1.3m) recorded as signed integer. In case of buttressed trees the height of the diameter measurement over the buttresses.

TREE_HEIGHT

Tree height is measured for 4 trees per plot. The trees that are selected for height measurement should span the range of diameters on a plot. Height can be measured with Vertex, Laser devices (Nicon Forestry, TruPulse, others), or mechanical devices like Blume-Leiss, Suunto or Silva clinomaster.

TREE_HCRB

Height to crown base is measured for the same trees (from same distance). Crown base is defined as the height of the first strong living branch of the crown. Small secondary or epicormic branches at the stem are not considered.

TREE_DAMAGE

Significant damages on the stem or crown in different classes. Only record damages that significantly affect the quality of the tree (e.g. large skidding damages at the stem) or tree growth (e.g. a completely broken crown).

The recording of damage classes is only relevant for timber production or commercial purposes. Some damages, however, might also relate to habitat characteristics (e.g. wooden caves).

In order to allow comparisons between different field teams, a code list of damage classes should be prepared.

3.7.1 DEAD_Variables

All measurements and observations taken for standing and lying deadwood. The deadwood assessment is integrated in the nested plot design.

DEAD_ID

Unique id number for each included piece of deadwood. Deadwood is included based on the middle diameter of the section inside the plot area (sections overlapping the plot boundary are not considered!). Similar to standing trees diameter thresholds are used for the two nested plots: Deadwood sections with middle diameter of more than 20cm are considered in the large radius. Sections with a middle diameter smaller 20cm and larger 10cm are included in the smaller radius only!

DEAD_TYPE

Deadwood category assigned by visual interpretation.

1: standing whole tree
2: standing broken tree
3: lying stem
4: lying branch
5: stump

DEAD_LENGTH

Length of the deadwood section inside the plot in meter with decimeter precision. In case of lying deadwood the length is measured along the axis with tape (in case of linear sections measurement with Vertex is also possible). In case of standing deadwood and stumps the height is measured. Minimum length is 50cm.

DEAD_D

Diameter of deadwood section in integer centimeter. For lying deadwood the middle diameter of the section inside the plot is measured by tape or folding rule. For standing deadwood the DBH is measured. For stumps the diameter of the cross sectional area is measured.

DEAD_DEC

Decay class of deadwood section by visual interpretation and physical test of wood hardness. Hardness of wood can be checked with knife or by testing the sound.

1: no decay (wood hard, bark on)
2: starting (bark loose, wood hard)
3: advanced (wood partly soft)
4: heavily (very soft, no contours anymore)

3.7.2 REG_Variables

Variables describing the regeneration. Regeneration is assessed in two sample plots per sampling location (regeneration cluster plot) that are installed on the radius of the smaller plot North and South of the sampling location and have a radius of 1.5m each.

REG_SPID

Plot id for the regeneration sub-plot per cluster.

1: Northern regeneration plot
2: Southern regeneration plot

REG_HCLASS

Height class of regeneration. Individuals are counted per height class.

1: 25-50cm
2: 50-150cm
3: >150cm and <5cm DBH

REG_SPEC

Species list (botanical name or local name) of regeneration.

4 Tree measurements

Single tree measurements start in North direction from the sample point and proceed in clockwise direction. All included trees are marked with a TREE_ID (or STEM_ID) for later selection of height measurement (temporary with chalk). The nested plots are considered simultaneously and included trees of different diameter classes are recorded in one single table.

Horizontal distance to the tree is measured from/to the stem axis at dbh height(defined as 1.3m height). Azimuth is measured towards the stem axis. In case that the distance to the tree is measured by laser device from the sample point, TREE_HDIST must consequently be measured to the stem surface.

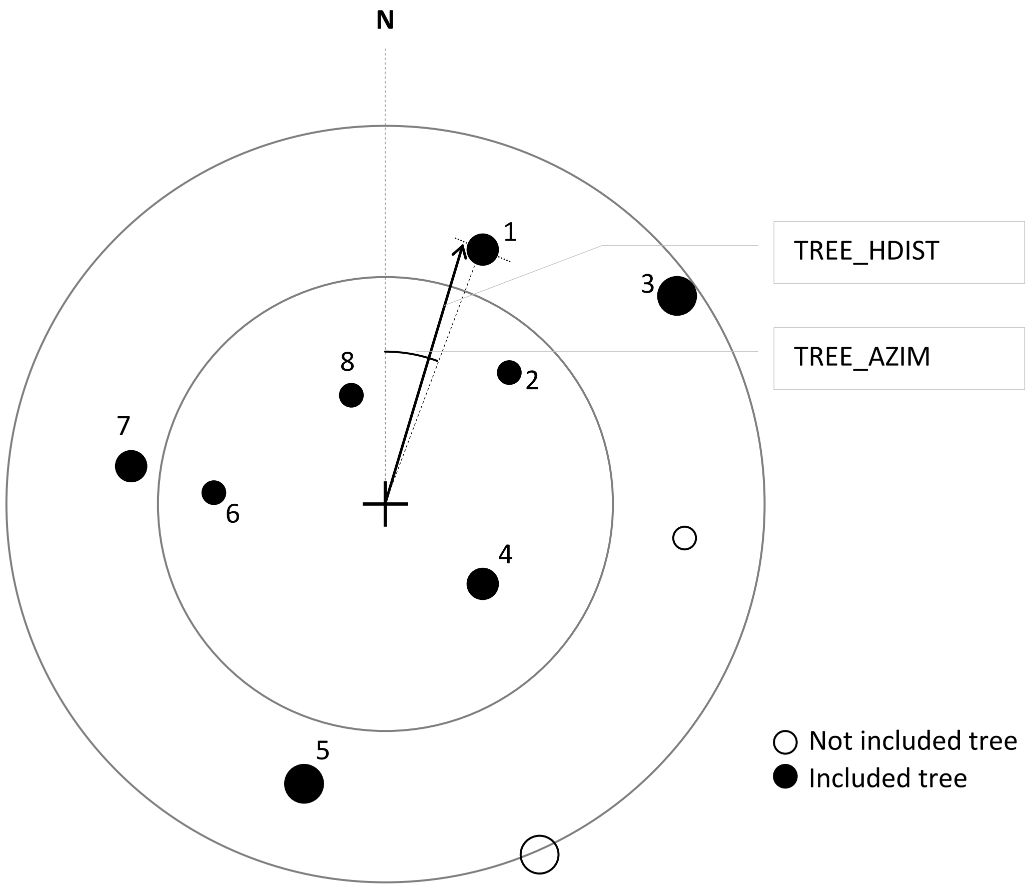

Figure 9. Order of single tree measurements and measurement of distance / Azimuth

4.1 Measurement of diameter

Diameters are measured for all included trees and for dead wood pieces (if an deadwood assessment is included). Diameter at breast height (TREE_DIAM) is measured in 1.3 m height from the ground with a diameter tape. The tape must be tightened perpendicular to the stem axis. Climbers growing at the stem have to be removed or the tape must be lanced below.

Figure 10. Measuring DBH (here 35.9cm)

Figure 11. shows some definitions how to measure DBH in special cases.

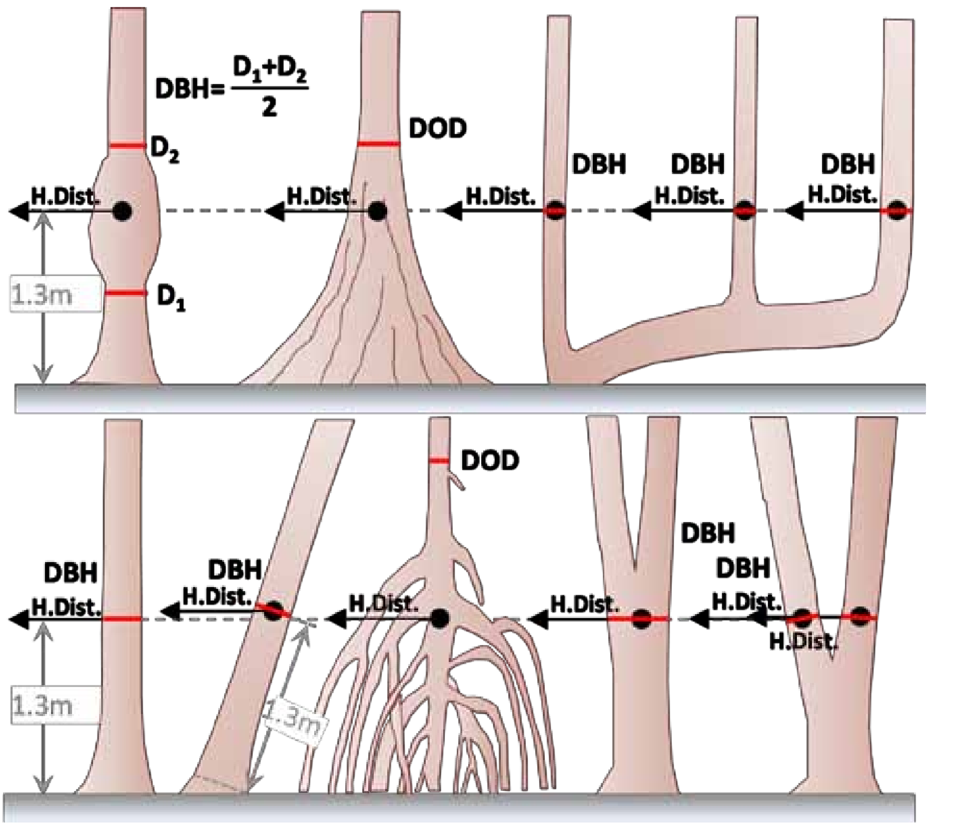

Figure 11. Definition of DBHand distance measurements for special cases

4.2 Measurement of tree height

At each sample point the heights of 4 trees of different diameters are measured. **Height measurements are done after all tree diameters are recorded**. The trees for which heights are measured should span the actual diameter range on the plot. Select small, medium and large DBH from the recorded plot data. Do not select trees with broken crowns or any other irregular shape as they will be outliers in the height curve.

Tree height is defined as vertical distance between tree top and ground level at the stem base. It is usually calculated based on measurements of horizontal distance to the tree and angles to the tree top and stem base with the trigonometric principle.

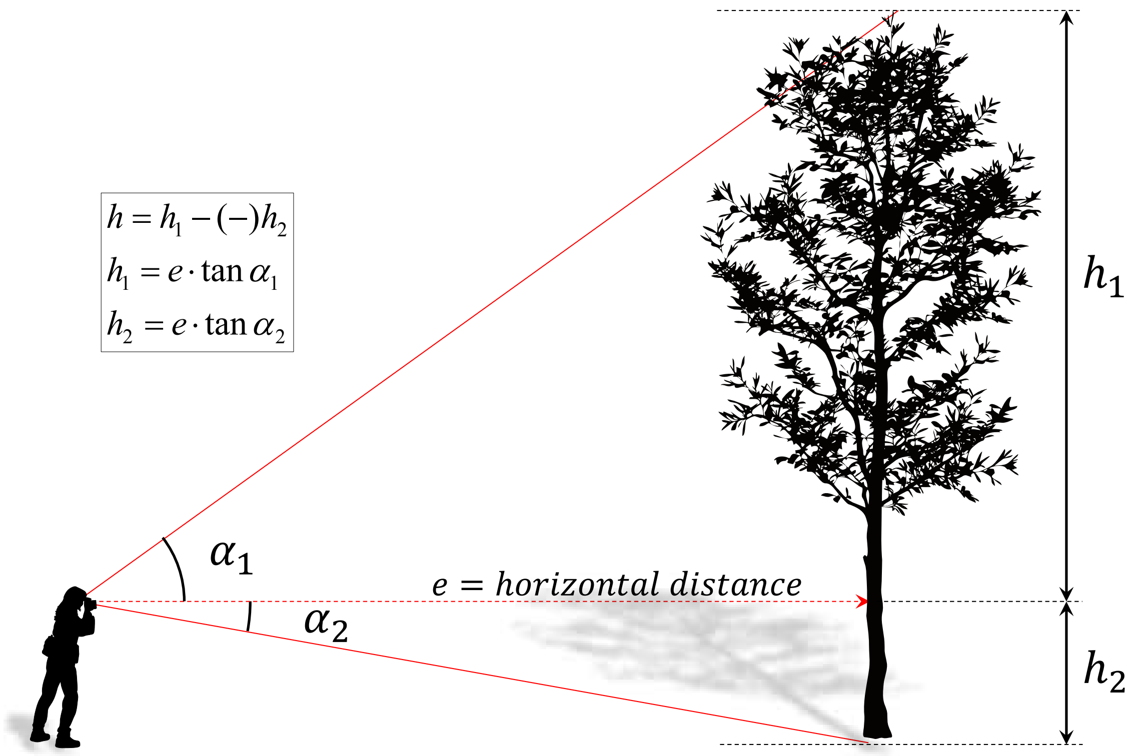

Figure 12. Trigonometric principle of height measurement

In the above figure h_1 is the height to the tree top and h_2 is the (here negative!) height to the stem base. Using the above formula $h=h_1-h_2$ it is important to consider the correct sing of the angle measurement. In case that the observer stands slightly below the stem base h_2 becomes a positive height. However, height measurement from a position far below the stem base is not recommended as the visibility to the tree top is limited and the risk of measurement errors is high. Using electronic devices, like Vertex or TruPulse, the calculation of tree height is done automatically.

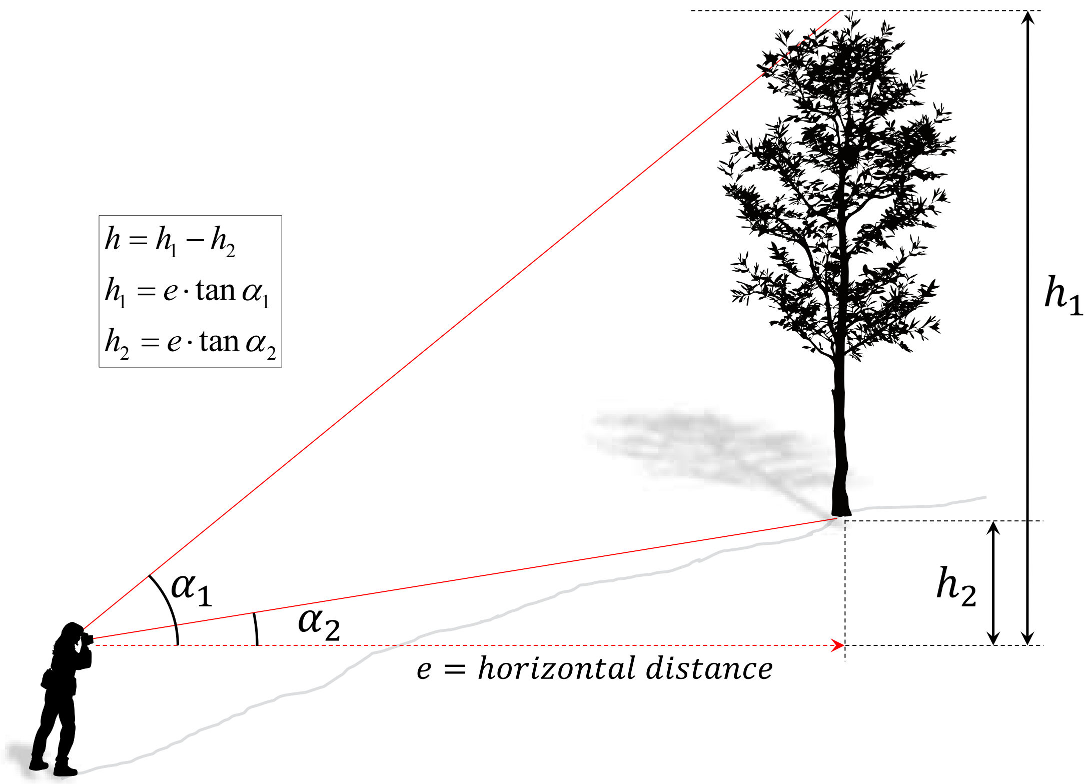

Figure 13. Calculation of tree height if the observer is standing below the stem base. Here, exactly the same principle is applied as in flat terrain and the same formulae. However, signs need to be observed! It is good practice in the field to visually check the plausibility of the measurements of h, h_1 and h_2 !

4.2.1 Possible measurement errors

In sloped terrain try to measure height from a direction perpendicular to the slope direction or downhill from a higher position. Avoid measuring big trees uphill standing below the tree, as this increases the probability of errors because of bad visibility of the tree top and extreme angle measurements! A relative small error in the angle measurement will lead to relative high errors in the calculated height.

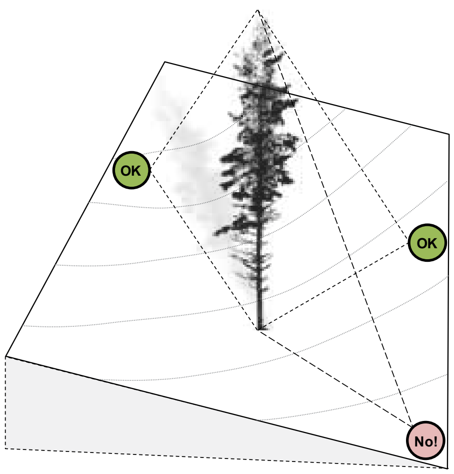

Figure 14. Correct positions for height measurements in sloped terrain

In case of oblique trees, measure height from a position perpendicular to the leaning direction. Measuring along the direction of leaning might cause high errors in distance measurements (not the correct distance to the horizontal projection of the tree top!).

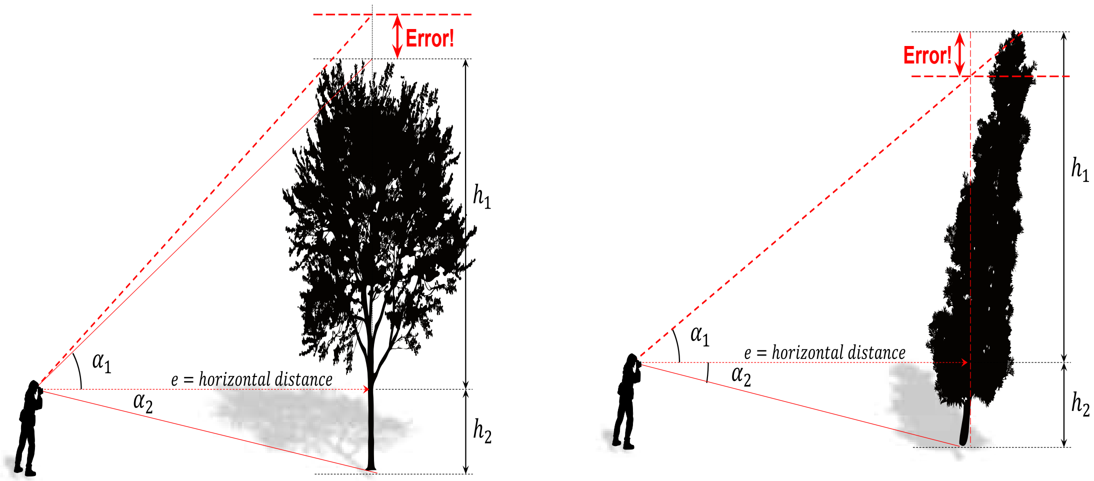

Figure 15. Measurement error because of misinterpretation of tree top or due to wrong measurement position in case of an oblique tree

If tree height is measured with Vertex, the position of the transponder on the tree should be 1.3m (check how the transponder height is set in the settings menu). As the distance measurement of the Vertex is based on sound signals the measurement is affected by temperature and air humidity. Therefore the Vertex should be calibrated regularly if conditions are changing.

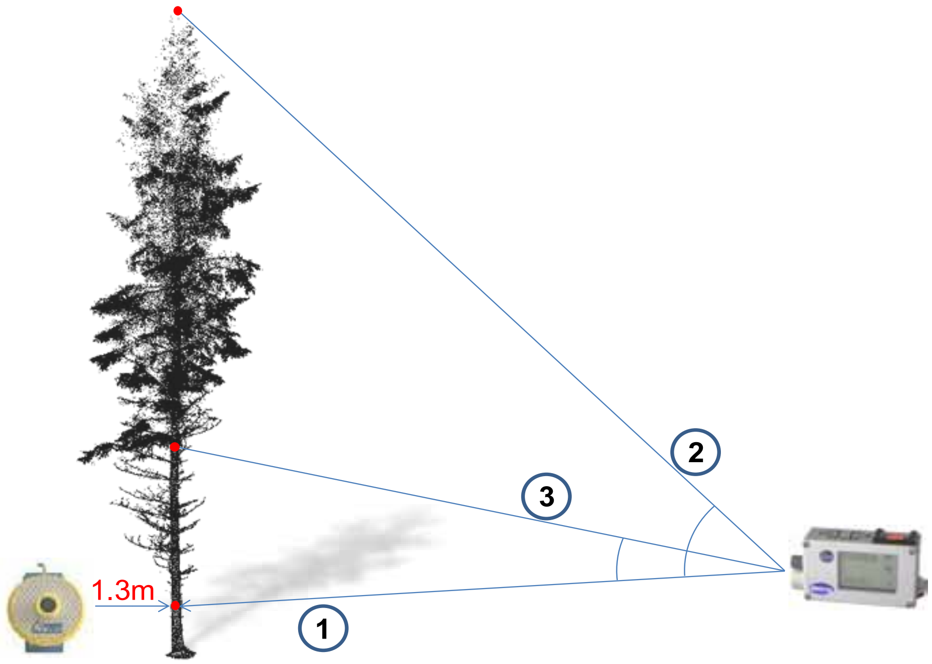

Figure 16. Tree height measurement with Vertex III: 1) measurement of distance and angle to the transponder (fixed at 1.3m), 2) angle measurement to tree top, 3) angle measurement to crown base

4.3 Regeneration assessment

The detailed assessment of the regeneration and its species composition might give insights into the silvicultural options for future stand development. Therefore a rough assessment of regeneration density (plants/ha) and main species in two regeneration subplots that are implemented in a distance of 6m to the North and South of the sample point. Both subplots together form a cluster plot. Observations from the two subplots have to be aggregated during estimation. As they are not selected independently they give only one observation.

For the three regeneration classes (25-50cm, 50-150cm, 150cm – dbh<5cm) the individuals are counted separately in the two regeneration subplots. The species (REG_SPEC) is assigned if identification is possible.

4.4 Dead wood assessment

Standing deadwood is assessed together with the live standing trees.

Minimum diameter for dead wood is 10cm, both for stump diameter and also for down dead wood pieces. This is an international standard; dead wood below 10cm counts as litter. Down dead wood is assessed on the nested circular sub-plots of 5m (from 10cm diameter at the thicker end onwards) and on the 10m sub-plot (from 20cm diameter at the thicker end onwards). Down deadwood is recorded only of the thicker end of the dead wood piece is inside the sub-plot area for the piece to be recorded. That is: the thicker end of the dead wood piece is the inclusion criterion, and NOT whether any section of a piece is within the sub-plot area!

Down deadwood assessments are very time consuming and should only be included if information on deadwood volume (e.g. as indicator for biodiversity or for carbon accounting) is clearly and explicitly formulated.

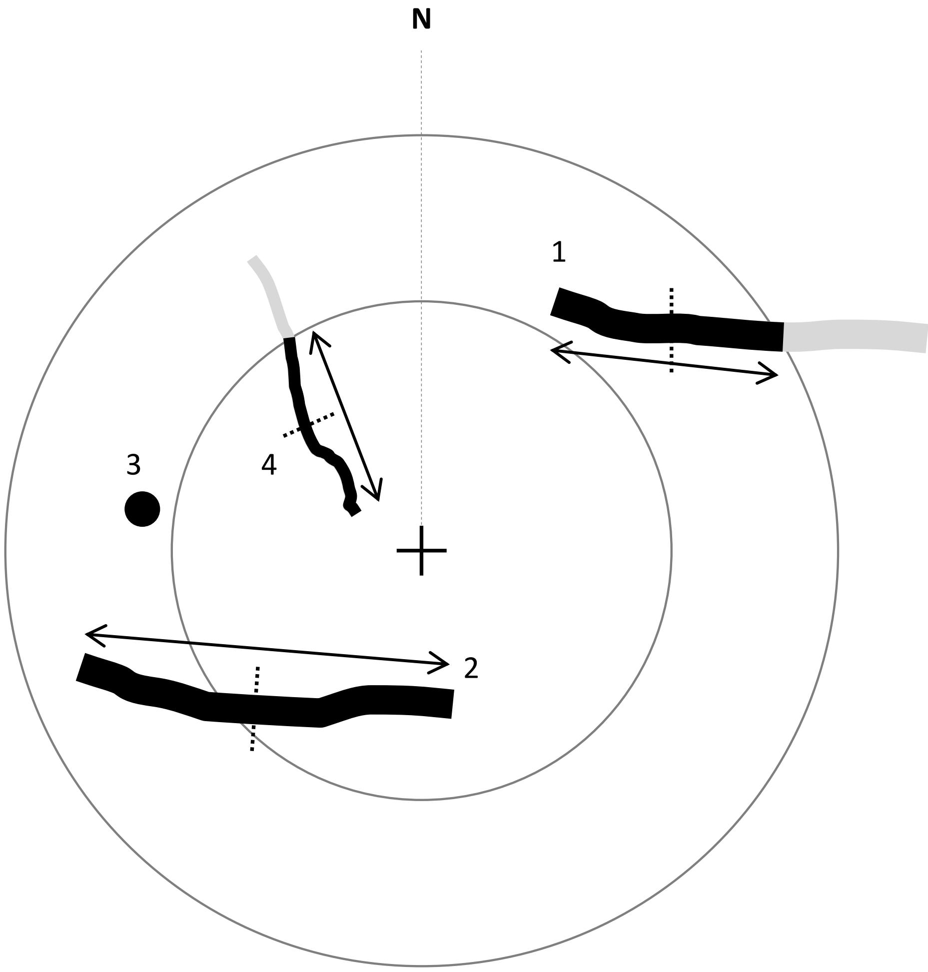

Figure 17. Dead wood assessment in the two nested circular dead-wood sub-plots. The circles mark here the thicker end of each piece and only dead wood pieces are recorded if the thicker end is within the corresponding sub-plot. The arrows illustrate the extension of the dead wood piece, but the length is measured as good as possible along the piece including curvature, that is: following as good as possible the white line in this graph. (1) and (2) are sections with diameters at the thicker end of more than 20cm and they are included in the bigger plot radius, (3) is deadwood with diameter of more than 10cm at the thicker end which is included in the smaller sub-plot only. For all dead wood pieces, the length goes to the point where the diameter goes below 10cm.

In case of forked deadwood pieces each segment is considered separately.