This project has received funding from the European Union´s Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 289437

ARANGE Deliverable D4.1

Improved Data Acquisition for Multifunctional Mountain Forests Management

21.08.2014

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Document properties

Document number	FP7-289437-ARANGE / D4.1
Document title	D4.1: Improved Data Acquisition for Multifunctional Mountain Forests Management (manuscript)
Author(s)	Emil Cienciala, Diethard Leber, Jana Beranová, Johanna Krautzer, Jürgen Leitner, Jan Tumajer, Manfred J. Lexer
Date of last revision	21.08.2014
Status	Final version
Version	4
Dissemination level	PU
Relation	WP 4, related to WP 1, WP 2, WP 3 and WP 5

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 289437.

Keywords:

forest management planning, ground survey, remote sensing, multisource inventory, ecosystem services

Abstract:

This is an overview of the data acquisition methods, incl. field survey and remote sensing, used for forest management planning in European multifunctional mountain forestry. Criteria and indicators for assessing the major ecosystem services are introduced and linked with assessment methodologies. It includes the survey results on the current practice on data and data acquisition methods in the ARANGE case study areas. Technological details of terrestrial methods are given in Annex I.

TABLE OF CONTENTS

1 Introduction....4

2 Ecosystem services and indicators in ARANGE....5

2.1 Timber production (P)....5

2.2 Protection against gravitational natural hazards (G)....6

2.3 Biodiversity and conservation (B)....7

2.4 Climate change mitigation: carbon sequestration and bioenergy production (C)....8

3 Methodologies used for assessing indicators of forest ecosystem services....9

3.1 Assessment methods used in forest inventories....9

3.2 Multi-functional inventories and assessment of forest ecosystem services-contribution of remote sensing....11

3.3 Linking assessment methods to criteria and indicators of ARANGE ecosystem services....14

3.4 Current practice (from ARANGE Case Study Areas)....18

3.4.1 Identification items and basic information on forest management....18

3.4.2 Data acquisition methods used in forest management planning....19

3.4.3 Inputs for forest management planning....21

3.4.4 Outputs provided by forest management plan....24

3.4.5 Implementation of forest management planning data....25

4 Summary....27

5 References....28

ANNEX 1....33

Potentials of terrestrial data acquisition methods....33

Introduction....33

Description of devices used for field data acquisition....33

Discussion and Conclusions....38

References....39

1 Introduction

During the recent decades, forest management in the European mountain areas has become heavily scrutinized. Managing forest resources must ensure a sustainable provision of several ecosystem services to human communities, therefore it must inherently address issues of manifold risks and uncertainties (e.g., Hannewinkel et al. 2011), including adaptation issues linked to changing environmental conditions (e.g., Yousefpour et al. 2013). Forest management must naturally also reflect often conflicting stakeholder demands that require adopting multicriterial decision making support (MCDM; e.g., Vacik et al. 2007) and optimization methods (e.g., Dieaz-Balteiro & Romero 2003). This all makes the subject of forest management planning challenging. Although there is a growing body of academic literature addressing the issues of contemporary forest management planning, the implementation of modern approaches into forest management practice significantly lags behind the suggested theoretical solutions. To a large extent, a successful forest management planning suited for multifunctional forestry remains largely dependent on efficient and adequate data acquisition methods.

Harmonizing economic development and sustainable use of natural resource is a long term societal challenge. Dependence on nature's benefits or ecosystem services is seldom appropriately recognized (Ash et al. 2010). Ecosystem services are a plethora of benefits that people get from nature. These are usually classified to (i) provisioning services, e.g., food, water and fiber (ii) regulating services, e.g., climate regulation and pollination (iii) aesthetic services including recreation and spiritual well-being and (iv) supporting services such as bedrock weathering and nutrient cycling. It is important to note that ecosystem services provide the essential link between ecosystems – their biodiversity and their functioning – and human society (e.g., Millennium Ecosystem Assessment 2005). An ecosystem management that attempts to maximize the production of one ecosystem service often results in substantial declines in provisioning of other ecosystem services (Bennett et al. 2009). Hence, efficient and successful ecosystem management aiming at multifunctional use of forests heavily relies on trustable information from forest management inventory. This must be based on the suitable set of indicators that are dominantly measured or assessed in ground surveys, commonly supplemented by information obtained from remote sensing.

An assessment of ecosystem services should build a bridge between the economic development and environmental communities by offering reliable information on the links between ecosystem management and the attainment of economic and social goals. This also applies for the European mountain forests, which become increasingly recognized and valued for their multiple services to society. Forests that are valued not only as a timber resource, but for positively affecting local and global climate, improving soil retention and water quality, protection from gravitational natural hazards, mitigating water events, facilitating pollination, improving landscape aesthetics, providing habitats for species, and being a source for invaluable genetic information.

Evidently, any reliable assessment of ecosystem services and monitoring their provisioning depends on appropriately selected indicators. A suitable definition of the term "Indicator" in ecological context is formulated by Harrington et al. (2010), who stated: "A simple, measurable and quantifiable characteristic responding in a known and communicable way to a changing environmental condition, to a changing ecological process or function, or to a changing element of biodiversity". Ecosystem service indicators must communicate the characteristics and trends in ecosystem services.

This material aims at reviewing the data acquisition methods, including both field survey and remote sensing, for the forest management planning in the seven case study areas of the ARANGE project (Lexer et al. 2009). We review these methods with respect to the assessment of the four ecosystem services (production – P, protection against gravitational hazards – G, biodiversity and conservation – B, climate mitigation through carbon cycling – C) addressed by the ARANGE project. We first introduce the criteria and indicators used for assessing these ecosystem services and then proceed to methodologies used for assessing these indicators. The latter also includes the result of the survey on the current practice on data use and data acquisition methods for forest management planning in the ARANGE case study areas.

2 Ecosystem services and indicators in ARANGE

The ARANGE project is specifically addressing four fundamental forest ecosystem services associated with multifunctional forest management in European mountain forests. They include 1] timber production 2] protection from gravitational natural hazards, 3] biodiversity and conservation and 4] climate change mitigation.

2.1 Timber production (P)

Timber production is a pivotal provisioning service of forests. Forest growth – and subsequently the provision of services by forest ecosystems – is dependent on local growth conditions that determine productivity and affect forest composition and biodiversity.

Criteria and indicators that are directly linked to timber production are specifically forest growth, standing volume and annual cut. The general national level European criteria and indicators formulated at the MCPFE Expert Level Meeting in Vienna 2002 include the following set of indicators applicable for the productive function: i) increment and fellings; ii) roundwood; iii) non-wood goods; iv) services; v) forests under management plans.

The indicators at the forest management unit level must focus on additional factors related to local conditions such as topography and forest type. Therefore, forest indicators at local scale may differ among the forest areas in Europe and/or also within a country.

For the purpose of model assessment of ecosystem services within the ARANGE project, the following indicators were selected and defined: volume of timber harvested, forest productivity, forest stocking and optionally timber yield assessment (Cordonnier et al. 2013).

2.2 Protection against gravitational natural hazards (G)

This ecosystems service is important for securing life, health and property of inhabitants. By this importance, the ecosystem service belongs to the social pillar of forestry. Due to various reasons of snow avalanches, landslides, rockfalls and others gravitational events, it is necessary to also differentiate the criteria and indicators of this ecosystem service.

The protective function against snow avalanches is focused on elimination of its formation. The effect of forest vegetation on eliminating landslides is limited. The role of rooting and weight of woody biomass is commonly insignificant in preventing landslides. The protection against rock avalanches, rock and stone falls is actually retentive and it is limited by the extent and character of the gravitational event. Still, in most mountain‘s environments, a vegetation cover is the only way to secure loose substrates. The integrity of upslope vegetation made by a multitude of plant structures and plant functional types is critical for downslide safety (Becker et al. 2007). Protection of slopes by vegetation cover is driven by the close linkages between plants, soils, and associated soil biota. The classic example of linked ecosystem services is the role of biodiversity in protection against gravitational natural hazards. Pohl et al. (2009) demonstrate the positive effect of plant diversity on aggregate stability. They suggest that high plant diversity is one of the most relevant factors for enhancing soil stability at disturbed sites at high elevation.

Bebi et al. (2009) describe avalanche disturbance regimes as two-way interactions in which forest structure and composition affect avalanches and avalanches, in turn, affect structure and composition. At a stand scale, avalanche disturbances typically result in forest communities that are characterized by smaller and shorter trees, shade intolerant species, lower stem densities, and greater structural diversity compared to many unaffected subalpine forests. At a broader scale, avalanche tracks provide increased landscape heterogeneity and edge density and can serve as firebreaks. This study also gives the specific values usable as indicators of avalanche protection: forest conditions that reduce likelihood of avalanche releases include crown coverage of above 30%, absence of gaps larger than 25 m in length, and increased terrain roughness associated with lying or standing trees that exceed snow-depth. However, it is a question to what degree an active forest management including eventual species change or coppicing contributes to strengthening avalanche protection as compared to passively managed stands (e.g., Krumm et al. 2011, Stokes et al. 2005, Jancke et al. 2009, Bigot et al. 2009).

There are no standardized criteria for this ecosystem service. The parameters for field observations to assess stand conditions with respect to effective protection against natural hazards were formulated e.g., by Brang et al. (2001). They specifically name ten parameters related to tree species composition, stand structure (e.g., developmental stage, variability in stem diameter, age distribution, tree aggregation, gap size distribution, etc.) and regeneration, which can be derived from field observation. An indicator system on expert knowledge was formulated by Frehner et al. (2005) to assess protection against rockfall, snow avalanches and landslides.

At the European scale, the protection against gravitational natural hazards is included under Criterion 5 "Maintenance and appropriate enhancement of protective functions in forest management". It covers two indicators, namely forest and wooded land area designated to i) prevent soil erosion, to preserve water resources, or to maintain other forest ecosystem functions and ii) protect infrastructure and managed natural resources against natural hazards.

For a regional scale, a recent project ProAlp (Bauerhansl et al. 2010) proposed harmonized indicators and estimation procedures for forest with protective functions against natural gravitational hazards. The methods cover both statistical field sampling and remote sensing approaches and their integration.

For the purpose of model assessment of ecosystem services within the ARANGE project, the Landscape Protection Index (% projected canopy cover area) was defined to characterize protection against gravitational natural hazards (Cordonnier et al. 2013).

2.3 Biodiversity and conservation (B)

Biodiversity is a meta-concept, composed of many attributes. The importance of attributes is relatively specific; there is no universal set of attributes and many of the proposed extensive indicators lists fail to be effectively applicable in operational forest management. A useful text on developing and using biodiversity indicators is offered by Failing and Gregory (2003). They discuss the common issues in working with biodiversity indicators and stress that a usable system of indicators should primarily be able to track how different management strategies and policies affect biodiversity.

Forests are an important source of terrestrial biodiversity in three dimensions including structure, composition and functional aspects (Paumalainen, 2001). This makes the issue of standardized indicators of biodiversity unfeasible as it largely depends on the spatial scale under consideration. However, the complexity of biodiversity assessment remains challenging also within a single biodiversity dimension and spatial scale and different approaches to construct suitable and practicable indicators are suggested in the literature (e.g., Neumann & Starlinger 2001; McElhinny et al.2005). Recently, a large effort has been specifically paid to standardizing biodiversity indicators usable in the context of the data collected by the National

Forest Inventory (NFI) programs (e.g., Winter et al. 2008; Rondeux & Sanchez 2010; Chirici et al. 2011).

At the level of forest management unit, the actual forest management is specifically important for biodiversity and conservation service. Biodiversity at that level can be evaluated using simple indicators or using their composites and specific indexes.

For the purpose of model assessment of ecosystem services within the ARANGE project, the following indicators were selected and defined: tree species diversity, tree size diversity, dead wood abundance and diversity, abundance of large living trees, bird habitat quality models (Cordonnier et al. 2013).

2.4 Climate change mitigation: carbon sequestration and bioenergy production (C)

The importance of forests for climate change mitigation is closely linked to productivity and sustainable forest management, which determine the use of forest to sequester carbon, use wood in products and provide bioenergy. International processes under UN FCCC significantly stimulated monitoring and reporting of carbon stock changes in forest carbon pools including biomass, deadwood, soil carbon components and harvested wood products (IPCC 2003, IPCC 2006), as well as the related research. However, forest management practice remains primarily concerned about sustainability of production, preserving biodiversity and protective functions of forest. This applies specifically for the mountain forestry, where the explicit potential of carbon sequestration is naturally limited due to both biological limitation and societal constraints (e.g., Seidl et al. 2007; Gimmi et al. 2009).

At the European scale, the adopted indicators related to forest resources and their contribution to global carbon cycles include the fundamental items including forest area, growing stock, age structure and/or diameter distribution and carbon stock.

The above indicators are well compatible with the information assessed routinely at the level of forest management unit with the exception of carbon stock itself. That information, however, can routinely be derived on the basis of the existing and auxiliary information related to the specific conditions at the local scale. Hence, carbon fixation by forests and the specific trends of the individual carbon pools can be explicitly quantified and monitored

For the purpose of model assessment of ecosystem services within the ARANGE project, the following indicators were selected: above ground and below ground carbon stock held in tree biomass, dead wood carbon stock, soil organic carbon stock and wood energy related to above ground biomass (Cordonnier et al. 2013).

3 Methodologies used for assessing indicators of forest ecosystem services

3.1 Assessment methods used in forest inventories

The evaluation of ecosystem services provided by forests is based on defined criteria and their indicators. A single ecosystem service can be evaluated using several criteria. For a single criterion, there may be several quantitative and qualitative indicators aiding the evaluation of a criterion. Specific indicators can be common for several criteria and several ecosystem services. It is important to assess not only the actual state of particular criteria and indicators, but often even more importantly their specific trends and development. Therefore, a methodological continuity ensuring repetitiveness of surveys and comparability of assessed indicators is a prerequisite for a sound and robust evaluation of ecosystem services.

At the spatial level of forest management units, most of the required information is or can be provided on a regular basis within the inventory process of forest management planning. There are three levels of inventory involved in forest management planning: reconnaissance, management and operational inventories. The reconnaissance inventory serves mainly to determine priority areas for more detailed inventories, usually conducted using satellite imagery and a field assessment program. Management level inventories are aimed at obtaining more detailed information on forest vegetation. It involves the acquisition of photography, GIS and ground sampling. Operational inventories are carried out on stand level with information including growing stock volume assessment. An operational inventory consists of compiling existing maps, reports and field data to assess the amount of volume available in an area of interest.

According to the above mentioned levels, the specific methods and approaches to assess individual indicators are applied. They can be categorized into the following groups: I) field surveys[1], II) remote sensing methods, III) utilizing existing mapping and data sources, IV) others (Table 1).

Historically, forest management planning has always relied on field survey and assessment of stand and site level parameters. This survey most commonly called stand-wise filed inventory method or inventory by compartments, aimed at providing the critical data for management planning. The information collected includes species-specific forest characteristic, traditionally combining angle-count, visual assessment and description. However, the general technological

[1] An overview on state of the art technology used in forest ground surveys is given in ANNEX 1

progress in the instrumentation for field measurement as well as in the remote sensing methods during the last two decades, have initiated changes in traditional forest management survey methods. Specifically, the progress is notable in implementing remote sensing methods. They become operationally deployable in stand-level management forest inventories specifically in the Nordic countries with flat terrain and relatively simple forest structure (e.g., Maltamo et al. 2011). Evidently, the effective inventory suitable for multifunctional forest management planning in mountain region should seek an optimal combination of stand and site level field survey and information provided by remote sensing, including airborne laser scanning.

Table 1: Categorization of major data acquisition methods and approaches

Category	Methods of data acquisition
I. Field survey	1) geodetic survey 2) stand-wise taxation survey (forest mensuration, callipering, etc.) 3) statistical survey (inventory) at the forest unit level 4) specialized survey at the level of land property or other higher level
II. Remote sensing	1) remote sensing techniques
III. Existing maps and data sources	1) cadastral land database in form of maps or numbers 2) growth and yield tables 3) management records 4) map of EEA forest types 5) elevation map 6) digital terrain model 7) geological and soil maps 8) map of areas under snow avalanches, landslide and generally gravitational risk 9) map of potential, natural vegetation (typological map of growth potential or similar) 10) map of specifically protected conservation areas (or similar) 11) nature protection records on rare species occurrence 12) forest management plan 13) records on snow avalanches and landslide events
IV. Other	1) owner or manager decision

3.2 Multi-functional inventories and assessment of forest ecosystem services-contribution of remote sensing

An optimized management of forest resources, especially when considering the ecosystem service dimension, requires a much greater volume of reliable and timely information about forest parameters. Conventional forest inventories, based on sample plots, can provide this information only to a certain extent, because they are restricted regarding spatial coverage and possible revision frequency (WWN 2011). Potentials of high-resolution spaceborne, airborne and terrestrial remote sensing techniques (Multispectral Scanners/Cameras, LiDAR, Full-waveform LiDAR, Hyperspectral Imaging, Synthetic Aperture Radar) as well as data management and interpretation technologies for multifunctional inventories and model assisted planning have evolved rapidly, especially over the last decade. The main characteristic parameters of remotely sensed information like the temporal, spatial, spectral and radiometric resolutions have been enhanced. This enables interpreters or automated routines, available in different software products, to classify more attributes of forests, thereby overcoming shortcomings of last generation sensors, limiting their applicability in forest management practice. Besides of improvements in the spaceborne sector, the design and development of smaller airborne platforms and sensors like Laser Scanners, Digital Cameras and Hyperspectral Sensors have resulted in improved data availability at reasonable cost. New improved classification and feature extraction methods for the assessment of the actual situation of forests, the generation of stand parameters and of information on individual trees have been elaborated. New procedures (matching techniques) were worked out to make use of forest parameters, available from existing inventories, for improvement and validation purposes of remotely sensed image information, thereby reducing time and cost for additional field survey (Yu et al. 2006; Hollaus et al. 2007).

Since the mid-1990s, when the first systems were invented, Airborne Laser Scanning technique (ALS) proved its potential to provide 3-D structural information of the forest with high spatial resolution. The second generation of laser scanners is capable to provide full-waveform ALS with a dense sampling pattern with more than 20 points per square meter. ALS data with a quality of at least one to four points per square meter are already available for large parts of Europe (e.g., Austria fully covered, Boreal region). Areas of specific interest are covered with higher point densities. Due to the fact that LiDAR data do not only provide terrain heights but also information about the horizontal and vertical distribution of forest canopies, a quantitative assessment such as tree height, crown diameter, etc. is possible. To obtain forest masks and canopy height models (CHMs) in a first step the difference between the Digital Surface Model (DSM) derived from the first pulse data and the Digital Terrain Model (DTM) derived from the last pulse data is calculated. In a second step the derived normalized DSM (nDSM) is filtered to remove artificial objects.

The extraction of quantitative forest parameters like stem volume and above-ground biomass is possible only by the integration of ALS data with local terrestrial inventory data by e.g., multiplicative regression models (Naesset, 1997, 2002, 2004; Naesset et al. 2004; Hollaus et al.

2007). Two main approaches can be distinguished when extracting forest and forestry data from airborne laser scanning. Area-based approaches (ABAs) and individual/single-tree detection approaches (ITDs) (Hyyppä et al. 2008, 2012). ABAs are widely used for standwise forest inventories. The prediction of forest variables is based on the statistical dependency between forest parameters measured in the field (training plots) and predictor features derived from ALS data (grid cells). Stand-level forest inventory results are then aggregated by summing and weighting the grid-level predictions inside the stand. In contrast ITDs are using pattern recognition methods to analyze the neighbourhood of laser returns, to locate individual trees and to map their features (height, species, crown diameter, crown volume). In the last years different algorithms for the segmentation of individual trees were developed showing quite good results using ALS data as well as digital panchromatic and multispectral images (Hyyppä et al. 2012).

Mora et al. (2013) successfully used Very High Spatial Resolution (VHSR) satellite imagery in combination with LiDAR for the characterization of stand attributes in the Canadian Yukon Territory. A summary and evaluation of different single-tree detection algorithms is given by Kaartinen et al. (2008), Vauhkonen et al. (2011) and Kaartinen et al. (2012). In nearly all of the case studies not all trees could be detected due to different segmentation errors, especially in alpine environments (Hollaus et al. 2006; Vauhkonen et al. 2010; WWN, 2011). Like Kaartinen (2008) showed the impact of increased laser point density is marginal when compared to the effect of the used ITD method.

When integrating ALS data with images of spaceborne or airborne multispectral scanners and digital multispectral cameras operating in the visible and infrared range of the electromagnetic spectrum, thereby utilizing the spectral information available in different bands/channels, the prediction of tree species is possible to a certain extent. An improved classification of tree species composition and of other timber-quality related parameters and environmental conditions of trees can be performed using Hyperspectral scanners having a multitude of spectral bands (up to 500). Like shown within the frame of the EU FP7 FleXWood project species recognition on tree-level could be improved by ALS combined with spectral information from multispectral or hyperspectral images, although the results vary depending on sample location and sample quantity (Vauhkonen et al. 2012).

Of particular interest is to combine the area-based and tree-level-based approaches in order to derive quantitative and qualitative forest information (estimation of biomass, volume, species composition; Vauhkonen et al. 2012). Using the above mentioned techniques Remote Sensing can contribute basic information like tree density and distribution, tree height and species composition for the assessment of the ecosystem function "timber/wood production" used within ARANGE (see chapter 2.1). Classification of laser scanning data or of other earth observation data combined with field methods can contribute to the monitoring of above ground carbon storage (see chapter 2.4) by assessing woody biomass liked shown within the frame of the CarboInvent project (Gallaun et al. 2003, 2005; Schlamadinger, 2006) and the LaserWood project (Hollaus et al. 2010). The availability of appropriate ground measurements from field plots is of crucial importance to establish relationships between the three-dimensional properties contained in the ALS point cloud (e.g., canopy height, canopy density) and the biophysical properties like biomass, to ensure that a reliable prediction is possible for a larger area (GOFC-GOLD 2010). For the assessment of the forest ecosystem function "biodiversity and conservation" (see chapter 2.3) remote sensing data can contribute information on canopy cover, tree species distribution, tree size diversity, and to a certain extent, information about the abundance of large standing living or dead trees using a combination of ALS and mutispectral/hyperspectral data.

Like mentioned above (see chapter 2.2.) the protective function against gravitational natural hazards like rock fall, landslides, avalanches and erosion - one of the ecosystem services tackled within ARANGE - is an important one (Cordonnier et al. 2013). Forests may generally have different functions with regard to the protection function against shallow and deep-seated landslides (reduced influence) and erosion. Root reinforcement can stabilize shallow landslides, depending on tree species, tree density and distribution and slope angle. Tree loadings can initiate landslides. Uneven aged forest cover, generally, can control moisture conditions, forest and vegetation cover controls the development of erosion features. The general assumption is that a well-structured above ground forest will have a corresponding well-structured and extensive rooting, thereby mitigating shallow landslides (Cordonnier et al. 2013). For the definition of linker functions (see chapter 2.2) Remote Sensing can contribute data on slope, aspect, length and morphology of slope (ALS-DTM), historic information on sliding processes and forest cover development (time series analysis of aerial images), and dendrometric parameters like stem density and height of trees (ALS_DSM), species distribution (ALS-DSM, spectral information available from multispectral and hyperspectral data), which in combination with field data and statistical information on environmental and growth parameters can be used to predict root reinforcement and tree loadings. In the case of rockfall the protective function of forests is efficient in the transit and deposition zone only. Protection forests, depending on their tree density, age distribution and species composition can act as a natural barrier against rockfall. In the case of rockfall Remote Sensing can contribute information on important parameters used as linker functions in ARANGE, like the location of the detachment areas (rock cliffs; ALS DTM), the initial fall height of blocks (ALS DTM), the distance between cliff and entry in the forest (ALS DSM), slope and slope roughness (high-resolution ALS DTM) and length of the forested slope (ALS DSM). Additionally dendrometric parameters like stem density (ALS-DSM), tree species distribution (combination of ALS with spectral information available from multispectral or hyperspectral data) and in combination with calibration data from field plots and local growth parameters provide predicted basal area and mean diameter at breast height. In the case of snow avalanches the protection function of forests is effective in the release zone only. Information on parameters governing the protection efficiency, like mean tree height (ALS DSM), value of canopy cover in the winter (high-resolution cameras, high-resolution multispectral data, ALS DSM), slope (ALS DTM), roughness of the forest floor (ALS DSM), size of gaps (ALS DSM, other EO data) and once again dendrometric parameters like stem density and the predicted basal area and mean diameter at breast height can be contributed by the interpretation of remotely sensed data.

3.3 Linking assessment methods to criteria and indicators of ARANGE ecosystem services

How do the assessment methods and approaches actually link to the criteria and indicators used for assessing individual ecosystem services (P, G, B, C) as considered for the mountain forestry within the ARANGE project? Let us first define an example set of the applicable criteria. Evidently, one could define several justifiable criteria sets that could be adopted across various mountain forest conditions in Europe, so the set shown in Table 2 is just one of the possible options. It includes altogether 14 criteria, including both qualitative and quantitative aspects of individual ecosystem services. Additionally, it is also stressed the importance considering overall stability of service provisioning, which applies to both productive and non-productive forest services. Therefore, the criterion of stability is formulated for each ecosystem service in our pilot example (Table 2).

Table 2: The ecosystem services provided by mountain forest ecosystems as considered in the ARANGE project and the respective applicable criteria

Ecosystem service	Applicable criteria
Production including biomass for energy production	C.1 - Wood volume and/or mass production C.2 - Quality of production in assortments or in monetary values C.3 - Production stability (security)
Protection from gravitational natural hazards	C.4 - Frequency and extent of snow avalanches C.5 - Frequency and extent of soil erosion and landslides C.6 - Frequency and extent of rockslides, rock splits and rockfalls C.7 - Stability (security) of providing protective service against gravitational natural hazards
Biodiversity and conservation	C.8 - Species diversity of forest ecosystems C.9 - Dimensional and age diversity of forest ecosystems C.10 - Spatial differentiation of forest (height and horizontal diversity - texture) C.11 - Genetic diversity of forest ecosystems C.12 - Stability (security) of providing service of biodiversity protection and conservation
Climate change mitigation	C.13 - Carbon stock in forest ecosystems and harvested wood products (HWP) C.14 - Stability (security) of carbon fixation in forest ecosystems and HWP

The particular indicators linked to the relevant criteria for the four concerned forest ecosystem services are listed in Table 3. The importance of a given indicator for the assessment of individual criteria is also expressed by using a categorization of "**main**" (denoted in bold font), "auxiliary" (denoted in normal font) and "*additional*" (denoted in italics). Note that an indicator may be applicable for one or more ecosystem functions that are consequently listed in the central part of the table. There are commonly several criteria (abbreviated as in Table 2) that may be evaluated with the help of individual indicators. Finally, Table 3 provides information on applicable assessment methods and category of methods (as in Table 1) for each indicator, which is listed in the last column.

Table 3: Overview of the four forest ecosystem services (P – production, G – gravitational hazard, B – biodiversity, C – carbon), applicable criteria (numbered as in Table 2) and indicators. The importance of indicators for assessment of individual criteria is ranked as "main" (bold font), "auxiliary" (normal font) and "additional" (italics). The first column lists the indicators that may be applicable for one or more ecosystem functions, which are consequently listed in the central four columns of the table. In the last column, the applicable category and method of data acquisition (Table 1) for each indicator is provided.

Indicator	Forest ecosystem service				Category of methods
	P	G	B	C	
	Applicable criteria (cf. Table 2)				
Terrain slope (°degree)		**4, 5, 6**			II, III$_{6,7}$
Altitude (m a.s.l.)	*1, 2, 3*	**4** *5, 6, 7*	*8, 9, 10, 12*	*14*	II,III$_{6,7}$
Geological bedrock (specific classification)	*1, 2, 3*	**5, 6** *7*	8 *10, 11, 12*	*14*	I$_1$, III$_7$
EEA Forest type classification (specific classification)	*1, 2, 3*	*4, 5, 6, 7*	8 *10, 11, 12*	*13, 14*	III$_4$
Natural tree species composition (% of forest land area)	*1, 2, 3*	*7*	8 *10, 11, 12*	*13, 14*	III$_{3,9,12}$
Forest land area (ha)	*1*		*8, 11*	13	I$_1$, II, III$_{1,12}$
Share of forest land to entire concerned area (%)			*8, 11*	*13*	II, III$_1$
Share of forest land area providing specific ecosystem service (% of forest land area)	**1**	**4, 5, 6**	**8, 11**	**13**	I$_1$, III$_{1,12}$
Share of forest land area by forest management regime (% of forest land area)	*1, 3*	**5** 4, 6 *7*	**8, 9, 10, 11** *12*	13 *14*	I$_{2,3}$, III$_{12}$, IV
Forest management intensity (% of forest land area)	1	5	**8, 9, 10, 11**		I$_{2,3}$, III$_{3,12}$, IV
Growing stock volume (m^3)	**1**			**13**	I$_{2,3}$, III$_{12}$
Assortments of growing stock (% by assortments)	**2**			13	I$_{2,3}$, III$_{3,12}$
Stem damage (%)	**3** 2	**7**	**12** *8, 10*	**14**	I$_{2,3}$, III$_{12}$
Annual total felling volume (m^3, m^3/ha)	**1** 3	7	12 *8, 9, 10, 11*	**13** 14	III$_{3,12}$
Annual planned felling volume (m^3, m^3/ha)	2		*8, 9, 10, 11*	13	III$_3$
Annual accidental felling volume (% of total)	**3** 2	**7**	**12** 8, 9, 10, 11	**14** 13	III$_3$
Annual main felling volume (% of total)	2		*8, 9, 10, 11*	13	III$_3$
Annual tending volume (% of total)	2		*8, 9, 10, 11*	13	III$_3$

Indicator	Forest ecosystem service				Category of methods
	P	G	B	C	
	Applicable criteria (cf. Table 2)				
Smallwood volume (m³)	*1*			**13**	I_{2}, III_{2}
Volume of dead wood left to decay (m³/ha)			**8** 10, 11	**13**	$I_{2,3}$, III_{12}
Share of lying deadwood left to decay (%)		4, 6	**8** 10, 11	13	$I_{2,3}$
Current increment (m³, m³/ha)	**1**			**13**	$I_{2,3}$, $III_{2,3,12}$
Volume stock by tree species (%)	**2, 3**	**7**	**8** 9, 10, 11	**13**	$I_{2,3}$, III_{12}
Tree species composition (% of forest area)	1, 3	7	**8** 9, 10, 11, 12	14 *13*	$I_{2,3}$, III_{12}
Total carbon stock (vegetation and soil) (t C, t C/ha)				**13**	$I_{2,3}$
Tree biomass carbon stock (t C, t C/ha)				**13**	$I_{2,3}$
Soil carbon stock (t C, t C/ha)				**13**	$I_{2,3}$
Humus thickness (mm)			**8**	**13**	$I_{2,3}$
Humus type (% of forest land area)			**8**	**13**	$I_{2,3}$
Risk of soil erosion (% of forest land area)	3	7	8, 12	13,14	I_{2}
Number of tree species (n)			**8**		$I_{2,3}$,III_{12}
Share of introduced tree species (% of forest land area)	*1*		**8**		$I_{2,3}$, III_{12}
Average tree age (years)	*1* 3	7	8, 9, 12 *10*	14	$I_{2,3}$, III_{12}
Forest age structure (% of forest land area)	**1** 2, 3	7	9 8, 12 *10*	14	$I_{2,3}$,$III_{3,12}$
Stand structure by canopy closure type (% of forest land area)	*1, 3*	*7*	**9, 10** 8, 11 *12*	13 *14*	$I_{2,3}$
Slenderness ratio (m/cm)	3	7	12	14	$I_{2,3}$, III_{12}
Share of forest land cover within 100 m below mountain tree line (%)		**4**			I_{2},II
Forest texture within 100 m below mountain tree line (%, specific classification)		**4**			I_{2},II
Occurrence of technical provisions to decrease gravitational risk (% of area under risk)		**4, 5, 6**			I_{2},II,III_{8}

Indicator	Forest ecosystem service				Category of methods
	P	G	B	C	
	Applicable criteria (cf. Table 2)				
Damage by water erosion (% of area under risk)		**5**			I_2,II,III_8
Frequency of gravitational events (n/year/area)		**4, 5, 6**			I_2,$III_{12,13}$
Area damaged by gravitational events (ha)		**4, 5, 6**			I_2,II,$III_{12,13}$
Protected area of nature conservation (ha)	*1*		**8, 9, 10, 11**		$III_{1,10}$
Occurrence of rare plant and animal species (n)			**8** 11		I_2,$III_{11,12}$
Occurrence of den trees (average number/ha)			**8**		$I_{2,3}$,III_{12}
Occurrence of genetically (phenotype) suitable trees or forest (% of forest land area)	*1, 2, 3*	*7*	**11** *12*	*14*	I_2,$III_{3,12}$
Occurrence of natural regeneration (% of forest land area)	*1, 3*	*7*	**11** *9, 10, 12*	*13, 14*	$I_{2,3}$,III_{12}
Threats to forest: destructive winds (% of forest land area)	**3**	**7**	**12** 9, 10 *8, 11*	**14**	$I_{3,4}$,III_{12}
Threats to forest: air pollution and acid rain (% of forest land area)	**3**	**7**	**8, 12** 9, 10, 11	**14**	I_4,III_{12}
Threats to forest: biotic factors (pest and diseases) (% of forest land area)	**3**	**7**	**12** 9, 10 *8, 11*	**14**	$I_{3,4}$,III_{12}
Risk of forest fires (% of forest land area)	**3**	**7**	**12** 9, 10 *8, 11*	**14**	$I_{3,4}$,III_{12}
Risk of gravitational events (% of forest land area)	**3**	**4, 5, 6, 7**	**12**	**14**	I_4,III_{12}
Fragmentation of forest area (length of forest border)			8, 11		II

3.4 Current practice (from ARANGE Case Study Areas)

To get an overview on data use and data acquisition methods for forest management planning in the European mountain forestry as represented by the ARANGE case study areas (CSA), a specific questionnaire survey was conducted. The questionnaire sought responses to the following basic questions:

1. What data acquisition methods are used for the mountain forestry management planning practice?

2. What indicators are monitored at the forest management unit scale?

The questionnaire was addressed to the CSA representatives who were either directly responding or facilitated obtaining the responses relevant to the respective CSA to the degree required. Generally, only one response from each CSA was requested, although more responses were received to some specific questions if different ownership categories with different inventories and approaches to management planning were used. The questionnaire had five sections, namely:

I. Identification items and basic information (formal part)

II. Methods used in forest management planning

III. Input for forest management planning

IV. Output provided by management plan

V. Utilization of results of forest management planning

The following material describe the information obtained summarized by the topics listed above.

3.4.1 Identification items and basic information on forest management

The responses received and evaluated in this material include all seven ARANGE CSAs. Two replies were received for the French CSA, each representing different ownership category and its corresponding area. Mostly, the respondents were the CSRs (4 of 8 respondents), in other cases the responses were received from the local forest managers, owners or other stakeholders. This information, together with the forest area specifically concerned, is summarized in Table 4.

Table 4: The questionnaire responses included, respondent category, forest ownership and the specific area of forest concerned for each CSA and/or ownership category within CSA.

Case Study Area	Respondent	Ownership represented	Forest area concerned
CS1 – Montes de Valsain, Cabeza de Hierro, Spain	CSR	National	10 651 ha
CS2 – Vercors Quatres Montagnes, France	Forest manager	Municipal	8 000 ha
CS2 – Vercors Quatres Montagnes, France	Other	Private	5 730 ha
CS3 – Montafon, Austria	CSR	Municipal	578 ha
CS4 – Sneznik, Slovenia	CSR	National	4 905 ha
CS5 – Vilhelmina, Sweden	CSR	Cooperative, other	10 405 ha
CS6 – Kozie Chrbty, Slovakia	Owner, other	Ecclesial	12 387 ha
CS7 – Shiroka Laka, Bulgaria	Forest manager	Cooperative	1 816 ha

Generally, the forest management was characterized as active on the most of the forest land area concerned, ranging from 79 % in Sweden to 97 % in Slovenia (85 % in average). The remaining forest area is strictly devoted to protection of natural processes and without any intervention.

In terms of actual management regime used, even aged, shelterwood and uneven aged forest management is applied according to the local conditions. The latter two forest management approaches generally dominate in all CSAs. The exception is Vilhemina, Sweden, representing the northern latitudes and boreal forestry. This CSA reports using mostly even aged, clear-cut management, which is practiced on 75 % of the forest area. Uneven-aged forest management dominates in Austrian and French CSAs. Slovenia reports about identical use of shelterwood management and uneven age management systems, while shelterwood management dominates in Bulgarian, Slovakian and Spanish CSAs.

3.4.2 Data acquisition methods used in forest management planning

The actual methods adopted in forest management planning may be regulated by the local legislation (Law, Directive, Standard, etc.). The legislative regulation is in place in four cases, namely in Slovenia, Slovakia, Bulgaria and French private forests. Elsewhere, the methods are not explicitly prescribed.

All CSAs report using the following components of forest management planning, namely i) stand-wise inventory or inventory at larger scale, ii) mapping of stand polygons/compartments, iii) yield regulation methods, iv) stakeholder involvement. Somewhat different approach to mapping is used in Sweden, which uses specific algorithms for ecological landscape mapping suitable for larger area units involved in the Swedish forest management planning. As for the stakeholder involvement in forest management planning, all CSAs report some involvement of other stakeholders with exception of the French CSA with the private forest ownership.

The specific data acquisition methods and approaches reported being in use for management planning in the mountain forestry of CSAs are listed in Table 5, sorted by frequency of the specific replies. It can be seen that estimation and descriptive approaches of stand parameters (forest taxation) is still the most common field assessment method used for forest management planning. However, the use of more advanced and objective data acquisition methods based on statistical inventory approaches becomes also important. As for the use of remote sensing approaches and products, all CSAs use aerial photographs for classification purposes and digitizing existing map layers. Creating maps by field delineation is also frequent (Table 5). Use of LIDAR and calibration by ground inventory is reported to be used, at least in pilot testing phase (research and development projects) in four CSAs, namely in Austria, France, Spain and Sweden.

Table 5: Data acquisition methods and approaches sorted by frequency as reported from the ARANGE CSAs. The corresponding planning component as used in the text is also attributed to each method.

Frequency	Planning component and specific methods of data acquisition
6	Mapping: aerial photographs classification
6	Yield: allowable cut derived from data
5	Mapping: digitizing of existing map layers
5	Inventory: estimation and verbal description of stand parameters
5	Mapping: field delineation
5	Stakeholders: information about plan output
4	Stakeholders: consultation on goals and preferences
3	Inventory: field/ground statistical inventory
4	Inventory: combination of RS and field verification
2	Inventory: remote sensing classification
2	Inventory: inventory on sample plots
3	Inventory: angle count sample
1	Inventory: volume and yield table
1	Yield: analysis of planning system

Also the list of general methodological approaches used in forest inventory at the level of management unit (

Table 6) suggests that the traditional inventory methods still dominate, although they apparently cannot provide sufficient and objective substance for indicators relevant to the spectrum of ecosystem services that the mountain forests offer. The use of statistical inventory methods at the level of forest management unit is reported from Austria, France and Slovenia.

Table 6: The list of general methodological approaches used for forest inventory at the level of forest management unit.

General approach	CS1 E	CS2* F	CS2# F	CS3 A	CS4 SLO	CS5 S	CS6 SVK	CS7 BL	n
Stand-wise inventory, area share					×	×	×	×	4
Statistical field survey, area share		×	×	×	×				4
Previous management records' update				×		×	×	×	4
Remote sensing methods - classical		×		×			×		3
Remote sensing methods – LIDAR	×	×	×*	×		×*			5(3)
Combination of approaches			×	×	×				3

* Scans available, not used yet; CS2*- CS2, public forest; CS2#- CS2, private forest

The reported use of remote sensing methods and products for forest inventory at the level of of forest management units suggests that the use of LIDAR scanning becomes increasingly common, although at preparatory phase in several instances (

Table 6).

The time interval for updating of forest management plans is mostly 10 years (5 CSAs), although the Austrian CSA reports an annual update. The time interval for updating information on forests is mostly identical, i.e., 10 years (4 CSAs), occasionally longer (France, 20 years).

Commonly (4-5 CSAs), the work on forest management planning components are outsourced and performed by from external bodies. Internal staffing is, however, also used for forest management planning, notably in French public forests, Slovenia and Austria.

3.4.3 Inputs for forest management planning

The input information used for forest management planning varies naturally among the countries, but remains also coherent in some basic variables. The list of input data used for forest management planning in the ARANGE CSAs is summarized in Table 7.

Table 7 shows that most of the frequently used information items relate primarily to biodiversity protection, whereas the information indices relevant for carbon (climate protection) ecosystem service are least frequent. This reflects the fact that in contrast to other ecosystem functions, forest carbon sequestration, CO_2 emissions and climate change issues are much more distant from the operational forest management practice as compared to the other, truly site-relevant ecosystem functions.

Table 7: The input information used for management planning sorted in descending manner by frequency (Freq.) of responses, with prescribed relevancy to particular ecosystem services (P – production, G – gravitational, B – biodiversity, C – carbon).

Information item (and/or indicator)	Ecosystem service				Freq.
	P	G	B	C	
Current species composition	x	x	x	x	8
Protected areas of nature conservation			x		8
Current stand structure			x		7
potential/natural tree species composition			x		7
Gravitational hazards	x	x	x	x	6
Occurrence of genetically (phenotype) suitable trees or forests (reprod. material)	x	x	x	x	6
Threats to forest: biotic factors	x	x	x	x	6
Tourist, leisure and spa facilities (roads, camps, etc.)					6
Archaeologically significant sites					5
Forest land area	x		x	x	5
Location of water resources					5
Natural vegetation			x		5
Occurrence of rare plant and animal species			x		5
Forest age structure	x	x	x	x	4
Introduced tree species	x		x		4
Risk of erosion		x			4
Risk of forest fires	x	x	x	x	3
Threats to forest: destructive winds	x	x	x	x	3
Landscape fragmentation			x		2

Natural stand structure			x		2
Risk of gravitational events	x	x	x	x	2
Territorial development constrains		x	x	x	1
Threats to forest: air pollution and acid rain	x	x	x	x	1
Tree biomass and tree carbon stock				x	1
Carbon stock in soil				x	0
Total carbon stock (vegetation and soil)				x	0

One of the vital information items related to forest survey methods is information level, distinguishing data at tree, stand or site level. The responses confirmed that the most common information used for forest management planning is that at stand and site level with 8 and 7 responses, respectively. The collection of tree-level data was reported only for three CSAs, namely in Austria, Slovenia and Spain.

Other important information concerns the spectrum of the collected data and their use in the management prescriptions. This is summarized in Table 8, which lists the indicators (variables) in terms of i) if such data are collected and ii) if specific management prescription exists for the given indicator. This particular information obtained from the ARANGE CSAs (Table 4) is summed for individual indicators and thereafter ranked as important if reaching 6 to 8 responses (highlighted in bold), semi-important (3-5 responses) or unimportant (1-2 responses, highlighted by italics). The most commonly used (i.e., most fundamental) information among the CSAs is that on growing stock volume, tree species composition, occurrence of natural regeneration, forest stand structure, introduced tree species, biotic factors representing threats to forest (pests and diseases) and state of forest road network. On the contrary, indicators related to tree biomass, carbon stock and soil properties are often not considered at all (Table 8).

Table 8: Individual indicators collected by inventories for forest management planning and their eventual use in prescribed management. The numbers indicate response frequency of the questionnaire respondents (cf. Table 4). The most important indicators are noted by bold font, the unimportant (least frequent) ones by italics.

Indicator	(i) Data collection		(ii) Prescribed management	
	Yes	No	Yes	No
Forest age structure	4	4	2	6
Current stand structure	**6**	**2**	**7**	**1**
Current species composition	**8**		**8**	
Introduced tree species	**6**	**2**	**5**	**3**
Stand dendrometric data	4	4	4	4
Growing stock volume	**8**		**7**	**1**
Assortments of growing stock	*1*	*6*	*2*	*5*
Total carbon stock (vegetation and soil)		*8*		*8*
Tree biomass and carbon stock		*8*		*8*
Humus thickness		*8*		*8*
Humus type	*1*	*7*		*8*
Soil carbon stock		*8*		*8*

Indicator	(i) Data collection		(ii) Prescribed management	
	Yes	**No**	**Yes**	**No**
Risk of erosion	4	5	4	4
Damage to soil by erosion or mechanization	*2*	*6*	*2*	*6*
Location of water resources	5	3	6	2
Occurrence of rare plant and animal species	3	5	3	5
Occurrence of genetically suitable trees or forests (reprod. material)	3	5	5	3
Threats to forest: destructive winds	4	6	4	6
Threats to forest: air pollution and acid rain	*2*	*6*	*2*	*6*
Threats to forest: biotic factors (pests and diseases)	**6**	**1**	**5**	**3**
Risk of forest fires	3	5	3	6
Risk of gravitational events	*2*	*6*	*4*	*4*
Occurrence of den trees	5	2	6	2
Occurrence of natural regeneration	**7**	**1**	**6**	**2**
Dead wood volume left to decay	4	4	3	5
Degree of naturalness of stands	*1*	*7*	*1*	*6*
Tourist, recreational and spa facilities (roads, camps...)	5	3	2	6
State of road network (classification of roads)	**6**	**2**	**6**	**2**
Sustainability of production	3	5	3	4

Specifically illustrative results were identified from the two respondents from the French CSA, representing the public and private forests, respectively. The forest management differs between the two holdings. It is, e.g., reflected by the fact that monitoring of deadwood volume, den trees and occurrence or rare plant and animal species and some other indicators is specific only to public forests, where the relevant forest management measures can thereby be also formulated.

3.4.4 Outputs provided by forest management plan

The information that is provided by the forest management plans differ among CSAs. Most notable, the Swedish forestry practice does not use planning in the traditional way as it is established in Central Europe, but relies on operative plans and information on stands updated annually as for growth and management activities. Hence, there are no mandatory outputs of forest managements applicable for Sweden. However, there are no mandatory outputs of forest management planning also in Austria, where forest management plans are actually elaborated on a voluntary basis. Therefore, the information on the output provided by forest management plans that is collated in Table 9 must be interpreted with care. The table highlights the output items reported from the ARANGE CSAs (Table 4). It is summed for individual output items and thereafter ranked as important if reaching 6 to 8 responses (highlighted in bold), semi-important (3-5 responses) or unimportant (1-2 responses, highlighted by italics). The most commonly used (i.e., most fundamental) output provided by forest management plans among the CSAs is that on denrometric/mensurational data at stand level and summarized for higher administrative and/or management units. This also includes the growing stock volume and current species composition. Other important information outputs include the management recommendations for forest units (stands), protected areas of nature conservation, information on natural tree regeneration and state of forest road network. Among the information items least represented are those on biomass and carbon stock and some other (Table 9).

Table 9: The list of information items provided as output provided by forest management planning, including the output format and note if it is requested mandatorily. The numbers indicate response frequency of the questionnaire respondents (cf. Table 4). The most important indicators are noted by bold, the unimportant (least frequent) ones by italics.

Output	Output format			Mandatory output	
	Maps	Data	Written descr.	Yes	No
Mean dendrometric/mensurational stand data	**3**	**6**	**2**	**6**	**1**
Summary of dendrometric data for administrative units	**2**	**7**	**3**	**5**	**2**
Summary of dendrometric data for total area concerned	**2**	**6**	**3**	**5**	**2**
Growing stock volume for stands	**1**	**7**		**5**	**2**
Growing stock volume for the total area concerned	**1**	**8**		**3**	**3**
Assortments of growing stock		3	1	2	3
Management recommendations for forest units (stands)		**3**	**6**	**6**	**1**
Management recommendations for administrative units		4	5	4	2
General management recommendations		1	5	5	2
Natural vegetation	3	1	2	2	3
Current species composition	**4**	**7**	**5**	**6**	**2**
Stand structure by canopy closure type	*1*	*1*	*1*	*2*	*2*
Forest age structure	1	2	3	2	3
Total carbon stock (vegetation and soil)		*1*			*1*
Tree biomass and carbon stock		*1*			*1*
Risk of erosion	3		2	2	3
Damage to soil by erosion or mechanization		*2*			*2*
Location of water sources	6		5	3	4
Occurrence of den trees	2	1	3	1	4
Dead wood volume left to decay	1	4	2	2	3
Degree of naturalness of stands		*1*	*1*	*1*	*1*
Protected areas of nature conservation	**6**		**1**	**6**	**3**
Occurrence of rare plant and animal species		1	3	1	5
Occurrence of genetically suitable trees (reprod. material)	2	1	3	3	3
Occurrence of natural regeneration	**2**	**5**	**6**	**5**	**2**
Tourist, leisure and spa facilities	5	2	5	3	3
Occurrence of introduced species	1	2	3	2	4
Threats to forest: destructive winds		1	3	1	4
Threats to forest: air pollution and acid rain			2	1	1
Threats to forest: biotic factors (pests and diseases)		2	4	1	5
Risk of forest fires	4	2	2	3	3
Risk of gravitational events	2	1	3	2	2
Forest land area	5	4	2	4	3

Output	Output format			Mandatory output	
	Maps	Data	Written descr.	Yes	No
State of road network (classification of roads)	**6**	**4**	**2**	**5**	**1**
Sustainability of production	1	3	2	2	3

3.4.5 Implementation of forest management planning data

The motives of forest management planning, being either mandatory or voluntary, were requested from CSAs to be ranked within the scale 1 (high), 2 (medium), 3 (low), 4 (none). The collated information sorted by mean priority values is shown in Table 10 below. The ranking is led by the motivation due to the law or certification requests, followed by the objective necessity for sound and effective management safeguarding sustainable use of forest resources.

Table 10: The motivation items for implementing forest management planning, sorted by their average priority (see the text for explanation).

Motive	Mean priority
Required by law (NA in Austria)	1.1
Compliance with the certification requests	1.4
To safeguard sustainability	1.6
Prerequisite for management	1.6
Own economic interests	1.9
Own environmental responsibility	2.0
Subsidy provided by government	2.6
For communication with stakeholders	2.8

The motivation ranking given in Table 10 does not give concise information on stakeholder involvement in forest management planning. From the specific responses received on this issue, the CSAs reported stakeholder involvement affecting forest management planning by the frequency listed in Table 11. Among the most important stakeholders are, besides the state administration on forests and nature conservation, the various interest groups focused on hunting, nature protection and others.

Table 11: The list of stakeholders affecting forest management planning, sorted by frequency of CSAs questionnaire responses (cf. Table 4)

Motive	Frequency
Interest groups focused on nature protection, hunting, etc.	6
State forest administration	6
State administration of nature conservation	6
Municipalities of the land area concerned	5
Regional subjects responsible for management of water resources	4
Interest groups focused on sport and tourism	4
Other (please specify): ministry, reindeer herders	3
Certification subjects	2

Network administrators (power lines, pipelines, road networks, etc.)	1
The neighboring landowners	1

4 Summary

1. It is apparent that the individual ecosystem functions are not equal in how they are considered in forest management planning. Traditionally, the productive function remains important also in mountain forestry, together with biodiversity and protection against gravitational natural hazards. However, carbon and climate issues are way apart from the forest management practice and planning. Climate change mitigation is a top-down driven policy that has not reached the operational forest management planning, which is reflected by the general absence of explicit criteria and indicators in the forest management planning and inventories linked to it. On the contrary, monitoring of biodiversity issues, is well supported by the current forest management inventories and planning process.

2. It is evident that most of the indicators required for monitoring ecosystem functions are based on field assessment or sharing existing map and data sources, and less so from remote sensing.

3. Remote sensing approaches in general show growing importance in supporting forest management planning by providing not only spatial information, but also including structural elements of forest stands (LIDAR methods).

4. Forest management planning is mostly based on stand and site level information. Since the modern remote sensing data may be focused on both tree and stand, it is apparent that an optimal data acquisition strategy should combine field survey and remote sensing, exploiting the best of the two approaches.

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ANNEX 1

Potentials of terrestrial data acquisition methods

Introduction

Field Technology devices are used for navigation to target coordinates, mapping, measurement (e.g., distances, vertical and horizontal angles, diameters), sample collection, data storage and context of existing sources. Fast recent development of modern technologies increases validity of collected data, reduces duration of field campaigns or enlarges the amount of sampled data. However, despite this development, field researchers still face limits of equipment they use.

The aim of this appendix is to provide summary of devices used for terrestrial data acquisition in the field of forestry.

Description of devices used for field data acquisition

A. RANGEFINDERS

In history, measurement of distances in the field has been performed directly using measuring tapes or battens or indirectly using trigonometric methods or rangefinders (Čada, 2007a). The last mentioned approach is nowadays the most used method for the fieldwork research. Its basic principle is measurement of time lag (t) between emission of sonic or laser signal and its return after reflection from the obstacle (reflector) in unknown distance (Fig. 1). Because the speed of signal (v) is known, the distance (s) can be calculated using simple equation:

$$2 * s = v * t.$$

Based on the type of signal, which is used by the device, rangefinders can be divided into two general categories. Laser rangefinders use coherent rays of photons of wave-length approximately 900 nm, on the other hand, ultrasonic rangefinders operate with short sonic pulses (Servyugin et al. 2005). Laser devices are able to measure objects in larger distances (100 - 1000 m) and are not prone to air temperature and moisture. On the other hand, they are limited by target visibility and hydrometeorological conditions (e.g. cloud, mist). Due to high speed of light, they lose the precision when measuring very short distances. Ultrasonic rangefinders are limited for measurement of short distances (meters-tens of meters), which is due to continuous loss of energy of a wavefront (Huygens principle) (Čada, 2007a). Because the speed of sound varies with air temperature and humidity, calibration of the device just prior measurement is desirable.

The signal can be aimed directly on the measured object, but reflector is usually used.

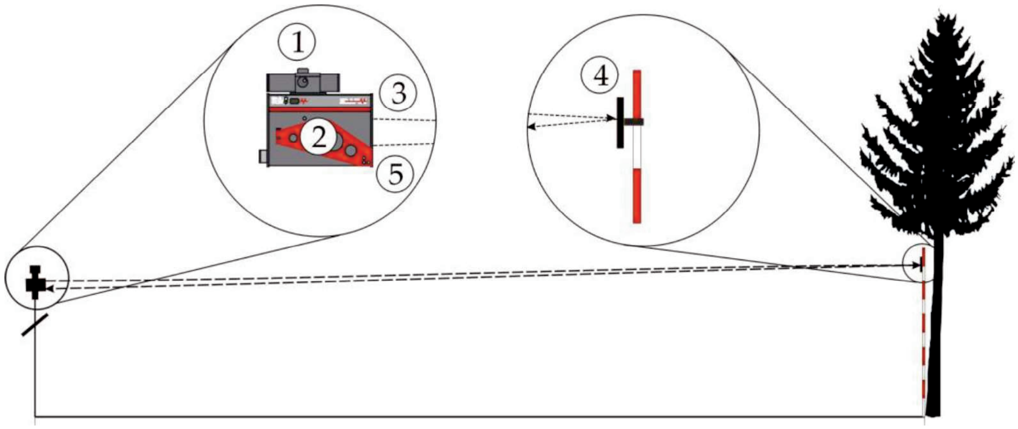

Fig. 1: Work of laser rangefinder (1. Aiming at target, 2. Generating signal, 3. Sending signal, 4. Reflecting signal, 5. Receiving signal and calculating distance)

B. TOOLS FOR HORIZONTAL AND VERTICAL ANGLE (SLOPE) MEASUREMENT

One of devices used for slope measurement is electronic tilt sensor. It consists of electrodes and electrolytic fluid permanently closed in a solid box (Fig. 2 left). The conductivity of system is proportional to the length of electrodes below the level of the fluid. Because the conductivity changes with air temperature, calibration before using is necessary. The other tool for slope measurement is accelerometer, which measures the acceleration of element (Fig. 2 right). Changes in slope lead to changes in the angle between gravity force and its tangential component, which generates acceleration.

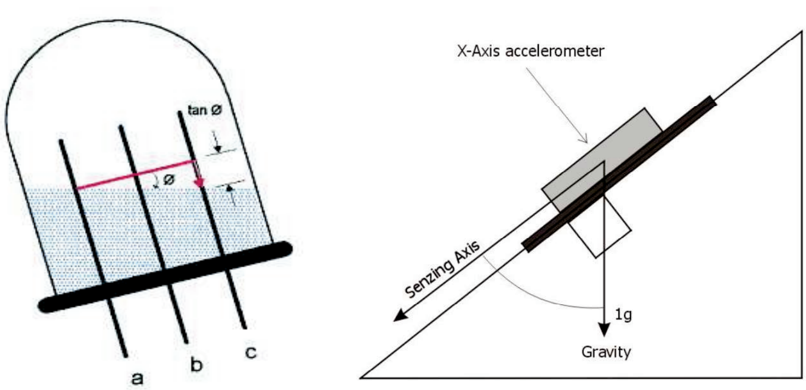

Fig. 2: Schematic diagram of tilt sensor (left) and principle of accelerometer (right)

The simplest tool for horizontal angle measurement is compass, which was probably invented in China during 4th century AD. As axis of Earth magnetic field is not the same as axis of planet rotation, compass does not point to North pole but to North magnetic pole. Data measured using compass must be corrected using magnetic declination (angle between axis of rotation and magnetic field) to get correct azimuth (Čada, 2007b). Magnetic declination differs from place to place, which is why electronic compass needs to be calibrated before starting the measurement. Electronic compasses consist of three core components: magnetic core, drive coil and sense coil.

The measurement of horizontal direction of some object doesn't have to be referenced to the North pole, but the angle can be determined in relation to any point of known coordinates (Čada, 2007 b). Angle encoder is tool used for this purpose which is not influenced by magnetic field. On the other hand, because the orientation is related to fixed point on the Earth, stability of the device is desirable for obtaining precise results (Čada, 2007b).

C. GLOBAL NAVIGATION SATELLITE SYSTEMS

Determination of your exact position is the primary prerequisite for sampling of geographical data (data containing geographical information about position) and subsequent statistical analyses of spatial distribution of phenomena and processes of interest. Traditional mean of your position determination using map and compass was almost completely replaced (for scientific field research activities) by Global Navigation Satellite Systems (GNSS) during last decade (Chivers, 2003). GNSS use trilateration – measuring of the distance between the object in unknown position and reference points in known locations – to determine coordinates of receiver position (Marek & Štěpánek 2009).

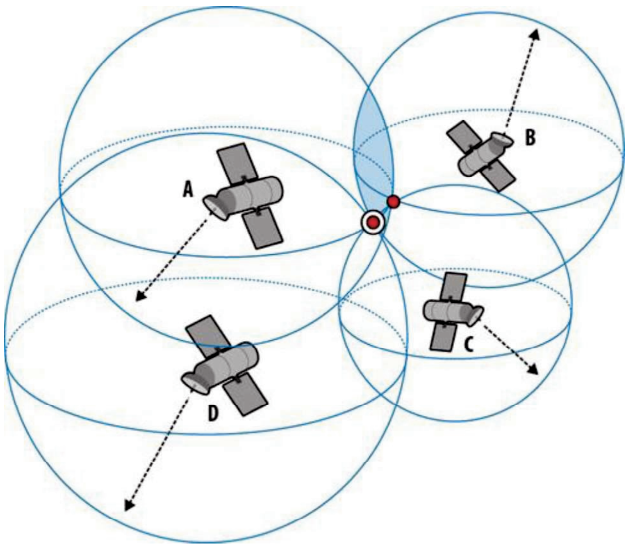

Fig. 3: Signal from 4 satellites enables determination of receiver position (http://answers.oreilly.com/topic/2815-how-devices-gather-location-information/)

Reference points in known locations are represented by satellites at a height of orbit approximately 20 000 km. Although they are in relative motion in relation to Earth surface, their exact position can be easily determined for every moment due to (i) precise shape of the orbit, which can be simply mathematically described, and (ii) continuous measurement of ephemeric gravitational pulses of Sun, Moon, planets and other cosmic objects slightly deflecting expected trajectory. From the time lapse between pseudo-random noise signals arriving from satellites and receiver signal, the distance of the satellite is calculated. Measuring the distance from one satellite provides surface of a sphere as a set of possible locations of the receiver. For two satellites available, the receiver is located on the circle circumference and the third satellite reduces the uncertainty only on two points of possible location (Fig. 3). Exact determination can be attained using signal of fourth satellite or assuming that receiver is located on Earth surface (Earth surface represents 4th sphere) (Bonnor, 2012).

GNSS devices provide fast and precise geographical data, however, there is still wide spectrum of sources of errors reducing the accuracy. The most important limitations are caused by changing speed of signal in troposphere and ionosphere, shifting of satellite on the orbit, reflections of the signal off obstacles or inappropriate spatial placement of visible satellites (high clustering of satellites near zenith provides generally less precise data comparing situation where there is wide angle between satellites) (Marek & Štěpánek 2009). Some of these errors can be fixed using special approaches (e.g. Differential Correction; Chivers, 2003), however, the last two mentioned problems are - together with great reduction of signal power during transmission through high water-content leaves of angiosperms - of special importance when measuring under the canopy. Using GNSS positioning devices in forests or other localities with limited view of sky, therefore, provides less precise data or require more time-consuming repeated measurement of coordinates (Marek & Štěpánek 2009). In spite of these limitations, also the quality of receiver plays the key role concerning the precision of positioning. Based on above mentioned factors, typical errors of measurement span from few centimetres to 15 meters.

Global Positioning System (GPS) is probably the world's best known GNSS designed in USA since 1970s. These days it operates with 32 satellites. Positioning system called Glonass was build also in Russia and uses 24 satellites. Similar projects of satellite positioning are being introduced in China (Compass-Beidou 2) and European Union (Galileo) (Bonnor, 2012).

D. TREE DIMENSIONS MEASUREMENT

Tools used for individual tree parameters measurement (like height, diameter or inclination) can be divided into contact and non-contact. Traditional means of contact data collection are represented by callipers and girth tapes, which provide discrete data about tree parameters in the moment of measurement. Continual data about stem lateral increment can be obtained using circumferencial dendrometers, which usually consist of steel belts spanned around stem, with recording device registering current diameter. Annual growth of stem volume and, if the temporal resolution of dendrometer is high enough, even diurnal fluctuations can be readily identified (Drew & Downes 2007; Biondi & Hartsough 2010) (Fig. 4).

Devices like Spiegel relascope or optical mirror callipers are traditional means of remote tree parameters measurement (Waguchi, 2004). Modern facilities (dendrometers) are usually combined with other optical tools, e.g. laser rangefinders. At least, optical instrument is equipped with remote diameter scope to manually subtract data and, subsequently, calculate parameters of tree morphology. However, some devices provide also direct calculation of diameter data.

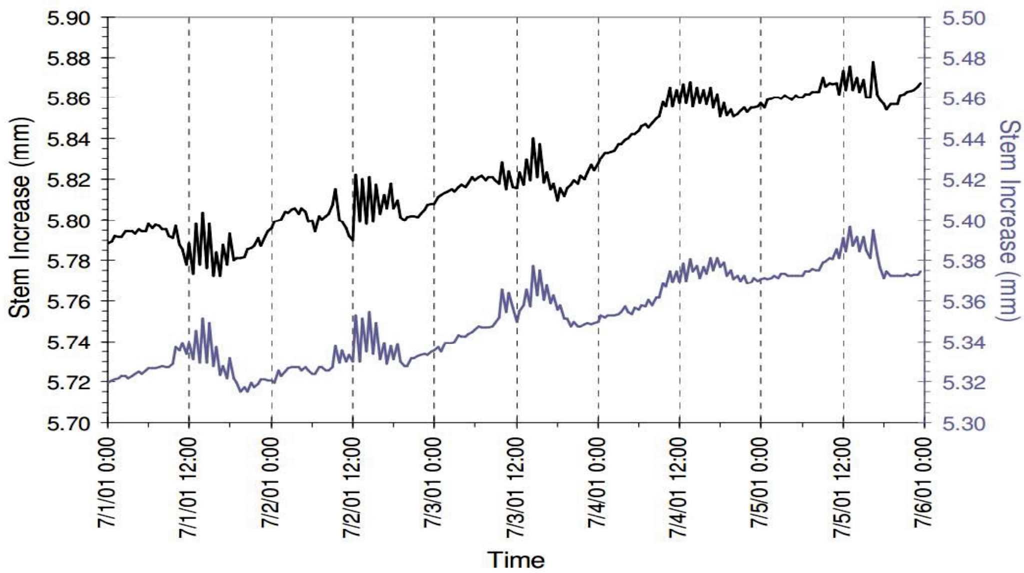

Fig. 4: Stem size patterns recorded using dendrometer during the first six days of July 2001 for two trees on research plot at Nevado de Colima, Mexico (Biondi & Hartsough 2010).

E. FIELD COMPUTER

Field computers represent key component of outdoor data-collection assemblies, not only in the field of forestry. They benefit the fieldwork in many ways, e.g., increase validity and integrity of collected data, reduce duration and costs or enable to use variety of complex measuring devices. Ordinary personal computers usually lack specific requirements for outdoor working, e.g. low weight, high mechanical endurance or sufficient battery with long life. The term field computers (or outdoor computers) states for personal computers specifically designed to fulfil the abovementioned needs (Dembo, 1983).

The history of field computers starts in 1981, when Osborne 1 was built. Although it is generally considered to be the first outdoor computer (Dembo, 1983), it only hardly meets requirements expected for modern field computers (weight ~ 11 kg). At the beginning, these devices were limited only for military purposes, but due to technology advance in 90s, they became accessible for public use. Nowadays there is wide spectrum available on the market.

Field computers differ in the form in which they are fabricated. Devices can be made as a rugged laptops, tablets or small handheld (PDA) or wearable computers. Although the construction of outdoor computers differs from one to another, there is also something we could consider as key backbone of components typical for field computers. Battery, which evolved greatly in past (from NiCd to NiMH and lead acid systems), still limits the endurance of the device in the field. In opposite to indoor use, display has to ensure good contrast also in the situations of strong daylight. Nowadays, outdoor computers are equipped almost exclusively with colour LCD displays. Its size and resolution depends on the form of computer – generally smaller are fabricated in PDAs, larger are typical for laptops or tablets. Input devices are also specifically designed to simplify data collection in outdoor environment. If the computer is operated via keyboard, there is usually only limited number of keys with specific functions or programmable. Tablets are almost exclusively equipped with touch screen.

F. TERRESTRIAL LASER SCANNING

Terrestrial Laser Scanning allows noncontact measurement of coordinates of specific points on objects of interest. It is done from ground based platform, which is the difference from airborne laser scanning. Method is highly useful for digitalization of difficult-shaped objects like cliffs, caves or trees. The measurement of distance is very similar to principle of laser rangefinder and due to automatic movement of laser generator in horizontal and vertical directions it produces continual model of surrounding environment. Main advantages of terrestrial scanners are fast measurement, great resolution (1 – 10 mm) and substantially automatic work of the device (Calders et al. 2014).

G. DENDROCHRONOLOGY AND XYLOGENESIS

If history of forest stand is the interest of researcher, dendrochronology provides cheap and effective method for its reconstruction. The basic principle of dendrochronology is reconstruction of dynamics of forest stand through studies of annual changes in tree-ring widths and anatomical structure of wood mass (Schweingruber, 1996). The most widespread tool for sample collection is Swedish corer (Presslers corer), which enables to extract small cylinder of wood mass from bark to pith. The great benefit of its use is non-destructiveness.

Xylogenesis is subdiscipline of dendrochronology which studies cambial activity in intra-annual time scales. This requires taking of samples during whole vegetation period from the same tree. So called Trephor – needle-like tool minimizing damage inflicted to tree – is used for the purpose of repeated invasive sampling (Rossi et al. 2006).

Discussion and Conclusions

Terrestrial data acquisition methods include wide group of approaches, which enable precise measurement and storage of data relative to individual trees and their close surroundings. Opposed to data collected using remote sensing techniques, which usually cover large areas, terrestrial data are generally attributed to sample field with limited dimensions. However, terrestrial data benefit researchers through providing information about direct status of forest stand (e.g., tree diameter, height and age structure), which are thorough findings only hardly obtainable from remote sensing data. Generally, terrestrial data acquisition techniques provide spatially isolated direct data about internal structure of forest stand, on the other hand, remote sensing data may efficiently describe overall characteristics of ecosystems on larger areas.

Despite significant progress in the quality of field measuring devices and subsequent data processing tools, awareness of methods limitations is still very important. Given the above, combination of terrestrial and remote approaches of data collection is highly desirable to overcome main limitations of both methodologies.

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