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Methodology for conducting inventory of forests in Tajikistan

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List of abbreviations

GIS – Geographic information system

SP – Sample plot

NWFPs – Non-wood forest products

RS – Remote sensing

GDEM – Global Digital Elevation Model

SRTM - Shuttle Radar Topography Mission

NASA – National Aeronautics and Space Administration

NDVI – Normalized Difference Vegetation Index

CGM – Chlorophyll green model

FP – Forest products

BA – Basal area

ASL – Above sea level

CRM - Chlorophyll red edge model

GPS – Global Positioning System

FAO – Food and Agriculture Organization of the United Nations

1. Foreword

Forests are an integral part of the natural landscape of Tajikistan. The forest cover of Tajikistan in general is considerably low and is under a strong pressure caused by the harsh environmental conditions. But despite this they play an important social and economic role for the local community. Due to the low social security and harsh rural conditions the local population needs to satisfy their demand for firewood and fodder for the cattle. The hard ecological conditions and the high anthropogenic impact cause a degradation of the remaining forests where productivity usually is very low and trees show very irregular growth patterns. Mainly the pressure to the forests was during the civil war in Tajikistan (1992-1997) when there almost wasn't any control by the government (State Forestry Agency). Thus we can assume that a lot of changes happened in the last decades. Currently there is no updated information about the current status of forest resources. A forest inventory has not been implemented since the independence from the Soviet Union in 1991. Another important factor that should be mentioned is that the crucial aspect of controlling and management system of forest dramatically changed. Therefore we propose a new modernized monitoring system that can satisfy the demands of the SFA and other involved stakeholders.

Designing and implementing a forest monitoring system that satisfies the described information needs is a very complex and challenging task as an adaption of standard inventory approaches to the local conditions is necessary which requires sufficient data (P. Magdon and L. Fehrmann, ForestEye report)

This methodology has been developed based on the field data from the tested forest inventory methodology which was elaborated with the support of the GIZ project "Adaptation to climate change through sustainable forest management" together with the Forest Eye research GmbH.

2. Introduction and preparation

1.1 Characteristics of forests of Tajikistan

Forests and trees are main elements of landscapes that play a very important role in the environmental sector of Tajikistan. Forests of Tajikistan mainly have a protecting function and they prevent the spread of erosion. The overexploitation of forests combined with uncontrolled grazing, continues to diminish the country's remaining forest cover at an alarming rate. Therefore, it is necessary to develop a sustainable strategy for the rehabilitation of existing forests in Tajikistan. Sustainable, managed forests play important roles in the environment and economy, and also have social and climatic significance (Kirchhoff and Fabian 2010).

1.2 Definition of forest in Tajikistan

The concept of forests is defined differently in various countries. According to the Forest Code of Tajikistan, forest is a set of natural vegetation, formed by natural and artificial ways on a specified territory, based on a set of trees and shrubs that interact with other components of wildlife, having important environmental, economic and social significance. The main characteristics of forests as defined by the Forest Code of Tajikistan are as follow:

- Minimal area of 0.5 hectares;
- Area covered with tree-forming plants of no less than 10%;
- Width of cover no less than 10 meters.

Despite the fact that this definition gives some quantitative and qualitative criteria, for example, measurement of minimal area, width, minimal cover and factor of interaction of wildlife with environment, the definition of forest according to this concept is sometimes impossible. For example, it is not clear whether tree crowns' projection (crown cover) or any other part of plant as a whole should be taken into consideration for defining minimal cover of forest area with tree forming species. Besides, the concepts of tree forming species are not defined, for instance, minimal height of trees and shrubs, etc. Based on that all plants, in principle, may be defined as tree forming species (Fehrmann L & Magdon P, 2014).

Alternative to the Tajik version of forest definition, other definitions of forest exist, for example, a definition that is officially accepted by FAO (Food and Agriculture Organization of the United Nations):

“Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity *in situ*. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest. Forest nurseries and seed orchards that constitute an integral part of the forest; forest roads, cleared tracts, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest; windbreaks and shelterbelts of trees with an

area of more than 0.5 ha and width of more than 20 m. Excludes: Land predominantly used for agricultural practices”.

The definition of forest accepted by FAO consists of enough qualitative and quantitative characteristics, and in principle, may be easily used in all countries. However, it should be mentioned that results of analyses of satellite imagery and field observation usually differ and it is practically impossible to determine some indicators with satellite images, for example: minimal height of trees (shrubs) (Magdon and others, 2014¹). Recent studies showed that even in case of using multispectral high resolution satellite images determination of height and difference of tree crowns and shrubs involves significant errors.

1.3 Types of forests of Tajikistan

Tugai - forests are riverside forests located in floodplains. Typical tugai forests can be found for example in Panjikent (Sughd region), in Barvoz (GBAO) or in Shitkharv (GBAO). As these types of forests have good water supply and nutrients in comparison to arid areas, they have high productivity and serve as an important habitat and corridor for wild animals. In addition, they play an important role for flood protection of surrounding settlements. Prevailing types of trees growing in tugai forests are small leaved species that grow relatively fast (for example willow and poplar), and thorny vegetation (for example sea buckthorn). Tugai forests are characterized by high dynamism and close interconnection with the activities of large rivers.

Tugai type forests differ by composition of species, stand height, depth of groundwater bedding, grass cover and their interconnection with floodplain relief. Main tree species in tugai composition are Asiatic poplar (blue poplar) and oleaster, and shrubs – tamarisk, buckthorn and willow bed. Being subordinated to water-salt regime of floodplains that is subject to significant changes, tugai forests also react to river behavior in their evolution, passing the stages of emergence, development and disintegration. The type of tugai community is a product of the interactions of forest and river systems. The occurrence of tugai stands is connected with fresh river sediments and is defined by the degree of river bank humidity and the physical composition of the sediment surface. Tugai forest plots are usually located along riversides and confined to river terraces, water bodies, channels and other elements of hydrographic network.

Juniperus - forests are evergreen forests growing usually on mountain ranges. Prevailing species in these types of forests are juniper, sometimes maple and almond trees are met. The density of these forests differs, depending on altitude and slope aspect. According to the legislation of Tajikistan, tree felling is prohibited in these forests, as these are soil protecting forests. However, due to low social security and harsh conditions, the local population highly depends on them. Juniperus forests are mainly used as a source of firewood for heating and cooking. Therefore they play an important environmental and socio-economic role in the region. However, it should be noted that after felling the juniperus forests regenerate very slowly because of hard conditions and shortage of nutrients in the soil.

Pistachio forests - usually represent very rare and light plantations, where trees are located in a considerable distance from each other, and their crowns, with small exceptions, do not interlace. An environmental constraint in such light dry forests is a shortage of moisture that causes sparseness of stand and density of root systems that stretch far outside the crowns. The pistachio type forests determine the landscape of the Southern Pamir-Alay and creates a peculiar belt of pistachio sparse forests that gird hillsides and foothills with wide strips on altitudes from 500 to 1700 meters above sea level. Pistachio

forests border below with treeless short grass semi-savannas, and on the top with thermophilic juniperus plantations, where Zeravshan juniper is the prevailing species. Main tracts of pistachio and almond tree plantations are concentrated in Danghara, Farkhor, Panj, Qurghonteppa and Khuroson forestry enterprises and less in Nurek, Hamadoni, Shahrituz, Dashti-Jum forestry enterprises and Esambay forestry of the Forestry Agency of RT.

Broadleaved forests – Broadleaved, mesophile tree-shrub species dominate in such forests that cover a mountain belt from 1000 to 2000 (2200) meters above sea level, mainly in central Tajikistan, south-eastern mountainous parts of the country and its eastern part, including south foothills of Hissar Mountains, Qarotegin range, the range of Peter the First, Darvaz range and partially the Western Pamir. The climatic conditions of a region occupied by these deciduous forests are most favourable for tree and shrub plants. There are is significant precipitation, moderate temperatures, higher air humidity, prevailing snow cover in winter months, the dry summer period is relatively short and only one month of August is rainless. Main types of forest trees growing in broadleaved forests are European walnut (*Juglans regia*), *Acer turkestanicum*, planes from European plane (*Platanus orientalis*) and fruit-tree plantations of apple, hawthorn, mountain ash and other wild fruit species.

1.4 Inventory of forests

Forest ecosystems and forest resources are complex elements, which cannot be understood without systematically generated data and information. We are always interested in receiving well-founded quantitative and qualitative information about the current status of forest resources. Forest inventory is a set of activities on collection of data about qualitative and quantitative characteristics of forests according to a statistically defined method. This is very important, as, due to the complexity, inaccessibility, size and volume of resources we cannot observe and measure everything. All activities that are conducted in the framework of a forest inventory must be statistically justified.

Another aim of conducting an inventory of forests is a description of changes in target variables defined in the field forms that took place during the specified time period. Studies conducted in one sample plot (SP) provide current information about forest resources, but not about changes that took place during a certain time. Therefore a regular system of inventory is needed, where periodic recurring measurements of target variables are conducted to detect changes.

1.5 Assessment and preparation of materials

The assessment and preparation of materials is one of the most important stages of a forest inventory. The starting point of planning the forest inventory is a thorough assessment of available information necessary for the achievement of the general aims of the inventory. In the framework of planning the inventory, a list of all variables and indicators to be studied should be defined and listed beforehand. Depending on the region the general goal of the inventory may be different. Therefore, in the very beginning of the activities it is necessary to get the opinion of local experts as well as to take into consideration the needs of local foresters (huntzman) that subsequently will be the main interested users of the results of your inventory. Then, all requested information should be translated into specific indicators and variables that will be studied. At the same time it is necessary to note that for each indicator subsequently a data model should be built.

1.6 Procedure for collection of available information

A list of all necessary activities that should be implemented at planning stage is presented below:

- Determination of general goals and scale of the inventory;
- Conduction of introductory seminars and presentations for representatives of local the forest enterprises;
- Determination of indicators for stakeholders involved;
- Review of available information;
- Collection of information on species of plants growing in this region;
- Terrain study.

1.6.1 Determination of general goals and scale of inventory

A comprehensive inventory is the basis for sustainable planning. However, every monitoring system (inventory) must have its own goals. Commonly, these goals are determined by the customer, for example, in our case the customer is the GIZ project that determines the general goal of conducting the inventory.

1.6.1.1 Scale

A relevant scale must be selected, depending on the goal of the inventory. If the goal of the inventory is a national assessment of forest resources, arrangements of sample plots for the entire territory of the country are needed. In case an inventory is conducted in a given forestry, the scale covers only the territory of the forestry. At the same time, it is necessary to take into consideration the opinion of customers, as data accuracy depends namely on the scale and number of the sample plots.

1.6.2 Conducting introductory seminars for stakeholders

After the determination of the general goals of the inventory, it is necessary to conduct introductory seminars for all stakeholders. Conducting such seminars helps avoiding misunderstandings between the involved research groups and other local institutions. It is necessary to explain in detail the goal and scientific nature of the inventory in the course of conducting such seminars. Representatives of local institutions, for example forestry enterprises, pasture committees, representatives of farm enterprises, etc. usually have extensive experience and knowledge about their region. Therefore studying opinions of local experts is a very important factor that should be taken into consideration. Depending on the opportunity, it is recommended to conduct this introductory seminar for the staff of forest enterprises separately.

1.6.3 Determination of indicators for stakeholders

Indicators under study are determined by the customer or local forestry enterprise respectively. It is necessary to conduct one session in working groups in the course of conducting introductory seminars, where foresters and the forestry administration determine what information should be collected in the first instance. While developing the list of indicators the research group should take into consideration the statistical approach of the whole process. However, it is also necessary to pay attention to the volume of examined information. In general, if there are too many indicators in the field forms their filling is uncomfortable and labour-intensive. Normally the forms of field data contain no more than 2-3 pages. We recommend using the form developed by our specialists (see Appendixes). This form was successfully tested in tugai and juniperus forests of Tajikistan and proved to be efficient.

1.6.4 Review of available information

It is necessary to review all available information for the successful planning of all activities of the inventory. Forest management planning was conducted practically in every forestry enterprise during the

Soviet period and forest mensuration description and working maps are available. It is safe to say that it is impossible to find other more detailed and accurate information about forest resources of this region. Therefore, it is necessary to study them in detail and use them in subsequent planning of both, field visits and office work.

1.6.5 Collection of information on species of plants growing in this region

Forest mensuration description also provides information about species of plants that grow on the territory of forestry enterprises. Experience shows that in some cases one and the same tree may be called differently in different regions, and sometimes differently in different villages of one region. While developing the list it is extremely important to take into consideration this fact and indicate all versions of names of plants in the local language. In this case it is necessary to ask for consultation of local foresters or representatives of local communities. It is recommended to have scientific Latin names, as the Latin names normally will be entered in the database.

1.6.6 Terrain study

Geographic, environmental and other characteristics of the region should be studied in the planning stage. Using geographic or topographic maps, hybrid layers of GoogleEarth satellite imagery or any other available data and in consultation with local representatives is necessary, in order to mark safe routes of movement for the field groups. In general, it is necessary to take the peculiarities of the region into consideration while selecting the sample plots for the field visits.

1.7 Analysis of satellite imagery

Using materials of remote sensing (satellite imagery) is a mandatory feature of forest inventory. Based on satellite imagery classification and mapping of forest resources, calculation of vegetation index and stratification of forests by types is conducted

The Agency for Forestry and Hunting of the Republic of Tajikistan has Rapid Eye satellite imagery with processing level L3A that covers almost all territories of the State Forest Fund. The mentioned satellite data were provided within the framework of the GIZ project “Adaptation to climate change through the sustainable forest management”.

1.7.1 Characteristics of Rapid Eye satellite images

German satellite system RapidEye is specially developed for monitoring of vegetation and has five channels covering visible and NIR (near infrared channel) range of electromagnetic spectrum. A unique feature of RapidEye is a group of five equally calibrated satellites that enable to take high resolution images once in twenty-four hours. In combination with nominal spatial resolution 6.5×6.5 m RapidEye has a big potential for forest monitoring. RapidEye images were successfully used for the piloting of the forest inventory in Panjakent.

There is a list of working processes of preliminary processing, including calibration and improvement in section 1.7.2 for RapidEye images are brought. During piloting of this inventory method in the course of field visits, the quality of preliminary processed images were assessed based on electronic copies and digital formats of working field maps in the field. The field visits confirmed the generally high quality of preliminary processing.

1.7.2 Adjustment of images (Preliminary processing)

One of most important and complex steps in analysis of materials of remote sensing is preliminary processing of images that is necessary for reducing effects caused by incorrect geometry, atmospheric conditions and influence of terrain complexity in regions. The following paragraphs provide a brief overview of the steps of the preliminary processing of images that should be taken before using the materials.

Geometric adjustment – of satellite images is a crucial point in the conducting of forest inventory based on materials of remote sensing, where images and collected field data should be combined in correct co-registration of all relevant datasets. Even if products (satellite imagery) of RapidEye company with L3A processing level are already ortho ready, standard errors less than 45 m occur, especially in remote regions with sharp terrain conditions, which is typical to many districts of Tajikistan. This leads to a situation where selected pixels and attributive data connected with them are not located within the borders of the plots. Therefore, it is necessary to have ground control points for georeferencing. It is recommended to mark ground control points in the field, which can be clearly defined on the images (for example, intersections, bridges and corners of large buildings). It is possible to conduct measurement with any mobile GPS devices of consumer class, but for more efficient results it is recommended to use GPS devices with low geometric errors.

Image calibration – Another important step towards an automatic image classification is the proper calibration of the observed reflectance. Beside the characteristics of the targeted objects there are many factors influencing the amount of energy that is recorded at the sensor including: the image acquisition geometry, atmospheric conditions and earth-sun constellation. To reduce these effects proper information about the atmosphere, geometry and sensors at the time of the acquisition is required. Some of the needed information can be derived from the metadata that is delivered for each Rapideye image by Blackbridge (e.g. sun azimuth, sun angle, exact acquisition time). To model the scattering and absorption effects in the atmosphere it is important to have information about the ozone, water vapour and aerosol contents at the acquisition time. Usually this kind of atmospheric information can be derived from the climate stations network of NASA (AERONET). Unfortunately, the only station in Tajikistan is located in Dushanbe which is too far away from the targeted project areas. Thus, a full atmospheric correction cannot be applied to the RapidEye images. However, as some information about the image acquisitions geometry is available from the metadata it is possible to calculate the Top of Atmospheric reflection (TOA) which is converting the digital numbers into the physical ratio of incoming vs. recorded energy at the sensor. With this procedure variation caused by differences in the Sun-Earth distance (date) and the acquisition geometry of images taken at different dates is reduced (P. Magdon 2015)

Topographic correction – The Topography of the earth's surface has a strong influence on the brightness of satellite imagery. Slopes exposed to the sun are brighter than slopes exposed to the opposite direction. This may have a problematic influence on the classification, as one target class (for example, juniperus forests) may appear differently depending on slope and exposition. Relevant technique for reducing the abovementioned effects, caused by terrain, is called topographic adjustment. Topographic adjustment is crucial in areas with complex topography and uneven terrain, as in the majority of the regions of Tajikistan. There are many adjustment algorithms, the use of which depends on relief model, and the quality of the topographic adjustment depends on the quality of the terrain model. The most well-known and freely available terrain model is SRTM that is issued by NASA and has a nominal spatial resolution of 90 m. Another global terrain model is GDEM, issued by ASTER, with a nominal spatial

resolution of 30 m. Despite the fact that GDEM has a higher spatial resolution than SRTM, experience shows that the quality of SRTM models suits better for the topographic adjustment of RapidEye images.

Image enhancement - Different enhancement techniques can be used to improve to increase the separability of the targeted classes (e.g. woody vegetation vs. pastures). Vegetation indices make use of the distinct reflection patterns of healthy vegetation with low reflections in the red and high reflections in the near infrared (NIR) spectrum. Additionally, texture indices that describe the variation of the reflection in a spatial neighborhood can help to differentiate the classes. For multi-temporal analysis either specifically designed multi-temporal indices or dimension reduction techniques like principal component analysis (PCA) can be used.

1.7.3 Calculation of plant (vegetation) indexes

The use of vegetation indices helps to improve the accuracy of the detection of vegetation (for example trees) in multispectral satellite imagery. The majority of indicators for indices are built on spectral characteristics in relation to live vegetation with high difference in reflection between red and NIR spectra. The most widespread index is NDVI, but the calculation of other indexes is possible for multispectral imagery as well, for example NDVIRE (Normalized Vegetation Index RedEdge), CGM (Chlorophyll Green Model), CRM (Chlorophyll RedEdge Model), etc.

1.8 Classification scheme and mapping

The classification key for the generation of the forest cover maps need to consider the criteria of the Tajik forest definition as specified in the actual Forest Code of the Republic of Tajikistan:

“Forest: a complex of natural vegetation formed naturally and artificially in a certain area by a community of trees and shrubs (no less than 10% of the area should be covered by wood-forming plants, with a total area not less than 0.5 hectares and a width not less than 10 meters) and other components of wildlife interacting with the environment and having important ecological, economic and social value.”

Not all criteria of the definition can be assessed during a classification of remote sensing images. However, the following quantitative criteria should be considered during the forest map generation:

- a community of shrubs of trees with a crown cover not less than 10%
- a minimum patch size of 0.5ha
- a minimum width of 10m

To implement the criteria of the forest definition a hierarchical classification key with different levels needs to be implemented. On the lowest level of such a classification key different land cover types are separated (e.g. woody vegetation, pastures, water bodies). In the next level the classes are aggregated into broader categories (e.g. forest / non-forest) by means of the class definitions implementing the determined criteria (e.g. minimum crown cover). Here GIS processing techniques and morphological image operators can be used to implement the various criteria.

The classification strategy mainly depends on the target variables and forest types. In our case we are interested in the assessment of the potential of RapidEye images for stratification of plots by forest types. Thus target classes are different types of forests, as it is shown in figure 1:

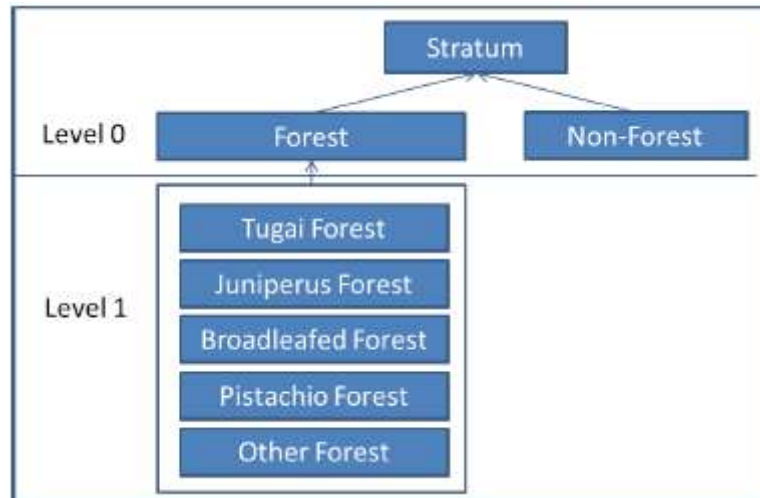


Figure 1: Example of hierarchical forest classification system

It is necessary to have a clear definition of forests types before the start of the classification, as criterion of each forest type should be determined for each plot (sample plot) separately. It is recommended to use a hierarchical classification system consisting of several levels, as shown above.

The forest definition according to the Forest Code or the FAO standard is applied in the first level (Level 0). Then a specific forest type (level 1) is determined for each plot, for example, tugai, pistachio or juniperus. For satellite imagery initially a criterion is determined for each stand (polygon or contour) “Forest” or “Non-Forest”. Then prevailing species of plants in the stand are determined, for example, Juniperus, Maple, etc. The forest type is determined by prevailing species (Magdon et al. 2014)

1.9 Accuracy assessment and area estimation

1.9.1 Accuracy assessment

To evaluate the quality of the generated forest cover map and independent accuracy assessment need to be conducted. Therefore, a set of ground truthing points need to be selected following a probability sampling design. All validation points are then assigned to one of the classes in each level of the classification key using the best available information. Such information can be obtained from field visits, visual image interpretation of high resolution satellite images or aerial images, expert consultations or existing maps with known high quality. In the proposed DSS design the points from phase 1 can be used for the validation if the classification was based on independent data, as recommended. This makes the design quite efficient as no additional data needs to be collected.

For each forest site an accuracy assessment protocol should be complied. Therefore, a confusion matrix comparing the classification results and the validation classes need to be generated and the following statistics calculated: Overall Accuracy (OA), Producer Accuracy (PA), User Accuracy(UA) and Cohens Kappa. The original confusion matrices should also be included in the protocol.

1.9.2 Model assisted area estimation

The confusion matrices are also used to estimate the forest cover for each forest site using the model assisted estimator described in Olofsson et al. 2013.¹ Therefore, the raw confusion matrices are converted into proportions. The weights of each class is calculated from the map proportion as predicted by the classification model. Using the described estimators, the mean forest cover, the forest area, the standard error of the mean and the confidence interval of the forest area estimated should be reported for each forest site.

1.10 Measurement of tree crowns with GoogleEarth® images

In addition to the approach of using RapidEye images for the determination of vegetation cover, an approach based on Google Earth imagery is also used the collection of information about the variability of tree density per specified unit of area in different forest types. For the majority of districts of Tajikistan high resolution images are available in the Google Earth system, which can be used to determine information such as number of trees per hectare and change of tree density per unit of area in different forest types.

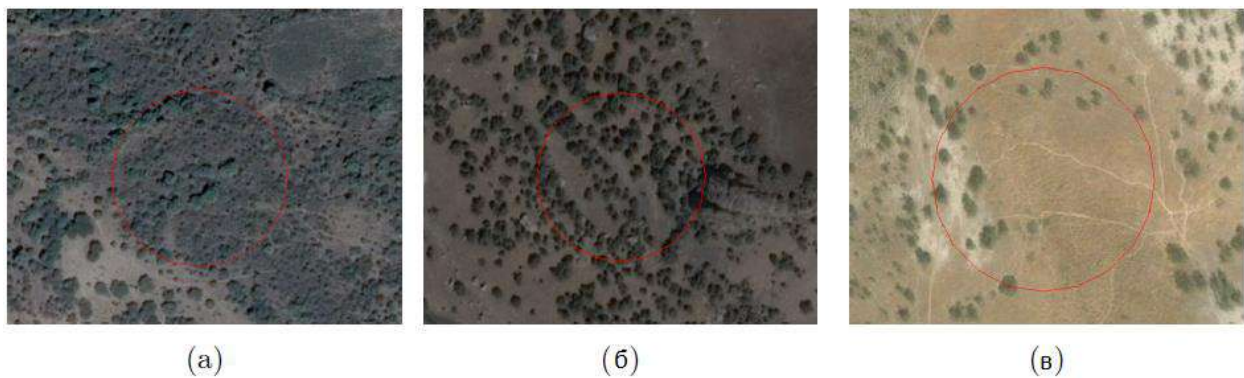


Figure 2: Different forest types in Google Earth images

In the framework of the method of double stratification sampling based on Google Earth the classification of sample plots into different strata is conducted (see first phase). The size of sample plots in the first phase corresponds to standard sizes according to the criteria of the respective forest definition.

1.11 Capacity development and team building

For efficient application of this methodology it is necessary to conduct practical and theoretical trainings for both, staff of local forestry enterprises and for respective service providers and scientific and research organizations. During the trainings, separate compact groups consisting of specialists from different agencies should be set up that will carry out the field activities. A group leader is selected for each team, who is the main responsible of the team and should have the following characteristics:

1. Have a good idea about the concept of forest inventory and should be able to deal with unforeseen challenges;
2. Have good knowledge of the local region and have good contacts with local foresters;
3. Have good cartography knowledge and ability to use GPS devices;

¹ Olofsson, P., Foody, G. M., Stehman, S. V., & Woodcock, C. E. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment*, 129, 122–131.

4. Regularly check the quality of the collected data in the field forms;
5. Notify the management of the forest enterprise and customer on progress regularly and submit interim reports in the process of the inventory.

The training for the field teams should be conducted in two stages. (I) theoretical part, where a detailed description of the use of all devices is provided, and (II) practical part, that should be conducted in the field with real sample plots. Capacity building for field groups should be provided in such a mode that all members could use devices and conduct measurements. One of the members of the team should get enhanced training on methodology of inventory and on the theory of sample plots as a whole. At the end of the training (advanced training) the level of knowledge should be checked by testing. The members of the team that pass this test will get a certificate for the completion of the course.

Training on data processing, use of database management system and mapping in GIS environment should be conducted for staff members, who are involved in mapping and data management. In our case, if these activities are conducted by local staff using stratified double sampling, where satellite imagery is mainly used, it is necessary to conduct a specialized training on remote sensing. It is recommended to attract relevant specialists for this phase as well as for the analysis and processing of images as a whole. With the aim of avoiding additional costs for processing, analysis and preparation of reports it is more reasonable to use available free software with open code, such as QGIS, GrassGIS, OpenOffice, OpenForris and SagaGIS.

If necessary, it is possible to organize trainings for decision makers that in future will assess the results of the forest inventory and should be able to interpret final reports.

2. Inventory design

2.1 Mapping management units

The proposed methodology relates to a large-scale inventory that covers large areas of forest. Using a planned two-stage approach, it is possible to get an assessment on different types of forests of a certain area extent and average conditions on each class. Therefore, the proposed approach of forest inventory is not intended for the delineation of management units. Large-scale inventory of forests should be clearly separated from forest management planning that is intended for planning and management of resources and other categories of the forest land. The inventory also provides information for the assessment of forest plantations, while forest management planning covers assessment, planning and management of all categories of forest land.

2.2 Sample plot

A sample plot (hereinafter SP) is a delineated part of forest land area, where each individual tree is counted and measured and a detailed description of the forest site is conducted. SPs are used as a standard that characterizes a certain category of land or plantations. A SP is set up with the aim of clarifying the correlation between assessed characteristics of a plantation and decoding signs that are determined by satellite images. Coordinates of the location of sample plots are determined based on the modeling of options of a net of samples according to data from satellite images. Sample plots are special forest areas, where long-term monitoring and scientific research are conducted. In addition, their aim is to track the development of natural ecosystems.

Using double sampling for stratification of different SPs is used for the first and second phases of inventory.

2.3 Idea of double sample for stratification method

The size of strata (layers) must be determined in advance in order to assess types of plantations (for all strata). If similar to our case of project regions, the sizes of strata (layers) for different types of forests are not known, a two-phase approach is used, when a relatively big number of SPs are selected in the first phase and it is determined to what stratum this SP belongs.

At the second stage (phase) stratified SPs are selected from the first phase. The direction of the second phase depends on a value of the variable determining what stratum the respective SP belongs to. Other target variables are determined and assessment errors are taken into consideration during this phase. After completion of the classification, a randomly selected smaller set of SPs in each forest type should be visited in the field. The classification in the first phase may be done with the method of remote sensing as described in section of 2.4

2.4 Integration of remote sensing into forest inventory (comprehensive approach)

The term “comprehensive approach” relates to the integration of remote sensing data into forest inventory. The integration of remote sensing data into forest inventory increases the general efficiency of the inventory. Large areas covered by satellite imagery are commonly used for different purposes: 1) stratification of forests by different forest types and 2) regionalization of estimates of ground sample plots and their transformation to larger scales with the aim of receiving cartography products. DSS (Double Sampling for Stratification) design as mentioned above, suits well for the integration of remote sensing data as an additional source of data in the first phase, where a large number of SPs is needed for classification. Vegetation mask received from RapidEye imagery may be used for the exclusion of non-vegetation territories.

2.5 First phase

The determination of sizes of forest types (strata) based on remote sensing data is done in the first phase. A systematic net of SPs is selected for the first phase. The distances between SPs are determined depending on the area of the territories and the accuracy of calculations, for example, 1 x 1 km. It is desirable to set a systematic net with a projected system of coordinates, for example, UTM in order to ensure the practical connection for the following field activities.

2.6 Second phase

Piloting stage – During the second phase those SPs from first phase that were determined as covered by forest according to the respective definition, are randomly selected in each stratum using generators of random numbers and a random number of SPs are studied in the field. For piloting 5% but not less than 20 SPs from the total number in one stratum are selected. After piloting stage the data is analyzed in order to define variability of target variables and to set final sizes of SPs in different strata.

Field studies – Nevertheless, the main factors influencing the selection of the number of SPs for field study are as follow: 1) volume of available resources for financing of experts; 2) availability of specialized equipment; 3) logistics and 4) experience of trained field groups. In other words, the selection of SPs for the second phase of field studies also depends on the available resources and not only on

statistical criteria. In the piloting stage it is necessary to pay attention to the time spent for the study of one plot. This is necessary for defining the optimal number of SPs that can be studied with the resources available.

2.7 Additional socio-economic studies

For some types of forests, for example, pistachio plantations in Danghara and Farkhor, it is necessary to get information about rates of harvest of fruits and other non-wood forest products (NWFPs). In principle such information can be collected during field measurements of the inventory. For the assessment of the quantity of nuts per tree in pistachio plantations such methodological approaches as estimation of average productivity of one trunk or platform can be used. Nevertheless, such additional measurements are quite difficult to assess in the field and they require studying another complex methodology that should be applied.

For the assessment of socio-economic data, such as the needs of the local population for the use of NWFPs, an additional survey (questionnaire) is conducted. Relevant heads of communities can provide detailed information on harvests and profitability in different years. It is crucial that the additional data is collected in spatial dependence with the biophysical data from the field plots. The survey should be conducted in a zone, which is located in close proximity to the SP, or in other cases, in the course of the survey it is necessary to indicate in a map the zones, for which such information is provided, mark GPS points of the place, where the survey was conducted after completion.

The survey should be conducted independently from the field activities in the frame of the inventory. All stakeholders should be involved in the process of drafting questionnaires. Interconnected socio-economic and biophysical data may be used for many purposes, for example, for identification of potential causes of degradation and others that should be taken into account. Drafting a good questionnaire is not an easy task and it is recommended to consult with local experts.

2.8 Data management

Data of all variables in the field forms should be kept in a relational database according to groups. It is recommended to enter the field data on the same day, if possible, in order to reduce complications during data entry, and for the possibility of checking reliability in real time. Besides, requested data (target variables) should not be redundant and the structure must be simple. A key table with specifications of all variables of the plot should be prepared. For each written value of the plot it should be clear in what sub-plot of SP net observations were conducted. In addition, all paper copies of the field forms must be kept in a central place or in a reliable carrier with subsequent archiving. It is recommended to prepare a relevant relational database for professional management of large volumes of datasets. We recommend using software with open source code, for example, PostgreSQL, OpenForris or OpenOffice Base.

2.9 Mapping and GIS analysis

GIS and remote sensing are used for producing relevant working maps for field teams. For each separate team it is mandatory to have a map of terrain and territory of the study. The location of SPs and most optimal routes to these points should be indicated in the working maps. Mainly GIS products with open source code are used during mapping.

3. Implementation of field work

3.1 Safety rules during field work

Personal safety of all team members during field work and transportation to plots has high priority! All team members must be informed about possible risks and relevant measures for their reduction or prevention. Each team member is responsible for regular checks of the personal safety of his team. Any team member can freely stop his field work as soon as he/she feels himself/herself uncomfortable or unsafe in any situation. Every team member must be informed that any incident in the field is a serious danger for the entire team and that irresponsible behavior of individuals is not acceptable. Most important measures that should be considered for risk reduction are the following:

Proper planning of field work is an important measure for risk reduction. Therefore, all decisions on planned field work should be taken on timely basis and all team members should be informed. As far as possible, spontaneous changes in planned activities should be avoided. Always take into consideration that time planning might be unacceptable or flexible. It is important to stopping work in the field at in time before it gets dark. Inform superior responsible persons or other team members about your daily working places.

Orientation: All members of the field team should know where they are working and should be able to describe their actual location if needed. Mobile phone network coverage should be checked regularly. Eventually, the point for last connection has to be marked at GPS receiver. Track the route to the sample plot in an area of hard access in order to be more confident on return! Keep to most safe route to sample plots, but not shortest one!

Equipment: Availability and functionality of the equipment must be checked directly before going to the plots. This includes checking charging status of battery for field radio stations, mobile phones and GPS receivers. First aid kit is a part of the field equipment.

Information: While working in the regions, where risks of outbreak of conflicts exist or with vulnerable political situations, it is recommended to have handout information material that describes the mission background in simple words. Owners of land plots or local communities may be very negatively inclined if strangers work on their land without proper explanation (without objective reason)! If possible, get into contact with these groups BEFORE you go to field plots and explain the scientific nature of the inventory with clear terms. If needed, attract local inhabitants for accompanying the team in the field during their work and helping them in orientation in the plots located in terrain of hard access.

3.2 Equipment and materials

It is recommended to have a list of devices adapted to calculations in the sample plot for more efficient implementation of work in the field plots. Most simple devices may be used, but eventually it is difficult to use them under certain conditions. It is more reasonable to use such tools as ultrasonic “Vertex” for doing measurements in circular sample plots. This device measures distance based on ultrasound that is able to pass through dense and thorny shrubs and bushes. Setting a circular sample plot with a simple measuring tape may be very difficult in the plots with dense understory plantations.

According to proposed methodology every field team should be equipped with the following tools:

Table 1: List of devices and materials for field work

Device/Materials	Quantity	Comments
Rucksack for devices	1	
GPS receiver/mobile GIS	1	Upload all necessary data
Compass «Suunto» or any other analog	1	Check declination
Vertex III + Transponder + support shaft	1	Regularly conduct calibration
Dendrometer	1	For selection of basal area
Measuring tape for diameter measuring (Pi tape)	2	Small bracelet (3m)
	1	Prepare for every project area
Overview map/scheme of works/ Field form + pencils	10	
Marking tape	1	1 roll for tree marking
Marking peg (50 cm)	10	Small peg for red marking
Measure tape	1	Height regeneration
Calculator	1	
Chalk	3	Temporary marking of trees
Reserve batteries	4	One additional set for all devices
Manual on field research and overview tables	1	Laminated version
First aid kit	1	

3.3 Organization of field team

For efficient work in the field and for safety consideration a field team should have not less than 2 persons (better 3 persons). Every person has a specific role and responsibility while conducting assessment in field condition and during measurements. The roles of team members may change from time to time in order to make field works less tiresome.

Responsibilities of different positions in the team are distributed as follow:

Navigator (manages GPS receiver and shows the way to sample plot) performs the following functions:

- Visual inspection and checking stock on the site. Determination of other variables on the site together with gauger
- Recording results of all measurements according to data of measuring devices in field forms

- Determination of segments of a sample plot
- Assistance in assessment of standing snags and assessment of regeneration

Registrar: stands in the central part of the plot (or in cross line) and writes down measurement results

- Visual inspection and checking stock on the site. Determination of other variables on the site jointly with gauger
- Recording all measurements according to indicators of a measuring device in the field form
- Measuring and recording of azimuth data
- Assistance in assessment of regeneration
- Conducting tests with “Bitterlich” densimeter or with any other analog

Gauger (“Jumper”): goes from one tree to another and conducts measurements

- Announcement of ordinal number of trees (writes down tree number on the tree with a chalk)
- Measuring and reporting variable trees
- Visual inspection and checking stock on the site. Determination of other variables on the site together with the registrar
- Assessment of regeneration

3.4 Location of sample plots in field areas

Location of selective sample plots is determined by provided sample scheme and is kept in the form of a set of road points (or in shape-files, if mobile GIS is accessible) in a GPS receiver. The field groups should jointly decide from what direction it is easier to reach location of the plot. In mountainous terrain with steep slopes it is recommended to approach places of sample plots from below or parallel to slope, as walking on the slope may be more dangerous because of limited visibility and steep slopes. Therefore it is recommended to keep a contour curve or DEM (digital elevation model) in every GPS receiver if possible. The path from motor highway/closest road should be tracked by GPS receiver (GPS receiver should be kept on) in a terrain of hard access!

3.4.1 Navigation with GPS

In order to start navigation to the place of a sample plot a route point is selected from a list of intermediate points of the route. Depending on the GPS signal and accuracy of positions the team may move to the location of the sample plot only with GPS receiver. Continuous measurements (2-3 minutes depending on signal reception) are taken in fixed position in a direct surrounding of the location of the sample plot. Remaining distance and direction angle to the target are used to find a sample point with compass and range finder. It is not recommended to walk with GPS receiver for final determination of a position! The GPS receiver regularly determines an average position from the signal received in the course of certain time interval, therefore, movement to different directions will not allow finding more accurate position. If the leaf canopy covering sample plot is too dense, for receiving stable GPS signal it is necessary to conduct continuous measurements in closest neighboring places, where a better signal is observed (for example closest gap in leaf canopy). Distance and direction angle to target can be read in GPS receiver, and a compass, sighting rod and range finder can be used for ground navigation. In this case it is important to measure horizontal distance or use a range finder that determines horizontal distance. In case of limited visibility or long distances the total distance is divided into segments of relevant length. For the navigation with a compass it is recommended to approach the target ascent under

good visibility.

3.4.2 Marking the center of the sample plot

After the determination of the location of a sample plot, it is recommended to mark the center with a temporary marking peg. In addition, the closest tree in the center of the plot must be marked with red marking tape. Additional marking of locations is recommended while setting permanent sample plots. The location of the permanent sample plots should be documented in details. It is possible to make markings with certain drawings on the produced working maps. The location of plots should not be marked with large installations, such as poles or lightfast paint on trees. It is because of the fact that such marking may have a strong influence on the management of these plots and it is more likely that the plot will not be used as usual, which can lead to serious deviations in the assessment of the natural conditions.

3.5 Work flow

All assessment and measurement activities in the plots should be conducted in a certain sequence. It is necessary to conduct the measurement in a similar order and mode in every plot that enables to remember measured values and is more efficient. After the marking of the plot center and the installation of the central bar of the “Vertex” transponder it is necessary to conduct the following actions:

1. Record exact time of beginning of work
2. Start detailed GPS measurement of the sample plot. Even after the determination of a location with the GPS device, the coordinates of separated positions still may change. It is important to get exact position in order to reduce the number of registration errors in subsequent integration with remote satellite imagery. Other stages of work may continue in the process of doing measurements.
3. Measure and fill in data fields in “MEASUREMENT” and “GEO_INFO” tabs.
4. Make visual inspection of stock of plantations inside and across border of the sample plot and fill in fields of data category “STOCK”.
5. Measure steepness of slope and exposition. Make visual inspection and fill in other indicators of “PLOT” category.
6. Conduct measurement of individual trees and fill in fields of data category “TREE”. Height of trees and crown radius are measured separately after when all remaining data of one tree are recorded.
7. Conduct measurement in sub-plots and write down results in the fields of data category “REG”
8. Record exact time of end of work.

3.6 Definition of data entry categories

Data entry field forms, which are observed in every sample plot, are divided into different categories (See annexes) depending on their measurement scale and/or relevant target object. Every variable is clearly defined taking into consideration measurement/observation scale, possible meanings (in case of ordinary or Boolean scale) and their accuracy. A list of form categories and their brief description is brought below:

- Data of “MEASUREMENT” categories: General information about target work, for example, date of assessment, list of team members, etc.
- Data of “GEO_INFO” tab: Geographical description of location of a sample plot, for example, coordinates, altitude above the sea level, etc.
- “STOCK” category: Characteristics of stand or cutting area, where a selected sample plot is located. This information relates to conditions of administrative division of borders.

- “PLOT” category: Variables describing the conditions in the selected sample plot. In some cases, the description of crown density of plantations or physical features of a terrain for correct assessment of plantations outside the sample plot must be taken into consideration as well. This allows correct interpretation of condition of the plot. These indicators describe characteristics that directly influence the trees growing in this plot and can be compared with remote sensing data that cover the area of the plot and its direct surrounding.
- “TREE” category: Measured data/observation on separate trees inside sample plot.
- “REG” category: variables characterizing condition of regeneration.

3.7 Description of fields for data entry

As it has been mentioned the field forms for data entry should be divided into categories. It enables to easily construct variables upon further data management and development of a database. The format of values is very simple: first a “name of category” is taken, then “_” character and finally “name of data entry field”, for example, “MEASUREMENT_Team”.

3.7.1 Brief description of fields for entering data category “MEASUREMENT” in the field form

Team: Name of a responsible head of a group or registrar (name of several team members may be written down). These data is needed if there will be any questions about the data entered, the relevant person(s) can be contacted.

Date: Date of assessment of a plot is recorded as follow: dd.mm.yy.

Time/beginning: Time of beginning of assessment (usually after marking of the sample plot) is recorded as follows: hh:mm.

Time/End: Time of completion of assessment (until time the plot is completed) is recorded as follows: hh:mm.

Record of time of the assessment is an important information that can be used for the optimization of the sample plot design. It can be compared with road conditions and can be considered for planning and determination of a size of sample plots for different types of forests (strata).

3.7.2 Brief description of fields for entering data category “GEO_INFO” in the field form

X: X-coordinates (eastern indication according to coordinate grid). Location of a sample plot point for basic coordinate grid given in UTM (42N / WGS84) or in any other similar coordinate system.

Y: Y-coordinates (northern indication on coordinate grid). Location of a sample plot point for basic coordinate grid given in UTM (42N / WGS84) or in any other similar coordinate system.

GPSX: Measurement of a position of X-coordinates (eastern indication according to coordinate grid) with GPS receiver. Marking of location of a sample plot for following joint registration of remote sensing data, given in UTM (42N / WGS84) or another coordinate system.

GPSY: Measurement of a position of Y-coordinates (northern indication according to coordinate grid) with GPS receiver. Marking of location of a sample plot for following joint registration of remote sensing data, given in UTM (42N / WGS84) or another coordinate system.

3.7.3 Brief description data for entering in the category “STOCK” in the field form

Stock of plantations is determined in areas, where a sample plot falls in. Visual overview/analysis should

be conducted only in relation to tree plantations. At the same time you should always take into consideration the factor of integration of researched data with materials of remote sensing (satellite imagery).

Origin: This indicator describes origin of plantations. In mixed plantations privilege is given to constituent specie that has main commercial interest.

The field may take the following values:

0. Natural regeneration
1. Planted/sowed plantations
2. Both (mixed plantations)

Mixture: Determination of a variety of tree species (variety class) within sample plot or surrounding plot by calculation of number of different (tree) types. Depending on context of data analysis this variable may be used in proportion to basal area and biomass or with materials of remote sensing. Number of tree species is an indicator of biodiversity.

The field may take the following values:

- 0: homogenous
- 1: mixed (2-5 species)
- 2: diverse (>5 species)

Vertical Structure: Vertical structure describes diversity of tree height and stock stratification (layer). The structure is observed by visual assessment of average conditions within and outside the area along border of a sample plot. This variable also presents interest for integration with materials of remote sensing, as it influences the check of identity of results of field assessments and projections based on remote sensing materials.

Examples of the vertical structure are brought in Figure 1

1. One-layered, same height
2. One-layered, different height
3. Several layers, clear distribution
4. Different structure of height with gaps
5. Absolutely different structure

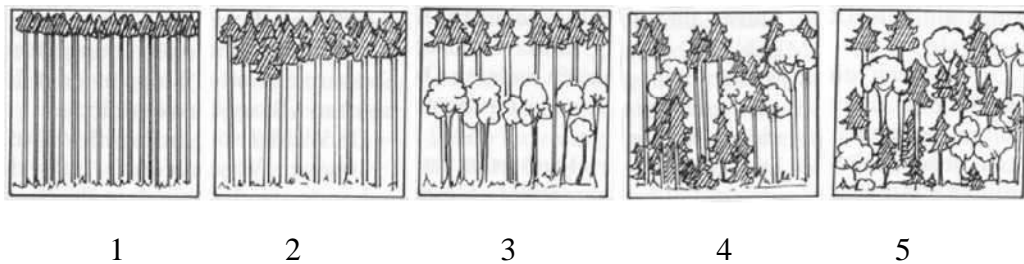


Figure 3: Example of transition between plantations of different tree groups in pistachio species.

Management: Describes general management condition of plantations. It is determined after visual observation of any evidences of good or bad management (for example stub or evidence of tree chopping). The indicator needs to be determined both in newly planted (young stands) and in mature plantings. If needed, in case of availability of evidences of livestock grazing, it is necessary to tick in a relevant indicator of data field (Sometimes two values can be optionally selected):

0: not managed

1: managed

- 2: no grazing
- 3: weak grazing
- 4: intensive grazing

Vegetation: Describes the condition of ground surface according to the following categories. The selected options must help in assessing risk of soil erosion and show pressure of livestock grazing in this plot.

- 0: bare soil
- 1: humus
- 2: grass
- 3: shrubs
- 4: sand/stone

Basal area (BA): Total area of section of a tree stem per hectare (m^2/ha) that is determined by prism-count method. This method may be applied only in those forests, where a good visibility of tree stems is observed.

Main indicative factors are 1, 2 or 4 that can be selected depending on density and distribution of diameter of stems. In case if with selected factor you counted less than 8 trees, correspondingly you need to select a factor below this factor. In this case observation should be repeated with smaller coefficient (factor). BA for the entire stock is calculated as follows: total number of trees calculated with a certain factor is multiplied by coefficient (factor). For example, if you calculated 8 trees with factor 2, then the result will be $16 \text{ m}^2/\text{ha}$, if with 4th factor, then $32 \text{ m}^2/\text{ha}$.

Observation of BA is made with dendrometer or other specialized devices. Description of the dendrometer can be found in the section devoted to measurement of stem of trees.

BA-F: Indicative factor (coefficient) that is used for calculation of area of the basal area for entire stock.

3.7.4 Brief description of data entering category "PLOT" in the field form

Measurement/observation is conducted within a sample plot. In some cases it is possible to conduct measurement/observation outside of the borders of the sample plot for correct assessment. It should always be taken into consideration that observation within sample plot has priority.

Degree of slope: Slope angle (measured in degrees) of sample plot, measured along central line of section of the sample plot with «Vertex» or «Suunto».

Exposition: Direction of slope steepness in this area. In case if aspect/exposition of the area has a slope of less than (<) 5 degrees, then "plain surface" option (option 9) is selected.

- 1. North
- 2. North-east
- 3. East
- 4. South-east
- 5. South
- 6. South-west
- 7. West
- 8. North-west
- 9. Flat (plain) surface

Surface: Form of surface (massif) in this area. This may be necessary for planning further planting measures in this area.

1. Strongly curved \cup
2. Curved \smile
- 3.
4. \frown
5. Strongly convex \cap

Forest type: Characteristics of forest types in this area (inside or outside the sample plot). This factor is also needed for further integration with remote sensing materials (further it is possible to represent the site of separate species and forests on thematic maps). In addition, it is possible to use sample plots as training polygons for general forest classification.

1. Pistachio
2. Floodplain/tugai
3. Juniperus
4. Broadleaved
5. Small leaved
6. Saxaul
7. Other

Stand closure: Average density of location of plantations within sample plot. Possible options of values:

1. Dense (crowns interlace)
2. Close (crowns touch)
3. Loose (one crown size between crowns)
4. Open (more than one crown size between crowns)

Erosion: Describes state of soil erosion in the area. For correct assessment it is recommended to have a manual on classification of erosion with photos. It may take the following values:

1. None (vegetation / top soil undisturbed)
2. Slightly (vegetation / top soil partly lost)
3. Serious (vegetation / top soil lost)
4. Heavy (bare soil affected by water / wind erosion / landslides)

3.7.5 Brief description of fields for entering data category "TREE" in the field form

The value is measured/observed on separate trees that enter or border a sample plot of certain design.

ID: Unique identification number of every tree in the sample plot. The number of tree is temporarily marked with chalk in order not to duplicate measurement for separate stems in future. In case of shrub plantations one and the same ID number is assigned to all single stems.

Bole ID: Unique identification number of every separate stem or branch of one tree.

Azimuth: Azimuth (horizontal direction) is measuring of a direction from center of a sample plot in relation to axis of tree tem. The azimuth is usually measured by registrar, who stands in the center of the sample plot with Suunto compass. The registrar must measure azimuth of trees strictly by certain direction and in relation to those trees, on which "Vertex" transponder is fastened (Figure 4).

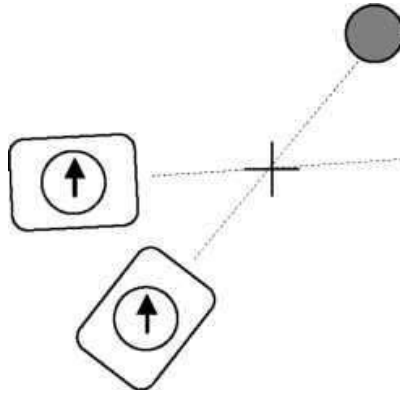


Figure 4: Azimuth of a tree measured by compass within sample plot.

Horizontal distance: The horizontal distance between separate trees and the center of the sample plot. According to available devices the distance may be measured in different ways:

1. Use of a laser device that enables measuring distance from the center of a sample plot to the tree. It is recommended to use this method in cases of free overview of stems (when stand closure is open). In this case a registrar determines whether the tree enters the borders of the sample plot or not.
2. Use of the ultrasonic device “Vertex”, with the help of which the distance from the center of the sample plot to a separate tree, on which transponder is fastened, is calculated. If “Vertex” was used for measuring the vertical angle of the separate tree, the device automatically measures the horizontal distance immediately after measuring the angle. In this case the registrar determines whether the tree enters the borders of the sample plot or not.
3. Use of a simple measuring tape. The use of a tape in dense forests is very uncomfortable as it is difficult to move with it between trees. It is necessary to conduct a slope correction in steep slopes, as significant errors may happen during measurement of horizontal distance. A small formula of slope correction is provided in the appendix of the field form.

Species code: A commonly accepted unique code for plants. If relevant code is accessible, then other records for such fields as TREE_Tree_species are not needed. In case a measured/observed tree cannot be defined, assign the value of NE (not established) to the field. A list of tree species and adopted national codes corresponding to them must be provided by ministries (agencies) coordinating this sector.

Tree species: Botanical or general name of trees and shrubs (in case you managed to define the tree, but relevant code is not known).

DBH: Diameter of tree at breast height measured perpendicularly to stem at height of 1.3 m from ground level with measuring tape having accuracy of 1 mm. Minimal recommended diameter is 7 cm. Trees or shrubs (or single stems of shrubs with several stems) with smaller diameter are reflected in the “REG” regeneration category of areas.

Deviation from DBH: Deviation from height of diameter determination. Deviating height of diameter determination in case if a stem is uneven at breast height (1.3 m). It is applied to forest types consisting of trees of small height, in which the determination of the diameter is impossible at this height, for example: pistachio plantations, tugai, etc. For plantations of such types it is recommended to determine one single height for all for determination of diameter.

Height: Data field for entering the height of single trees. If the number of plantations and trees exceeds

10 pieces in a sample plot, the plantations are selected according to diameter distribution. The idea is to measure trees with a certain diameter range. Minimal measuring diameter is determined beforehand according to goals of conducting the inventory. The height of plantations may be measured with such tools as: ultrasonic «Vertex», laser meters «Nicon Forestry», «TruPulse» or mechanical devices, such as «Blume-Leiss», «Suunto» or «Silva clinomaster». For more detailed instruction on measuring the height, see section on measurement of separate trees.

Level of damage: Significant damage to stems or crowns of plantations of different classes. It is recommended to record only damages that have significant impact on the quality of trees. Proposed levels (options) of damages may be changed according to context of the inventory.

- 1: Broken crown
- 2: Harvested for firewood
- 3: Mass felling
- 4: Damaged by grazing
- 5: Damaged by insects
- 6: Other

3.8 Description of methods used for tree description

3.8.1 Basal area estimation

The total basal area is the sum of area of all end-grain sections of separate trees (measured at DHB at height of 1.3 m) per hectare. A sample study by the prism-count method (or «Bitterlich» sample, sample of number of angles, sample of plot variable) suits well for assessment of this indicator. Basal area is measured from the center of every plot by dendrometer or another relevant device (Figure 5). For example, while using the «Bitterlich» device it is necessary to do the following actions: a) hold the device in a distance of 50 cm from the eyes; b) look through the central hole, by selecting certain a factor count number of trees with visible DHB (it is desirable to measure on clockwise direction, Figure 5). Start counting from northern direction and do not forget to count first tree in order to avoid double stock-taking! Selection of BA factor (coefficient) depends on density of stems and diameter distribution. Based on statistical considerations it is recommended to use the same factor (coefficient) in all areas of the same forest type.



Figure 5: Use of «Bitterlich» tool

3.8.2 Measuring scattered trees

Measuring scattered trees starts from the northern direction of the center of the sample plot and further in a clockwise order. All measured trees are marked with corresponding numbers “TREE_ID” for further height measuring (temporary by chalk).

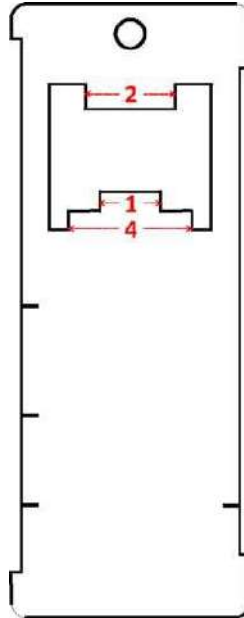


Figure 6: Gottingen dendrometer with basal area (BA) factors 1, 2 and 4. For detailed information about the device (also in Russian) see <http://wiki.awf.forst.uni-goettingen.de/wiki/index.php/Dendrometer>.

All data with different diapasons of diameters are recorded in one table. The horizontal distance to a tree is measured from or to the axis of the stem at the height of 1.3 m. Azimuth is measured in the direction of the stem axis. In case, when the distance to a tree is measured with laser device, TREE_HOR.DIST must be measured from center to the stem surface (see figure 6).

3.8.3 Height measuring

Usually during pilot phases of an inventory the height of 10 trees in one sample plot is measured. Taking into consideration the determination of tree diameter at breast height, these data enable to get a model of height of species of specific trees. The height of a tree is a vertical distance between the top of a tree and ground level along the base of the stem (Figure 6). The calculation is done based on the measurement of the horizontal distance to the tree and the angle towards the tree by trigonometric principles.

In the figure below (Figure 8): h_1 is the height to the top of a stem, and h_2 (in this example as a negative example!) is the height up to the base of the stem. Using the below formulas $h = h_1 - h_2$ it is important to take into account the correct sign of angle measurement. In case, a position of an observer is located a bit lower than the base of the stem, h_2 becomes a positive height. Nevertheless, measuring height from a position lower than the base of stem is not recommended, as visibility of the top of a tree is limited and the risk of measurement errors is high. Possible errors during height measuring may be avoided or reduced by following practices:

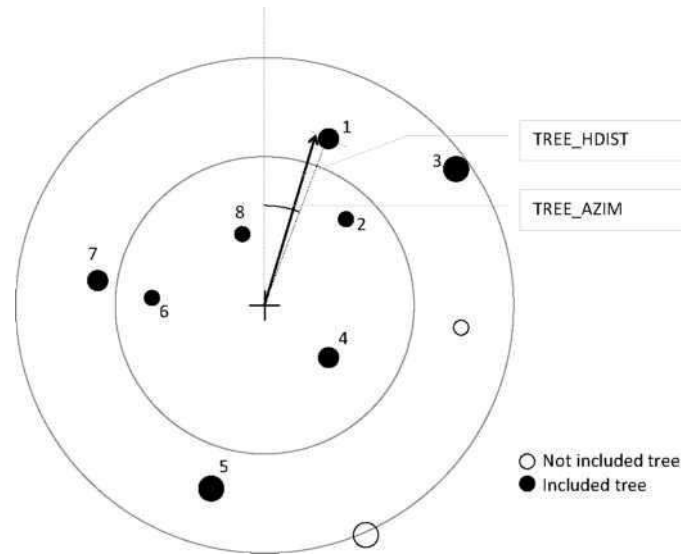


Figure 7: Order of measuring scattered tree and measuring distance/Azimuth.

- There should be enough distance to the tree (about one tree in length)!
- Make sure that you directed the tool up to the level of the top of a tree that is located right on the stem axis (up to which the distance has been measured)!
- At steep slopes try to measure the height in a direction perpendicular to the direction of the slope or at descent from a higher position. Avoid measuring big trees from a position lower than stem base, as it increases probability of errors as a result of bad visibility of the top of trees and extreme angle conditions. A relatively small error in measuring angle leads to big errors while calculating the height of trees.
- In case of bent trees (trees growing crookedly) measure the height from a position perpendicular to sloping direction. Measuring along sloping direction may lead to big errors during measurement of distances (incorrect distance to horizontal projection of the top of tree!).

3.8.4 Height measuring for shrubs

Some of the studied forest types are characterized by a mixture of relatively small trees and shrubs. Typical form of height and habitus of bushes and big shrubs usually leads to relatively weak connection between diameter and height. Bushes are characterized by formation of many branches growing in radial direction, and total height correlates weakly with total area of the basal area of all stems and area of (horizontal) projection of crown (namely average width of crown). Nevertheless, the height is also recorded for shrubs in the course of experimental (pilot) study. Additionally, a study of relativity of width of crown for different species is conducted in the course of piloting.

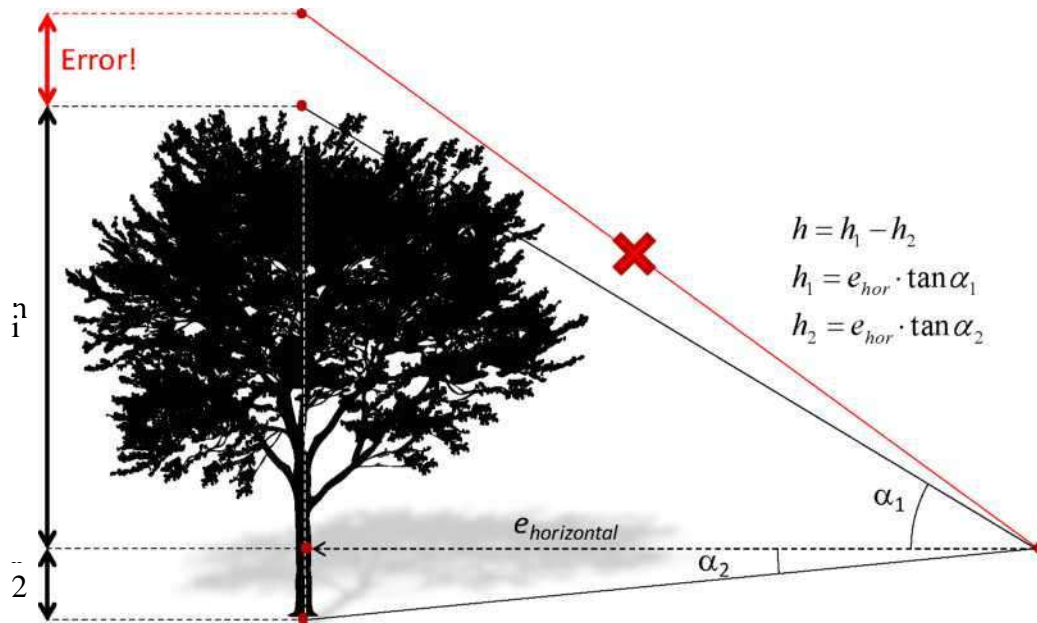


Figure 8: Right measurement of tree height according to trigonometric principle and possible errors as a result of incorrect interpretation of the top of tree.

3.9 Device for height measuring

3.9.1 Suunto clinometer

“Suunto” clinometer is a device that is used for measuring bending and height of trees within fixed distance (15 m, 20 m) to a tree using trigonometric principle. It can be used as a mechanical alternative for recommended “Vertex” device (however “Vertex” is also needed for checking diameter of sample plots, and not only for height measuring!). “Suunto” measures angle of bending to the top and base of tree. If the device is used from fixed horizontal (!) distance, the height of tree can be read from the device scale for relevant distance. Some “Suunto” devices include an optical range finder for measuring fixed distances (15 m, 20 m) and an overview for scale of height. Both measurement and scaling is done with the help of “**Silva Clinomaster**” device; the device additionally has a scale for measuring bending. If the distance to a tree cannot be measured as a horizontal distance, then it is necessary to do slope correction. Relevant table of correction is located on the back of the device (Figure 9).



Figure 9: Hypsometer «Suunto» with optical principle for fixed distances.

In the context of planned assessment of crown width, “Suunto” may be used for determination of horizontal projection of shew edge of the crown.

3.9.2 Ultrasonic «Vertex III»

Total height of a tree and height of different branches may be measured with the ultrasonic tool “Vertex III”. “Vertex” calculates the tree height based on trigonometric principle from distance and measurement angle (Figure 10). “Vertex” works according to principle of calculation of the distance to a transmitter that is fixed at the height of 1.3 m on a tree with the help of ultrasound.

In favourable conditions it is possible to measure through underbrush (nether vert) or bushes that will be very important taking into consideration shrub vegetation in some forest types. Nevertheless, the sound signal may be disturbed by sound of insects, wind or heavy rain, fall of leaves and other sounds. Therefore it is recommended to have always “Suunto” clinometer as a reserve tool.



(a) Vertex III

(b) Transponder fixed on the tree.

Figure 10: «Vertex» clinometer and ultrasonic range finder.

For resetting “Vertex” parameters or returning to the main menu, press DME + IR! For measuring height of tree, do the following actions:

1. Switch on transponder (hold the transponder directly in front of Vertex and press DME: two sound signals = switched on (ON), 4 sound signal = switched off (OFF))
2. Install the transponder on a tree at the height of 1.3 meter (check installation menu for preliminary fixed height of the transponder).
3. Find a place, from which you can see the transponder and top of the tree (the distance should be \geq to expected height of tree).
4. Switch on Vertex (press ON) and select a height regime.
5. Point to the transponder and press ON until the red cross starts blinking (distance and angle to the transponder is measured, “Vertex” is ready for measuring angle to the top of tree).
6. With a blinking crossing point on the top of the tree (OBS: this not necessarily highest point for your actual visual angle!), press ON until the crossing point stops blinking. First angle is measured and relevant height is saved. Vertex is ready for measuring second height from the same position. The crossing point again starts blinking.

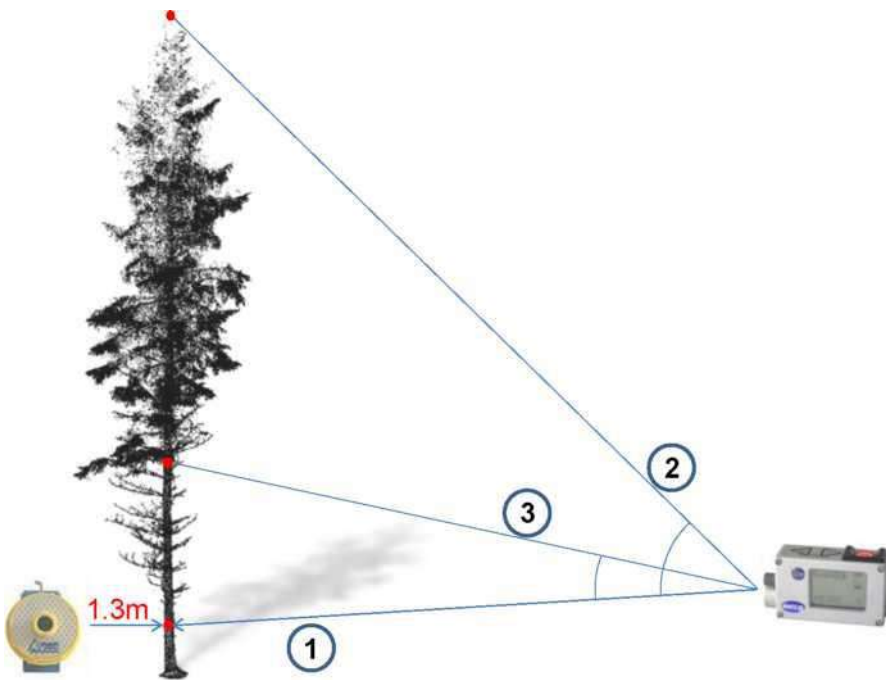


Figure 11: Measuring height of tree with Vertex III: 1) Measurement of distance and angle to transponder (fixed on 1.3 m), 2) measurement angle to the top of tree, 3) additional height to crown base.

7. Reload «Vertex» by pressing DME + IR

Vertex needs a regular calibration! Air temperature and humidity influence measurement. At everyday work the calibration should be repeated at least once in three days. Therefore switch on “Vertex” and select calibration regime. Place transponder on a fixed distance of 10 m (check settings for preliminary distance of calibration) and press DME until getting calibration validation.

Vertex device is also used for setting proposed circular field sample areas. Thus the active transponder is placed on a pole in the sample plot. The transponder is fixed at 360 degrees to sound mirror that is fixed on the pole. With this setting it is possible to measure a distance from any tree in the center of the plot. Here “Vertex” replaces a tape, which is difficult to use in dense and thorny ground vegetation.

3.9.3 Determination of diameter

Diameter at breast height (TREE_DBH) is measured at the height of 1.3 m from ground with a measuring tape for determination of diameter. The measuring tape for determination of diameter has Pi scale that enables reading diameter right on the tape. The tape should be stretched perpendicularly to stem axis. Plants growing on the stem or other vegetation should be removed (Figure 11). As it has been mentioned, DBH measurement is impossible for shrubs and bush trees that have different height levels.



Figure 12: Measuring DBH with measuring tape for determination of diameter (here 35.9 cm).

Figure 12 shows ordinary determination of DBH measurements for some special cases that might happen in the course of implementing field activity. In case if trees are located on sloping surface, initial mark of DBH measurement (1.3 m) always relates to upper side of the slope. In case of uneven stem, higher and lower measurements can be accepted, and an average out of two measurements is calculated. If trees have developed several stems below control height, they are considered and taken into account as separate trees (but receive the same TREE_ID). If diameters are measured at height different than 1.3 m (for example for small shrubs), the height of measurement is recorded.

3.9.4 Crown width

The average radius of horizontal projection of the area of crown of trees and its relation to DBH is an important information, which can be used in the context of integration of remote sensing. Usually correlation between both variables is very strong within one species or species of the group, and may be described by allometric model. In the context of experimental inventory the relevant data should be collected in order to study the possibility of forecasting DBH from crown radius that can be observed only in case of having high resolution image. Correlation between crown width and DBH is needed later for each of the main tree species. Such measurements of crown width can be implemented in those areas that are intended for use as training data for integration with materials of the remote sensing.

The average radius of crown is determined with two perpendicular measurements of crown width (in case of asymmetric or elliptical projection of the crown, these two directions should be determined in such a way so that both, maximal and minimal crown expansions are taken into consideration). Horizontal projection of maximal crown width is determined with “Suunto” clinometer.

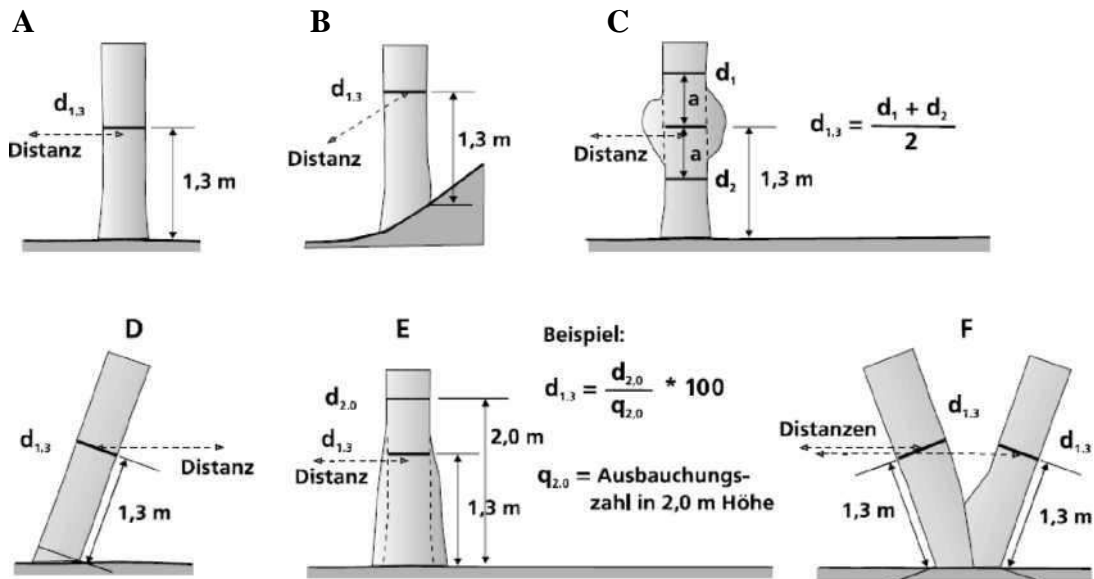


Figure 13: Ordinary determination of DBH (and distance) measurements for different cases

(Figure 13). The scale of the device has a small track for zenithal angle (in imaginary point just “higher on vertical” in a specific place). Indication of external edge of crown (picking up this point from zenithal mark on scale) allows determining location of horizontal projection of the crown edge. This point is temporarily marked with a peg. Horizontal distance between two opposite marginal edges is measured with a tape or “Vertex” with precision of mm. Out of two perpendicular crowns an average values is calculated and recorded in a special field form.

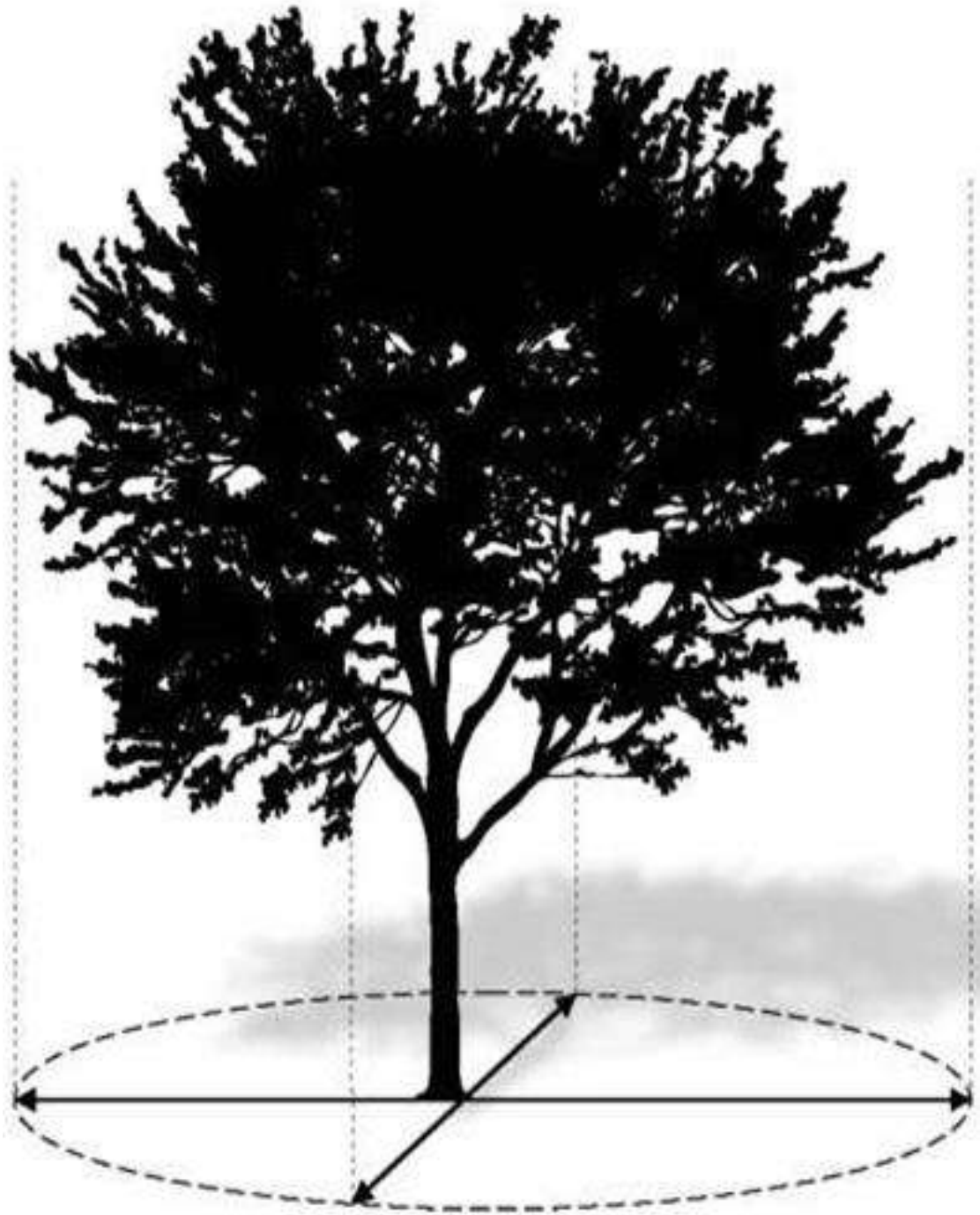
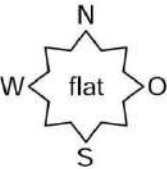


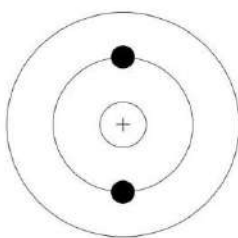
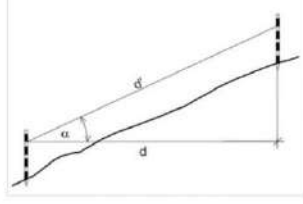
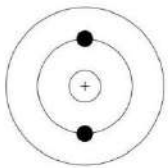
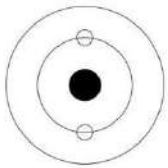


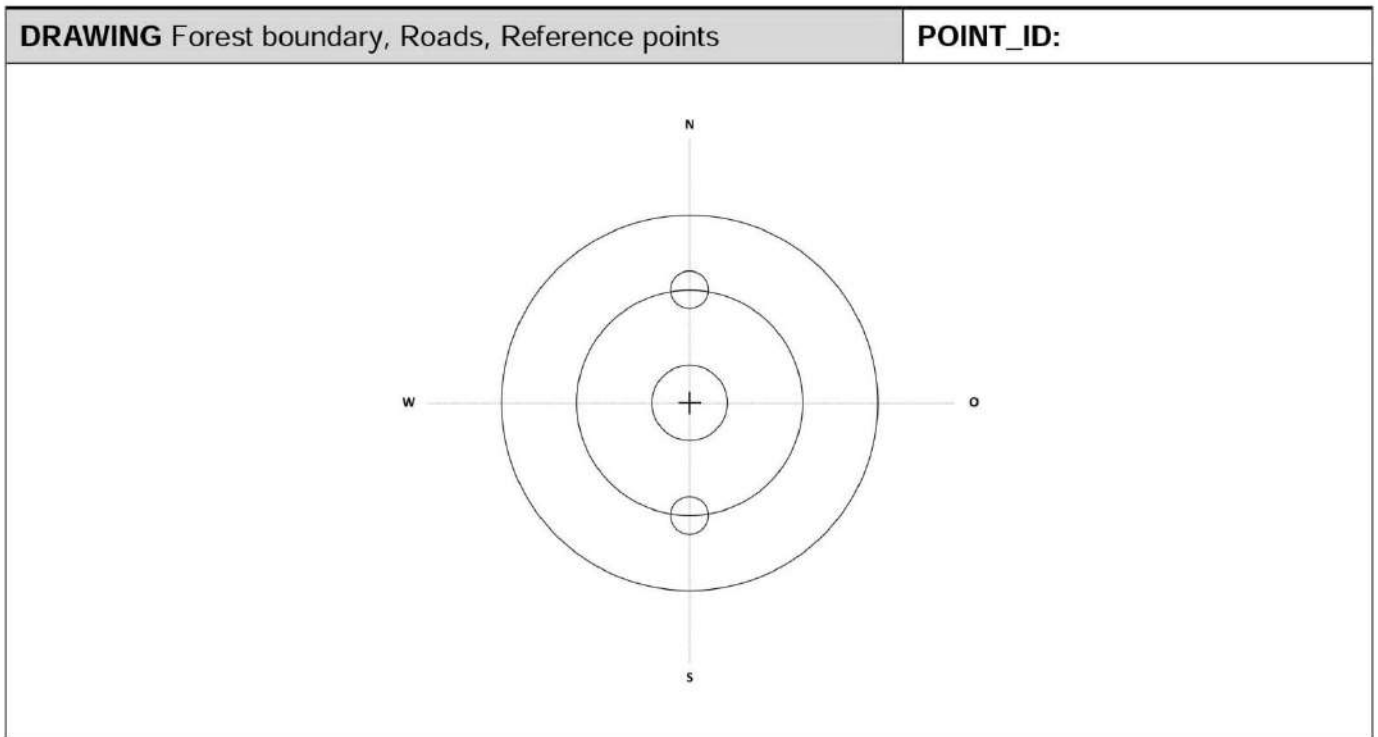
Figure 14: Measuring crown width

4. *Appendix*

SAMPLE		POINT																											
TEAM		ID																											
DATE		X																											
TSTART		Y																											
TEND		XGPS	PDOD / Error:																										
		YGPS																											
		HSL																											
STAND																													
ORIGIN	MIXTURE	VERTICAL STRUCTURE	MANAGE	GROUND VEG.	BAF	BA																							
<input type="checkbox"/> natural <input type="checkbox"/> planted <input type="checkbox"/> both	<input type="checkbox"/> pure <input type="checkbox"/> 2-5 sp. <input type="checkbox"/> >5 sp.	<input type="checkbox"/> one layer, same height <input type="checkbox"/> one layer, var. height <input type="checkbox"/> multiple layers <input type="checkbox"/> var. structure in gaps <input type="checkbox"/> complete variable	<input type="checkbox"/> managed <input type="checkbox"/> unmanaged <input type="checkbox"/> no grazing <input type="checkbox"/> fair grazing <input type="checkbox"/> intensive g.	<input type="checkbox"/> bare soil <input type="checkbox"/> humus layer <input type="checkbox"/> grass <input type="checkbox"/> herbaceous <input type="checkbox"/> sand/stone																									
PLOT																													
SLOPE	ASPECT	TERRAIN	FORST TYPE	CROWNCLOSE	EROSION																								
		<input type="checkbox"/> very concave U <input type="checkbox"/> concave  <input type="checkbox"/> flat ----- <input type="checkbox"/> convex  <input type="checkbox"/> very convex n	<input type="checkbox"/> Pistachio <input type="checkbox"/> Riparian/Tugai <input type="checkbox"/> Juniperus <input type="checkbox"/> Broad-leafed <input type="checkbox"/> Xerophytic	<input type="checkbox"/> dense <input type="checkbox"/> close <input type="checkbox"/> loose <input type="checkbox"/> open	<input type="checkbox"/> no <input type="checkbox"/> slightly <input type="checkbox"/> serious <input type="checkbox"/> heavy																								
COMMENTS																													
LEGEND																													
Plot design 	Slope \angle° $\angle\%$		Correction ($\cos\alpha$)		GENDER: For Pistachio trees gender is assigned to each stem: 0=female 1=male																								
	<table border="1"> <tbody> <tr><td>10</td><td>18</td><td>0,98</td></tr> <tr><td>15</td><td>27</td><td>0,97</td></tr> <tr><td>20</td><td>36</td><td>0,94</td></tr> <tr><td>25</td><td>47</td><td>0,91</td></tr> <tr><td>30</td><td>58</td><td>0,87</td></tr> <tr><td>35</td><td>70</td><td>0,82</td></tr> <tr><td>40</td><td>84</td><td>0,77</td></tr> <tr><td>45</td><td>100</td><td>0,71</td></tr> </tbody> </table>				10	18	0,98	15	27	0,97	20	36	0,94	25	47	0,91	30	58	0,87	35	70	0,82	40	84	0,77	45	100	0,71	$d = d' * \cos\alpha$
10	18	0,98																											
15	27	0,97																											
20	36	0,94																											
25	47	0,91																											
30	58	0,87																											
35	70	0,82																											
40	84	0,77																											
45	100	0,71																											

REG (25-50cm and 50-150cm) in regeneration subplots					
RPLOT	SPEC	HCLASS 1	HCLASS 2	BROWSED	HCLASS: 1=0-50 cm 2=50-150 cm 

REG (> 150cm) in 2m plot around sample point					HCLASS: 3=>150 cm <7cm dbh 
REG_DCLASS	SPCODE	SPEC	COUNT		



Checklist

- POINT_ID on every sheet?
- Tree heights measured?
- Time recorder (TEND)?
- All devices complete?

List of literature

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Ferhmann L., Magdon P. (2014). Recommendations for the development of a monitoring system for different forest types in Tajikistan, project report.

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