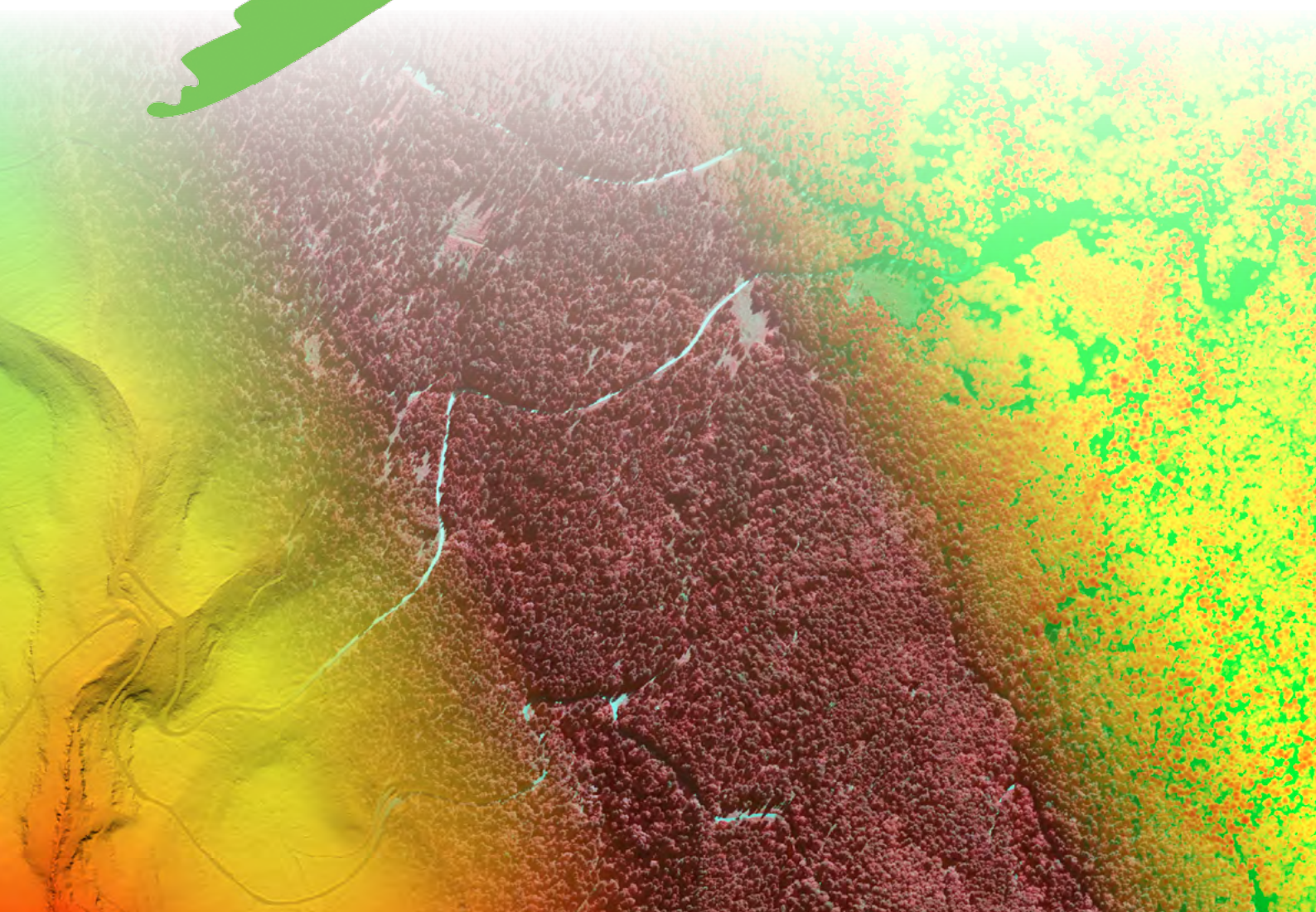




# Forest Logistic Planning Strategies

*Good practices  
for the Alpine forests*



Interreg Alpine Space project - NEWFOR  
Project number 2-3-2-FR  
NEW technologies for a better mountain FORest timber mobilization  
Priority axis 2 - Accessibility and Connectivity

This project has been co-funded by the European Regional Development Funds,  
and achieved under the third call of the European Territorial Cooperation  
Alpine Space Programme 2007-2013

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e-edited november 2014

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# Index

<b>Foreword</b> . . . . .	<b>7</b>
<b>Introduction</b> . . . . .	<b>10</b>
Forest meets technology	11
The NEWFOR project	12
A brief introduction to LiDAR	14
References	15
<b>Forest resources &amp; LiDAR</b> . . . . .	<b>16</b>
Forest area delineation	18
Forest structure assessment	19
Growing stock estimation	22
Growing stock change detection	24
Single tree detection / benchmark	26
Deriving multi-scale forest information maps based on ALS raster data	30
New remote sensing platforms / UAVs for forest applications	32
New challenges: broadleaves forests	34
Critical nodes and future opportunities	34
<b>LiDAR</b>	<b>34</b>
<b>UAV</b>	<b>34</b>
References	35
<b>Forest accessibility</b> . . . . .	<b>36</b>
GIS-based procedure for road construction planning in high mountain forest areas	37
Harvesting technologies used in the Alpine Space	39
<b>Best practices on timber harvesting: a case study in Montafon, Austria</b>	<b>40</b>
<b>Conclusions related to harvesting technologies</b>	<b>40</b>
GIS-based Decision Support Systems for ground-based harvesting optimization	41
<b>Sylvaccess: a model for the automatic mapping of forest accessibility</b>	<b>41</b>
<b>FPI (Forest Path Identifier): a GIS-tool to predict forest machinery extraction routes using Aerial Laser Scanned derived data</b>	<b>42</b>
<b>CableHelp: a numerical tool to optimize the set-up of cable yarding operations</b>	<b>43</b>
<b>SimulCable, a software to optimise the line implantation for cable yarding</b>	<b>44</b>
<b>NCW – NEWFOR Cableway, a software solution to visualize skyline design in cable yarding</b>	<b>45</b>
<b>Library(NEWFORCC) – a R package for forest cable crane planning</b>	<b>47</b>
Remote sensed data for forest road planning support	49
<b>Using high resolution data for forest road engineering</b>	<b>50</b>
Critical nodes and future opportunities	51
References	52

<b>Forest&amp;industry connectivity . . . . .</b>	<b>53</b>
State of the art of transport in the Alpine Space	54
Structure of the enterprises	54
Fleet composition	54
Organisation	55
Conclusion	55
Test of existing tools for optimization	56
Forest road data base in the Alpine Space	56
NavLog	56
GIP: (Graph Integration Platform)	57
FLO (Forest Logistic Optimization)	58
The Slovenian forest roads' information database	59
Critical nodes and future opportunities	59
<b>Costs &amp; benefits evaluation . . . . .</b>	<b>60</b>
HePromo – the Productivity Estimation Tool	61
Testing on pilot areas: the French case	62
NEWFOR – BFW – Online Forest Machinery Database	64
Ad 1. Machine utilization - usage time	64
Ad 2. Depreciation for fixed assets	64
Reference values used for cost calculation	65
Searching for a machine	66
WoodChainManager - online tool for the visualization of production processes and cost estimates	68
Example of tool use	69
Critical nodes and future opportunities	73
References	73
<b>Logistical planning strategy . . . . .</b>	<b>74</b>
NEWFOR-WebGIS, online tools for interoperability, data access and analysis	76
What is NEWFOR-WebGIS	76
How NEWFOR-WebGIS works	77
Access and initial view	77
Available layers	77
Tools	78
Interoperability potential	79
Technical details	80
Structure	80
Loading and pre-processing data	80
Critical nodes and future opportunities	81
The events	82
NEWFOR Summer School	82

<b>Conclusions</b> . . . . .	<b>83</b>
Recommendations for an efficient mountain forests action plan in the Alpine Space	84
Specific and technical recommendation	86
Forest structure evaluation	86
Forest roads planning and industry connectivity	86
 <b>PILOT AREAS</b> . . . . .	 <b>88</b>
Italy	
Asiago plateau	89
"Gardesana Occidentale" Regional Forest	91
A.S.U.C. Pellizzano	93
Susa Valley	95
Slovenia	
Begunjščica	97
Leskova dolina	99
Germany	
The "Allgäu" district: Immenstadt and Sonthofen	101
Austria	
Montafon Forstfonds	103
Tiroler Unterinntal	105
France	
Quatre montagnes	107
Jura	109
Savoie and Haute-Savoie	111



# Foreword



Mountainous forests comprise some of Europe's most stunning, yet inaccessible landscape. Although forests represent a key resource of mountain environments, their valorisation is hampered by accessibility constraints. A comprehensive understanding of such remote terrain via an efficient mapping, management, harvesting and transport of wood products, is thus integral to their exploitation as timber resources.

Forests fulfil multiple functions in mountainous areas. They have an ecological function as host of many habitats and species. They also are a leisure area for social activities such as hiking, skiing... From the economical perspective, the production of renewable resources like timber and fuelwood has positive effects both at global scale, with climate change mitigation, and at a local scale with rural employment and the development of a regional value chain. The objective of preserving and improving the development of mountain forests is a point of public interest.

However, managing forests in mountain territories is a difficult task as topography and climate set strong constraints inside a complex socio-economical framework. In particular, a precise mapping of forest biomass characteristics and mobilization conditions (harvesting and accessibility) is a prerequisite for the implementation of an efficient supply chain for the wood industry. Usually, the available information is currently insufficient to provide, at reasonable costs, the required guarantees on the wood supply and on its sustainability. With the recent development of new remote sensing technologies, such as Light Detection And Ranging (LiDAR), and modelling tools based on the use of Digital Terrain Model (DTM) and implemented in Geographical Information Systems (GIS), major improvements regarding the evaluation of the forest growing stock and accessibility are now possible.

Upon this highly valuable information, decision-making tools must be built to optimize the investments in forest infrastructures required for a cost-effective wood supply while securing the sustainable management of forests, and to support the implementation of an efficient European policy for mountain forest management. This is one of the Alpine Space Programme's aims, which seeks "to overcome the disadvantages of location factors and to promote the Alpine Space as a dynamic economic region in Europe".

In order to propose adapted, efficient and pragmatic responses to this technical and economical context, the project NEWFOR (NEW technologies for a better mountain FORest timber mobilization) was built up by a consortium including researchers and managers from the 6 alpine space countries. The NEWFOR consortium was composed of 14 institutes. The key aim of this project was the improvement of mountain forest accessibility for a better efficiency of wood harvesting and transport in a context of sustainable forest management and wood industry in changing climate. This general objective has been fulfilled by creating, testing and transferring adaptable, robust support decision making tools dedicated to mountain forests management.

Four operational objectives have been fixed and reached after the 3 years duration of the project NEWFOR:

- 1.** Sharing of knowledge and development of tools regarding the use of an innovative remote sensing technology (LiDAR: aerial and terrestrial laser scanning) for forest growing stock location, characterization and evaluation of mobilization conditions.
- 2.** Sharing of knowledge and development of tools for the optimization of timber harvesting and transport from the technical and economical points of view.
- 3.** Identification of actions and tools requirements at regional and local level.
- 4.** Development of methodology and tools, in cooperation with political decision makers at regional level, dedicated to improve the connectivity between forest resources and wood industries.



The project has targeted a broad range of end-users: local authorities, public administrations, forest administrations, road and transportation administrations, forest owners, forest practitioners, forest industry managers, NGOs, political decision makers and policy-makers, and also forestry students. The target groups of end users have been involved as part of the partnership network and/or members of the reference panels.

The practice oriented outputs of the project (state of the arts, tools, maps, manuals) have been designed for broad distribution and dissemination via transnational workshops, conferences, training course, one summer school on sustainable mobilisation of wood in Europe. All these deliverables are freely available on the project website: [www.newfor.net](http://www.newfor.net). The mapping systems developed by the NEWFOR consortium has been consolidated for the project's pilot areas via an online WEBGIS platform.

It's our great pleasure in the name of the NEWFOR consortium and acting as the lead partner of this project and the leader of the workpackage dedicated to logistical planning strategy, to present this e-handbook which concatenates its major results. We are certain that the technologies pioneered on the project's pilot areas, and presented in this e-book, will supply foresters and politicians with detailed resources and examples to make critical business and policies decisions.

*Grenoble the 30th of November 2014*

**The lead partner  
of the  
Interreg Alpine space project  
NEWFOR  
F. BERGER**



**The leader  
of the  
workpackage  
«Logistical Planning Strategy»  
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# Introduction



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## Forest meets technology

Forests and mountain territories carry out different functions towards society and all inhabitants of alpine space. Their contribute to the stability and general development of population and economy of mountain areas has always been fundamental. Most of these functions are guaranteed and maximized through forest management, which is inspired to the principles of sustainability. Mainly due to the topographical conditions (slope and terrain roughness), management of mountain forest is much more onerous than lowland forests.

A deeper knowledge of localization and quantification of woody biomass, of its qualitative characteristics, of the accessibility and mobilization conditions and possible connections with the wood industry is an essential pre-requisite for the planning and development of a sustainable supply chain (Lingua *et al.*, 2012).

Actually, this information is lacking or incomplete, and often data collection on the ground is no more economically sustainable. New tools for data acquisition are now available and they allow to obtain big amount of information on wide areas in a short period of time.

In the last decades, a technology called LiDAR (Light Detection And Ranging) is finding its way within the forest sector, from both terrestrial laser scanner and aerial one (Pirotti *et al.*, 2010; Pirotti *et al.*, 2012). This instrument is an active sensor (light is emitted and received back to collect the information), in contrast to ortophotos or satellite images (sunlight is refracted by the object to the sensor). It allows to obtain information either on the ground surface (DTM – Digital Terrain Model) or on the forest canopy surface (DCM - Digital Canopy Model) and, by subtraction, a CHM (Canopy Height Model) is derived.

LiDAR data have been used by now for the evaluation of the forest biomass and the localization of the position of single trees (Hollaus *et al.*, 2009, Corona *et al.*, 2012; Pirotti *et al.*, 2012), fuel load estimation (Erdody and Moskal, 2010), terrain and torrent morphological models (Tarolli, 2009), identification of forest habitats (Garcia-Feced *et al.*, 2011), identification and localisation of forest roads (White *et al.*, 2010). New applications of this technology come up day by day following the increasing availability of data and tools (software and new algorithms for elaboration). Often, the new laser scanning campaigns are launched for purposes different from forestry, mainly connected to safety or prevention aims (e.g. natural hazards) or urban planning, but can be successfully used as a support for the forest planning activities (even with issues linked to data resolution or acquisition period).

Within this context, the NEWFOR project (NEW technologies for a better mountain FORest timber mobilization) aims to promote and develop the use of new technologies for the support of forest management and planning, favouring the spreading and sharing of the technical knowledge within the countries of the Alpine region. Indeed, the project is funded by the Alpine Space Programme 2007-2013, which is part of the European Territorial Cooperation Objective that, altogether with 13 other programmes, contributes to the transnational cooperation improvement among the European regions ([www.alpine-space.eu](http://www.alpine-space.eu)). The Alpine Space Programme concerns an area of approximately 450.000 km<sup>2</sup> and a population of about 70 million people. The area includes all the Alpine range as well as hilly and flat territories close to it. General aim of the program is to increase the competitiveness and attractiveness of the area, through the development of common actions and collaboration.

## The NEWFOR project

NEWFOR (NEW technologies for a better mountain FORest timber mobilization) is a research project funded by the Alpine Space Programme. It brought together 14 institutions from 6 Countries of the alpine space (Table 1), among which are research institutes, universities and local authorities.

The project has been structured into 8 Work Packages (WPs), 3 of which were directly connected to the general management (WP 1-3) and the other 5 related to the different topics to develop to reach the final objectives.

WP 4 dealt with forest resources assessment through the usage of LiDAR technology and high precision orthophoto. These technologies can provide an accurate evaluation of the forest biomass, reducing the necessity of ground controls, which are very expensive in mountain areas. Within this WP, moreover, all the information related to the already present LiDAR data on the entire alpine space, analysing their characteristics and aims of acquisition with a particular focus to forestry applications have been collected.

WP5 aimed to analyse the accessibility to the forest resources, i.e. the possibility to access to the woody biomass identified by the previous WP. Two main elements have been considered; on one hand, it has been taken into consideration the presence and the characteristics of the forest roads while, on the other hand, the whole network configuration has been weighted as support to the wood harvesting techniques. In the mountain areas, topographical conditions (slope and terrain roughness) often constitute a technical and economical limitation to a rational wood harvesting. A first step in this direction has been to use the data derived from LiDAR (high resolution Digital Terrain Models) to evaluate the accessibility of forest resources. Algorithms were developed within a GIS software in order to obtain as much information as possible to define the suitable harvesting method. Moreover, the use of LiDAR for forestry purposes can provide for identification and characterization of forest roads (Pirotti *et al.*, 2012). As demonstrated by White *et al.* (2010), characterization of road features as slope and width, is possible without significant error. For this reason, another working purpose has been the development of methodologies for road network identification, estimating the error in relation to density and typology of the forest above it, nevertheless considering the morphology of the terrain (slope and terrain roughness). Correct determination of the transversal profile of the road has then been verified in order to estimate the error within the application of the high precision digital terrain models in the quantification of volumes during cut and fill operations as proposed by Aruga *et al.* (2005), but

considering full waveform data. Furthermore, it has been possible to develop GIS models for the planning support to maintenance intervention and transport management. Finally, an analysis of the state of the art of harvesting systems used on the alpine range has been carried out.

WP6 dealt with the connectivity within the forest supply chain, analysing where the resources are located and all the logistics connected to the mobilisation from the forest to the industries. One of the main output has been the optimization of the road network, for what concerns both density and quality, that can be studied through Network Analysis tools or navigation systems mounted on the vehicles.

WP7 focused on the cost-benefits analysis to guarantee sustainable management. Taking in consideration all the concepts developed from the previous WPs, it has been possible to assess the optimal strategy also from an economic point of view, deeply evaluating the opportunities and the threats of each considered system.

WP8 worked to collect all the available information from the previous WPs, in order to define a logistical strategy based on the data analysed, to provide a support scheme to the forest managers and policy makers. Furthermore, another important aim has been the dissemination of the results

The project started on September 2011 and concluded in December 2014, for a global duration of three years. All the activities have been carried on in different test sites within each country and implemented by each partner. In these areas, common procedures and tools have been developed and tested, both on present and specific collected data.

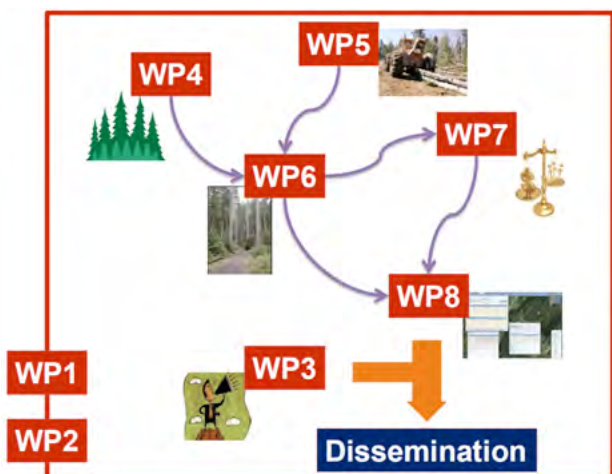


Figure 1: organisation of Working Packages within the NEWFOR project

**Table 1: List of project partners and their location within the Alpine Space (modified from [www.alpine-space.eu](http://www.alpine-space.eu))**

ID Partner	Description	Nation	Role
Irstea (ex-Cemagref)	National research institute of science and technology for environment and agriculture, Grenoble regional centre, Mountain Ecosystem Research Unit	France	Project Leader WP1-3 Leader
TORG	Office of the Tyrolean Regional Government - Tyrolean Forest Service	Austria	
BFW	Federal Research and Training Centre for Forests, Natural Hazards and Landscape Department of Natural Hazards and Alpine Timberline	Austria	WP7 Leader
Stand Montafon	Stand Montafon - Forstfonds	Austria	
ERSAF Lombardia	Regional Authority for Agriculture and Forestry	Italy	
PAT-SFF	Autonomous Province of Trento Forest and Wildlife Service	Italy	
FCBA	Technological institute for Forestry, Cellulose, Construction Timber and Furniture	France	WP6 Leader
SFI	Slovenian Forest Institute	Slovenia	
LWF	Bavarian Forest Institute Department Forest Management	Germany	WP5 Leader
UNITO	University of Torino DISAFA Department	Italy	
TESAF	University of Padova Land Environment Agriculture and Forestry Department	Italy	WP8 Leader
TU-WIEN IPF	Vienna University of Technology Institute of Photogrammetry and Remote Sensing	Austria	WP4 Leader
SFS	Slovenian Forest Service	Slovenia	
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research	Swiss	



## A brief introduction to LiDAR

A laser scanner is based on the usage of a laser (Light Amplification by Stimulated Emission of Radiation) beam to calculate the distance between the sensor and a target through the intensity and delay of the returning part of it. This creates the so called "point cloud" from which it is possible to define a surface based on the different returns. With a high number of points per square metre the accuracy of the survey can increase till errors of few millimetres (Bienert *et al.*, 2006). Traditionally, even if the instruments do not differ so much, these devices are distinguished depending on the support on which they are mounted:

- Terrestrial Laser Scanner (TLS): a high accuracy instrument capable of giving back a 3D image of the stand; thus, finds many applications in standing timber measurements and optimal harvest decision-making (Keane, 2007);
- Airborne Laser Scanner (ALS): usually thought for fixed-wing aircrafts, is possible to be used also on helicopters;
- Spaceborne Laser Scanner: takes often the name from the project/satellite in charge, like the well-known ICESat. For the development of this issue see Lefsky *et al.* (2005) and Simard *et al.* (2008).

For what concerns dynamic surveys (vehicles, aircrafts or satellites) the system itself is composed by a laser scanner, a position and orientation system (POS), realised by an integrated differential GPS (DGPS) and an inertial measurement unit (IMU), and the control unit (Wehr and Lohr, 1999). It measures the distance between the sensor and the illuminated spot, retrieving three-dimensional information by transmitting short-duration pulses and recording the reflected echoes, every one of which is identified by the three spatial coordinates (x, y, z) (Gobakken and Naesset, 2009) and the so called GPS time that univocally characterize a pulse (Gatziolis and Andersen, 2008). The very powerful laser beam used is highly directional and due to its physical characteristics has the advantage to be shot within small intervals and collimated with high precision.

On an average, the available wavelength may vary between 800 and 1000 nm, but in this range is still capable of hurting the eye. Working on higher wavelengths (close to 1500 nm) it is possible to reduce this inconvenient, adding also the advantage that the maximum flight range can be extended to more than 1500 m and the background sunlight radiation is very low (Wehr and Lohr, 1999). By the way, it is important to evaluate the one in use due to the fact that an extremely high frequency cannot work properly on high reflectivity surfaces like ice.

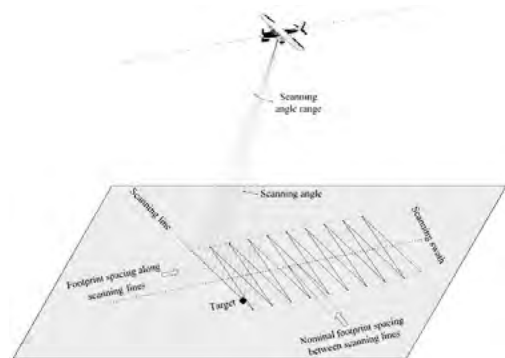


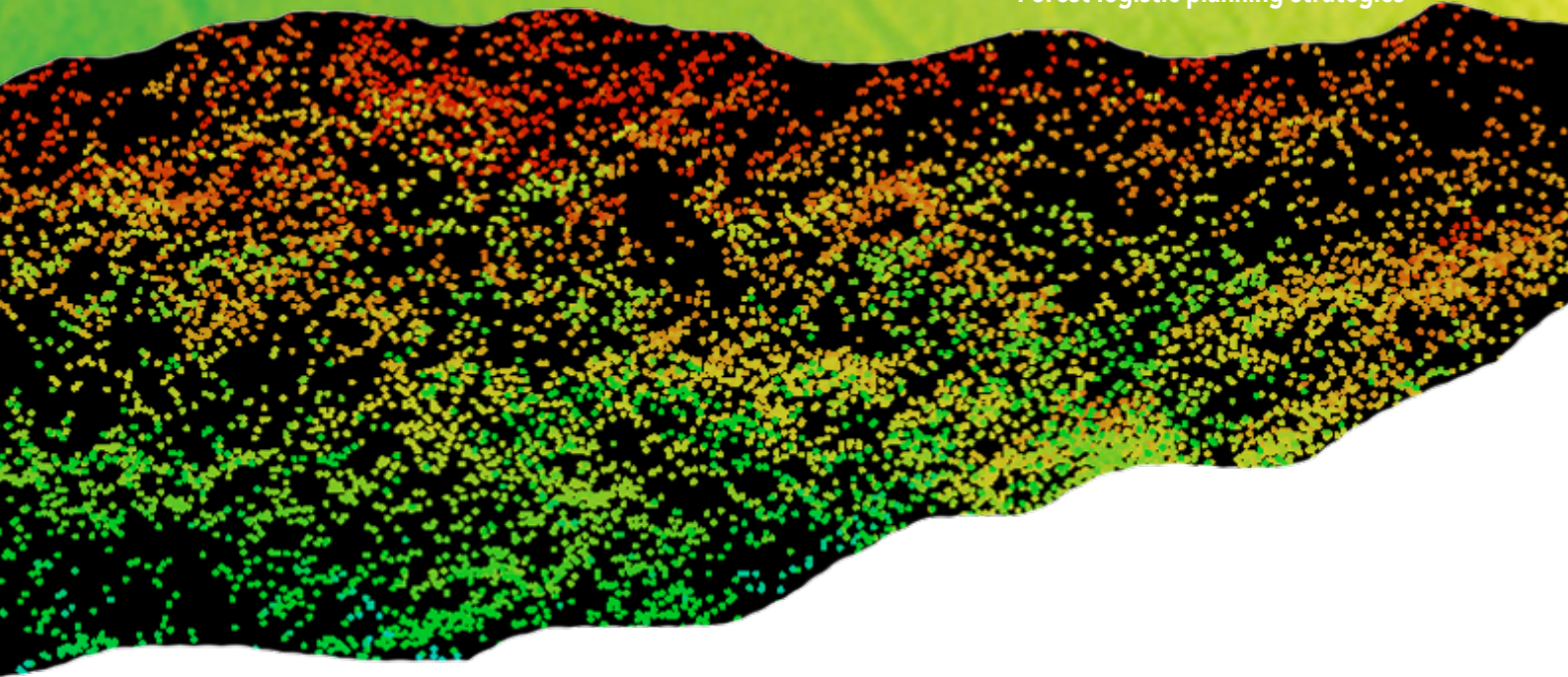
Figure 2: General scheme of an ALS survey and basic terminology (from Gatziolis and Andersen, 2008)

Below are some basics characteristics of LiDAR data, following the framework given in Gatziolis and Andersen (2008, Figure 2):

- Scanning frequency: the number of pulses or beams emitted by the instrument in one second and, thus, defined in Hertz (Hz). With the increasing in frequency it is possible to achieve higher densities of discrete returns even increasing the speed and elevation of the aircraft, accelerating the survey and reducing the relative costs;
- Scanning pattern: the spatial arrangement of the pulse returns on the target surface; can vary from seesaw to linear or elliptical, depending on the mechanism used to direct pulses across the flight line (oscillating or rotating mirror);
- Beam divergence: the beam tends not to keep the cylindrical shape of the true laser and creates a narrow cone. This divergence is measured in millirad (mrad, usually between 0.1 and 1.0) and, spreading the energy on a bigger area, brings to a lower signal-to-noise ratio;
- Scanning swath: the width of the scanned path, given by the combination of the scanning angle and the aboveground flight height;
- Footprint diameter: is the diameter of the beam on the ground from a specific height; the energy is not uniform over its extent and decreases radially from the centre following a two-dimensional Gaussian distribution;
- Number of returns per beam: is the maximum number of individual returns that can be extracted from a single beam;
- Pulse density: measures the spatial resolution and depends on the ratio  $1/(\text{footprint spacing})^2$ , where the denominator is the distance between the centres of two beams' footprints on the same scanning line;
- Return density: often confused with the pulse density, is the mean number of returns per square metre.

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# Forest resources & LiDAR

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The role which mountain forests play is extremely varied. Their contribution to the stability and overall development of life and economic factors in mountainous regions is highly significant. The production of renewable resources like timber has positive effects on climate change consequences attenuation, employment and makes for a strong regional value chain, which in turn has an enormous impact on rural development. The objective of preserving and improving the efficiency of mountain forests is a point of public interest and can only be guaranteed if the planning and implementation of all respective measures are integrated into an adequate and well-known socio-economic context. Managing forests in mountain territories is significantly more cost intensive than in plain ones. This is due to the topographic conditions, climatic adversity and limited access which drive partly the economic context. A good knowledge of the forest biomass location, its characteristics and mobilization conditions (exploitability, service roads, and mobilization costs) is a prerequisite for an effective wood harvesting and transport and for a sustainable wood industry. This knowledge is currently insufficient to provide at reasonable costs, the required guarantees on the wood supply and on its sustainability. Improving an efficient and robust evaluation of the forest growing stocks (volume and quality) and its accessibility are the efficient measures to mobilise sustainably more wood from mountain forests. As building forest roads and other infrastructures are often complex and expensive, the availability of financial resources is a key challenge. This could be achieved by providing technology and financial support. With such knowledge and tools it will be then possible to develop an active and sustainable cultivation of mountain forests and an efficient European mountain forest management policy.

Recent developments in LiDAR technology – also called airborne laser scanning (ALS) data, combined to other available data sources (aerial photographs, aerial photo series by UAVs,...), are now allowing a precise and fine mountain forest resource quantification, qualification and mapping. Integrating this technology will provide an innovative response to the challenges of a precise and robust knowledge on the available growing stocks. The actions of the WP4 (named "Forest Resources & LiDAR") have the overall objective to test (e.g. benchmark for single tree detection algorithms), to optimize (e.g. for forest area delineation, growing stock assessment) and to develop new tools (e.g. growing stock change assessment, forest structure estimation) using data which are acquired by these new technologies.

Based on these overall project goals, in the framework of the WP4, the following relevant objectives were formulated:

- Collection and sharing of knowledge regarding the use of an innovative remote sensing technologies (LiDAR & UAV) for forest area and growing stocks location, forest structure assessment and single tree parameter estimation;
- Identification and testing of currently available LiDAR data processes and development of new processes adapted to mountain conditions in order to obtain the actual distribution of growing stock, stand structure and other parameters useful to characterize mountain forests;
- Determination of the LiDAR data to be acquired on pilot areas to obtain a detailed map of the volume distribution and forest structure;

The results of WP4 are the basis and prerequisite for WP5 to 8 (see following chapters), building the background for the setting up of specific models dedicated to an adapted logistic planning strategy taking into account the accessibility and availability of growing stocks, the economic conditions and the mountain forest ecosystems services.

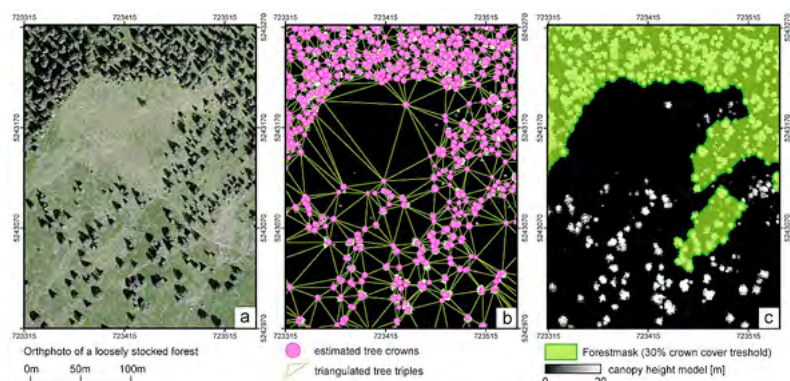
## Forest area delineation

A fundamental task in forest management is locating and analysing forested areas. The delineation of forested areas has a long tradition in forestry and therefore worldwide different forest definitions exist to define whether an area can be classified as forest or non-forest. The delineation task is critical as a broad field of applications (i.e. obligatory reporting) and users (i.e. governmental authorities, forest community) rely on this information. The results determined from these applications are highly dependent on the fundamental input parameters size and position of the delineated forest areas. In the past mainly aerial images were used for a manual or semi-automated delineation. Shadow effects limit this task, particularly for detecting small forest clearings and the exact delineation of forest borders on a parcel level. Additionally, the quality of the results of a manual delineation is subjective and variable between interpreters and may lead to inhomogeneous, maybe even incorrect datasets. An automatic delineation of forested areas based on LiDAR data can overcome these limitations in most cases. Within the NEWFOR project the method of Eysn *et al.* (2012) was applied to several NEWFOR pilot areas characterized with different forest structure and growing conditions to detect forested areas. The method relies on four clearly defined geometrical criteria (min. area, min. height, min. width and min. crown coverage) which are subsequently checked against LiDAR data. The criterion land use is not considered as this information can hardly be obtained from remote sensing data. Other data sources, such as the cadastre, are needed to gather this information. From a hierarchical point of view, the four geometrical criteria have equal rights. To apply these criteria to remote sensed data, a hierarchy has to be defined with respect to a processing chain. For instance, it would make no sense to check the minimum forested area if there is no potential area detected yet. In this approach, the hierarchy is defined as follows: (1) min. height, (2) min. crown coverage, (3) min. area and (4) min. width, whereas (3) and (4) are checked in an iterative process. The minimum height criterion is applied by height thresholding the canopy height model within the vegetation mask. For the crown coverage calculation

the 'tree triples' approach as described in Eysn *et al.* (2012) was used. This approach provides a clearly defined reference size for calculating the crown coverage and overcomes limitations such as smoothing effects or dependency of the kernel size and shape of the moving window approach, especially in loosely stocked forests. The crown coverage value is calculated for each tree triple independently and therefore an interaction with neighbouring triples is not considered. The minimum area criterion is applied by using standard GIS-queries. The areas of all valid polygons are calculated for the potential forest mask fulfilling the height- and crown coverage-criterion. The minimum width criterion is applied by using morphologic operations (open, close) based on the intermediate result fulfilling the criteria height, crown coverage and area. For this operation, a circular kernel with a radius of 5 pixels (pixel size 1 × 1 m) is used to eliminate narrow forested areas that do not fulfil the criterion. This operation is also related to the area criterion, because the removal of narrow areas leads to changes of the forested areas. Therefore, an iterative process of checking minimum area and width is applied.

The usage of these clearly defined geometrical criteria as defined in the method of Eysn *et al.* (2012) delivers robust, repeatable and comprehensible delineation results. This is significant when the results are used for obligatory reporting or change detection based on multi-temporal data. Especially at loose stocked forests where the forest / non-forest decision is demanding the most the proposed technique for checking crown coverage works reliably (Figure 3). The method is fully automatically, can be applied to large areas and fulfils the requirements of an operational application. Different forest definitions can be considered by the method. Therefore an application to different areas / countries with different restrictions is enabled. Furthermore the method was easily applied to the local forest definition requirements of the different pilot areas within the NEWFOR project. For the pilot area Immenstadt in Germany the automatically derived forest mask was compared to a manually delineated reference mask. The resulting confusion matrix shows a Kappa of 0.83 and an overall accuracy of 93%.

Figure 3: Delineation of forested areas based on LiDAR data. A) orthophoto of a loosely stocked forest B) Estimated tree crowns and detected tree triples based on LiDAR data C) Delineated forest areas (presented semi-transparent as overlay of a z-coded canopy height model)



## Forest structure assessment

In the following sections, four approaches for the derivation of structurally relevant parameters from ALS data are described. These are (1) crown segments (2) compactness of vegetation (3) vertical layer structure (VLS) of vegetation and (4) canopy cover (CC). These parameters exploit the information collected by ALS to describe vegetation structure and how different patches of vegetation are inter-connected in terms of vertical structure of the plants building the patches.

The main aim of the crown segmentation is to extract individual trees in forested areas. In the approaches described here, the segments are also used as reference unit for the calculation of structural parameters based on the 3D point cloud. To create the tree crown segments, an edge-based segmentation procedure is applied on the nDSM (Höfle *et al.*, 2008). It delineates convex shapes in the nDSM by finding concave edges between them. The main criterion for the edge detection is a minimal curvature in the direction perpendicular to the direction of the maximum curvature.

The compactness of vegetation refers to the relation of a vegetation patch's surface, defined as the area of its enveloping canopy, to the volume enclosed by it. Thus in the following text it will be referred to as surface-to-volume ratio. The parameter basically relates to the 3D shape of a vegetation patch and how the patch is inter-connected with other patches. It is calculated on the basis of a so-called difference DSM (DSMdiff), which comprises the height difference of the highest and lowest occurring ALS echo in a grid cell without consideration of terrain echoes. The DSMdiff is a measure of vertical vegetation extent, its multiplication by the grid width results in the vegetation volume. The vegetation surface is derived as the sum of the area of all visible lateral faces, the top and the bottom face of a cell column in the DSMdiff. Finally, the ratio of the surface and the volume are computed for each raster cell and assigned to the vegetation segments (Mücke *et al.*, 2010).

For the derivation of the VLS and the CC the capability of ALS to penetrate the foliage and to provide direct height measurement of canopy and sub-canopy strata, as well as the forest ground is exploited. A so-called penetration index for different vegetation height intervals is calculated based on the 3D point cloud as a measure of

penetrability and geometric structure. The definition of the height intervals can either be done in an absolute (i.e. a-priori fixed heights for each level) or in a relative way (i.e. percentage of maximum occurring height). To enable a comparison of the layer structure information assessed by the forest inventory (FI) and the ALS data, the ALS data within the FI sample plots were extracted. At the GPS measured positions of the sample plot centres the ALS data were selected within the area of a sample plot plus a buffer zone of 1 m to consider border effects. The DTM was used to calculate the normalized echo heights of the single ALS echoes, which were subsequently needed for the selection of the echoes belonging to the respective height levels as defined in the FI. For every defined height level, a 1 m resolution raster map was created containing the number of ALS echoes in each cell. If a cell contained ALS echoes, it was counted as covered. The sum of all overgrown cells per height level results in the total CC of a single height level.

Additionally, an area-wide forest structure map was derived on the basis of e.g. relative height intervals (i.e. 0-33%, 34-66% and 67-100% of the maximum relative height per each before derived crown segment). For each segment the number of points per height layer and the total number of vegetation points are determined. Finally, the ratio of these quantities (penetration index) is computed (Mücke *et al.*, 2010). For the generation of the forest structure map a decision tree based classification approach is used to classify the segments and determine the number of vertical forest layers based on the penetration index.

Generally it can be stated that the delineation of single trees or tree crowns in dense deciduous forests is a challenging task. As the applied segmentation algorithm detects convex objects separated by concave areas, it works very well for single trees with clearly distinct crowns. But especially older or larger deciduous trees often develop large crowns with multiple maxima which results in multiple convex areas and these are therefore represented by more than one segment. A further limitation occurs in very dense young deciduous forest, characterised by a smooth canopy surface leading often to segments that include multiple trees.

The vegetation surface-to-volume ratio can be seen as a proxy for the compactness of a particular landscape element. Changing compactness along a geometric element implies a change in structure and consequently permeability. This permeability is of significance for certain species, e.g. highly adapted birds, whose requirements do not allow structural changes within their habitats. In Figure 4a the computed vegetation surface-to-volume ratio is shown. A high voltage power line runs right through the study area crossing several vegetation corridors. It is clearly visible in the ratio image that the character of the vegetation structure is changing significantly below the power line. For evaluation of the results, visual examination of the 3D point cloud had to be used, because of the lack of an adequate ground truth measurement method for the proposed surface to volume ratio. A profile view is given in Figure 4b. It can be seen that the changing of the corridor vegetation character, as indicated by the ratio, is supported by the 3D point cloud. In this case the power line acts as a natural barrier, which is a disturbance in this particular habitat or corridor.

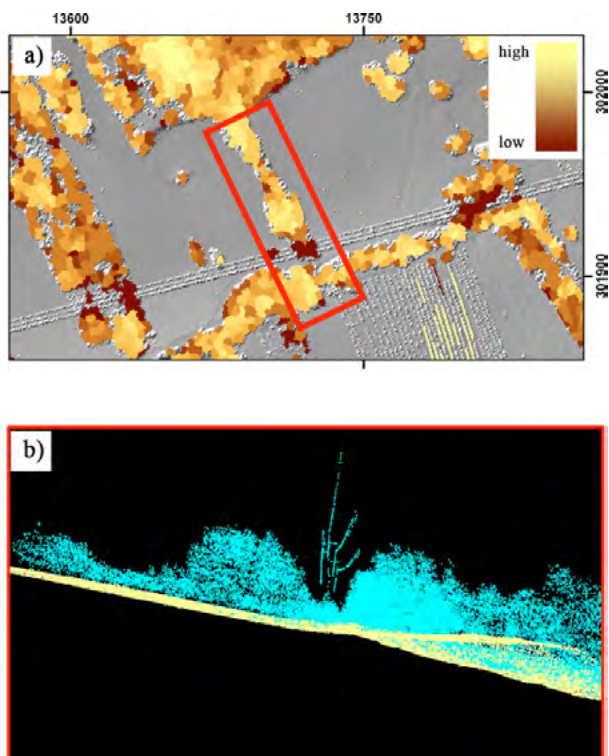


Figure 4: (a) Surface-to-volume ratio calculated on segment basis, (b) Vertical profile of the point cloud showing the differing character of vegetation in an area where also the surface-to-volume ratio significantly changes (adapted from Mücke et al., 2010). Terrain points are in yellow, vegetation points are in turquoise

In Figure 5 the canopy cover maps of individual a-priori fixed height levels (V1, V2 and V3) are shown. The total CC is shown in V4. For quantitative evaluation of the results of the derived layer structure and CC on plot level, scatterplots were derived (see Figure 6). All three single levels V1 to V3, as well as the total CC represented by level V4 exhibit significant scattering. The upper levels V3 and V4 reveal a linear relationship of FI- and ALS-derived CC. However, linear relation is only weakly distinguished in the lower levels V1 and V2, clearly showing an underestimation by the ALS-based method because of the absence of echoes in this canopy strata (Figure 6). This indicates that future research on this topic will need to concentrate on the development of a predictive model describing the relationship of FI- and ALS-based layer structure and CC, and considering the drawback of missing echoes in any stratum.

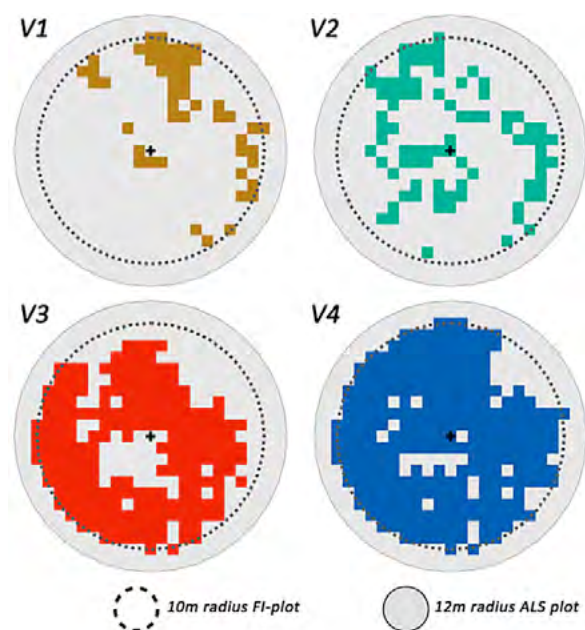


Figure 5: Example of canopy cover derivation based on ALS echo distribution. Levels V1 (brown) and V2 (green) clearly show an under-representation of the respective vertical layers due to the lack of echoes

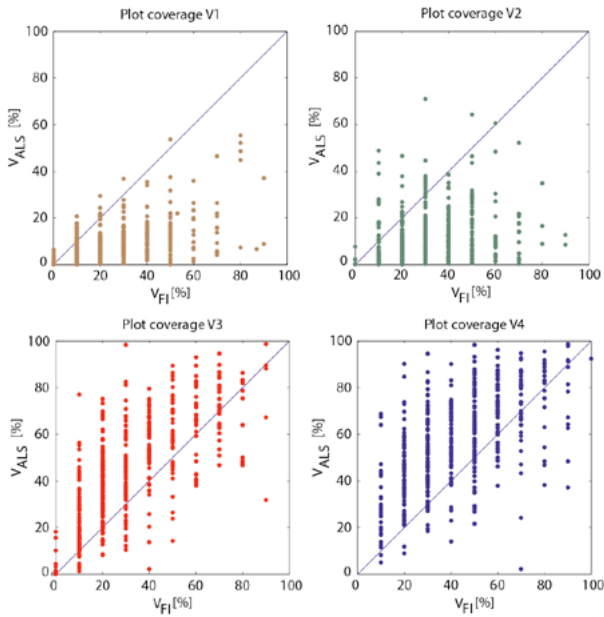
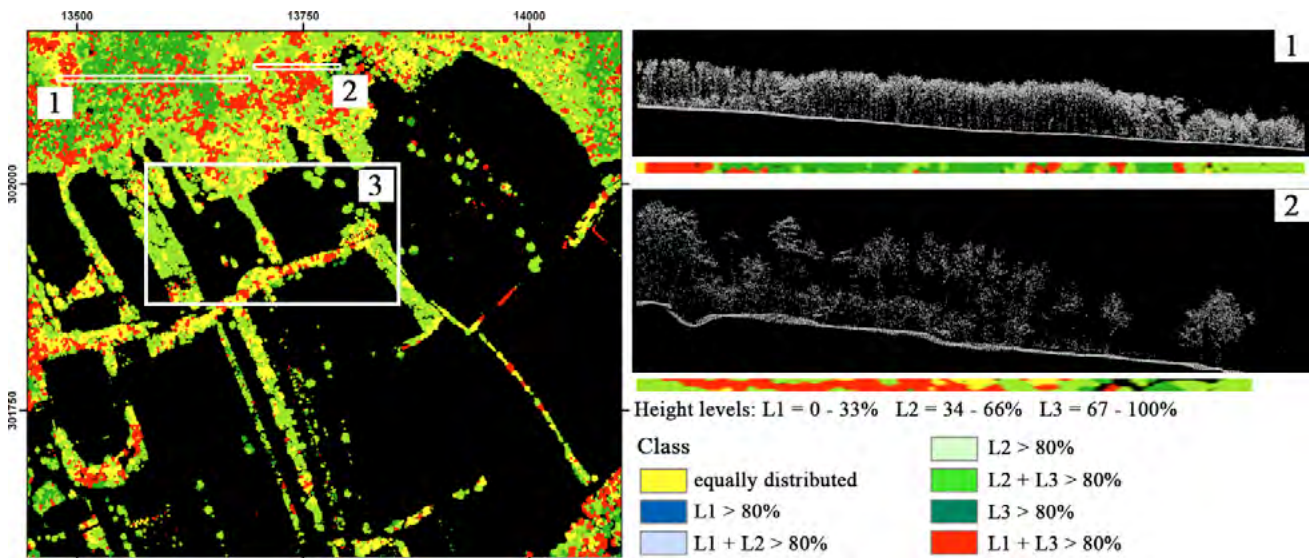


Figure 6: Comparison of FI- and ALS-estimated canopy cover

Figure 7 shows a resulting forest structure map and two profiles of the 3D point cloud, which are meant to display the structural diversity. Four dominant types of vegetation structure could be identified: L1 + L3 > 80% (red), L2 + L3 > 80% (light green), L3 > 80% (dark green) and equally distributed structure (yellow). Below the profiles the corresponding lines from the forest structure map are given. They demonstrate that the classification result corresponds very well with the actual structure of the forest. Deviations could be observed in areas with high local variations, which cannot be accounted for by using the proposed method because inner segment variations are not considered.

Figure 7: Left: Forest structure map calculated on segment basis (white lines show profile locations, white rectangle Nr.3 shows location of Figure 4). Right: Profile views of the ALS point cloud. Below the profiles the corresponding lines from forest structure map are given (adapted from Mücke et al., 2010)



## Growing stock estimation

A common way to acquire information about forest resources is to perform terrestrial forest inventories. The obtained information is spatially limited and therefore area wide forest management in terms of harvesting planning is limited. Remote sensing technology i.e. LiDAR allows an area wide mapping of the forest resource (i.e. growing stock) and provides the forest community with information suitable for area wide planning. Integrating this technology into the wood supply chain can provide an innovative response to the challenges of a precise and robust knowledge on the available growing stocks. A limitation of many LiDAR based growing stock models is the lacking sensitivity to local forest conditions. This means that growing stock models are often calibrated for large areas, local changes of the forest structure are not considered and the resulting models are smoothing the local situation. Within the project NEWFOR the model of Hollaus *et al.* (2009) was applied to several pilot areas located in different Alpine Space countries in two different ways: A) A general growing stock model was calibrated and applied for entire pilot areas and B) growing stock models were calibrated for different strata. For the stratification different information obtained from remote sensing data was used. This information can for example be a tree species classification as presented in Waser (2012) or a crown coverage map as presented in Eysn *et al.* (2011). The calibrated models were applied and tested for the NEWFOR pilot areas.

For estimating the growing stock the method described in Hollaus *et al.* (2009) is applied. This method assumes a linear relationship (Eq. 1) between the growing stock and the ALS derived canopy volume, stratified according to four canopy height classes to account for height dependent differences in canopy structure.

$$v_{FI} = 10^4 \cdot \sum_{i=1}^m \beta_i \cdot v_{can,i} \quad (\text{Eq.1})$$

where  $v_{FI}$  represents the stem volume ( $\text{m}^3/\text{ha}$ ), calculated from the forest inventory data,  $m$  is the number of canopy volumes and is set to four and  $\beta_i$  are the unknown model coefficients. The canopy volumes ( $v_{can,i}$ ) are calculated based on Eq. 2.

$$v_{can,i} = p_{fe,i} \cdot ch_{mean,i} \quad (\text{Eq.2})$$

where  $p_{fe,i}$  represents the relative proportion of nDSM pixels within the corresponding canopy height class to the total number of nDSM pixels within a circular sample plot area with a radius of 12 m and  $ch_{mean,i}$  is the mean height of the nDSM pixels within the corresponding

canopy height class. The four canopy height classes are defined with the following height limits:

$ch_1$  - 5 m to 15 m,  $ch_2$  - 15 m to 25 m,  $ch_3$  25 m to 35 m,  $ch_4$  - 35 to 50 m.

The stratification based on remote sensing data was carried out fully automatically and is applicable to large areas. The criterion "species" classified the forest into areas of deciduous, mixed and coniferous forest, whereas the primary species classification can be derived from classification of aerial images as for example described in Waser (2012) or from full-waveform ALS data classification as shown in Figure 10. The criterion "crown cover" classified the forest into areas with dense or sparse coverage. In total six different models can be calibrated and applied using these criteria. In contrast to a general model without stratification the stratified model increased the accuracy. This was expected as the general model does not account for local changes in the forests appearance and different strata might be incorrectly represented (Figure 8).

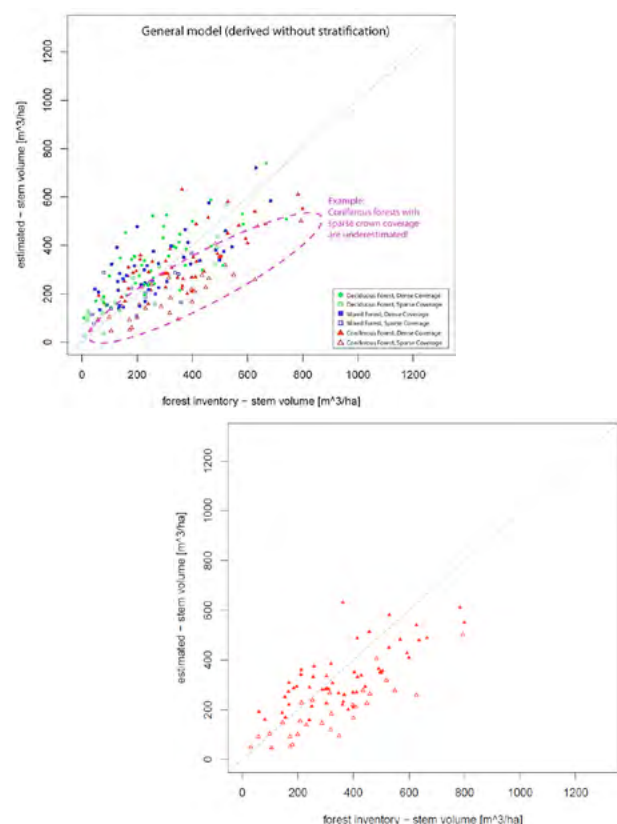


Figure 8: Left: Calibration Scatterplot of a general growing stock model. The data is classified and colored to six different strata to visualize over- or underestimations for the different strata. Right: Subplot of the two classes coniferous dense and coniferous loose stocked. The class coniferous loose stocked is clearly underestimated in the non stratified model.

The relative standard deviation of the residuals between estimates and reference could be enhanced by 4%. The results of the tests within the project prove that growing stock maps with very high spatial resolution can be derived from remotely sensed data. These maps allow comprehensive forest management for large areas and serve as input data for various forest planning activities. The level of detail of growing stock maps in operational use is still under discussion. However, this discussion

within the project consortium show a first trend for aggregating the resulting growing stock map, because it is too detailed for most applications. The aggregation could be performed by resampling the data to cell sizes of several meters (see Figure 9) or by aggregating the data to stand levels or to forest management units.

Figure 9: Derived growing stock map for a subset of the pilot area Montafon, (left) 1.0 m and (right) 5.0 m spatial resolution

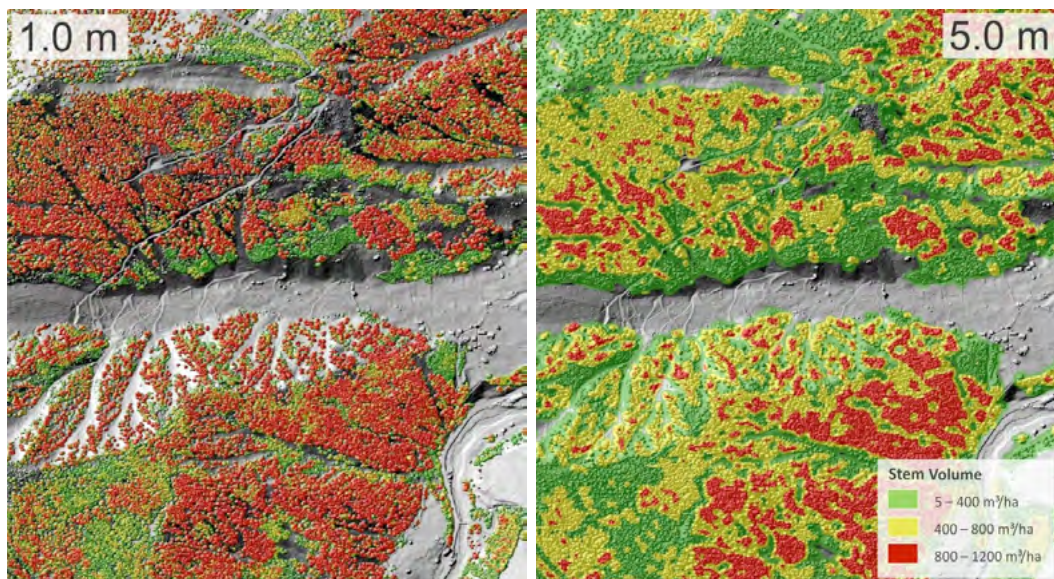
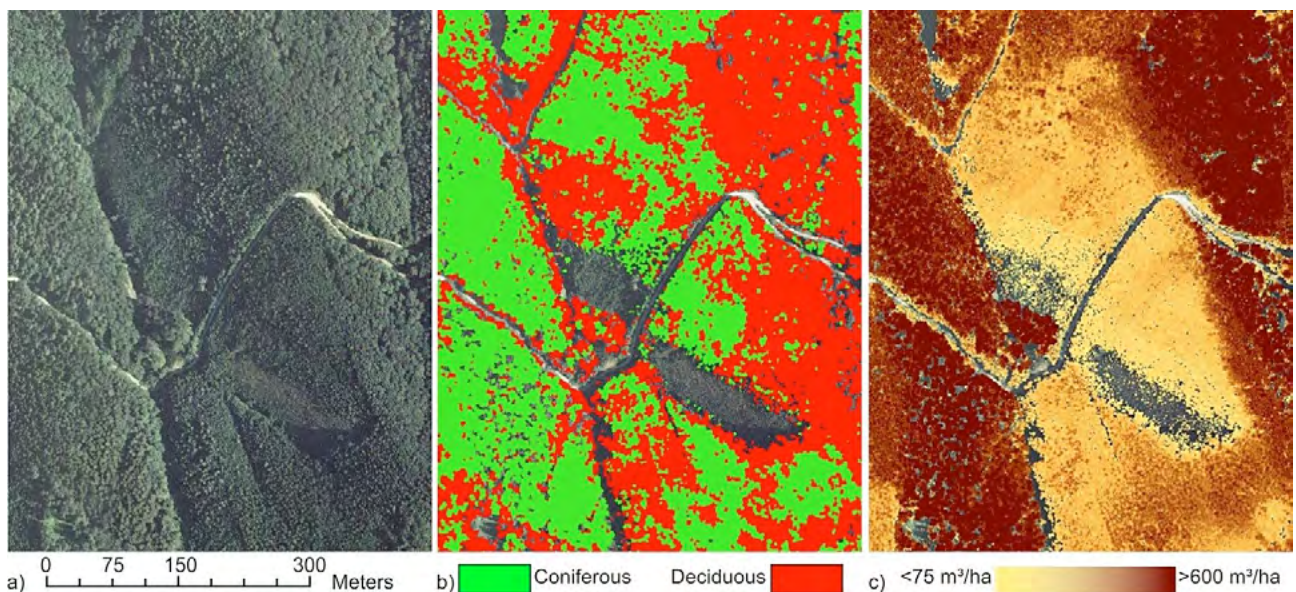


Figure 10: (a) Orthophoto ©Bing maps, (b) classified tree species map and (c) tree species dependent stem volume map

In Figure 10b the classification result into coniferous and deciduous forest based on full-waveform ALS data is shown. The classification can be used for stratified growing stock modelling as shown in Figure 10c.



## Growing stock change detection

The high potential of airborne laser scanning (ALS) data for forestry applications has been confirmed in many studies during the last decade. The open question is still the application of ALS data for monitoring applications. Due to the ALS data acquisitions costs re-acquisition are rare until now. Consequently there is on one hand a lack of data and on the other hand a lack of knowledge of using multi-temporal ALS data for forest monitoring tasks.

Therefore, the capabilities of ALS data for operational forest monitoring of growing stock were analysed in the pilot area Montafon, Austria. In addition to two ALS data sets forest inventory data for both ALS acquisition times are available for this study.

In the first processing step topographic models are calculated and differences between the models originating from inaccuracies in the georeferencing are minimized. To avoid errors in the assessed growing stock change originating from digital terrain model (DTM) errors due to different terrain point densities, one reference DTM is used for both dates. It is assumed that the DTM within the forests does not change during the two ALS acquisitions. Thus the DTM is determined from the ALS data set with the higher point density to derive a DTM with higher accuracy. For the calculation of the DTM the hierarchic robust filtering approach described in Kraus and Pfeifer (1998) is applied, which is implemented into the software Scop++ (2012).

For the derivation of the digital surface model (DSM) a land cover dependent approach described in Hollaus et al. (2010) is applied. This approach uses the strengths of different algorithms for generating the final DSM by using surface roughness information to combine two DSMs, which are calculated based (i) on the highest echo within a raster cell and (ii) on moving least squares interpolation with a plane as functional model (i.e. a tilted regression plane is fitted through the k-nearest neighbours). Finally the two nDSMs (DSM2004, DSM2011.) are calculated by subtracting the DTM from the DSMs. The spatial resolution of all topographic models is 1x1 m<sup>2</sup>.

The differences of the DSMs have shown that especially height differences of stable objects between the two surface models originating from strip differences or errors in the georeferencing have to be minimized using e.g. a least square matching (LSM) in a first step.

The calculated normalized digital surface models (nDSMs) are used as input for the growing stock regression models (see previous chapter). Each data set is calibrated with the corresponding FI data and the derived growing stock maps are compared.

For differentiating between exploitation and forest growth the area is classified into areas with an (a) increased (= forest growth) and (b) decreased (= exploitation) surface height. As for each ALS data set small differences in the tree crown representation within the DSMs can occur morphologic operations (i.e. open / close) and a minimum mapping area of 10 m<sup>2</sup> are applied to the DSM difference map. For each classified area (exploitation, forest growth) the changes for the assessed growing stock is analysed separately. To test the transferability of the calibrated growing stock models from acquisition time to the other, the calibrated models are applied to the ALS data which was not used for the calibration. Finally the derived growing stock maps are validated with the corresponding FI data.

In Figure 11a an orthophoto overlaid with the mask of corresponding objects that are used for the LSM is shown. These objects represent mainly open areas, roofs and streets and are distributed over the entire area. In Figure 11b the DSM difference map (DSM2011-DSM2004) is shown and indicates a vertical shift between the DSMs of 0.17 m averaged for the masked objects. Calculating the LSM of the identified objects 3D shift parameters are determined and applied to the DSM2004. In Figure 11c the difference map between the DSM2011 and the shifted DSM2004, LSM is shown, whereas the average difference is minimized to 0.07 m. Due to this height adjustment the remaining height differences can mainly be connected to changes of tree heights and consequently to growing stock.

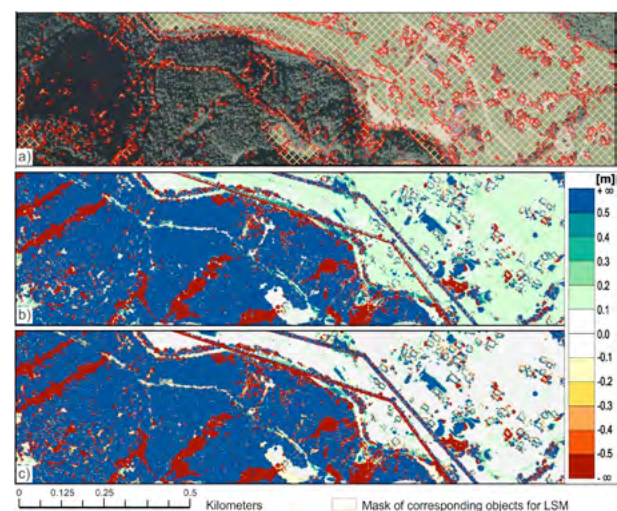


Figure 11: (a) Orthophotos from 2012 with a spatial resolution of 0.25 m overlaid with the mask of corresponding objects that are used for LSM, (b) difference of DSMs (DSM2011-DSM2004) before and (c) after the LSM. Red colours indicate exploitation of forest, green/blue colours indicate forest growing



It could also be shown that the growing stock changes derived from the estimated growing stock maps are similar to those derived from the forest inventory data. For both models a similar accuracy could be achieved. The relative standard deviation derived from cross validation is rather high for both models and can mainly be explained by the angle gauge measurement using only one fixed basal area factor of four, which leads to discontinuities in the statistically calculated FI growing stocks on a plot level. A further explanation is the fact that for the first ALS data set the ALS flights took place between 2002 and 2005, whereas the FI data was collected in 2002. This means that changes in the DSM (i.e. forest growth, exploitation), which are available in ALS data acquired in the years 2003 to 2005 are not considered in the FI data.

To test the transferability of calibrated models to other ALS acquisition times the calibrated model from 2011 was applied to the ALS data from 2002-2005. The corresponding scatterplot shows a very high agreement between the two models. A similar result is derived for the ALS 2011 data.

In Figure 11 the difference map of the estimated growing stocks (2011-2004) overlaid with the detected exploitation

areas is shown. The visual validation shows that the applied work flow for detecting harvested areas work well even on the level of single trees. Using GIS tools the total amount of harvested growing stock can be calculated for example for each exploitation polygon. For the estimation of the forest growth an averaging within homogenous areas (e.g. forest stands) is required to avoid errors originating from different tree crown representations (i.e. due to varying ALS point density, ALS sensors, ALS acquisition properties, wind effects, etc.) on a single tree level. Based on the FI data the growing stock increased from 2002 to 2011 of 43.0 m<sup>3</sup>/ha in average for the used 184 sample plots. Using the estimated growing stocks derived from the ALS data an average difference of 42.5 m<sup>3</sup>/ha is observed.

Based on the findings of this study it can be stated that ALS data is an excellent data source for change detection of forest parameters (i.e. growing stock). Furthermore these analyses have shown for the first time that calibrated regression models can be transferred to ALS data from different acquisition times, which opens up interesting possibilities for operational forest inventories.

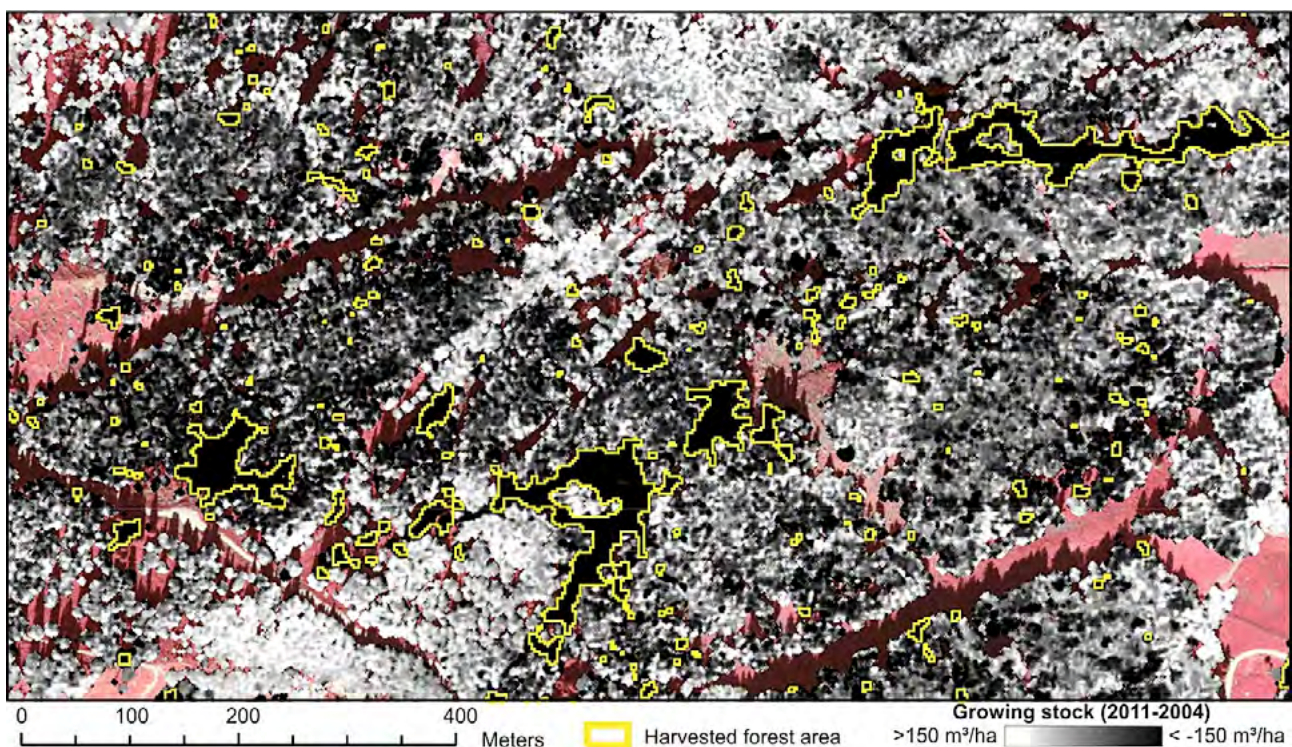


Figure 12: Difference map of estimated growing stocks (2011-2004) overlaid with the detected outlines of the harvested forest areas. In the background a CIR orthophoto is shown

## Single tree detection / benchmark

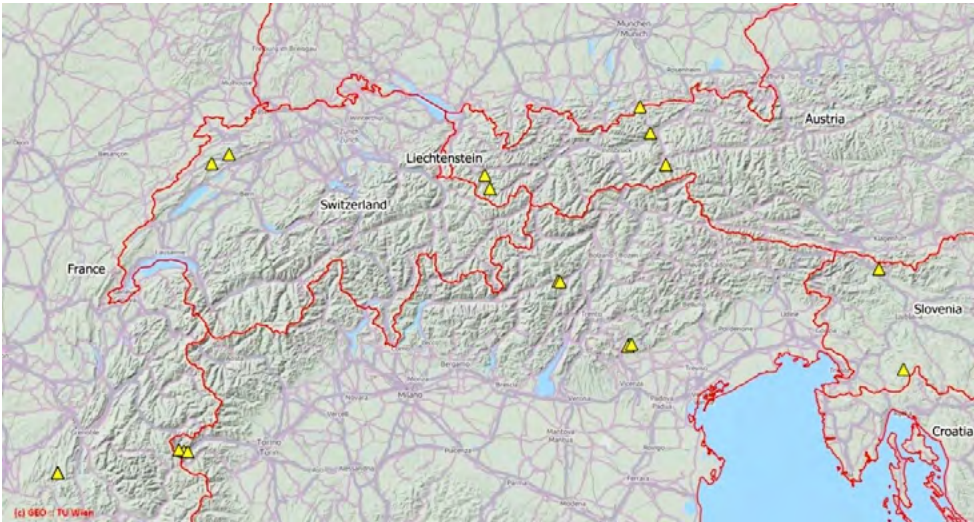


Figure 13: Study areas used for the single tree detection benchmark

A single tree detection benchmark based on airborne laser scanning data was carried out to show the potential of existing single tree detection methods. A unique dataset originating from different regions of the Alpine Space, covering different study areas, forest types and structures, was used within this benchmark. In total eighteen study areas in five countries in the alpine space were investigated (Figure 13).

For all study areas ALS data and a digital terrain model (DTM) were provided to the benchmark participants. Based on these data the participants had to automatically extract single tree information by applying their algorithm. In total seven Institutions applied their methods to the benchmark dataset (Table 2). The minimum requirements were the extraction of tree position and tree height as well as a description of the used algorithm / workflow. Forest inventory (FI) measurements (fully calipered plots) were used as a reference to test the different detection results.

The benchmarking process covers seven general steps. Initially a quality check of the input data (1) was performed. This was followed by the detection process of the partners using their methods (2), the matching process to link the detection results to the ground truth data (3) and finally the investigation of the matching results. The benchmarking results are prepared in different Levels of Information (LoI), starting with investigations based on study area (LoI-4) and detection method (LoI-3). Additionally investigations per forest type (LoI-2) and

an overall performance (LoI-1) of the benchmark are presented.

### 1) Quality check of input data

The quality check of the ALS and FI data was carried out to ensure a consistent level of quality. All study areas are sufficiently covered by ALS data. The ALS data are free of gross errors. Heterogeneous point densities from 4 points / m<sup>2</sup> up to 120 points / m<sup>2</sup> are given. The quality of the FI data was investigated by performing a questionnaire regarding the FI data. The responsible NEWFOR partners reported information regarding absolute and relative accuracy of the FI data as well as general information about the study areas.

For absolute Georeferencing GPS is widely used for surveying the plot location. In a post-processing step the plots were manually co-registered to the remote sensing data. The estimated absolute accuracy after manual co-registration is  $\pm 2.0$  m.

State of the art for relative tree measurements within a plot is using compass bearing and tape / electronic ranging for measuring tree positions and using a Vertex system for measuring the tree heights. The reported relative accuracy varies from  $\pm 0.3$  m to  $\pm 1.0$  m for the horizontal part. For the vertical accuracy a value of  $\pm 1.0$  m was reported by all partners.

## 2) Single tree detection by participants

In total eight methods were applied to the benchmark dataset (Table 2). Most methods rely on local maxima detection in a rasterized CHM. Beside that also purely point cloud driven methods were applied. All participants were able to apply their method to the given dataset.

ID	PP	Name	Method	Type
1	LP	Irstea	LM+Filtering	R
2	PP5	FEM	LM+Region Growing	R
3	PP7	SFI	LM+Multi CHM	R
4	PP10	TESAF	LM+Watershed	R
5	PP11	SLU / TUWien	Segmentation+Clustering	R+P
6	PP11	TU Wien 3x3	LM3x3	R
7	PP11	TU Wien 5x5	LM5x5	R
8	PP12	SFS	Polyn. Fitting+Watershed	R

R...Raster; P...Point Cloud; LM...Moving Window for local Maxima

Table 2: Overview of applied methods

## 3) Matching process

A fully automated matching procedure for linking the detection results (test trees) to the FI data (reference

trees) was established and applied for the NEWFOR single tree detection benchmark. This methodology enables clear and reproducible testing.

In this paragraph a short summary of the matching procedure is given. Starting from the highest test tree within a study area, the restricted nearest neighbouring reference trees within a defined neighbourhood are detected and marked as matching candidates. Restricted nearest neighbouring introduces height criteria and neighbourhood criteria which need to be fulfilled to match two trees (Figure 14). Trees with the best neighbourhood and height scores are matched. This means that not always the "simple" nearest neighbouring trees are connected. The procedure is applied to all detection results of the participants. The outputs of the matching process are qualitative and quantitative statistical parameters as well as vector layers for being displayed in a GIS system.

A visual inspection of the matching results shows a good agreement (Figure 15). The height and neighborhood criteria ensured correct matching results in most cases. Especially the height criterion ensured that tall trees are not connected to nearby small trees. The results of the automatically matching were validated by visually interpreting 699 randomly selected matching results in a GIS environment. The manual interpretation shows an overall accuracy of 97%.

### Tree matching - General steps

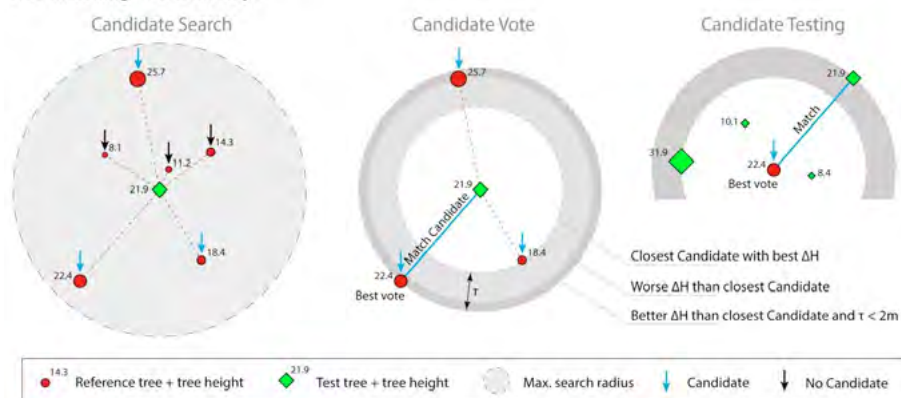
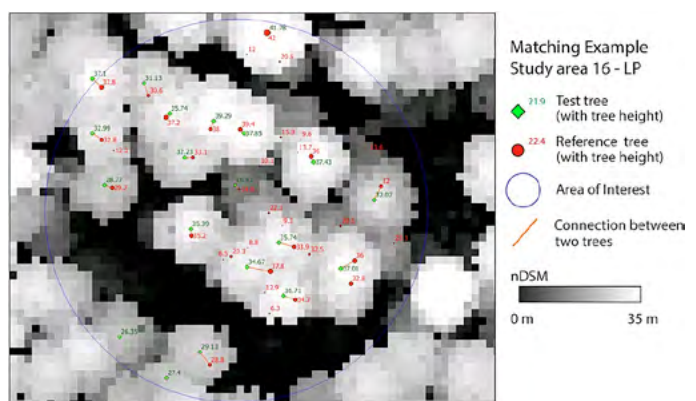


Figure 14: General steps of the tree matching procedure

Figure 15: Automatic matching result of participant "LP-Irstea" for study area 16. The data is displayed as overlay of a canopy height model (CHM)



The following quantitative statistical parameters about detection rates and spatial accuracy are presented:

- Matching (assignment) rate → Total number or rate of matched trees
- Commission rate → Total number or rate of Test trees which could not be matched
- Omission rate → Total number or rate of Reference trees which could not be matched
- $H_{\text{Mean}}$  → Mean of horizontal matching vectors (2D Vector between Test and Reference)
- $V_{\text{Mean}}$  → Mean of tree height differences ( $\Delta H$  between matched Test and Reference)

Additionally summarizing statistics (root mean square) are presented if multiple study areas or methods are investigated.

The results of the matching process are presented in different Lol. Lol-4 enables exploring the detection results on the study area level while Lol-3 gives information on the method level. Lol-2 shows the results for different forest types. Finally, Lol-1 shows the overall performance of the benchmark.

For all Lol the qualitative and quantitative parameters obtained in the matching process were plotted in two different barplots. One plot focusses on the different rates found in the matching process while the other focusses on the spatial accuracy. The barplot "Detection Rates" is sorted upwards to the commission rates. An example is presented in Figure 16. For Lol-4 the amount of trees in different height classes were plotted in additional barplots.

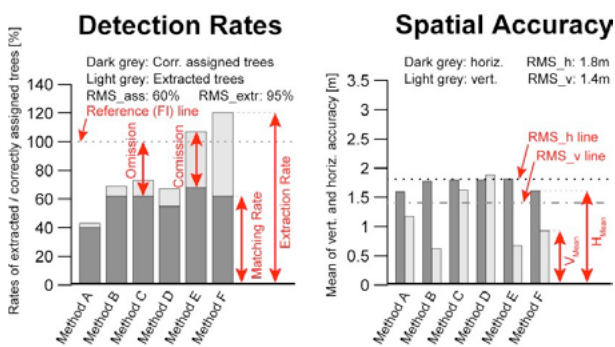


Figure 16: Barplot examples for the detection rate statistics and the spatial accuracy statistics

### Detection results on the study area level (Lol-4)

In general, it could be seen that the vertical distribution of tree heights seems to have a major impact on the detection / matching results of the different methods. The more the trees are vertically distributed the lower

the matching rates are. The matching rates in different height layers indicate that especially in the lower height layers more advanced methods as for example 3D clustering in the point cloud can detect more trees than methods that rely on local maximum detection based on a rasterized canopy height model

Matching results with a high matching rate combined with a low commission rate indicate a good matching result. The best detection result was obtained for an old forest stand with high trees and no understory vegetation. The lowest detection result was obtained for a multi layered forest with a high amount of trees in different height layers. In a summarized view the results show that multi layered forests are challenging for all tested methods.

It can be assumed that a higher point density can be linked to a higher penetration rate and therefore small trees in subdominant layers might get mapped more efficiently. One tested study area shows a point density of 121 pts / m<sup>2</sup> and the inventory data shows a strong vertical distribution of the given trees. Even with this very high point density only the worst detection result of all study areas could be obtained. It seems that even very high point densities do not help to achieve better detection results for complex forest structures. However, investigating the effect of different point density on the detection results was not scope of this study.

### Detection results on the method level (Lol-3)

The best ratio between a high matching rate and a low commission rate was found for method LP-Irstea which consists of a local maximum search in a canopy height model using a moving window approach. In contrast to other comparable local maximum methods, this method uses variable window sizes in the moving window approach. The variability of the kernel size seems to be an advantage compared to methods based on static kernel sizes.

The method of PP5-FEM shows comparable matching rates to the method of LP-Irstea but shows a twice as high commission rate. In the lower height layers up to 10 m tree height only up to 5% of the extracted trees could be correctly matched. However, the method is based on rasterized ALS data and therefore the rather low matching rate in the lower height layers was expected.

The methods PP7-SFI and PP11-SLU are based on 3D operations in multiple canopy height models or directly in the 3D point cloud while method PP11-TU3x3 is based on local maximum detection in a canopy height model which uses, compared to others, a small kernel (3x3 pixels). High commission rates in the results of these methods indicate over performance which means the methods produce high commission rates. Beside the fact

of high commission rates the method of PP11-SLU shows up to 17% of correctly matched trees in the lower layers up to 10 m tree height. Compared to other methods this is clearly the best result.

The method of PP10-TeSAF shows a good matching rate but unfortunately also the commission rate is high, which means that the method found many trees which could not be linked to the reference data. In the lower layers below 10 m tree height up to 7% (RMS) of the available reference trees were correctly matched.

The method of PP12-SFS shows a high matching rate paired with a low commission rate. Based on these values the results of PP12-SFS are close to the results of LP-Irstea and are one of the best within this benchmark. In the lower levels with tree heights up to 10 m the method obtained a matching rate of up to 9 % which counts together with PP20-TESAF and PP11-SLU to the best obtained result. Like other methods that rely on maximum search in a rasterized CHM the low rate can be explained by the methodology.

### Detection results based on forest type (Lol-2)

The class of single layered coniferous forests shows the best results of all tested classes. This result seems feasible as coniferous trees show, in most cases, a clearly defined tree crown shape. This means that the tree top appears as a clear peak in the canopy height model. Since most of the tested methods within this benchmark rely on local maximum detection a canopy height model, the good result for single layered coniferous forests was expected. The best performing methods for this forest type were the methods of LP-Irstea, PP10-TESAF and PP5-SFI.

The class of multi layered coniferous forest as well as the class of multi layered mixed forest show the lowest matching rates in this benchmark. The commission rate of the multi layered mixed forest is twice as high as the rate found for the multi layered coniferous. The low matching rate can be explained by the methodology of the tested methods. Trees in lower layers are challenging for all tested methods. The high commission rate for the multi layered mixed forest can be linked to more complex crowns for deciduous trees. The best results for the multi layered coniferous forest were obtained by PP12-SFS, PP10-TESAF and PP5-FEM. The best results for the multi layered deciduous forest were obtained by PP12-SFS, PP10-TESAF and LP-Irstea.

The single layered mixed forest shows the second best matching rate for the classified results. Unfortunately a very high commission rate is given. The high rate can be explained by the fact that deciduous tree crowns tend to be more complex than coniferous ones. Single tree crowns may consist of multiple local peaks in the canopy height model that may be correctly detected as local maximum but do not represent the tree stem. The best performing methods for this forest type are LP-Irstea and PP12-SFS.

### Overall performance (Lol-1)

The overall performance brings together all matching results from all tested methods. An overall matching rate of 47 % (RMS) was found (Figure 17). This value aligns with the benchmark results of other published single tree detection benchmarks. The overall best performing methods are LP-Irstea, PP12-SFS, PP5-FEM and PP11-TU5x5. The other four methods show too high commission errors. For the spatial accuracy, a horizontal accuracy of 1.7 m (RMS) and a vertical accuracy of 1.0 m (RMS) could be obtained. These values are comparable to other previously carried out benchmarks. The performance of the different methods differs more for the tree detection than for the extracted tree heights.

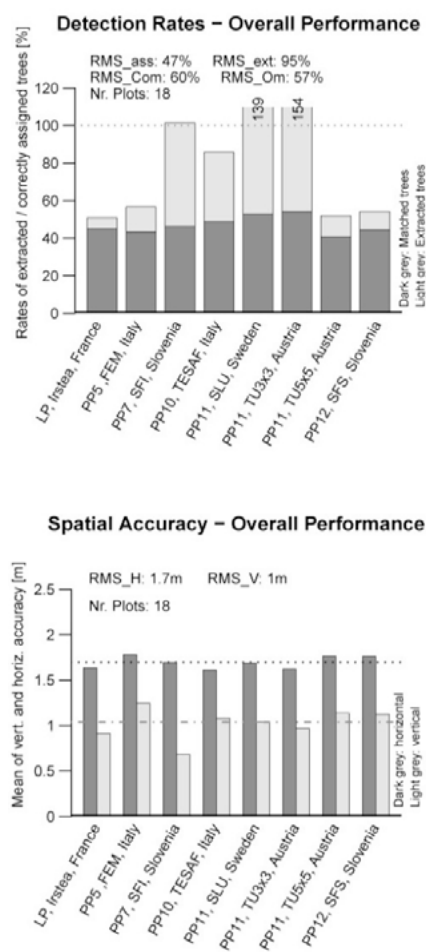


Figure 17: Overall performance within the NEWFOR single tree detection benchmark

It could be shown that forest inventory data can be automatically linked to remotely sensed data. The summary of the single tree detection benchmark provide a good overview of the performance of the different detection algorithms for the individual forest properties and can therefore support practitioners for selecting the appropriate algorithm for detecting single trees. Detailed information about this benchmark can be found in the NEWFOR report "Single tree detection benchmark".

## Deriving multi-scale forest information maps based on ALS raster data

The communal administration *Stand Montafon Forstfonds* manages a forested area of almost 89 km<sup>2</sup> in the Montafon valley (Austria, Vorarlberg). Forests cover a large extent in predominantly steep terrain at 1200 m above sea level and higher. These forests provide vital protection against avalanches, rock fall, debris flows and landslides to the villages and infrastructural facilities. Spruce forests (*Piceetum*) predominate, mixed forests composed of *Picea abies*, *Abies alba*, and *Fagus sylvatica* (*Abieti-Fagetum*) as well as beech forests (*Fagetum*) can be found at lower altitudes. ALS data is available for the complete area from two time steps (2002/2004 and 2011, point density between 4-60 pts/m<sup>2</sup>). Data from the first acquisition were already examined in terms of their useful integration in forest management planning. Based on these first experiences (cf. Maier *et al*, 2008) the demand for multi-scale information maps derived from ALS data has been formulated (deductive approach):

- The information maps should reflect height information of forest canopy within a 3-level image object hierarchy. The hierarchy represents a lower (similar to) tree crown level (TCL) and a higher forest stand level (FSL), which are derived by segmentations of the normalized digital surface model (nDSM, GSD: 0.5 m) and/or derivatives. An additional, more generalized, segmentation level above (TopoL) should represent specific site conditions driven by topography factors. The image segments on the highest level reflecting a combination of objects of the lower levels, criteria to define the delineation of these larger objects are based on the digital terrain model (DTM) and derivatives;
- The derived image objects should fulfil certain criteria (deductive approach) relevant for forest management: TCL should reflect a median area of 25 m<sup>2</sup>, a median area to border ratio of ~0.9 (compactness indicator). FSL should reflect a median area of 530 m<sup>2</sup>, a median area to border ratio of ~3.7 ;
- The method should be reproducible, transparent and repeatable for the application on future ALS campaigns;
- The target scale for the final height information maps should be 1:5000 for in-field use and forest management planning.

Following these requirements the implementation was conducted in an object-based image analysis (OBIA) environment, allowing the integration of additional input data (forest mask, administrative units) and the connection of image objects, rasterized ALS data as well as ALS point cloud data.

The multi-resolution segmentation algorithm (Batz and Schäpe, 2000) was selected for the regionalization of the ALS raster data on the three different scales. The classification for TCL and FSL was based on the tree height classes referring to forest development stages used in regional practical context. The 90th percentile per object served as the height classification basis. In addition, the objects were attributed with several information derived from the rasterized ALS data.

For obtaining representative results according to the object-size and object-form requirements, an iterative segmentation and classification algorithm was developed in CNL (Cognition Network Language, applied in eCognition 9.0, Trimble Geospatial). The algorithm was tested on two subsets with an extent of 2500 x 2500 m. The iteration was fully automated, the relevant parameters changed for each iteration (scale parameter by increments of 5, whereas the shape parameter and compactness by increments of 0.1). To obtain 'meaningful objects' for forest managing purposes a different combination of input data on the FSL was tested. Combinations tested encompassed calculations of nDSM and nDSM filtered within a 3 x 3 median window, as well as the filtered nDSM in combination with the slope derivative of the DTM (to incorporate specific characteristic of the mountainous area). Based on the huge amount of resulting segmentation and classification layers, the algorithm automatically selected a subset, matching best with the deductive requirements. Figure 18 shows the result of the approach for a subset of the area.

The subsets of segmentation and classification results were cross-checked by image interpretation experts, and the short-listed results were successfully validated by practitioners and forest managers in the field. Selected parameters for building the 3-level image object hierarchy are given in Table 3.

Level	layer	scale parameter	shape	compactness
TCL	nDSM	10	0.6	0.6
FSL	nDSM (3x3 median filtered) Slope of the DTM	50	0.6	0.4
Topol	DTM Hillshade of DTM (sun inclination = 42.5°; sun azimuth = 180°)	1000	0.5	0.5

Table 3: Selected parameters for building image object hierarchy by using multi resolution segmentation

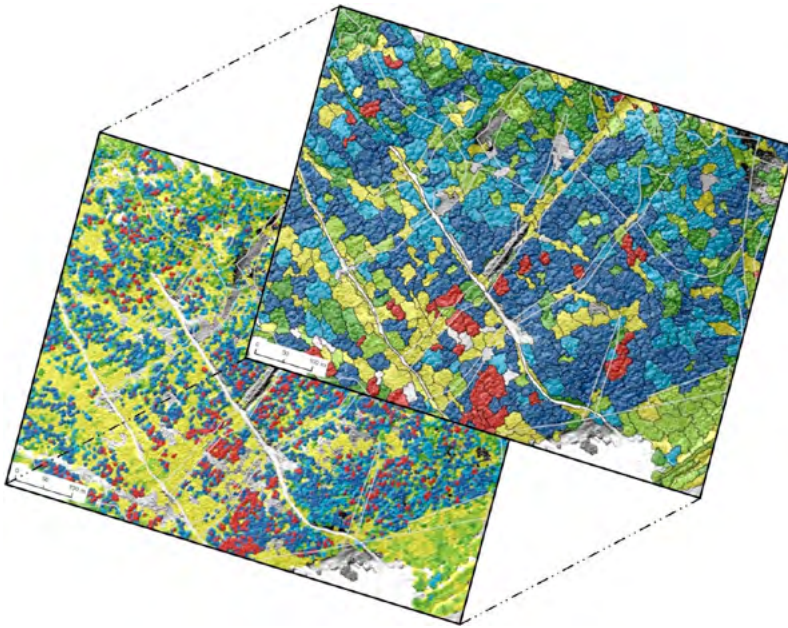


Figure 18: Subset of the resulting multi-scale forest information maps (right: FSL layer, left: TCL layer). Colours are indicating tree height classes referring to forest development stages used in regional practical context. Patches are classified according to the 90th percentile of height above ground; no colour: < 1.3 m or not forest, yellow: 1.3 to 6 m, light green: 6 to 11 m, dark green: 11 to 22 m, light blue: 22 to 29 m, dark blue: 29 to 33 m, red: > 33 m

Based on the field validation the final maps were calculated for the Montafon area (ca. 237 km<sup>2</sup> forested and ca. 89 km<sup>2</sup> are maintained by Stand Montafon), resulting in a database of almost 7 million objects on the TCL, 300,000 objects on the FSL and 8,000 objects on the TopoL. The object-based image analysis with a multi-level segmentation (Figure 19) followed the strategy of (1) data pre-processing: including the steps of merging (LiDAR-)image mosaics (105 mosaics with size 2500 x 2500 m) and calculating derivatives, (2)

incorporating additional data of a forest mask layer and administrative boundaries and (3 to 5) segmenting FSL, TSL and TopoL, as well as calculating a merged FSL layer and exporting object feature statistics of each layer (object size, object perimeter, object to perimeter ratio, several percentiles of height, minimum and maximum values of height, standard deviation of height). Finally TCL and FSL were classified according to the above mentioned classification scheme.

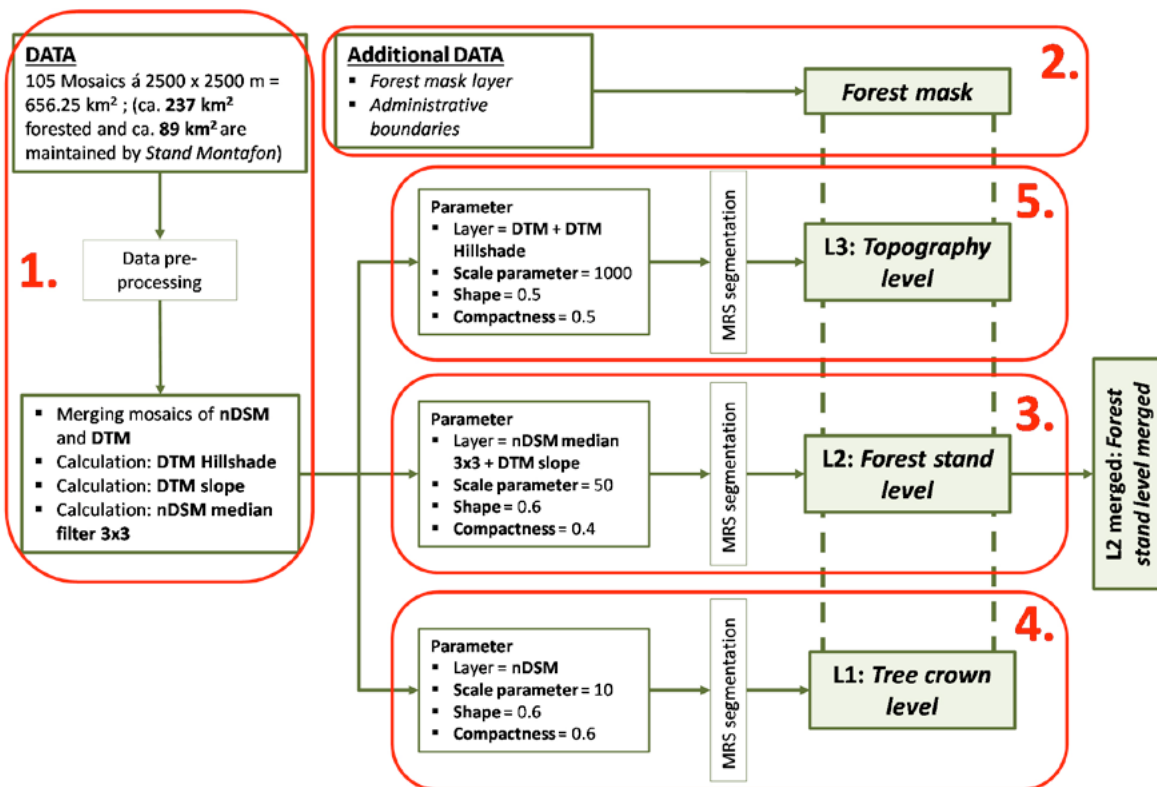


Figure 19: Strategy on deriving multi-scale forest information maps of the Montafon area (ca. 237 km<sup>2</sup> forested)

## New remote sensing platforms / UAVs for forest applications

UAV – unmanned aerial vehicles are a rapidly upcoming method for remote-sensing data acquisition, mostly aerial images and derived products. By now, the systems are light-weight and cost-effective, the development and miniaturization of the sensors and their reliability enable a relative safe operation with good chance of success. UAVs are quickly ready for operation almost everywhere and every time. Limitations – specially in mountainous and forested environments - result mainly from weather conditions (wind!), visibility, availability / existence of landing sites, GPS signal quality and last but not least legal constraints.

Most common forms are small, electrically powered model planes with wingspans from 2–3 meters and multi- and helicopter respectively. They are piloted by an operator via remote control (RC), assisted by an autopilot on-board (Figure 20).



Figure 20: Fixed-wing UAV, built and used in NEWFOR-project. ([www.bfw.ac.at](http://www.bfw.ac.at)); Fixed-wing UAV "Mentor" (top), starting the UAV (bottom)

Autopiloted UAVs are navigated by a small on-board GPS/INS-unit. At the ground station, the mission planning is prepared and flight path, flying height, velocity and trigger are defined. The mission itself runs fully automated, wireless communication allows tracking the actual position of the platform and adapting the flight plan if possible. In addition to the fully automated mode, a semiautomatic and a manual mode, e.g. for landing in case of signal loss or other unexpected problems, is available. The flight has to be supervised by a qualified pilot, who is able to take over the direct control of the UAV. The range of the UAV depends mostly on its size and shape, because it always has to be visible and controllable for the pilot. The maximum flying distance for the above mentioned "Mentor" is about 1000 meters. Flight-attitude data are logged and either transmitted to the ground station in real time or downloaded after the flight. If synchronized with the camera-data the position and angles of the camera can be reconstructed (parameters of exterior orientation, EOP).

Technical limitations can hinder the acquisition of images, especially in remote and steep (forested) regions. For fixed-wing UAVs suitable landing places are required. Narrow, rough forest roads or clearings are often the only possibilities in dense forested areas, but represent a high risk of damage. In case of no or low-quality GPS signal, a manual flight control can be essential, with all drawbacks for image processing (overlap, area coverage, high rotational and angular deviations, oblique images, no EOP). Without EOP, the automated image matching process may be impossible, because of the lack of clearly defined features. Because of limited payload and space in the fuselage, UAVs are equipped with light-weight consumer cameras or SLR. The camera is triggered by the RC and takes images either in predefined intervals (e.g. every two seconds) or at predefined locations. The images normally are stored on a SD-card and downloaded after the mission.

In a first step the aerial images have to be georeferenced. For a first rough estimation of the image position and orientation the logged data from the GPS can be used. For higher accuracies ground control points are needed. In larger mountainous areas or dense forested regions this can be a challenging and time-consuming task, because ground control points often are simply not visible, hard to establish and/or measure with reasonable accuracy. A variety of open-source and commercial dense stereo matching tools are available to manage the matching of the images and the construction of a 3D-point cloud.



Algorithms (feature detection SIFT, SfM), adopted from computer vision and widely used for close-range photogrammetry or terrestrial photography are used. In a highly automated way it is possible to estimate camera geometry and calculate a 3D model from a set of overlapping images, invariant to scale, orientation, distortion and illumination changes (Figure 21). Point clouds as a result from image matching can be further processed in a similar manner than point clouds from ALS or TLS and are often combined with ALS data. In Figure 22 results from the pilot area Montafon are shown,

where a dense matching was performed within Photoscan and a 3D point cloud with more than 76 Mio points was generated. A cross section of the generated point cloud is compared to the ALS data. It can be clearly seen that, within areas of vegetation, no ground points can be matched. Although not every tree appears as single unit in the 3D point cloud generated with the matching software, the hull of the top tree crown is provided and could therefore be used for forestry parameter estimation.

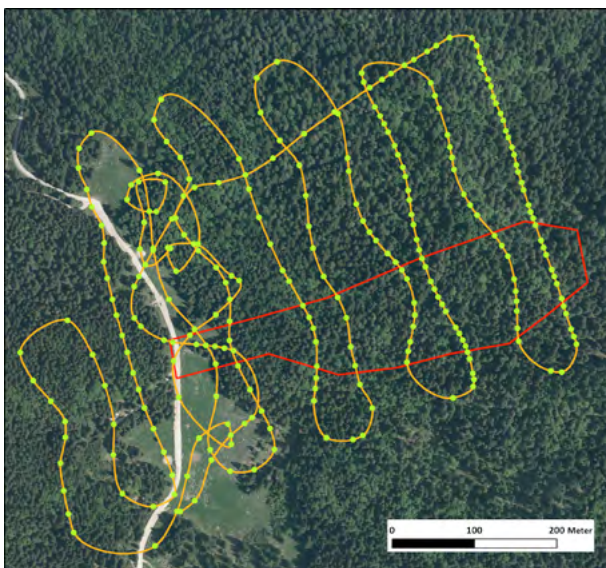


Figure 21: Results of a UAV-mission. Flight-path and image locations (Asiago test site) (left), 3D-model of the Asiago test site, constructed from 260 aerial images (right)

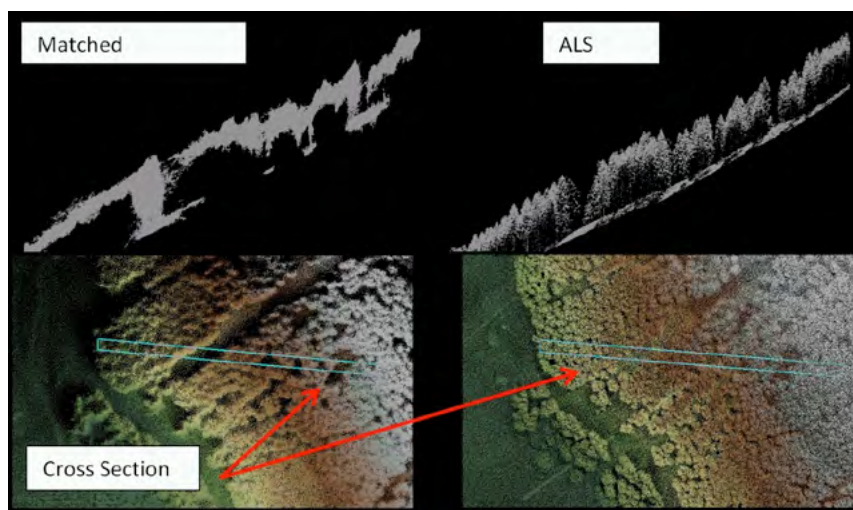


Figure 22: Cross-section of point clouds from the pilot area Montafon, derived from (left) UAV and (right) from ALS

One of the greatest advantages of this new technique is its high flexibility and the relatively low operational costs. Therefore UAVs have a high potential to provide high temporal resolution in small areas of interest. The miniaturization of the sensors and the increasing reliability of the navigation systems make UAVs to an instrument for operational applications. In contrast to standard aerial imagery, the better resolution of the data offers new possibilities for developments in image analysis.

## New challenges: broadleaf forests

Within the last year of the project, a new test site (Gardesana forest, Northern Italy) was added by ERSAF, in order to test the LiDAR technology on mixed deciduous forests. With the help of the Italian NEWFOR partners, the same field data were collected to compare the ground parameters with those extracted from the LiDAR survey.

Problems with single-tree detection emerged in all the cases where the forests are mixed, with presence of coppice stands or multi-layered structure. The dominant layer have bad results due to the shape of the broadleaved crowns and the trees within the dominated layer are not detected from the analysis of the point cloud (Figure 23).

For what concerns coppice stands, the presence of more than one sprout within the stump complicates the detection of all single stems. This could be considered as a good reason to apply a different method such as an area-based methodology, in order to extract information from LiDAR variables. Otherwise, another solution would be to work directly on the LAS point cloud and not to raster-based methodology that starts from Canopy Height Model (CHM).

Unfortunately, at the moment these questions remain unanswered and can constitute a starting point for future projects.

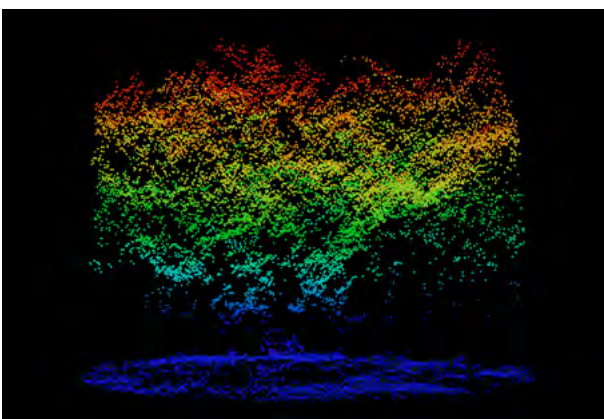
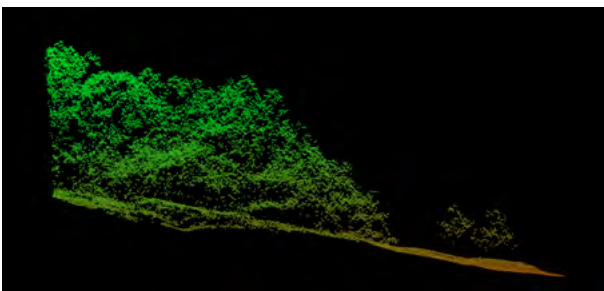


Figure 23: Examples of point clouds in deciduous stands

## Critical nodes and future opportunities

### LiDAR

#### Cons:

For change detection applications data are not available for every Alpine country yet. In some Alpine countries the LiDAR as well as forest inventory data availabilities are limited.

#### Pros:

Objective and reliable methods for forest area delineation, growing stock estimation and forest structure assessment could be developed within this work package. It could be shown that the optimized algorithms are suitable for large area applications and that they can be used for downscaling in situ forest inventory plots based on remote sensing based 3D information.

The future activities are focusing on new and optimized UAVs with different sensors (i.e. UAV LiDAR) for small scale applications. For large scale applications data fusion (i.e. LiDAR and aerial images or high resolution satellite images) has a high potential for operational forest applications in Alpine regions. Furthermore, standards of the derived forest attributes are needed to guarantee the comparability of different regions as well as acquisition times.

### UAV

#### Cons:

- At the moment, the most challenging tasks for the application of UAV in mountainous forests are: finding appropriate take-off/landing areas, taking into account visibility and undisturbed communication from remote controller to receiver in the UAV;
- GNSS-availability for automatic flying mode;
- Possibility to place ground control points to be measured with topographic precision for accurate georeferencing and orthorectification.

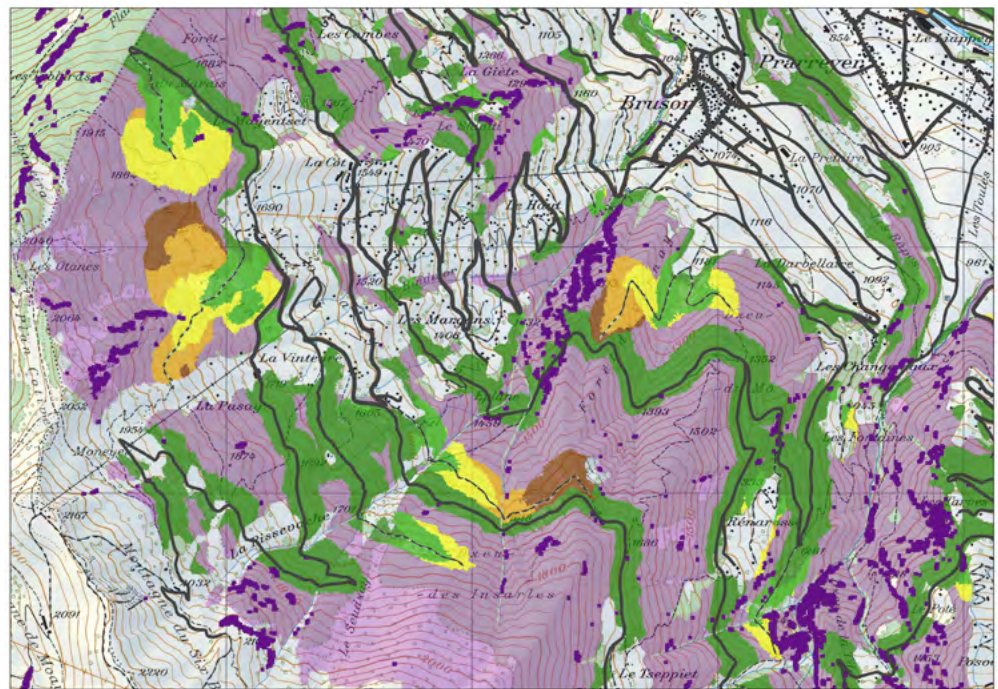
#### Pros:

UAV are flexible, have low operational costs and can provide, high-resolution data for local investigations. Further development of navigation instruments and image analysis methods will drive the use of this technology for forestry applications.

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# Forest accessibility



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High mountain forests fulfil multiple functions in mountainous areas. They have an ecological function as host of many habitats and species. They also are a leisure area for social activities such as hiking or skiing. One of the most important functions is to protect the living space against natural hazards. From the economical perspective, the production of renewable resources like timber and firewood have positive effects both at global scale, with climate change mitigation, and local scale with rural employment and the development of a regional value chain. The objective of preserving and improving the development of mountain forests is a point of public interest. Therefore, an adequate access and opening up of forest with forest roads and extraction lines are necessary.

After the identification of timber-growing stocks and the existing forest functions, the following step in efficient forest management is the evaluation of the accessibility of the mountain forests. Successively the current status of usage of harvesting technologies in the Alpine Space, and the lack thereof, have been identified. Finally, in order to illustrate the possibilities connected to the use of geographic information systems (GIS), a full set of tools have been developed as standalone or add-on software. This will support practitioners and enterprises related to forestry with helpful free tools.

## GIS-based procedure for road construction planning in high mountain forest areas

Mountain forests have a role in several functions – the so-called multi-functionality of forests. To maintain and improve forest functionalities accessibility to forest areas is important. Construction of forest roads can cause conflicts of interest between the different functions. For example timber production (economical function) and touristic use (recreational function). For these reasons there is the need to develop a sound methodology for increasing accessibility which respects and weights the diverse importance of the functions to minimize conflicting situations between users. Assessing potential negative impacts caused by forest roads is important. Forest roads can have direct or indirect negative impacts.

To plan and assess operations related to augmenting accessibility in mountain forest, most relevant geodata are generally available, such as digital elevation models, topographical information, land use maps, geology maps and forest management plan.

The forest function plan includes different functions like recreation, water protection forest, climate protection, soil protection and avalanche protection. Forest roads affect forest functions. Impacts of roads can be either positive, neutral or negative. The neutral approach of potential impacts by roads is usually the optimal solution.

Two fundamental issues should be taken in account:

1. Environmental impacts of forest roads on forest functions
2. Influence of the environment on the forest roads

The suspected or assumed influences should be evaluated by their significance concerning the following points:

- effective direction (positive, neutral, negative) and intensity;
- time of their occurrence;
- duration of their occurrence;
- probability;
- spatial extent (local, small-scale);
- reversibility;
- mitigation of negative impacts;
- geographical distance effects.

Because of its geometrical dimensions, a forest road represents a significant intervention in the environment and therefore in the forest functions. In the order of the constructional measure, there are three main ways of action (interaction) of forest roads on the local environmental situation:

- forest structure;
- terrain morphology;
- hydrological condition.

To realize the influence of forest roads on forest functions, it was necessary to establish a local context. As an example, a pilot area was selected in Bavaria.

The first step was to divide the area into cells with a side length of one hundred meters (virtual 1 ha grid; Figure 24). This allows to set both variables of extensive character, as well as line and point elements in relation to each other. All available maps (forest map, forest function map and so on) were aggregated with the grid squares. That means we know exactly the share of the different forest function within the cells. To each cell, the sum of the area of each forest function was assigned. The most important area is the area with two or more functions.

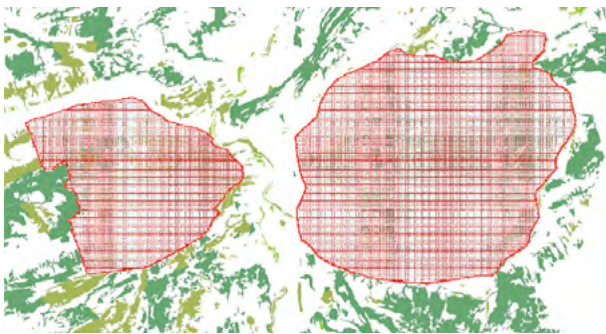


Figure 24: The pilot areas divided into 1 ha cell (grid = red colour)

The different forest functions were given different weights according to their significance towards living space of the people (Table 4). As a whole, forty five different categories of forest functions were classified and weighted. Because there are no objective facts, which allow to define an objective weighted impact, in Bavaria a subjective weighting done by experts has been used.

Forest fonction	Weighting
Protection forest Bavarian Forest Act	1
Natural monument (areal)	8
Special areas of conservation (FFH)	6
Soil protection forest	2
Climate protection forest	5
Avalanches protection forest	6
Water conservation forest	2
Water conservation forest zone I	9
Spring area (5 m)	7
Highland moor	9
Landslide	8

Table 4: Example of forest functions mapped in Bavaria (extract)

The weight is then multiplied by the area of the respective functions within the cell and an impact value was obtained for each function. All the impact values of the different functions within the cell were added up to obtain one single impact value for each cell. These values have been normalized between 0 and 1 to allow a direct comparison between different areas and to standardize the application within different databases. The output table can be connected to a raster model, allowing an immediate visual presentation of the results within a GIS. To classify the data we used the classification of "natural breaks" which is based on a modified form of Jenks Caspall algorithm, provided by ArcMap®. The generated map (Figure 25) delivers hints on preferred corridors for a possible opening up of forest areas. A progressive increase of the number of classification levels allows a stepwise improvement of possible corridors for forest planning.

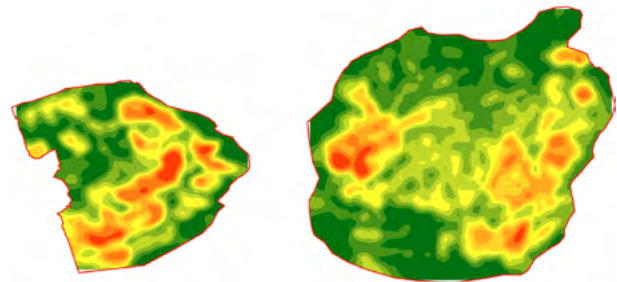


Figure 25: Suitability map for new corridors (green colour: advantageous; red colour: avoid if possible)

## Harvesting technologies used in the Alpine Space

Several procedures are used for mechanized harvesting in the Alpine Space. Besides decreasing harvesting costs, the choice of the procedure is decisive for the conservation of soil and of forest biomass. From an economical point of view, it is important to select the most favourable procedure dependant on the starting situation. The state-of-the-art on harvesting technologies, according to topographic conditions, was described and exemplified with data from the partner countries where possible.

An important harvesting technology in the Alpine Space is chainsaw felling, extraction (full tree = stem + crown) and tree processing by mountain harvester (Figure 26).

Here follows a short description of a "mountain harvester" technology (Table 5).

### Operating range/requirements

**Hillslope:** up to 100 (140) % depending on logging direction (uphill or downhill).

**Opening up:** basis opening up by forest roads.

**Assortment:** full tree.

**Felling volume:** because of the high costs of the system, a big amount of timber is necessary, at least 500 m<sup>3</sup>.

### Course of the procedure

**Felling:** chainsaw felling, possibly with the support of ropes.

**Extraction:** full tree extraction by cable crane after or during the felling.

**Tree processing:** by mountain harvester, possible piling with a forestry tractor or/and skidding trailer.

### Risk

The technology treats the stand with care.

**Soil:** no soil compaction, sander marks by dragging full trees.

**Stand:** damages to the trunk of the trees next to the rope path, caused by extraction with cable.

### Working safety and human engineering

**Working safety:** safe tree processing due to the use of the mountain harvester.

**Human engineering:** hard work by setting up the cable crane

### Profitability

According to the workload, a high performance index is attainable.

### Manpower requirement:

- felling and rope handling: three persons;
- tree processing: one person.

**Organizational work:** medium up to high

### Other matters

The place where a mountain harvester operates is on the forest road. Some mountain harvesters, such as the Moutny 4000 M6, are able to do uphill and downhill extraction from the same position. These harvesters can

reduce unitary costs, but there is a significant higher effort required for arranging the vehicle.



Figure 26: Mountain harvester (photo: F. Binder)




	Forest stand	Skidding line	Forest road
Cutting			
Logging			
Skidding			
Piling			

Table 5: Mountain harvester (combination of cable crane and processor)

An example of best practice to get an overview of the applied forest technologies in the Alpine Space is the Federal State of Tyrol, in Austria. Figure 27 provides information about applied harvesting and extraction techniques for forest stands in the hand of non-governmental persons or organizations and covers about 75% of the Tyrolean forest area. The topmost line indicates the development of the timber harvesting volume during the last decade up to the year 2012. The lines below give the ratio of the applied machinery during this time in the harvesting volume. The application curve of (mountain) harvesters (lower most line) shows a slight but clearly recognizable increase of harvested timber volume. Compared to the indicator curve of processor usage, the increase is clearly steeper. Initially, cutting by chain saw reflects the same progression as the overall harvesting trend but then seems to decrease slightly during the last three to five years.

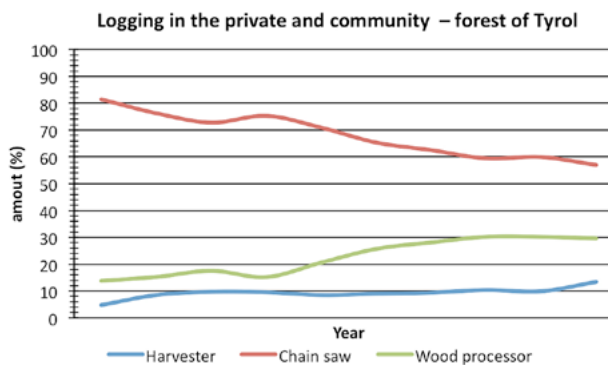


Figure 27: Timber harvesting techniques used in Tyrol during the decade (2003 – 2012)

## Best practices on timber harvesting: a case study in Montafon, Austria

On the basis of the interpretation of orthophotos, cableways' position is planned and plotted on the available stand map. Nevertheless, it still takes two people in the area with a compass and ranging poles to mark and fix the route; a difficult task, considering the steep and rough terrain. Definition of the route is conducted by the responsible forester's assistant, who has good knowledge of the topology. Despite the available maps, two or more inspections are necessary to account for circumstances visible neither on the aerial photo nor the terrain model.

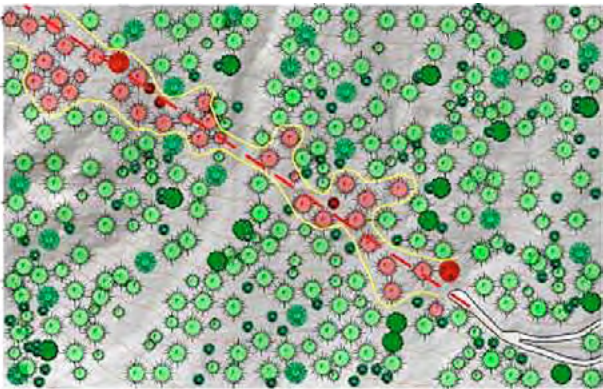


Figure 28: Schematic illustration of cable logging. 1. Starting from the forest road, the line survey of the cable way (dashed red line) is conducted in the field. 2. Afterwards, the trees that should be cut (marked red) are selected and marked according to silvicultural criteria. 3. The result of the harvest should be a stable and structured inner edge with several small gaps

The professional felling of trees by chain saw requires a lot of experience and skill. On the one hand, regeneration groups must be saved in the best possible way, on the other hand, a suitable felling direction must be found to prevent felling and skidding damage on the remaining stand. Modern forest engineering like hydraulic felling wedges facilitates the felling process. The accumulating heavy timber is usually limbed in the forest. Thin branches on small-sized wood are either limbed by chain-saw or by

processor nearby the timber yard. The assortments can be processed ergonomically and safely, as well as being piled by forest excavator with mounted tongs.

The skidding of the trees is normally done with cable cranes (with collapsible mast) as well as sledge winches for long distance cableways. The length of the routing lines varies greatly, depending on degree of opening-up and topographic conditions. At an average of around 400 running meters, mobile cable cranes can be installed and dismantled quickly and are therefore the most cost-efficient. To span higher lengths, however, long distance ropeways with sledge winches are used. With this method, the timber is exclusively skidded downhill using gravity.

Using cable logging in steep terrain limits the length of logs to 4-10 meters. In order to prevent damage to the remaining stand, regeneration and soil, the logs have to be transported levitating. In case of uphill skidding, long logs can be pulled with one side up in the air.

## Conclusions related to harvesting technologies

In some of the participating countries (e.g. Bavaria and Austria), the number of harvesters and forwarders appeared to strongly increase during the last two decades. The other countries point out the same tendency, but still on a lower level.

It seems that capabilities of working on steeper slopes by highly mechanized machines have now come to a physical limit. In the field of harvesting techniques, indeed, any revolutionary innovation is expected in the near future.

Minor improvements probably will be made in the fields of ergonomics and conservation of soil and stands. Tendencies to develop more and more specialized equipment (according to terrain situation and character of the growing stock) will stay at a constant level or even decrease. On the part of the manufacturers of harvesters, development costs are extremely high and only low production numbers are to be expected. This means high investment and maintaining costs also for the customer. The threshold of amortization costs is hardly reachable. It is to be expected, that new investments will mainly be made in the course of replacing older machines.

Forestry machines usually operate in high sensitive and vulnerable ecosystems, particularly under mountainous conditions. Damages/injurious effects on soil and forest stands mostly cause follow-up costs that quite often exceed the proceeds. Highly trained personnel with regard to machine operating and maintenance is therefore of high importance.

To increase revenues and, above all, gain better overall benefits, the consideration of complete working processes and the logistic chain instead of particular machinery becomes apparent.



## GIS-based decision support systems for ground-based harvesting optimization

An accurate evaluation of forest accessibility and planning of forest operations are increasingly required for a sustainable forest management policy that needs to mitigate soil and environmental damages, to better adjust forest management strategies and to better predict the economic value of timber.

In recent years, several decision support systems (DSS) have been developed that consider factors derived from terrain morphology in order to classify the terrain according to the possibility of using different extraction systems (Lubello, 2006; Krč and Košir, 2009; Kühmaier and Stampfer, 2010; Zambelli et al., 2012; Pellegrini, 2012). All these models, however, are primarily developed for a large scale planning, being designed for the use of DTMs with a resolution that does not allow the evaluation of the terrain micro-morphology. According to this, even the estimation of factors that directly affect the technical and economic feasibility of forest operations, such as the maximum extraction distances, are not properly evaluated.

Recently other GIS-based approaches have been used in order to include ALS derived factors in a comprehensive model in order to output an optimal path for forest machinery movement. All these studies were related to the Scandinavian context (Suvinen 2006, Suvinen and Saarilathi 2006, Mohtashami et al. 2012) where the most important limiting factor for the definition of the movement path was represented from the ground-bearing strength capacity.

Several DSS tools have been developed within the NEWFOR project and are reported in the following sections.

### Sylvaccess: a model for the automatic mapping of forest accessibility

#### Sylvaccess – Skidder

Starting from spatial data (forest road network, forest areas, topography and obstacles) and different parameters filled by the user (maximum distance from the road network, maximum slope, maximum winching distance uphill and downhill...) the model identifies the accessible areas with a skidder from the forest tracks and the forest roads. Some others outputs of the model allow to quantify the difficulty of the operation: total distance from the tree to the forest road, detail of the distances (skidding distance in forest, skidding distance on track, winching distance). Finally, the model identifies the optimal forest areas that have the same connection to the public road network.

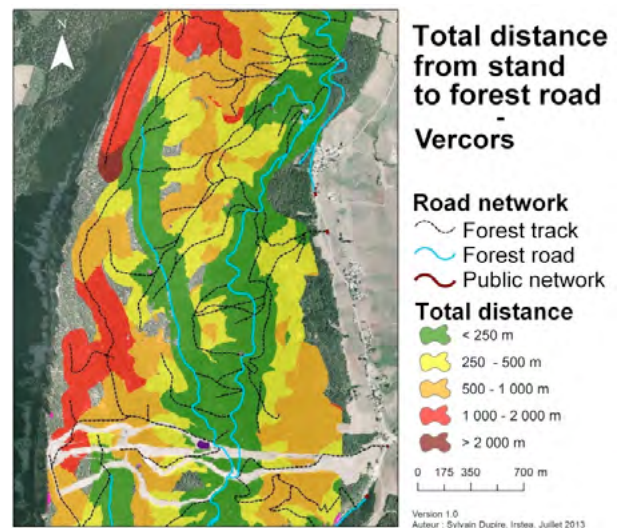


Figure 29: Example of the outputs of Sylvaccess Skidder

#### Sylvaccess – Cable

This model also uses spatial data and different parameters related to the cable yarding equipment. The model tests all the possible cable lines in the test area. For each of them it calculates the load trajectory and the cable tensile forces taking into account cable elasticity and deflection. The model optimizes the layout of each line and returns the best location for intermediate supports. All the results are gathered in a database. The best locations for covering a forest with cable crane can be generated from this database according to different scenarios (optimize the operational cost, optimize the timber volume extracted, or optimize the area impacted by the operations...). It is possible to generate different maps from the scenario chosen by the user.

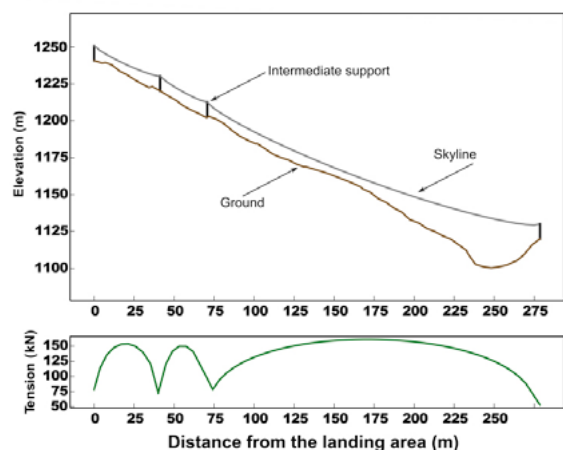


Figure 30: Optimization of a single cable line. Best location for the intermediate support and evolution of the skyline tensile force according to load position



*Figure 31: Map of the timber extraction index (total volume extracted on a single cable line divided by the length of this line). Areas with an index  $> 0.6 \text{ m}^3/\text{m}$  are potentially the most interesting for cable yarding operations*

### Outlook of possible applications

These models allow automatic mapping to identify areas currently inaccessible to forest operation material and to assess the difficulty of the two major operating systems used in steep slopes harvesting. The program uses the open source language Python 2.7 which ensures the portability of the model.

Sylvaccess is a spatial decision support tool that provides outputs for decision makers and forest managers respectively to select the best planning of forest road projects and choose the best forest operation system on the terrain and on the forest stands.

However, the model for the cable requires a high-resolution digital terrain model (ideally generated from LiDAR), which is unfortunately not available everywhere.

Future developments plan the integration of new equipment (harvesters and forwarders) and a module for estimating forest operation costs.

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### FPI (Forest Path Identifier): a GIS-tool to predict forest machinery extraction routes using Aerial Laser Scanned derived data

The inputs of the model are DTM (raster layer), CHM (raster layer), Single Tree positions map (point features), not accessible areas (polygon feature), harvesting area (polygon features) and landing area (polygon features).

The conceptual framework of the model can be divided into two parts. In the first one the map with tree position, the terrain roughness and the presence of areas where traffic has to be avoided (for example the presence of endangered natural features, low bearing capacity areas) are considered to create a first map of terrain tractability (TrS) through a raster reclassification process. In the second part terrain tractability map is used as cost surface raster for the definition of the least cost path from the harvesting point to the landing, considering the maximum lateral inclination (tilting angle) and the limiting slope values that are user-defined parameters.

The final output of FPI tool is the feasible route layout with the lowest cost index from the forest to the landing.

The result of the application of FPI tool shows that many improvement can be gained for in the estimation of extraction distances as linear distances from harvesting site to landing site (normally considered in the evaluation of the accessible areas); these differ in average by -26% from the real extraction distance along the skid road while the extraction distances estimated by model FPI differ in average only by +5.5%. Furthermore the inclusion of terrain micro-topography and the presence of obstacles on the ground allow to evaluate more precisely the local possibility to use a harvesting technology.

The precision gained in the forwarder extraction route prediction using FPI model is satisfying, especially if we consider the main purpose of the model to support forest operation planning with information about extraction distances and location of the skid roads.

The analysis of the accuracy of the model FPI output shows that the approach and the developed methodology can actually provide a considerable support to the planning of forwarder yarding operation, as it is able to consider together all those factors with most influence on the possibility of movement of the machinery in the forest.

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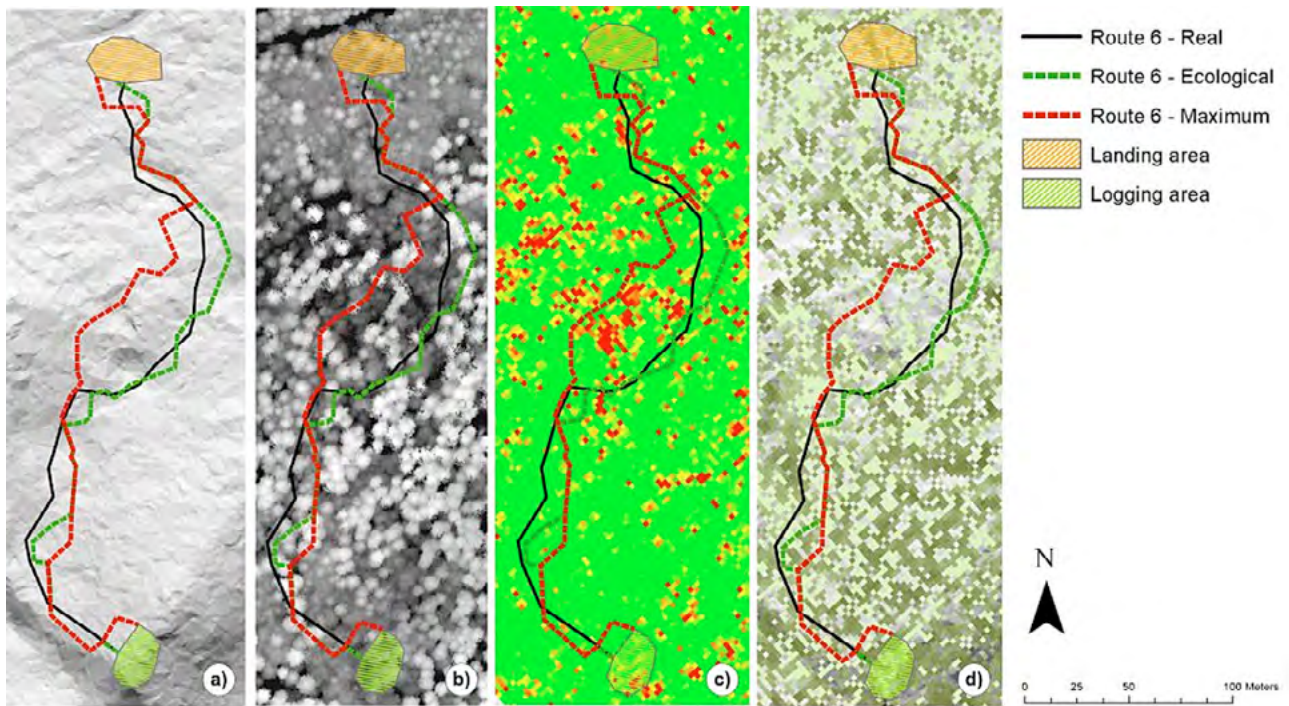


Figure 32: Example of model output for Route 6 (Site 4), with respect to hill-shading of DTM (a), CHM (b), terrain roughness (c) and cost surface considering all previous factors (d)

## CableHelp: a numerical tool to optimize the set-up of cable yarding operations

### How to appreciate the difficulty of implementing a cable yarding operation in a particular location?

Cable yarding systems constitute an adapted solution for steep-slope harvesting in mountain forests. However, it requires many specific skills for both forest managers and operators. A significant part of the operation costs is due to the set-up and dismantling of the cable line. Forest operators have to deal only with their experience in order to choose the best way as well as the best location of intermediate supports.

The aim of CableHelp is to provide a reliable and user-friendly tool able to optimize the cable layout and the location of intermediate support.

### Process of the model

The following figure shows the general process used by CableHelp.

The topographic inputs of the model can be taken from two different sources. The first sources are GIS data such as Digital Terrain Model (DTM) and a shapefile

containing all the cable lines the user wants to test. Once imported, the model draws the profile of each line from the GIS data. The second possible sources are text files containing directly the profile of the line.

The user has then to fill cable system characteristics, default values are proposed for different equipment.

Finally two simulation options are available. The first one consists in testing a known configuration and sees what the consequences on the cable layout are. The second one is a complete optimization of the cable line layout taking into account the safety of operators and skyline and mainline properties.

The outputs of CableHelp are the optimal positioning of intermediate supports, the load path and the evolution of skyline and mainline tension according to load position.

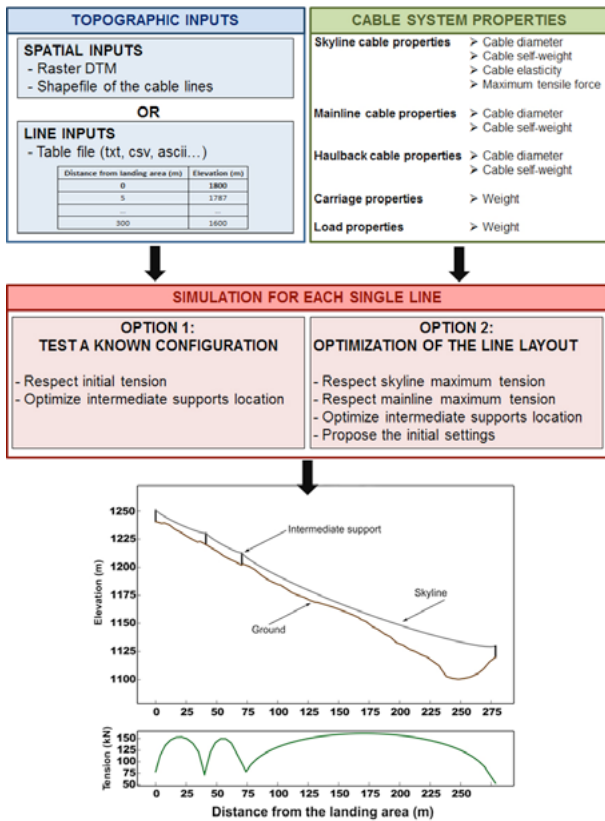


Figure 33: CableHelp workflow

### Cable structure mechanics and experimental validation of CableHelp

CableHelp relies on the mechanical approach proposed in Irvine (1981). Irvine's equations have been adapted to cable yarding specificities and programmed in the open source language Python 2.7. The model has been validated with both small scale and real scale field experiments. The average error observed during the validation is less than 1% for the load path and less than 3% for the tension.

### Outlook of the possible uses and future perspectives

CableHelp can easily be interfaced with GIS software to provide a quick overview about the opportunity of a cable yarding project.

Future development will include further integration with GIS data such as raster data representing stand volume and vector data representing obstacles as well as an economic analysis of the operation cost. These new data allow adding information on available timber volume on the line extent and extraction costs to current outputs.

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## SimulCable, a software to optimise the line implantation for cable yarding

In mountain areas, some foresters use cable yarders in logging operations. The necessary study for the line planning can be made by a few forest specialists and requires a lot of time. Indeed, sometimes this work is done twice: once by the owner or forest manager, once by the logging company. A lot of logging site parameters have to be taken into account: topography, positions of the pylons and their numbers, maximum tension of the line, etc. All of these parameters determine the cost of the line installation.

FCBA (forest and wood technical institute) and ONF (public forest manager) have developed in 2010 a software to help logging enterprises to do the best choice for the line implantation.

SIMULCABLE use input data on the topographic profile coming from different sources such as digital elevation models (from LiDAR), papers maps, or in-situ measurements. With the position of the cable yarder, the terminal pylon and the parameters of the cable (section, strength, weight,...) the software calculate the forces needed for the cable in charge.

The output of SIMULCABLE is a visualisation in 2D or 3D, showing the position of the cable yarder and the line in charge. Moving manually the pylon when the cable is near or on the floor generate a new simulation. The result of calculation (tensions in the cable) gives also information about the pylons and shrouds. The user can easily simulate several positions of the cable line considering the topography, the forest stand and the potential yield. With these simulations, the user can determinate the number of supports, and the right position of them. Finally, he can choose the optimal location of the intermediate supports.

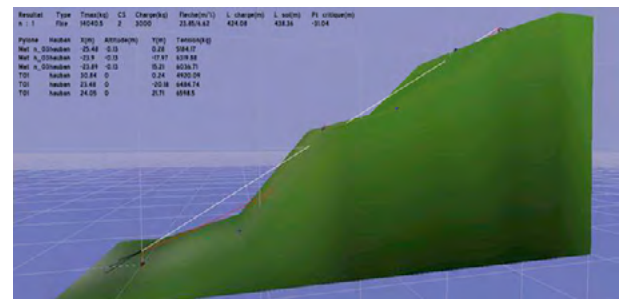


Figure 34: 3D visualisation after calculation without line supports

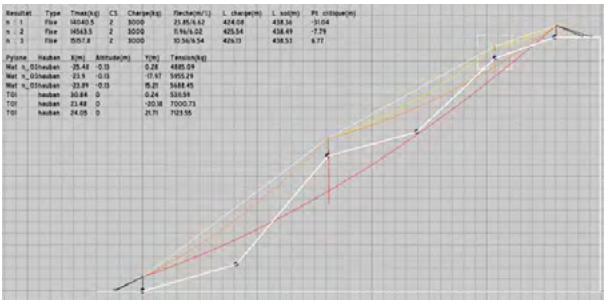


Figure 35: Final 2D visualisation after adding 2 intermediate supports

Within the NEWFOR project, some changes have been done, to improve:

- Automatic positioning of pylons: the software uses some parameters (security coefficient, high of the pylon, minimum high from the ground for example 4 meters), calculate different positioning and choose the best one (minimum of support, and higher line from the ground). The user has the possibility to change manually this position if he wants to.
- The anchor was not calculated as the main line. Now, the user has the possibility to include the main anchor (of the main cable), in order to know the total length of the used cable. For the calculation, this new section has to be out, because a part is below the minimum level (4m).

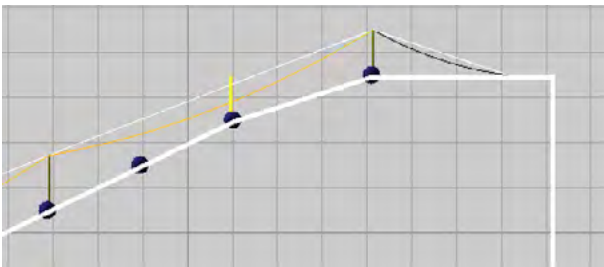


Figure 36: line tension calculation

Some other small adaptations have been done, for a user-friendly utilisation.

This software is really helpful for the forest operators who avoid losing time in the field for the determination of the support positioning.

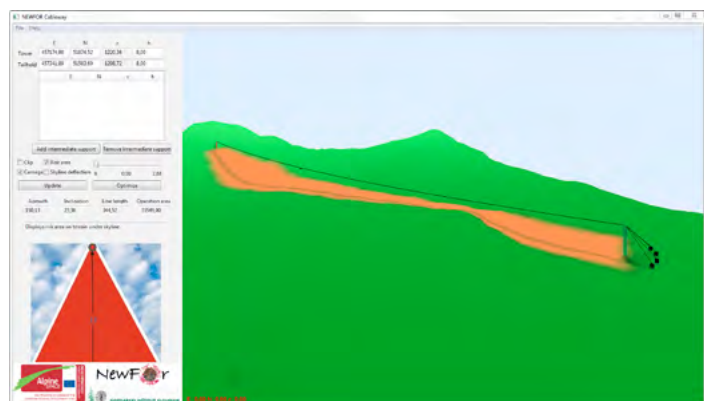
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## NCW – NEWFOR Cableway, a software solution to visualize skyline design in cable yarding

In the steep Alpine terrain, wood production with the use of cable yarders is the prevalent timber extraction technology. Planning of pilot tracks of cable lines (skylines) is crucial for optimal functioning and rationalization of costs. With known procedures, we shall be able to calculate suspension cable sags, assume the number and places of intermediate supports and ascertain the possible load that the system will safely bring from working site in the stand to the standing place of the yarder on the forest road.

For more accurate calculations, certain input parameters are required. The most important is the value of data originating from the terrain model itself, given that the key conditions for setting-up a forest cableway after preliminary planning are often associated with professional on-site estimates. Important information is usually obtained directly in the field when laying-out yarding cableway, e.g. (i) is the machine's scheduled standing place adequate, (ii) are there enough suitable trees available for anchoring, (iii) is there a solid and healthy tree positioned where intermediate support is predicted, (iv) is the final support situated in the scheduled cable line. Accurate LiDAR data, on the other hand, enable us to determine the cable line on the basis of realistic and up to date information through the cabinet study as well.

Figure 37: 3D visualisation of LIDAR topographic data and skyline tower and tailhold/end-support tree location



It is important that the user visualizes the line and is able to tune certain parameters (such as heights of intermediate supports) optimizes the envisaged costs or effects, independently from the chosen method of detailed cable line planning. Such interactive visualization is possible with the NEWFOR Cableway (NCW) tool. Based on Java programming language, this tool enables 3D visualization of cable line and of optionally selecting snapshot of the terrain. The parameters of the machine and cables are also predefined, and the user can insert some options regarding such parameters. The final purpose of the programme is the presentation of the selected line in space, with the optimization of intermediate supports and load, as well as a visualization of dangerous zones.

Figure 38: 3D visualisation of predicted intermediate supports and deflection of skyline under payload

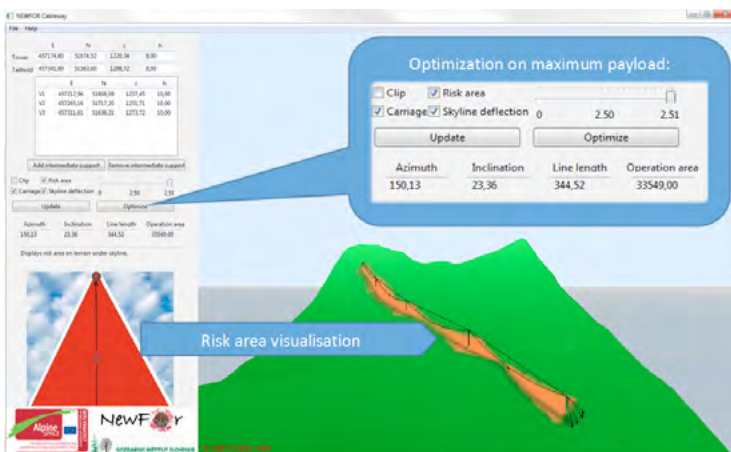
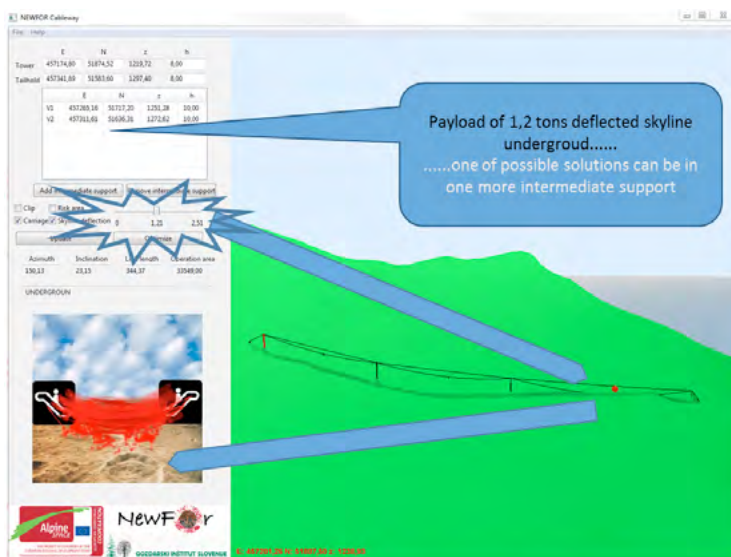


Figure 39: 3D visualisation of skyline and working risk area after adding third intermediate support and maximized payload

The tool can be used in combination with the "NEWFOR Web-GIS tool" application (see later section), which allows to export data regarding the digital terrain model and the individual cable line to the NCW program data folder. Personalized data (e.g. GNSS survey of the field) or other records (e.g. topographic data) in .txt format can of course be used as well.

The following steps are taken when using the NCW program: (i) selection of the source of the topographic data (digital terrain model), (ii) entering data of the yarder crane's standing positions or (iii) of the final and scheduled intermediate supports, (iv) visualization of the optimal load, the suspension cable sags in the work fields, and of the data on the line such as cable length, azimuth, line inclination and worksite's predicted surface area, which is productively covered by the line. Additionally, visualization of risk areas during wood yarding is provided, as well as visual warning of the exceeding sags, suspension cable's unsuitable angles of refraction or inappropriate anchoring, if the optimized data are supplemented or entered individually.

NCW zipped file (25 MB) is available to download on NEWFOR Website link: <http://www.NEWFOR.net/NEWFOR-cableway-forestry-cable-crane-skyline-in-3d/>. Long distance cable yarding skyline visualization based on parameters and calculation of skyline design-project methodology originally published by Pestal (1961). Authors are not responsible for any unauthorized or/and commercial application of software, which is at development stage. Video introduction of NCW was presented at French mid-term conference in presentation linked here: [http://www.NEWFOR.net/wp-content/uploads/2013/11/Cable\\_way.avi](http://www.NEWFOR.net/wp-content/uploads/2013/11/Cable_way.avi).

NCW software provides in menu bar also a help section with basic instructions, button descriptions and controls instruction for 3D viewing.

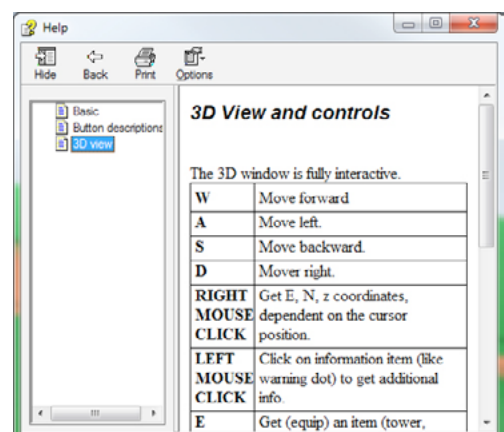


Figure 40: NCW software user's manual in help window

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## Library(NEWFORCC) – a R package for forest cable crane planning

R is a free (open-source) software environment for statistical computing and graphics (<http://cran.r-project.org/>). It is a versatile object-oriented programming language with strong graphic and demonstration functions. The R community continues to evolve and expand, actively developing new extensions known as libraries. R is a command-line program. This lack of interface may prove particularly challenging for a new user. However, it is specifically the software's code that gives R the capability to repeat commands and to create a user's own methods for data processing and visualization. From this perspective, R greatly exceeds the so-called 'black-box' programs.

In project "NEWFOR" we developed a library(NEWFORCC), package for cable crane planning, especially for finding optimal location for intermediate support(s) (Figure 41). LiDAR derived digital elevation model (DMR) represent a source data for ground profile extraction, while canopy height model (CHM) can be used for (dominant) single tree detection, suitable for intermediate support(s).

The NEWFORCC library is dependent on the following packages already available for R: (i) raster - for reading, writing, manipulating, analyzing and modeling of gridded spatial data, (ii) sp - provides classes and methods for spatial data, (iii) rgdal - provides bindings to the Geospatial Data Abstraction Library (GDAL) and access to projection/transformation operations, (iv) rgl - includes functions for 3D interactive graphics (Figure 42) and (v) rgeos - represents interface to Geometry Engine - Open Source (GEOS) using the C API for topology operations on geometries.

Using function setSpar users set the location of head and tail spars while cable crane characteristics can be specified using function setChar. Following parameters can be defined: a) maximum height of the head spar (in m), b) maximum height of the intermediate support (in m), c) maximum height of the tail spar (in m), d) load capacity (in kN), e) weight of the carriage (in kg), f) weight of the skyline (in kN/m), g) maximum tension (kN) and h) and minimum clearance (in m).

Function getProf extracts values from a digital elevation model at the locations of other spatial data. In default case getProf returns the values of the cells of a dem that are touched by a line. If the width of buffer is specified getProf returns the values of the cells of a dem that are covered by a polygon, defined as a buffer around skyline.

Core function of library(NEWFORCC) is the optimizeCC function, that finds optimal solution for location or

intermediate supports. At the moment only Pestal equation for mid-span deflection is implemented. Possible argument of a function is location of potential intermediate supports, derived from digital canopy height model from LiDAR data.

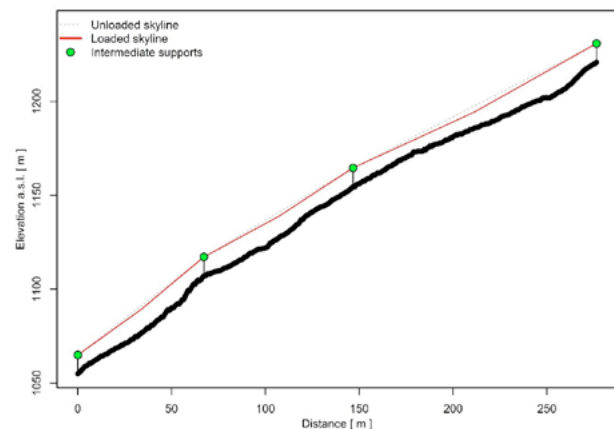


Figure 41: An example of single cable crane layout with intermediate supports

The following summary information about the intermediate supports are obtained using function getSupp; a) locations (x and y coordinate), b) height of the supports, c) distance from head spar, d) elevation of skyline of a unloaded cable ( $z_0$ , a.s.l), e) elevation of skyline of a loaded cable ( $z_1$ , a.s.l) and f) tensile force at the place of intermediate supports. The results could be plotted in 2D (Figure 41) or 3D view (Figure 42).

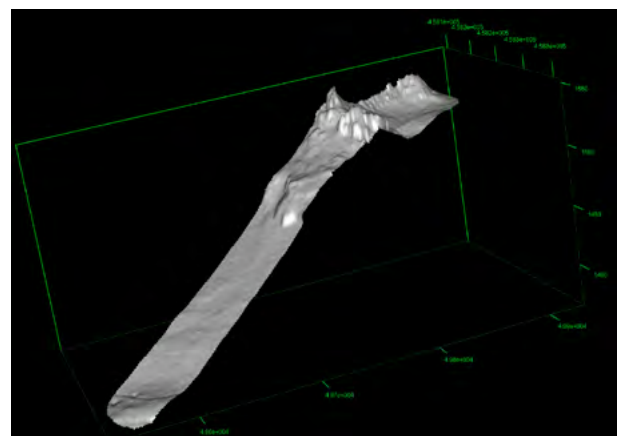


Figure 42: An example of 3D view of terrain below single cable crane

An example of usage library(NEWFORCC) is presented below:

```

> library(NEWFORCC) # Forest cable crane planning
> library(raster) # Geographic data analysis and modeling
> library(sp) # Classes and methods for spatial data
> library(rgdal) # Geospatial data abstraction library
> library(rgl) # 3D visualization device system (OpenGL)
> library(rgeos) # Interface to Geometry Engine-Open Source (GEOS)

> setSpar(CL) # Set head and tail spar

      [,1]      [,2]
[1,] 457586.7 52115.9 # xy coordinates of head spar (tower)
[2,] 457485.9 51858.5 # xy coordinates of tail spar
> dem <- raster(«dem.tif») # import digital elevation model
> plot(dem) # plot digital elevation model
> plot(CL, add = TRUE, lty = 3) # plot CC skyline line

> setChar(CC) # Set CC technical characteristics

      [,1]
[1,] 10 # maximum height of the head spar (in m)
[2,] 10 # maximum height of the intermediate support (in m)
[3,] 10 # maximum height of the tail spar (in m)
[4,] 18.5 # load capacity (in kN)
[5,] 350 # weight of the carriage (in kg)
[6,] 0.019 # weight of the skyline (in kN/m)
[7,] 100 # maximum tension (kN)
[8,] 2 # minimum clearance (in m)

> CCp <- getProf(dem, CL) # extract z values from a dem
      # dem - digital elevation model
      # CL – CC skyline line
> CCp3d <- getProf(dem, CL, width) # extract xyz values from a dem
      # dem - digital elevation model
      # CL – CC skyline line
      # buffer width parameter (in m)

> open3d() # open a new rgl device
> surface3d(CCp3d$x, CCp3d$y, CCp3d$z) # plot 3d CC skyline surface
> CCs <- optimizeCC(CCp, CC, isp = NULL) # CCp – CC profile
      # CC characteristics
      # isp = xyz of possible
      # intermediate supports

> CCf <- getSupp(CCs) # summary information of cable crane
      x      y      dist      z0      z1      T.force
H.Spar 457586.7 52115.9 0.0 1065.0 1065.0 96.85
Span 1 457574.7 52085.2 33.2 1090.7 1088.8 97.34
Supp 1 457562.4 52053.8 67.2 1117.1 1117.1 97.84
Span 2 457548.1 52017.4 106.5 1140.6 1138.5 98.28
Supp 2 457533.6 51980.3 146.7 1164.6 1164.6 98.74
Span 3 457510.1 51920.4 211.6 1197.7 1194.4 99.37
T.Spar 457485.9 51858.5 276.4 1230.8 1230.8 100.00

> plot(CCp, type = «l») # plot CC skyline profile
> lines(CCf[, c(«l», «z0»)], col = «red») # add unloaded skyline
> lines(CCf[, c(«l», «z1»)], col = «green») # add loaded skyline
> coordinates(CCf) <- ~x+y # set coordinates to create a SP object
> writePointsShape(CCf, «CCf.shp») # write SP object to a shapefile

```

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## Remote sensed data for forest road planning support

An optimal planning of forest harvesting and logging relies on an up to date forest roads network. Ideally this network allows automatic routing for optimizing the transportation routes. Additionally the combination of growing stock maps and a routable forest roads graph enables efficient planning and optimizing of cable cranes. In contrast to public roads, which are of high interest for the society, forest roads are often not mapped or were mapped with insufficient information for routing. Therefore the task of updating the forest roads network is fundamental for heading into the direction of an efficient forest management and wood supply chain. Within the project NEWFOR a semi-automatically method for extracting forest roads from LiDAR data was developed. LiDAR data can deliver terrain information below dense canopies which enables an extraction of forest roads even in dense forested areas. This is an advantage to methods which purely rely on orthophotos. The developed algorithm relies on a weighted graph, automatically extracted from LiDAR data using watershed methods and slope information of the terrain. Additionally information from orthophotos is used. Based on this graph the forest roads are extracted as follows. A human interpreter defines starting and ending points of road sections. Between these points the shortest, highest scored path within the weighted graph is automatically found. Using this method the forest roads network is sequentially extracted by the interpreter in a very efficient way. Based on the extracted geometry additional attributes are automatically derived and assigned to road sections. The method was applied and tested for the NEWFOR pilot areas.

The weighted graph methodology enabled fully automatically processing of the input data and was applicable to different datasets as they exist in the NEWFOR consortium. For both, steep as well as flat terrain, sufficient information could be extracted from LiDAR data and orthophotos. To enable comfortable digitizing of forest roads in a functional Open Source GIS environment, a Quantum GIS Plugin was implemented. Based on the weighted graph and knowledge from a human interpreter a topologically correct forest roads network could be extracted using this Plugin. The sequentially digitization process delivers user controlled results where errors can be corrected immediately during the process. This is a big advantage to fully automatically methods where only little user interaction is given. The semi automatically digitization process was found to be more efficient than a manually extraction as large road segments can be digitized easily. Additional

attributes as for example road width, curve radii and gradient of segments were derived for the extracted roads (Figure 43). This information is important for routing purposes. Attributes can also be extracted from existing datasets originating from other sources as for example Open Street Maps. For the Austrian pilot area a visual inspection of the extracted roads compared to a manually extracted reference layer was performed and showed a good agreement. Especially in dense forested areas the use of LiDAR data performed well compared to a digitization purely based on orthophotos. Related to a sufficient wood supply chain it could be shown that the updating process of the forest roads network can be performed in an efficient way by using remote sensing data.

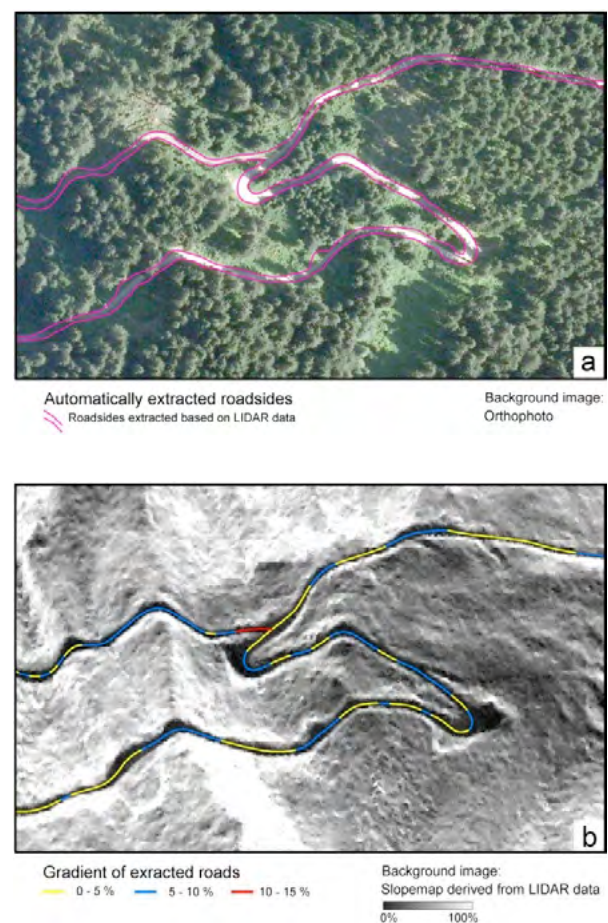


Figure 43: Example for extracted forest roads.  
a) Automatically delineated roadsides b) Extracted road network. The road segments are colour coded by gradient

## Using high resolution data for forest road engineering

Forest road engineering concerns both the road network planning (Cavalli and Grigolato, 2010) and the design of new forest roads (Stückelberger *et al.*, 2007) as the improvement and the up-grading of the road standard of existing forest road.

In the last decades applied research on LiDAR for forest road engineering has shown the potential of high resolution data for forest road design (Aruga *et al.*, 2005; Contreras *et al.*, 2012), for forest road network planning (Bont *et al.*, 2012) and for road geomatics identification (Craven and Wing, 2014).

However understanding about the application of high resolution digital model terrain (DTM) for forest road re-engineering is still little known.

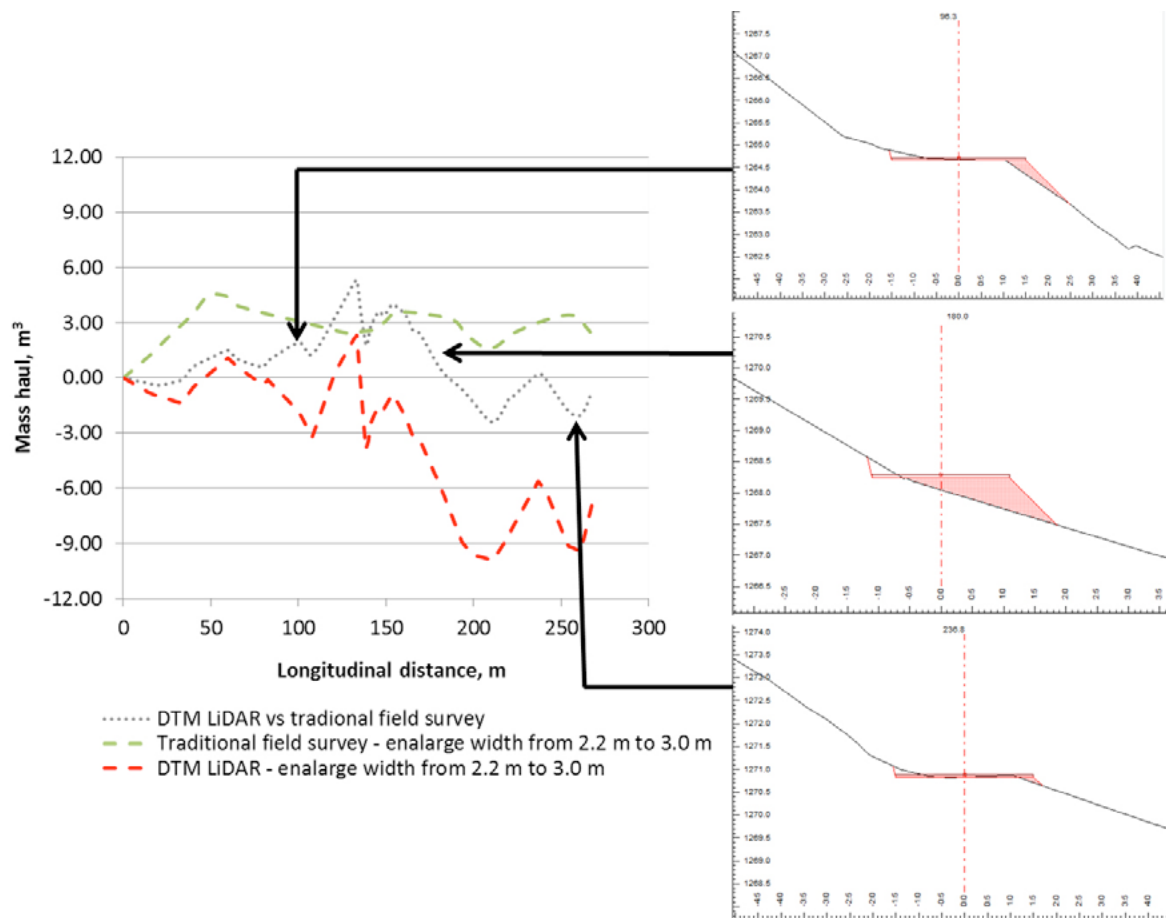
In order to verify the possibility to use high resolution DTM or ground LiDAR points to forest road re-engineering, the accuracy of forest road traverse section was investigated in the Asiago plateau test site.

A significant difference appeared between the forest road traverse sections extracted by high resolution DTM to the forest road cross-section surveyed by traditional method. The reliability of the forest road cross-sections depends mainly from the density and the distribution of the LiDAR ground points which are used to create the DTM. Distribution and density of LiDAR points are influenced by the density of the forest canopy and the distribution and the size of the trees (Figure 44).

The difference between the cross sections extracted by DTM and the cross-sections surveyed by traditional method counts for 11.8%. When the forest cross-sections are completely under canopy the difference is definitely higher than when the forest cross section is partially below canopy.



Figure 44: Example of the density and the distribution of the ground points used to extract the forest cross-sections below forest canopy



As an example, it is possible to compare the mass haul for a standard improvement of 300 m of road in terms of carriageway (passing from 2.2 m width to 3.0 m width). It is evident the high difference between the use of cross-section automatically extracted by the high resolution DTM and the use of forest road cross-section directly surveyed in the field (Figure 45).

Figure 45: Comparison between the mass-haul derived by using high resolution DTM and the mass-haul extracted by tradition field survey. The mass-haul is an example concerning the improvement of the forest road carriageway from 2.2 m to 3.0 m under a dense forest

## Critical nodes and future opportunities

The analysis of the forest operations in the Alpine Space currently shows big differences among the different nations. The biggest difference regards the organization of the forest operation enterprises in terms of size and type of used machine. Big differences are present in some cases (Italy) also among the single regional administrations. The common trends regard the shifting towards a high level of mechanization, that in some countries is already established, but in others still represents an issue.

The main issue concerning this trend regards the type of infrastructures that should have the standards to allow the bigger machine to operate safely.

The use of the Decision Support Tools developed within the project shows a big potential in helping the planning of forest operation, even at the operational level.

The application of the derived maps proved to be a useful tool to orient the execution of forest operation, and the future investments within the project test-sites.

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# Forest & industry connectivity



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In countries of the Alpine Space (AS), transportation logistic is an economic, technical and ecological challenge. The methodologies deployed in each country differ, both in terms of material and in terms of organization. We will focus here on transportation from forest road to the first processing unit. This phase requires the use of specific materials, especially in the AS, that do not allow the transport of other goods. This

is the biggest problem for optimization of logistics: every ride will be full one way and be empty on the return, consequently costs are quite high. In this chapter we present the WP6 activities. We described the organization in each country and tested some existing tools in order to identify their limits and advantages. The final outcome is recommendations and specifications for new tools or improvement of existing tools.

## State of the art of wood transport in the Alpine Space

### Structure of the enterprises

In general, the size of business in the timber industry is relatively small; the transport sector is not different from this point of view. In most Alpine countries, transport enterprises which are independent from the timber industry own from 1 to 5 trucks. However, in Austria and especially in Slovenia, companies who have 5 to 20 trucks are more common. These small operators often operate at a very local scale (150 km of radius). It is also important to notice that these companies, because of their specific road materials, are exclusively specialized in the transport of round wood and cannot carry other goods.

### Fleet composition

Fleet composition differs greatly across the Alpine space. In most cases, two factors will determine the choice of materials: the topographic conditions and the industrial demand. That is why in Slovenia and in Austria, where most of the round wood is buy in short logs (4 to 5 meters), most of the fleet is composed of 3 axle trucks with 2 axle trailers. The main advantage of this system in

the Alps, where forest roads are often steep and narrow, is represented by the following: (i) the truck can move with the trailer as long as the road allows it, (ii) it can leave the trailer on a timber yard in the forest, (iii) move to the forest site where the timber is prepared and perform loading operations, (iv) move back to the timber yard, (v) load the trailer with the crane, (vi) get the load for the truck at the forest site and move with the trailer to the sawmill. Such organization allows transport companies better access to forest sites even at further distance from the road side.

In France, the fleet composition is completely different, timber lorries are made of a tractor and a dolly. This method allows French transport companies to haul logs up to 21 meters, and to have a lower empty weight. Again, this choice depends on the sawmill supply chain methods and also on the harvesting system. In Slovenia some of the transport is also made with long logs, but semitrailers are used.

In terms of regulations: the payload is an important factor of competitiveness of the supply chain. For 5 and 6-axles truck the authorized payload is 44 tons except 40 tons in Slovenia. In France, the maximum payload can reach 48 tons and 57 tons on specific roads respectively for 5-axle and 6-axle trucks.

## Organisation

Generally, the planning of roundwood transport is made by the factories:

- Large sawmills, pulp mills and chipboard factories are giving a monthly planning (with also decade or weekly indications) to their wood procurement companies. They have developed an efficient logistic to optimize the timber supply according to their daily demand. The purpose is also to reduce storage space and idle time for transport companies.
- Small sawmills give transport instructions in a more erratic way... when they need roundwood in their timber-yard. Sometimes they still have their own harvesting and transport means (equipment's and human resources).

## Conclusion

Until now, transport enterprises and wood procurement companies or services (in mills) do not use any support systems for the optimization of roundwood transport. Many reasons can explain this situation:

- Structural aspects: haulage enterprises are very small. There are very few big companies likely to use this kind of tools, which is efficient with a fleet of at least 15 trucks.
- Cultural aspects: the development of collaborative tools could be the solution but the enterprises (haulers and first transformation mills) do not want to share their information with their competitors.
- Habits: haulage enterprises put forward the "good" knowledge of local drivers to justify the non-use of geo-localization system. However, the difficulty in navigation is clearly existing for new drivers.

The wood supply chain includes several steps from prospection to forestry work, from transport to reception at the transformation site. Along the chain, several actors are involved, exercising different activities (extraction, transportation, management of stocks, etc). For each of them, information and communication technologies represent an opportunity to access information in real time for better planning, control and management of the entire logistic chain.

The use of standard information exchange or GIS tools can help to fulfil some needs of the sector.

Forest road databases, geo-localization of wood piles are likely to bring some economic gain to the actors involved in wood procurement in all Alpine countries.

## Test of existing tools for optimization

### Forest road data base in the Alpine Space

The overview on forest road database in the Alpine Space shows that numerous bases exist; some of them have been launched at the beginning of the 2000's.

The utilization of those tools is various. The recording of the existing forest road network - and other equipments like crossing, turning or loading places – in GIS application is the main one. The applications are also used to display and simulate the effects of new opening-up of roads on the future harvested volumes when data on the forest stands are analysed simultaneously. It can be also the base for specific studies dedicated to the choice of harvesting systems as the first parameter to be taken into account is the forest road network (see WP5).

The second set of utilization is the recording of maintenance works that are done on the forest road network and is also a tool to plan and quantify the future works to realize.

As logistic optimization is concerned, the main utilization is the visualization of the way to go to the stock piles or to the woodlot (for visiting the woodlot before the sale). Until now, the existing systems are only used at offices and printed documents are sent to the end-users (logging companies, transport companies...) by email or fax. Only few experiences have been conducted in terms of embarked equipments for displaying maps in trucks.

The existing forest road databases have never been used for route guidance, as the data formats are not compatible with those tools. NavLog system is the only one that has defined a specific file shape and a specific program so that the connection between the public network and the forest network can be established for route guidance (see below). The quality of this connection has been evaluated in the frame of NEWFOR project by two partners.

Another important topic is the up-grading of the data. Two levels must be considered. The first one is relative to the way the accessibility of each road section is defined in relation with new trends in the field of transport material. For example, in 10 years, transport by tractors decreased and some old forest road classifications should be up-graded. So there is a need to have a common classification approach of the forest roads in the AS with the possibility for each country to go further in details if they consider it as necessary. The second level is the «real time» up-grading of the data to inform the end-users transport companies, logging enterprises...)

to communicate temporary changes in the road such as closed sections, obstacles, damaged bridges. This is a key point if data are used in a route guidance system.

### NavLog

Today, navigation using a GNSS system is very common. This technology is increasingly used in the forest sector, and new solutions appear such as NavLog to meet these needs. Numerous studies demonstrate the financial impact of searching the piles of wood with respect to the total cost of transport. Wasting time to pinpoint the location of deposits, and additional fuel consumption time cause additional costs and damage to the environment and serving network.

An essential condition for the creation of a navigation system is the availability of data regarding the forest road network and its carriage payload (type of surface, width of roads, radius of bend...). In Germany a non-governmental organization has created a standard, GEODAT, for forest activities. This standard classifies forest roads according to their carriage payload and their specific characteristics. Roads can then be plotted in a navigable vector file called ShapeFors. Forest network data from the field are the responsibility of the forestry companies who are using them. In return, NavLog gives them a free file with their data after it has been scanned and controlled. It also gives them access to a geographic information system (GIS) where all the partners can enter information and update it. Temporary information can also be added. For example, access to a forest road may be temporarily prohibited if one forest company occupies the road (e.g. with a cable tower).

In the NEWFOR project, the NavLog system was studied by the Tyrolean Office of the Regional Government (TORG). The idea was to test the German system in three steps, in order to figure out the capacity of adaptation in the AS.

- Step 1: The road network of Tyrolean test area was integrated into the NAVLOG network
- Step 2: An online training with NAVLOG web-client was made
- Step 3: Field test was realized with local foresters in the test area Wildschönau



At the end of the first test, Austrian users noted some important points: (i) first of all, the road graph of the Tyrolean government was more accurate and complete than the NAVTEQ graph in rural areas and forests (Figure 46) and (ii) the Web-client seems to be very complex, and cannot be used by local foresters without training or advice, even if the local foresters in Tyrol have the knowledge over the routes.

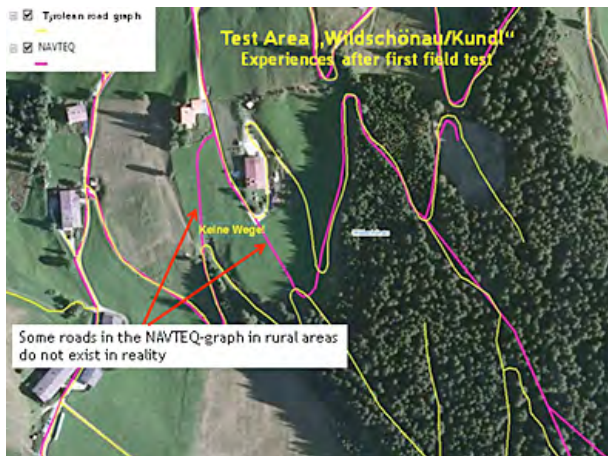


Figure 46: Accuracy of NAVTEQ data

## GIP (Graph Integration Platform)

Over recent years Austria's public authorities have been using parallel systems for data storage regarding transport infrastructure. The so-called Graph Integration Platform (GP), which has now been implemented across the whole country, can be seen as a link that has been missing between these parallel systems.

The GIP is a nationwide reference graph, which provides a digital map of Austria's transport network available to all authorities. Hence, no more multiple or parallel data storage systems are needed. Since there is only the traffic-relevant information being stored on the graph, also a link to data storage systems of the different disciplines is possible (project partner's specialized data bases, e.g. Tyrolean Forest Road Data Base). All past information are being stored, ensuring restorability at all levels.

The greatest improvement the GIP brings is the centralized data storage with decentralized data updating via a network client. This means that the data owners are responsible for data permissions and quality. Thus, the transport network is continuously updated and correctness and completeness of the reference graph can be ensured.

The reference graph is also usable for route navigation systems. It covers all types of transport (passenger car traffic, public transport, cycling, walking) and is

capable of proposing intermodal combinations. The Traffic Information Austria (VAO) agency, which provides calculation of routes and up-to-date traffic data free of charge, uses the GIP as a basis for the optimization of routes. In terms of Austrian forest roads, the following attributes are traffic-relevant and therefore are stored in the graph:

- Code (ID), Name
- Street category (legislative basis)
- Load bearing capacity
- Functional road class (traffic value)
- Use condition (wayclass according to trafficability, minimal width, maximum inclination, etc)
- Traffic direction
- Turning options
- Parking places for trailers
- Gates

Using the Graph Integration Platform as the data base for the processing of Austrian forest roads but also as a basis for route guidance systems offers several advantages.

- Homogeneous structure regarding geometrical data processing and relevant attributive information
- Routing information can be stored on the graph
- Integration of the rural public road network (which might be critical for wood transport)
- Routing information also available for other operational duties (e.g., emergency call centre)
- Less effort on updating forest road network (Web Client)
- Data transfer for navigation systems possible

As an outcome of the cooperation between the Austrian Forest Services, the GIP coordinators and the Federal Ministry of Agriculture, Forestry, Environment and Water Management, the guideline "Integration of Austrian forest roads into the GIP" has been realised and has to be discussed on a national level with the regional forest governments. Not only an interchange of ideas and requirements has been created, the guideline now provides a basis for the data handling of forest roads. A consistent accuracy of the graph can be ensured.

[GIP.gv.at](http://GIP.gv.at) is a joint project of the Austrian federal states (Tyrol, Salzburg, Carinthia, Styria, Upper Austria, Lower Austria, Burgenland), ASFINAG (motorway operator), ÖBB Infrastructure (Austrian Railways), the Austrian Federal Ministry of Transport, Innovation and Technology and their partner ITS Vienna Region. The Austrian Association of Cities and Towns is an associated partner.

## FLO (Forest Logistic Optimization)

Within the project, the advantage that existing tools can give in terms of optimization has been investigated. Several tools currently available on the market were identified, and one of them has caught our attention: FLO (Forest Logistic Optimization) from the North-American company Trimble. The flexibility it offers was an important advantage in relation to the practices of the Alpine timber industry.

Trimble Forestry features the FLO system for a complete software for transportation management. The FLO system in its complete version optimizes truck scheduling with automatic load assignments, mobile messaging and routing/navigation for truck drivers. The FLO office software manages the information and automatically dispatches trucks to the appropriate landings for load pickup. With the ability to view real-time location and status of each vehicle of the fleet, FLO software allows the transport manager to react to exceptions and make last-minute changes. This kind of software can reduce loading wait times, eliminate traffic bottlenecks that waste time and fuel, and gain more backhaul opportunities.

In order to test this software three different approaches have been defined based on the observation of the current situation of wood transport in the AS (Figure 47): (1) a French transport company who owns more than 15 trucks, (2) a transport purchaser: a sawmill located in the French Alps (3) and a third approach with an association of transport companies is also possible. Such organization does not exist until now, but the advantages brought by optimization with a higher number of trucks can justify the goal of such associations. During the project, only the first situation has been tested.



Figure 47: The 3 different approaches for the use of an optimization software

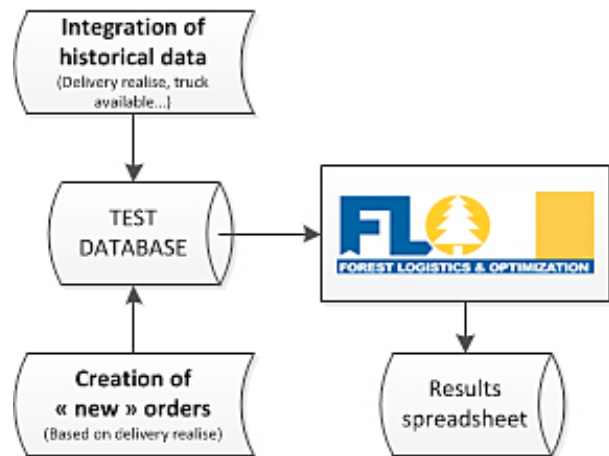


Figure 48: First test made with FLO (Past Data).

The first methodology was to quantify the advantage of optimization, based on past data (Figure 48). Historical data of the company have been integrated with those based on the deliveries realized during one month. After this work of integration, the FLO software was run by Trimble and analysed in two weeks. These first analyses gave good information on the flexibility of the software. The purpose of this first work was also to adapt the software to the French regulation environment. Maximum daily driving time, payload regulation, and trucks specificities were integrated quite quickly in the program.

After some intermediate tests, first results revealed that, during two weeks, FLO was able to dispatch 26% of new loads. Such figure needs to be precise, because to estimate these new loads, FLO selects information from past data and duplicates some of the loads. The historical data of the company was effectively not precise enough and complete enough for the software because only the delivered loads were available and not all the orders. To avoid this "bias" a new test should be based on "real-time" data.

The advantage of using "real-time" data in a test is that the software will also integrate urgent orders, truck problems and lots of daily data such as the following: (i) truck breakdown, (ii) truck delivers to unplanned location (iii) harvest site becomes unavailable due to weather or other issues, (iv) delivery site becomes unavailable, (v) delays due to multi-truck line-up harvest site or delivery site.

## The Slovenian forest roads information database

Within the whole Slovenia a ramified network of forest roads is present, primarily designed for forest management. For easier management of forest roads we have organized an information system, which represents a smaller, but important part of the integrated forestry information system. The basic unit of the system is a forest road in its entire length and it is composed of a module of records regarding forest roads and a module for the monitoring of their maintenance. Both modules contain attribute and graphic data, which are uniformly managed for the whole country. The design of the system is based on relational database theory and it has been meant to be open, dynamic and modular. Its data is also included in the central cadastral register of public infrastructure.

According to the data model, a web application for records regarding forest roads was designed. The purpose for creating the web application is to have a comprehensive base for planning (openness, new lines of forest roads, ...), direct collection of data (e.g.: damages on forest roads,...), enable usage for different users (fire fighters, etc), user friendly system, comprehensive solution, overview of the situation across the country in whole and in real time, transparency, easy combination of different information.

The complete system was presented as "best practice example" and, with some results of the NEWFOR project, also during IUFRO World Congress 2014 in Salt Lake City, USA (BEGUŠ J., TROBIŠ T., 2014: The forest roads information database system, scientific poster).

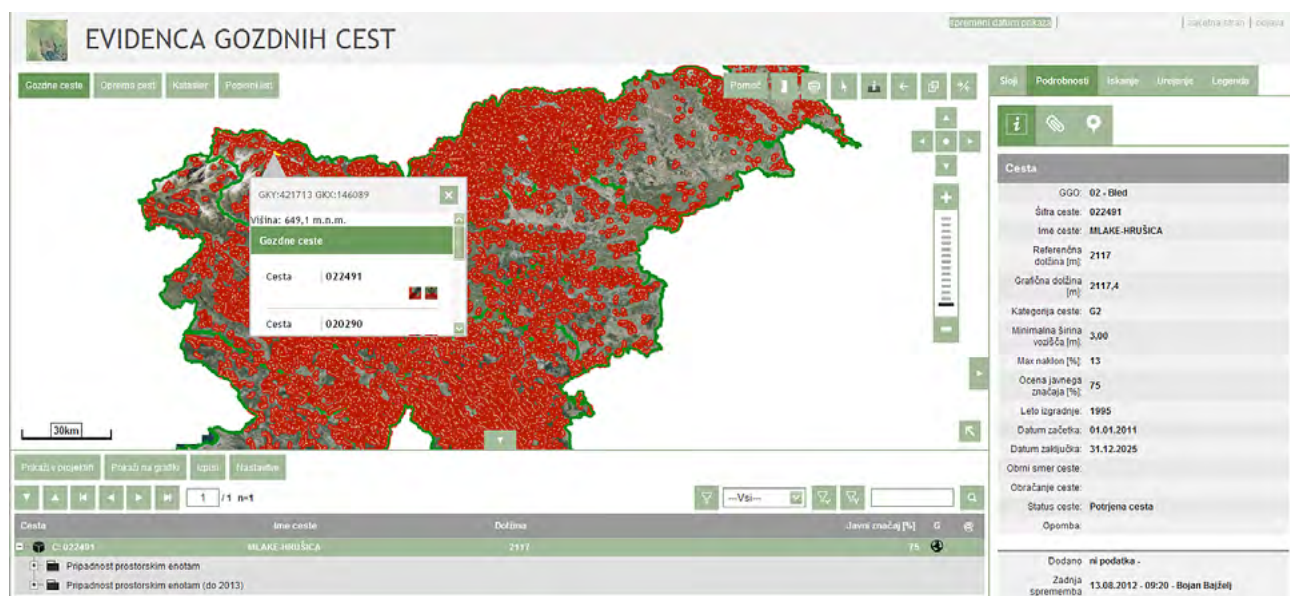


Figure 49: Web-based GIS application and user interface

## Critical nodes and future opportunities

A database of forest roads is fundamental for their maintenance and the planning of forest operations and the mobilization of the wood resource.

Due to local differences across the Alpine countries connected to the road typology and the transport organization, it is difficult to imagine a widespread usage of navigation systems on the whole territory (e.g. Italy).

# Costs & benefits evaluation



## Authors:

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Within the Work Package 7 “Cost and benefits evaluation”, the activities focused on web-based tools for better estimation of costs of timber harvesting operations. Such tools should enable forest owners to easily and accurately plan harvesting operations with expected positive marginal results. In combination with improved inventory data, a better decision basis for the estimation of the costs and benefits of tending operations on steep slopes could be achieved and the mobilization of such timber reserves accelerated.

After the review and discussion of several currently available web-based tools, the free software HeProMo by WSL (Swiss Federal Institute for Forest, Snow and Landscape Research) and the forestry equipment and machinery database by BFW (Research and Training Centre for Forests, Natural Hazards and Landscape), available on disc, have been selected for further investigation.

## HeProMo – the productivity estimation tool

The timber harvesting productivity model “HeProMo” is a computer model for calculation of time and costs of various harvesting methods. It has a modular structure and permits both the calculation of parts of the harvesting chain as well as entire processing chains.

With HeProMo pre-calculations and various tests may be performed. This makes it also suitable for the derivation of flat approaches, for example as a basis for contractor agreements. The software can help entrepreneurs to create offers and allows forest companies and forest owners to check entrepreneur offers critically. Sensitivity analyses help to assess the influence of individual input variables on the outcome. With its modules, it also supports the re-use in other applications such as simulation models and information systems, and that is why HeProMo is also ideal for training and use in schools and courses.

HeProMo was developed as part of the WSL research program “Management of sustainable forest management” and is a Windows software with user-friendly menu-based navigation. A ReadMe file with information on installation and use as well as comprehensive documentation and user help for the individual models of HeProMo are available.

The model calculations were tested as part of the NEWFOR project in various test operations in France, Italy and Slovenia.

The models perform very well in the CTL (cut to length) process. Less useful were the models used for the whole-tree method in cable-based harvesting. In this regard, data were collected as part of the test runs by means of which the tool should be further improved.

Since HeProMo is currently only available in German version, an English translation was performed in the framework of the NEWFOR project. The “English Glossary for HeProMo” is available on [www.newfor.net/download](http://www.newfor.net/download). Instructions are indicated for each input fields.

More information about the software can be found at [www.waldwissen.net](http://www.waldwissen.net).

Authors of HeProMo: Fritz Frutig, Vinzenz Erni, Oliver Thees (WSL, Switzerland)

To be able to perform HeProMo pre-calculations, data on the harvesting systems used are required. In order to support this purpose, an online database has been created within the NEWFOR project. The BFW database (see page 64) contains data from approximately 750 forestry among available machinery and equipment and allows the calculation of the costs of their involvement in a timber supply chain.

## Testing on pilot areas: the French case

In the French Alps, logging operations with cable crane are not common (Grulois 2007, Pischedda *et al.* 2012). Indeed, less than 50,000 m<sup>3</sup> are harvested annually by five French Alps companies and some teams from Switzerland, Austria, Italy and Slovakia that occasionally perform in the area.

Harvesting delivery prices (wood purchase not included) are about 40 €/m<sup>3</sup> and are generally considered as "higher than they should or could be". Taking into account the high degree of uncertainty concerning productivity (under the influence of bad weather conditions, limited market for large timber, organizational and planning difficulties due to insufficient road network, landing places, trucks availability, etc), logging contractors voluntarily increase the logging service price, which is finally quite disconnected from productivity.

The calculations within the software HeProMo have been based on field studies in cable crane operations. Using data from a single skyline, the software calculates the time of installation of the line, the productivity, and the cost of harvesting (€/m<sup>3</sup>), but it does not take into account the felling costs. Indeed, the result is a prevision based on existing productivity models and this principle has been validated (Becuwe *et al.* 2010, Frutig *et al.* 2010, Mine 2008).

Within the project, measurements on different timber yards from French enterprises in the Alps were gathered. All logging sites were visited (description of the stand, the logging operation, field conditions), and time studies were done for at least one line, according to the European harmonized protocol AIR3-CT94-2097. Time sheets were provided to enterprises for documenting their schedules and activities (installation time linked with the number and type of supports, productivity, length of the line...). Field survey gives the opportunity to validate the collected data. At the end of 2013, 80 skylines on 34 logging site were investigated.

The methodology (Figure 51) aimed to determine final costs through two main different approaches:

1. HeProMo software.
2. FAO methodology (1992), according to which the cost calculation is based on the real duration of harvesting operations and the global harvested volume of the logging operation in the field, associated to the daily cost of materials and men:

$$\text{Calculated costs (€)} = \frac{\text{material's daily cost (euros/day)} * \text{duration (number of days)}}{\text{global volume (m}^3\text{)}}$$

The comparison has also been done with the real costs, which represent negotiated price by the logging contractor with the owner of the wood (forest owner or wood procurement company).

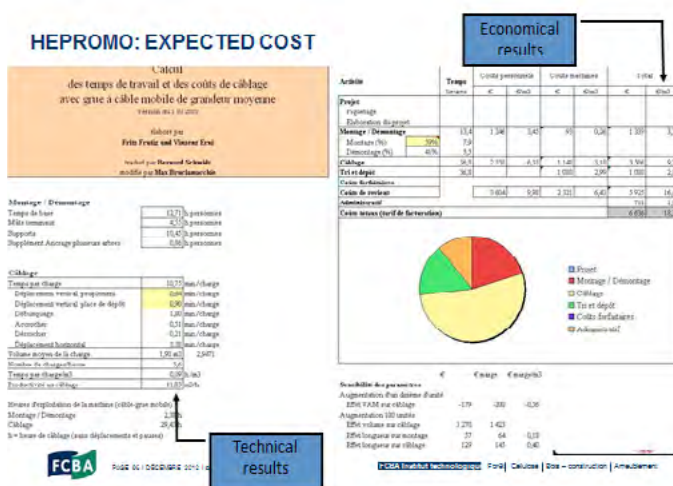


Figure 50: results of HeProMo (French version)

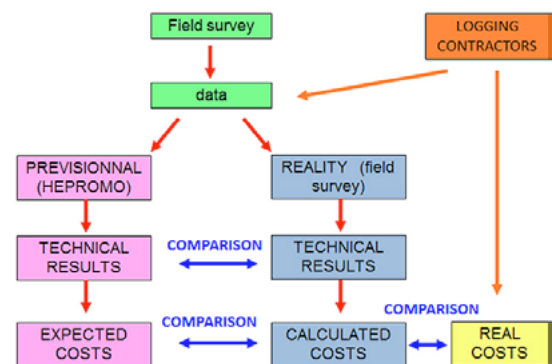


Figure 51: Methodological approach for cost comparison

Beyond the comparison of operating costs, field data were also compared to other results from HeProMo software: installation time, duration of the total cycle of the carriage, productivity, etc. Factor analysis was used to identify the main parameters to be taken into account within the development of specific or adapted productivity models.

Finally, a part of the dataset has been put aside and will be used for the final validation of these new productivity models.

For the cost calculation and comparison, the same costs per hour for the machines and men have been considered. Costs calculated from the software HeProMo appear systematically lower than the ones calculated on material's daily cost, with an average of 33%, or 9 €/m<sup>3</sup> (Figure 52). In addition, the variation of the two costs is not regular and can not be adapted by adding a coefficient.

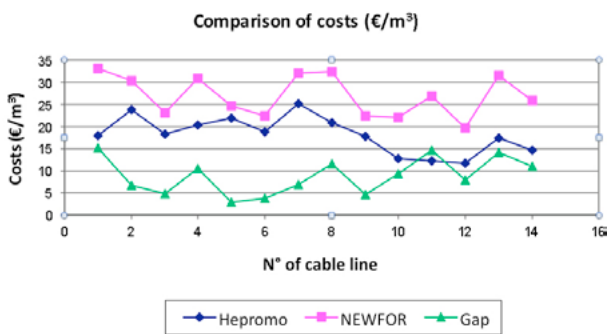


Figure 52: Comparison of costs between HeProMo software and NEWFOR studies

The study of the productivity also shows irregular variation between HeProMo and time studies. The average gap is 20% and presents 2.6 m<sup>3</sup>/h of difference (Figure 53).

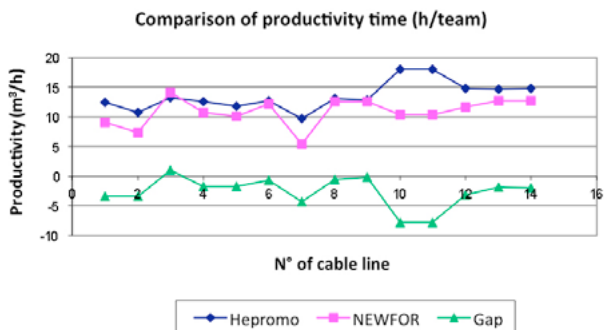


Figure 53: Comparison of productivity between HeProMo software and NEWFOR time studies

HeProMo is built with data coming from logs and not full tree extraction. In France, most of trees are harvested

with top and branches. Consequently, the commercial volume carried on the trolley is less important. Measured productivity of French teams is often lower than HeProMo, but with regular variation (0.5 m<sup>3</sup>; Figure 54) which probably represents the weight of branches.

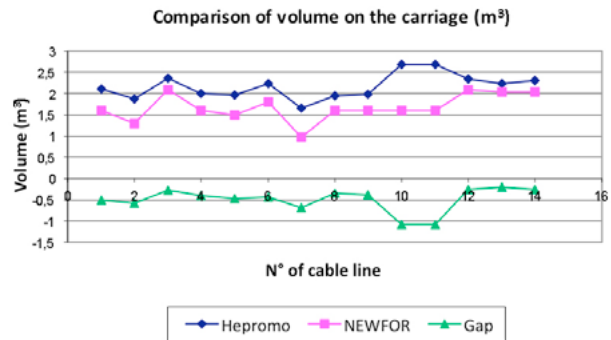


Figure 54: Comparison of volume on the carriage between HeProMo software and NEWFOR studies

The irregular variations of the costs and productivities between the two situations (France and Switzerland) does not allow using the HeProMo software in French conditions.

This case study revealed the need to develop specific models for productivity and costs determination of whole tree cable yarding. In these new models the installation time linked with the type and the number of supports should also be included. This should help the contractors for the elaboration of their price.

Moreover, the comprehension of the impact of external factors (roads, trucks logistics...) should lead to recommendations for improving the global system and reducing the cost of cable yarding operation in the Alps.

Further smaller experimentations have been carried out also within eleven sites in Slovenia (SFS) and some cases within the Lombardia region (Italy, ERSAF). As for the French case, all the preliminary results indicate that further data collection and model development should be taken into account in order to have a tool as much adherent to reality as possible.

However, it is a user-friendly tool allowing rapid data entry and quick overview of cost of the work and machinery, at satisfactory knowledge of the terrain and environmental conditions. Also the influence of different types of technology of work and strength of various influential factors on the cost of harvesting can be relatively quickly tested. The tool can be useful to private forest owner or entrepreneurs for a preliminary cost estimation.

## NEWFOR – BFW – Online forest machinery database

At the Research and Training Centre for Forests, Natural Hazards and Landscape (BFW), Department of Forest Engineering and Economics a machine and device database was listed, regarding about 750 forest machinery and equipment, with device-specific characteristics, production and sales addresses and guide prices. The department (now newly organized at the Forestry Training Centre in Gmunden) has built on behalf of the collaboration platform forest-wood-paper a first online database for energy wood production equipment in 2007. The actual online database (Version 1.0 - 2014) is the product of the experience on databases gained by BFW within the "Forest-Machinery-Data-CD" (2008) and provides the possibility to perform cost calculations for operating hours of machinery and equipment according to three different schemes of the following organizations:

- Federal Research Centre for Forests, Austria (BFW),
- Council for Forest Operations and Forest Technique e.V., Germany (KWF)
- Food and Agriculture Organization of the United Nations (FAO)

These three calculation procedures differ:

1. In determining the useful life of machinery and equipment from annual operation hours and technical service life in years;
2. In the calculation of depreciation for asset values (depreciation) of cost of acquisition and salvage value.

### Ad 1. Machine utilization - usage time

KWF and FAO calculate the actual time of use of the machinery from the assumed cumulative use in machine hours and the planned annual capacity utilization in hours as a linear relationship. Due to technical obsolescence, a maximum usage time is defined for each machine category.

In the calculation method of BFW the reduced economic life is calculated according to a hypothetically defined functional correlation between the useful life in operating hours, the economic life in years and the annual equipment utilization developed by Mayer and Eisbacher based on experience reports.

The assumed relationship between technological obsolescence and annual load of a machine, running in the shape of a parabolic function is shown in the following graph of specialized forest tractors. This hypothetical

assumption was adapted from Pröll and Bauer (1995) for newer machine systems, such as harvesters and forwarders.

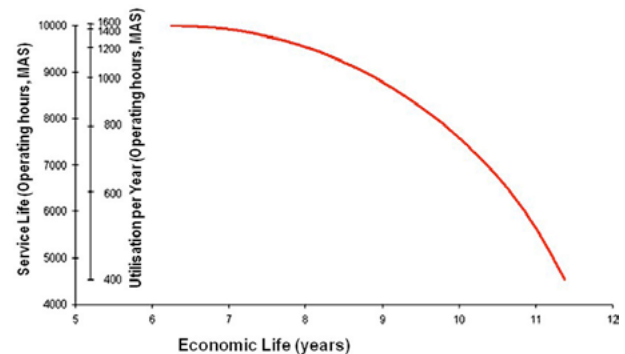


Figure 55: Potential service life period for a Skidder

### Ad 2. Depreciation for fixed assets

KWF and FAO calculate a salvage value of the equipment after the end of operational use. In the FAO costing 10 to 20%, in the KWF scheme, depending on the machine category, 15 to 40% of the replacement value is assumed as salvage value. In the calculation scheme of KWF the total technical service life and the according to the salvage value reduced operational lifetime (= depreciation period) is distinguished.

The FAO defines depending on operating conditions for various agricultural and construction equipment (for forestry only Wheel Skidder) various numbers of hours for the useful life, the remaining useful life is left open. For skidders, the useful life in average conditions is determined with 10,000 operating hours (MAS). This corresponds with the value published by KWF.

The BFW model uses the linear depreciation to total consumption of the value. Therefore, a salvage value upon sale before reaching the overall technical service life results from the calculation book value at the time of sale.

As in the publications of FAO, very few concrete values for the variable factors, such as repair costs and annual operating hours could be found for forestry, the values published by the KWF according to consultations of entrepreneurs, which are used also by the BFW, were used for all of the three calculation models.



If there are purchaser prices, the machine costs are calculated automatically following the three schemes on basis of the determined average annual hours of use - and presented - directly comparable - in three columns.

All input variables can be changed by the user as desired and individually appropriate equipment costs can be easily calculated at the push of a button.

It is important to remark that all the fields of the input column must be completed for the cost calculation.

Note that only the direct costs of the machine or equipment are calculated per hour of operation.

It lacks in considering the cost of operation, the overheads price for supplying, management and deployment organization, as well as approaches to the compensation of the entrepreneurial risk and entrepreneurial service. With the exception of fuel prices all the prices and cost approaches as well as the result of the calculation are shown without VAT.

## Reference values used for cost calculation

Operating hours = Machine working time (MAS)	The entire period of use of a device. For motor-driven machines, the operating hour is equated with the engine running time.
Maximum service life in operating hours (MAS)	The highest possible total number of hours that a device can be used economically. In the BFW scheme, this is achieved with the maximum annual equipment utilization. In the FAO and KWF schemes, it is based on exceeding the usage threshold.
Reduced service life in operating hours (MAS)	The number of hours, which a device can be utilized economically, reduces by technological obsolescence and use with decreasing annual equipment utilization. The reduced service life is calculated linearly by the FAO and KWF models, falling below the usage threshold. In the BFW model the maximum service life is achieved only at 0 MAS / year. The reduced service life is calculated using a parabolic equation, wherein the time period of the reduced economic life is given on the x-axis and the annual operating hours are to be applied in the y-axis. The reduced economic life multiplied by the annual operating hours gives the total number of hours that can afford a machine economically.
Economic life in years - Reduced Economic life in years	Period in which the device can be used with economic success = Period through to technical obsolescence. Decreases after reaching the maximum technical life with increased annual equipment utilization in operating hours. In the BFW model the devices cost is always with a reduced usage time, calculated with the proposed functional relationship between service life in operating hours, annual utilization and economic life in years, since the maximum economic life is only achieved with unused machine.
Utilization threshold (MAS/year)	Technical total usage in MAS divided by the period through to technical obsolescence in years.
Annual device utilization (MAS/year)	Number of operating hour in a year.
Depreciation amount	The depreciable amount is the purchase price less estimated salvage value.
Depreciation period	(Reduced) Economic life in years.

Depreciation method	Linear depreciation. Depending on the annual equipment utilization, which affects the total service life in operating hours, equal depreciation charges, distributed over the total service life hours, are resulting. For components of the machine with lower service life in operating hours, as the device itself, depreciation values are calculated separately.
Interest costs	The interest costs are calculated at the BFW model for half the purchase price with a constant height throughout the entire service life in years. Following the calculation schemes of FAO and KWF, the interest costs are calculated from the half of the purchase price plus the salvage value at a constant height throughout the entire service life in years.
Repair costs	The calculation of repair costs is done by multiplying the depreciable amount by a coefficient derived from experience. The repair cost coefficient therefore represents the ratio between total repair costs at maximum service life in operating hours and the device factory price. KWF and FAO assume constant repair costs on total life . In the BFW model is presumed that the cost of repair / operation hour increases with increasing annual device utilization in the ratio of reduced service life to maximum service life.
Costs for Equipment Storage and Protection	It is recommended to calculate costs for equipment storage for units with a space requirement of more than one cubic meter. Different cost rates for simple shed or laid walled rooms should be considered.
Insurance costs	All insurances - completely or partially - related to refueling and functioning of the machine.
Fuel costs	Fuel costs are calculated on an average fuel consumption, based on past experience. Lubricant costs are also calculated as a percentage of the cost of fuel on the basis of experience.

The machine or equipment cost per hour of operation are obtained by adding the individual partial amounts.

Date of data: See the respective information field within the technical data.


## Searching for a machine

In order to search for a specific machine, one of the main categories listed in the menu should be selected. Then the corresponding equipment / machinery category is chosen by clicking on the icon. Data will appear sorted according to alphabet list of recognized machines with some of the main characteristics.


General information about the machine will be shown by clicking on its name: manufacturer or distributor (within Austria), a detailed description and a calculator to calculate the hours of operation costs according to the method of BFW, KWF and FAO.

The calculation of machine hour cost is done automatically by the experience of the BFW, if purchase prices were announced by the manufacturers. The user is free to replace all the parameters of the cost through his own experience and perform then an individually adapted machine hours cost calculation for his particular circumstances.


**FORSTMASCHINEN**  
database



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Ground based logging      **Category Cable based logging / Tower yarder**      Back | Selection list

Cable based logging

Felling & Processing

Reduce to pieces

Equipment & Sundry

Search

Impressum

General information	Technical data	Producer / distributor	Economy / calculation
Type in your own numbers here and press <input type="button" value="Calculate"/>			
Annual workload	<input type="text" value="1100.00"/> hrs.		<b>BFW   KWF   FAO</b>
Suggested price	<input type="text" value="175000"/> €	<b>Costs per hour</b>	
Max. operating hours of economic use	<input type="text" value="9000"/> hrs.	Depreciation	<b>Cost of depreciation per operating hour = Pr / (Nr * JA)</b>
Max. years of economic use	<input type="text" value="14"/> years	Interest	<small>Pr...Price of machinery/equipment</small>
Maximum annual workload	<input type="text" value="1800.00"/> hrs.	Repair cost	<small>Nr...Reduced time of economic use in years</small>
Interest rate	<input type="text" value="5.00"/> %	Garage cost	<small>JA...Annual workload in operating hours</small>
Cost of repair as a prize coefficient	<input type="text" value="0.90"/>	Depreciation of skyline	
Required garage space	<input type="text"/> m <sup>3</sup>	Interest skyline	
Cost of building per cubic meter/yr.	<input type="text"/> €	Depreciation of anchor cables	
Fuel consumption	<input type="text"/> l/h	Interest anchor cables	
Fuel price	<input type="text"/> €/l incl. VAT	Depreciation of tow rope	
Cost of lubrication as pct. of fuel price	<input type="text"/> %	Interest tow rope	
	<b>Skyline cable</b>	Depreciation of aux. rope	
Suggested price	<input type="text" value="13800"/> €	Interest auxiliar rope	
Max. operating hours of economic use	<input type="text" value="3900"/> hrs.	Depreciation of haulback line	
Max. years of economic use	<input type="text" value="6"/> years	Interest haulback line	
	<b>Tow rope</b>	Fuel and lubrication	
Suggested price	<input type="text" value="4768"/> €		
Max. operating hours of economic use	<input type="text" value="1300"/> hrs.		

Figure 56: cost calculation with BFW forest machinery database

For further information:

<http://bfw.ac.at/fmdb/maschinen.web>

or contact: Nikolaus Nemestóthy, BFW, Austria.  
nikolaus.nemestothy@bfw.gv.at .

Authors of the BFW Forest-Machinery-Data-CD, (4th Edition 2008): Richard Bauer, Eiko Gatterbauer, Hans

Hauer, Georg Kindermann, Johannes Lugmayr, Nikolaus Nemestóthy, Peter Preier, Gerald Schnabel, Hannes Schönauer, Herbert Spicar,

Authors of the Online-Forest-Machinery-Database 2014, Version 1.0: Oliver Cwiertnia, Hans Hauer, Nikolaus Nemestóthy, Peter Preier

## WoodChainManager - online tool for the visualization of production processes and cost estimates

For a preliminary estimate of costs, an online tool for the visualization of production chains with accompanying calculations made in the business process (production, service) has been developed by the Slovenian Forestry Institute within the framework of NEWFOR project. The very first forms of production chain visualization are found in literature from the early 1970s and can partially be associated with the time when machine cutting began to be practised in the forests. The visual approach in description of technological systems is no novelty in Slovenia either, although it has so far been used more or less for research purposes only, i.e. as a tool for easier understanding of differences between technological systems. The basic tool for description of technological models is the matrix, which visualizes cutting and haulage from the standing tree in the forest stand to the forest products at the final user. Changes in the processing of trees (e.g. standing trees, trunkwood and logging residues, roundwood (assortments), woodchips) are thus arranged on the ordinate axis. On the abscissa, on the other hand, the course of hauling or transport from the standing tree via different categories of forest roads to the warehouse on the forest (truck) road and finally warehouse at the final user (biomass logistics centre, sawmill, boiler room ...) is defined. The intersections in the matrix indicate the places where certain process or the state in conversion of forestry-wood assortment is modified (e.g. limbing or final cross cutting can be carried out in the stand on the skid-road or even on forest road). This online tool has been named "WoodChainManager" and is freely accessible by all users at <http://wcm.gozdis.si/>. The user independently determines which processes or operations will be implemented or included in the forest production chain (cutting, limbing/ bucking, cross-cut, making of woodchips, haulage/transport) and the location where they are to be carried out (forest stand, skid trail, skid road...). Hereinafter, the online tool automatically offers the user a range of technologies with which he can implement the selected operations at selected localities. In the operations that envisage shifts along thoroughfares (hauling or transport) as well, he also selects the locality where transport is to end. Algorithm of the online tool uses logical controls that enable the user to select unreal production chains or lead him to the selection of a logical and real combination of machines. Here the user can choose between several different machines and their appertaining additional equipment, such as various types and versions of adaptive machines for tractors (winches, forestry trailers...) and additional equipment for tractors (safety cabin, chains ...).



Figure 57: Visualization of forestry-wood chain using the online tool

In the first phase of the online tool's development for visualization of forestry-wood production chains, the tool with calculations of mechanization costs was additionally equipped. We focused on the simple cost calculation method, which at the same time reflects the state of actual costs in the forestry production chain. The online tool offers the user a range of standard parameters or cost items. The more demanding users, however, have the opportunity of changing the offered average values with their own data (e.g. engine power, annual use, purchase value...).

Parametri stroja			
Stroj	Traktor - štirikolesni pogon (75-94 kW)	Traktor - štirikolesni	
Moč motorja	85,00	kW	85
Nabavna vrednost	41.700,00	€	41.700
Amortizacijska doba	12,00	Year	12
Amortizacijska doba	10.000,00	Hours	10.000
Letna raba	500,00	Hours	500
Vrsta goriva	1,00		1
Faktor vzdrževanja*100	0,80	%	0,8
Fiksni stroški v €/leto	5.977,00	€/Year	5.977
Fiksni stroški v €/uro	11,95	€/Hour	11,95
Variabilni stroški goriva in maziva	17,12	€/Hour	17,12
Variabilni stroški vzdrževanja v €/h	3,34	€/Hour	3,34
Stroški skupaj v €/h	32,41	€/Hour	32,41

Shrani parametre

Figure 58: Calculation of costs for the selected technology enables a simple input of one's own parameters (e.g. purchase value, annual use...)

## Example of tool use

For a better understanding of the online tool's functioning, individual steps from the entry in the tool to the successfully created production chain are presented hereinafter. (👉①) – the number in parenthesis indicates commands (mouse click). Each step in the instructions is furnished with serial numbers of commands. Commands are followed by turns; they cannot be skipped and are recommended not to be repeated in order to implement them successfully (if the command (👉①) has already been executed, it is not to be repeated). With each step, the sequence begins again.

Picture of the palm equipped with number indicates the place on the picture where confirmation of command is envisaged (click) in the WoodChainManager online tool.

Example:

Example of the WoodChainManager online tool's use is presented in one of the most classical types of forest production, i.e. combination of standard cutting with chainsaw and hauling with tractor. The production chain begins in forest stand, when wood cutter falls a tree, delimits it and cuts the stem top off. This is followed by hauling of roundwood with tractor and use of winch along the skid-road to the forest road. This technological model involves the system of stemwood hauling according to the so-called full-length method, given that tractor driver saws the trunkwood with chainsaw (after disconnecting the cables and prior to wood levelling) into assortments only in the timber yard at forest road. Transport of assortments from forest road to the final user is envisaged with forest transport composition.

To simplify it all, the text is divided into separate forest production phases:

Phase 1: Cutting and trimming with chainsaw in forest stand

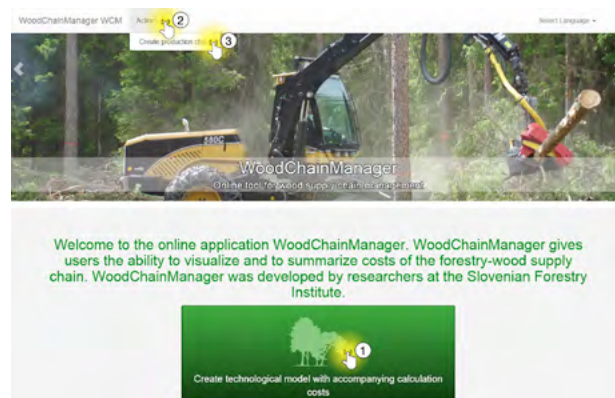
Phase 2: Hauling with tractor to forest road

Phase 3: Sawing (bucking) and making of assortments on forest road

Phase 4: Transport of assortments to end user with forest transport composition

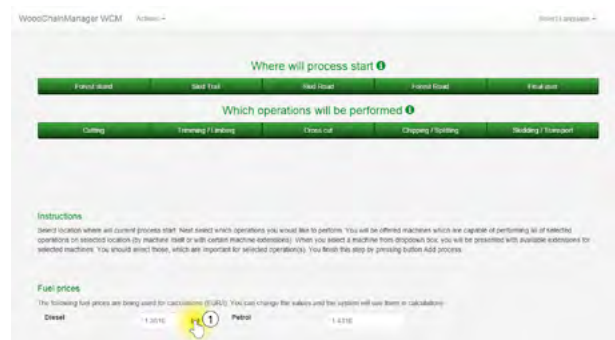
### Step 1

By clicking on the box "Create technological model with accompanying calculation costs" (👉①) on the entry page, the process of production chain preparation is started. This can also be done by using the drop-down menu "Actions" (👉②), where the box "Create production chain" (👉③) is found.



### Step 2

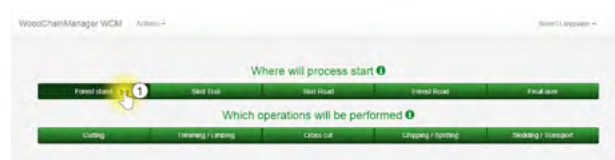
During step 2, the price of fuel is initially stipulated by clicking on the box "Petrol" or "Diesel" (👉①) and new value entered. Fuel prices are, otherwise, automatically updated each Tuesday.



### Step 3

During step 3, the location where production chain is to start is stipulated. This is done by clicking on one of the locations offered in advance (forest stand, skid road, forest road or final user) (👉①).

Example: In the chosen example, production begins in forest stand, which is why the selected location turns to a darker colour when clicking on the box "Forest stand" (👉①).



### Step 4

During step 4, we have to choose among the processes we wish to implement on selected location, stipulated during the preceding step. We can choose among five processes stipulated in advance, i.e. cutting, trimming,

cross cutting (sawing through), making of chips or firewood and hauling or transport. Hereinafter, the online tool automatically offers us the range of technologies that can carry out the selected processes on selected location. If the process "Skidding / Transport" is chosen, the online tool automatically offers us the selection of locations, where the process of hauling or transport is to end.

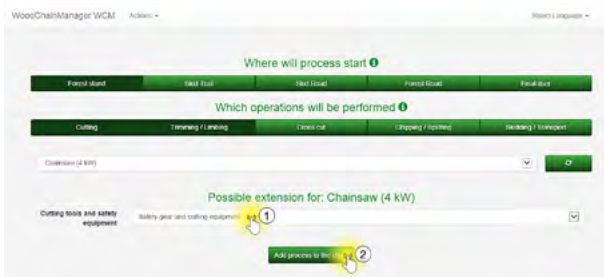
Example: In the selected example, wood cutter fells and delimits a tree. This is why both "Cutting" (1) and "Trimming / Limbing" (2) are selected with a click. A few seconds later the programme offers us a selection of technologies, amongst which the appropriate is chosen (chainsaw in the selected example) (3).



**Step 5**

If accessories or upgrades exist for the technology selected during step 4, we can choose among possible accessories during step 5 (1). The selected technology and processes are included in production chain with click on the box "Add process to the chain" (2).

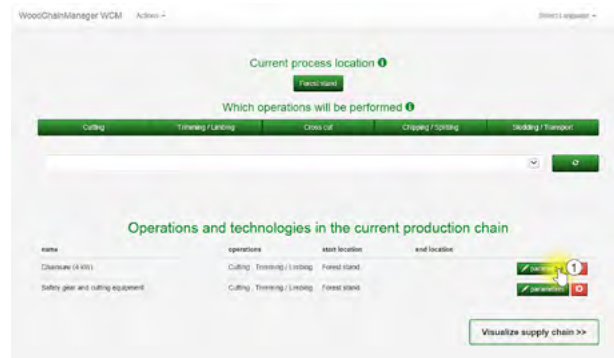
Example: In the chosen example, we can also select the accessory "Safety gear and cutting equipment" (1) and end with a click on the box "Add process to the chain" (2).



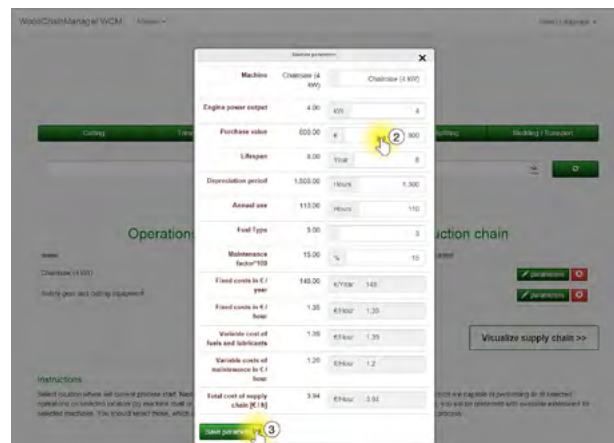
**Step 6**

As soon as the user successfully concludes the entry of the first process (technology) into production chain,

he gets control over the selected technologies and information on operation with location.



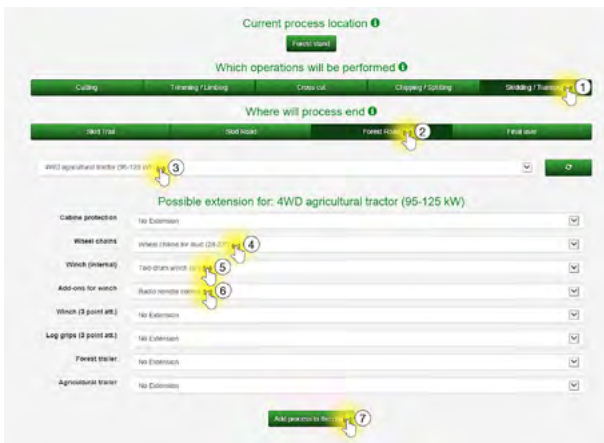
The online calculation tool utilizes parameters (data) stipulated in advance for all available technologies. The user can view the input data with a click on the "parameters" box (1). With a click on the box of individual parameter (2), the user can change certain data or enters the data that concern his technology (e.g. purchase value) or his conditions of work (e.g. annual use). The grey coloured boxes represent the already calculated parameters (or factors), which therefore cannot be changed. The user confirms the change in parameters with a click on the "Save parameters" box (3).



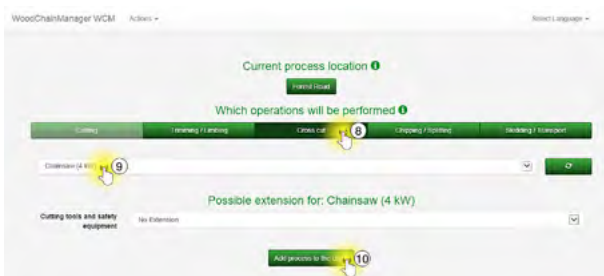
**Step 7**

Hereinafter, steps 4, 5 and 6 are repeated, until all processes or envisaged technologies for the selected production chain are entered. Step 3 does not need to be repeated, considering that the WoodChainManager online tool already knows the place of the current process on the basis of preliminary steps, which means that it does not need to be stipulated once more and cannot be changed at the same time as well.

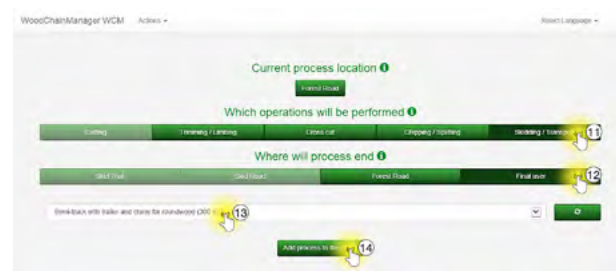
Example: Production chain is continued within the selected example with tractor haulage to the truck (forest) road, and as the online tool already knows the place of current process from preliminary steps, this does not need to be stipulated any longer. The process "Skidding / Transport" (1) is selected, then "Forest road" (2) stipulated as location where the process is to be terminated, and a suitable technology (e.g. 4WD agricultural tractor..) selected from the range of technologies (3). After choosing the technology, suitable accessories are selected as well. In the event of tractor hauling, numerous upgrades are possible (e.g. forestry wheel chains (4), built-in winch (5t) (5) and radio control (6)). It is therefore necessary to consider what we shall add, given that every accessory brings additional costs to the production chain. With a click on the box "Add process to the chain" (7) we conclude the matter and hereinafter examine the parameters as described in step 6.



Example: In the selected production chain, transverse cutting of stemwood is envisaged on the truck road as well, which is the reason why we select the mentioned process ("Bucking/transverse cutting" (8) and chainsaw (9) or technology with which the selected process is to be implemented. With a click on the box "Add process to the chain" (10) we conclude the matter and hereinafter examine the parameters as described in step 6.

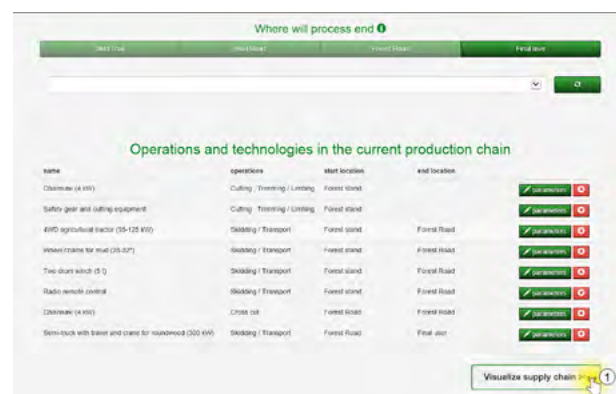


As the selected production chain ends with transport of assortments to the final user with forestry transport composition, the above mentioned process "Skidding / Transport" (11) is selected, as well as the location where this process is terminated ("Final user") (12) and technology with which we wish to implement the selected process (e.g.. "Semi-truck for roundwood with crane and trailer") (13). With a click on the box "Add process to the chain" (14) we conclude the matter and hereinafter examine the parameters as described in step 6.



### Step 8

In the last step we are left only with conclusion or, in the first place, a review of all selected machines / technologies in the production chain. If all operations and technologies envisaged in the selected production chain are stated in the list of processes (see under "Operations and technologies in the current production chain"), there follows only a confirmation, together with a graphic display of production ("Visualize supply chain" (1)).



### Step 9

After a successful selection of all operations and technologies, the online tool offers the user a report that includes:

- Costs of mechanization in the selected production chain (with a possibility of simplified and detailed display) and total costs of the selected production chain;

WoodChainManager VCM

Actions (2) Create production chain (3)

### Costs of selected processes

Print (1) (0 workpieces)

Simple table

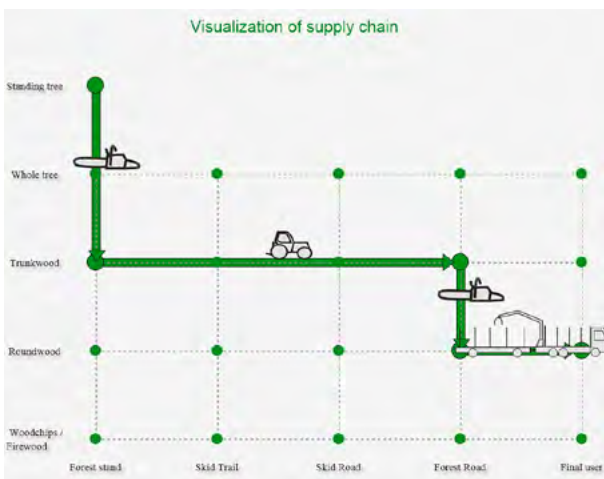
Machine	Fixed costs in €/ year	Fixed costs in €/ hour	Variable cost of fuels and lubricants	Variable costs of maintenance in €/ hour	Total cost of supply chain (€/ h)
Chainsaw (2 400)	145 00€	1,39€	1,39€	1,20€	3,98€
Stability gear and cutting equipment	111 00€	0,30€	0€	0,42€	0,72€
4WD agricultural tractor (90-125 kW)	768 33€	13,34€	23 69€	4,28€	41,31€
100hp chains for road (26-32")	143 33€	1,79€	0€	0,50€	2,29€
Two drive winch (3 t)	860 00€	2,01€	0€	2,40€	4,41€
Skidder remote control	173 00€	1,21€	0€	0,88€	2,09€
Chainsaw (2 400)	145 00€	1,39€	1,39€	1,20€	3,98€
Skidder truck with trailer and crane for skidder (200 kW)	23800 00€	79,50€	16,42€	14,93€	100,85€

Full price used for calculation: Chain: 1,2019 €/hour + 4,4212 h

Detailed table

Total cost of supply chain [€/ h]: 159.49 €

- and a sketch of forestry-wood production chain.



Calculation of total costs per hour and visualization of selected forestry production chain renders the user a solid preliminary estimate of costs. Further development of the online tool depends on its financing, but in any case it would be reasonable to carry on with its development and upgrading the tool with additional economic and environmental components that play an important role in forest production. A close target is to upgrade cost calculation in such a way that calculation of costs per production unit (e.g. €/m<sup>3</sup>) will be enabled as well. Within the environmental component framework, the development is aiming at developing a decision-making tool, aimed at assessing the adequacy of selected technologies in forestry-wood chain according to given terrain and weather conditions. This decision-making tool can also serve as a device in the implementation planning or preparation of work. With the use of this decision-making tool, indeed, do not achieve a direct production rationalization, but present the environmental aspect of production chains in the woods. The decision-making tool is in the first place intended for preparation of work, although it is also useful in the implementation of operations in changing working conditions (e.g. dampness at worksite or machine failure, due to which substitution mechanization is to be selected or additional / unforeseen machine used to fill the capacities).

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The user has the option of printing the prepared report by pressing "Print" (1) or saving it in electronic form. On the basis of several prepared reports, the user has a good control over different production chains. To prepare a new technological model or chain, click on the box "Actions" (2) in the upper left corner and on the box "Create production chain" (3) and start composing a new chain (step 2).



## Critical nodes and future opportunities

**Cons:** this system requires a constant update of the available products and their costs

**Pros:** offers a basic “standardisation” of cost calculations.

Future perspectives can include the opening of the system to different countries, allowing wide possibilities for usage all over the Alpine range and more.

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# Logistical planning strategy



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In the framework of the NEWFOR project, several tools have been developed according to each WP goals and activities.

It has been evident quite from the early stages of the project that it was impossible to build a single DSS (Decision Support System) tool able to catch all the facet of mountain forest management. The choice was thus to create different tools able to use or create data from or for each other. The concatenation of these tools is able to provide a powerful support system, and the modular structure guarantees a high flexibility.

Since almost all the forest related data are characterized by a spatial information, the use of GIS platforms for performing the analysis or for providing the input data to the tools was the best solution. The strategy adopted in NEWFOR was to use as much as possible open source or freeware software and to create user-friendly tools.

In order to facilitate this task and potentially to guarantee to all the potential stakeholders to access the results and data obtained in the project, a WebGIS has been implemented (Figure 59).

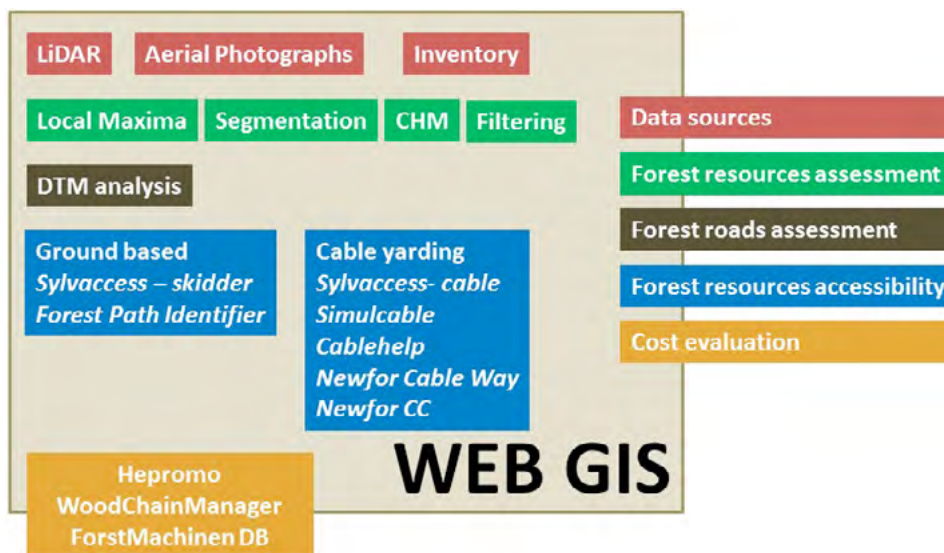


Figure 59: Schema of project components

## NEWFOR-WebGIS, online tools for interoperability, data access and analysis

In this digital era, surveying technologies allow the acquisition of large amounts of data, which get capitalized when correctly stored, shared and analysed. In the NEWFOR project data consist of several formats and data types, acquired from LiDAR flights and derived from processing raw data of different kind. The objective of the NEWFOR-WebGIS is to provide a tool for interoperability between partners' data and users which want to access the data, launch advanced processing, and potentially use it also for further processing with their own software.

### What is NEWFOR-WebGIS

NEWFOR-WebGIS is a geospatial infrastructure hosting a database management system with spatial and non-spatial data, as well as modules and tools for data representation and processing. The functionalities follow a "software as a service" paradigm. All functionalities are hosted on a server that manages data access and the tools for processing.

From a practical point of view, the project partners and future potential end-user can access the NEWFOR-

WebGIS with an interface available from any web-browser (IE Explorer, Mozilla, Chrome etc...). There is no particular requirement in terms of hardware and software for the users. Access is done by entering a specific URL (<http://newfor-websig.grenoble.cemagref.fr/>) on the browser, thus accessing the initial page (Figure 60). Clicking on the NEWFOR project logo, or on each partners' dedicated space aggregated by country clicking on the countries' flag, will take the user to the interface.



Figure 60: Initial page to enter the portal of NEWFOR-WebGIS.

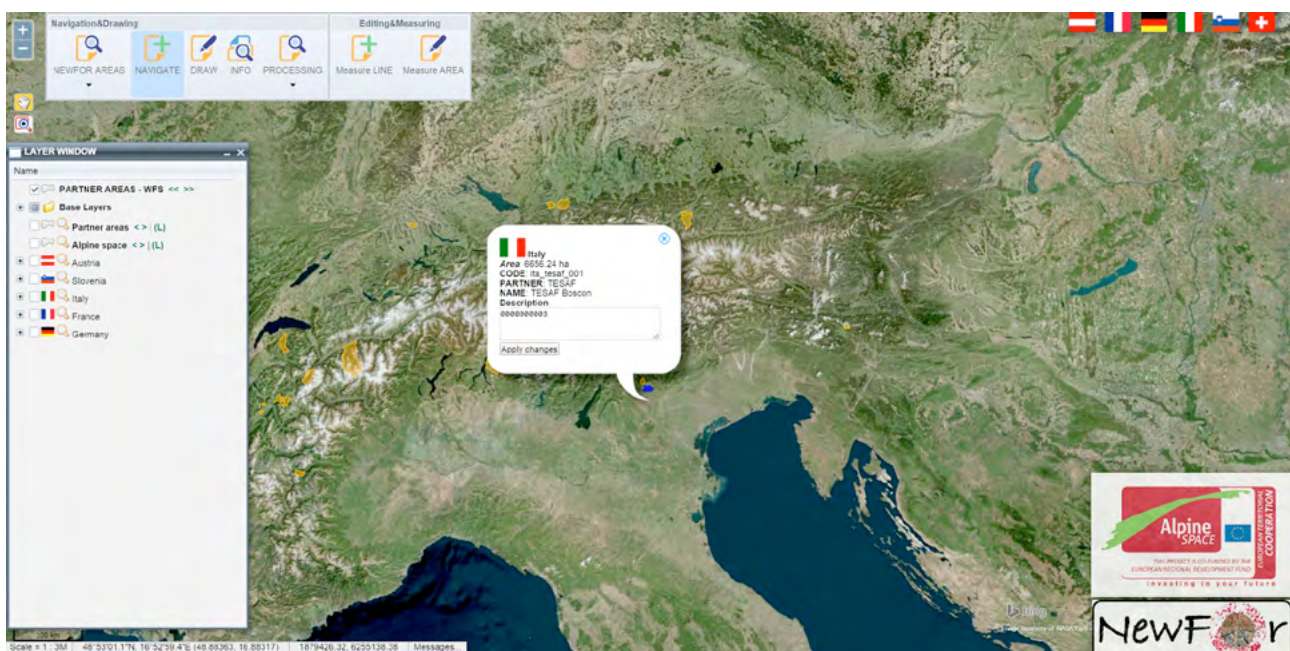


Figure 61: Initial view of main portal of NEWFOR-WebGIS with partner areas as selectable orange polygons

## HOW NEWFOR-WebGIS works

### Access and initial view

The user opens any internet browser in his PC and by means of the address (URL) of the NEWFOR-WebGIS gets into the initial entry page (Figure 60). From clicking the main Alpine Space logo, the user is directed to the main portal, with an overall view of the Alpine Space area (Figure 61). From there he can view the partner study sites as orange polygons and he can see each area's detailed information by clicking on it with the mouse.

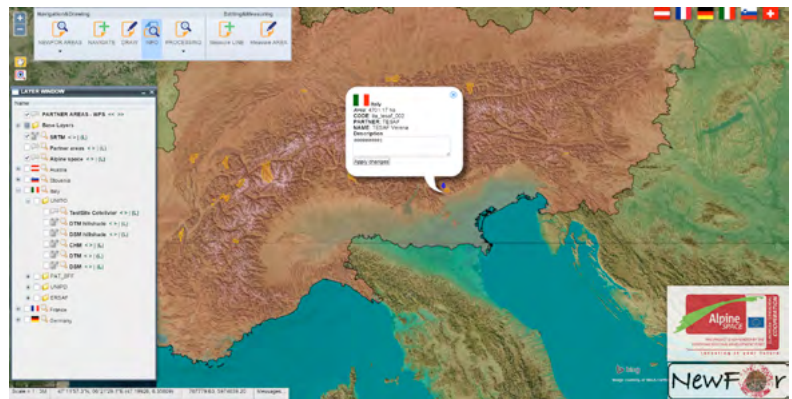


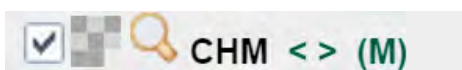
Figure 62: NEWFOR-WebGIS interface with Alpine Space area

### Available layers

There are three types of layers loaded in the portal:

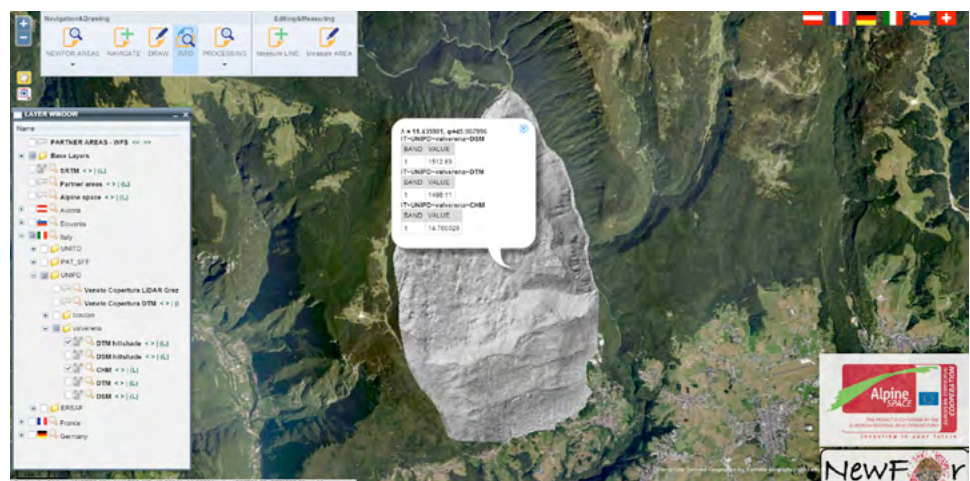
1. base layers from third parties, which are available, to this date, from Google and Bing services (aerial, street or hybrid maps);
2. base layers from the project, with project-level information, e.g. the whole Alpine Space area and the single study sites of the partners (Figure 62);
3. partner data layers, where queries and zoom are enabled (Figure 63).

For each layer the user can use the icons in the menu, which appear near the layer's name (see image below), which have the following functionalities from left to right:



1. a checkbox to flag for showing and hiding the layer; upon showing a loader appears while the server processes the data. It is advisable to unflag any layer which is not being viewed directly;
2. an icon representing raster or vector data. In the example in the image above it is a raster, in case of vector data the icon will represent points, lines or polygons depending on the data type;
3. a zoom icon to go directly over the data;
4. the name of the layer;
5. "<" and ">" characters to change transparency of the layer;
6. "M" opens a window that loads the metadata associated with that layer.

Figure 63: Partner study site with query results over DTM, DSM and CHM



The user has access to all data divided into folders and subfolders. From more general to more specific levels, folders are containers grouping data related to each country, each partner and partner's sub-areas or other distinctions that it decided to create in its directory. Loading and managing data is done via ftp; for more details see the following section, "Loading and pre-processing data". The organization of information layers is visible in Figure 64, where in section (A) the menu shows data divided in countries and partners; each

visible dataset can be zoomed into and its transparency changed. This last possibility is not only for aesthetics, but useful for visual interpretation of the data, as it is possible to combine multiple overlapping layers and see the composition of land cover from aerial images and other information from the other layers. In the example in Figure 64 in section (B) we can see a shaded relief model derived from processing the digital terrain model (also available in the portal), which in turn was created from the LiDAR survey over the area.

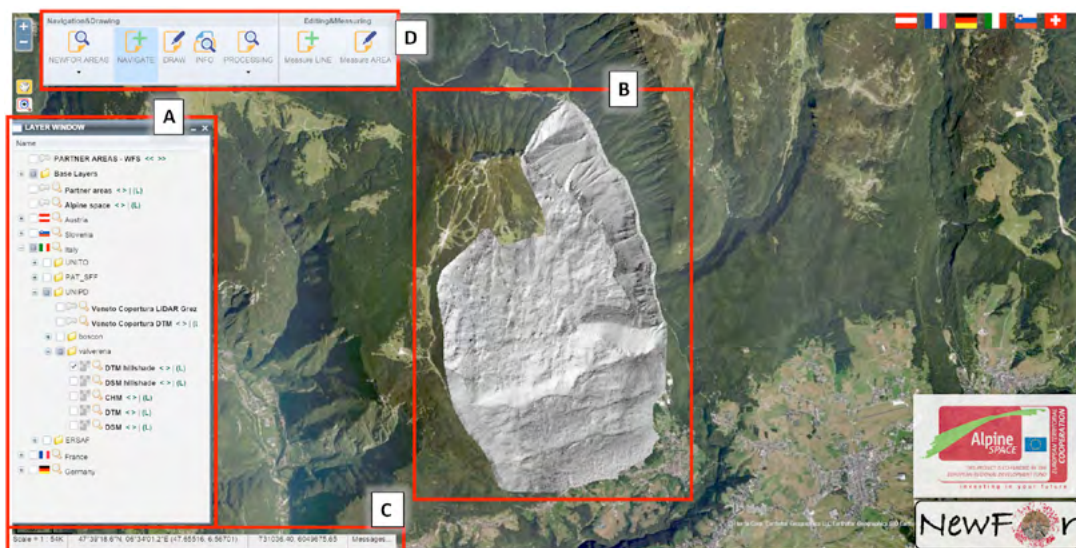


Figure 64: Different parts of the portal: see running text for details

## Tools

There are two types of tools available in NEWFOR-WebGIS, the first type is related to simple query tools which operate directly on the map, the second type is the group of advanced tools which allow to operate on the original data via server-side execution.

In Figure 64 in section (C) a bar shows, from left to right, the scale of the current view, the coordinates of the mouse pointer; the latter are shown in latitude and longitude, with both coordinate pairs reported in sessagesimal and sessadecimal formats (left and right respectively). The rightmost coordinates are in the projected pseudomercator system.

Also in Figure 64 in section (D) the toolbar on top allows the user to measure distance and area using the two right-most buttons. The "info" button on the same toolbar, when selected, allows the user to click with the mouse on top of any of the partners' layers, and launch a query on the original data that are stored on the server (Figure 63).

The more advanced processing is done by going to a study site and then, depending on the type of process, carry out a task which is chosen from the "processing"

button in the top toolbar shown in Figure 64 in section (D). In the following example the task is to extract forest-related information over an area around a polyline (which might be the line of a cable-line). In Figure 66 the user draw the polyline over the northern part of the study site. He then selects from the drop-down menu of the "processing" button the "profiling" tool. This will make the "advanced processing window" appear (Figure 65) and the system automatically defines a list of rasters whose data are spatially under the drawn polyline, and allows the user to choose from this list using a drop down menu. The chosen rasters will be used as data source for calculating profile, volume estimation, and canopy height value distribution function. The user also chooses a buffer distance from the polyline which he drew. The buffer will create a polygon that delimits the area where the height data will be processed. When the user presses the "Launch process" button then a window appears with log data which reports the advance of the process, updating every five seconds (Figure 66 window on the right). In this example the digital models of the surface and of the terrain (DSM and DTM respectively) will be used to create a canopy height model (CHM) and the value of the cells in the CHM will be used to make further estimation of distribution of canopy height, and volume estimation (Figure 67 and Figure 68).

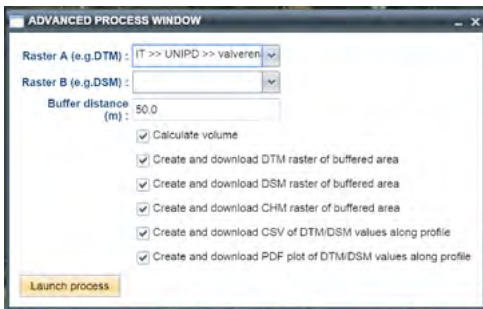
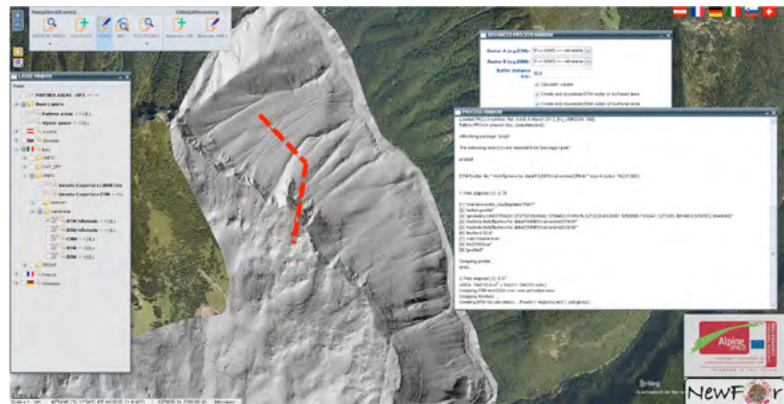


Figure 65: Advanced processing window, with drop-down menu for choosing rasters to be processed

Figure 66: User draws a polyline over the study site (red line) and processing is done over that line (windows on the right).



## Interoperability potential

At the end of the process described in the previous section, the user can also download a pdf document with the results, and a textual representation of the profile data – i.e. the height values of the DTM and DSM along the polyline (Figure 68). The latter is in delimited text format, and can be used as input for any software which allows to import spatial data in textual format.

The strength of the NEWFOR-WebGIS portal is not only in the developed functionalities, but on the way that it is structured, which allows to extend functionalities without investing so much time as it is usually required initially. Linking existing software can be either done directly on the server, by passing the partner's data as input to the software via interaction of the user with the NEWFOR-WebGIS portal, or, in case the software is on the client's machine, by adding an extra-passage, i.e. downloading the data and importing it in the software manually.

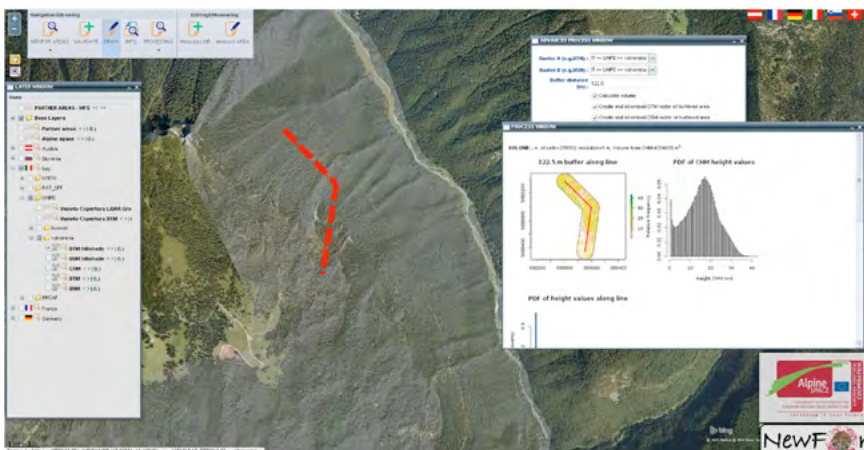
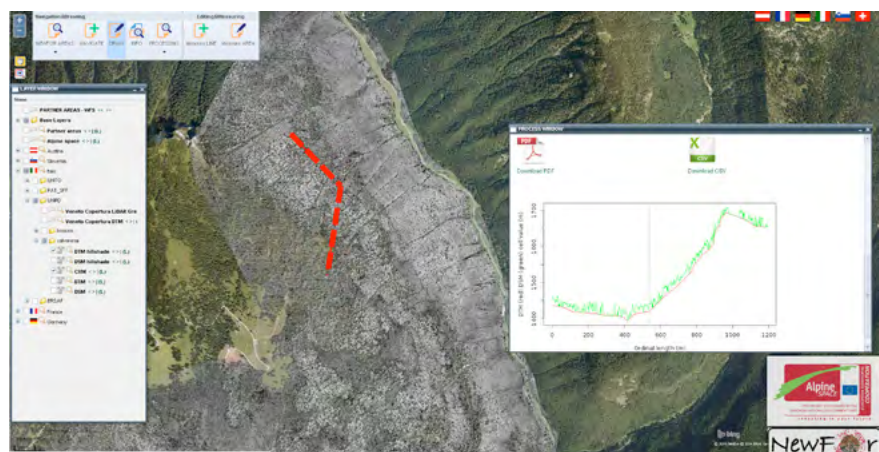


Figure 67: Results from processing of the "profiling" tool

Figure 68: Results from processing of the "profiling" tool



## Technical details

### Structure

Being a complex infrastructure, NEWFOR-WebGIS is made up of different parts, which have been implemented using open source (OS) libraries. Each part can be roughly divided into:

- I. visualization segment – using a web page and web-scripting with a mapping engine it projects the data on the users' screen;
- II. data management segment – currently using a file-based system managed via BASH scripts and geo-spatial libraries, it allows to organize data in terms of path and characteristics in order to be used by the other two segments;
- III. geo-spatial processing segment – using R-cran with spatial libraries, it allows advanced processing of the raw user data which is available.

The following OS libraries were used extensively: UMN Mapserver, OpenLayers, GDAL/OGR and R-cran with their latest versions at the time of the project. The following programming/scripting languages were used to implement the portal and the ancillary scripts: C++, PHP, R and Javascript. All the above projects are open-source.

### Loading and pre-processing data

Partners or potential end-users upload their data in a common container, i.e. disk drive, accessible via FTP protocol from any network. The shared disk space is mounted on a Debian Linux machine where the NEWFOR-WebGIS is hosted. The following are recommendations for the preparation and formatting of the data:

- I. use georeferenced GeoTIFF for raster data and georeferenced shapefiles for vector data;
- II. make sure that the coordinate reference system (CRS) is included, either by hard-coding in the file itself (e.g. in the GeoTIFF file) or as ancillary files (e.g. the \*.prj file in the shapefile model);
- III. raster files should not have, when possible, pixels with null values, and if it is necessary to have null values in the file then make sure that they are correctly defined in the file itself;

- IV. raster files should not have pixels with outlier values, to avoid low contrast when applying the default linear colour scale stretch over the values (e.g. a raster file representing canopy height values, thus with a value distribution from ~0 to ~50, with a single outlier pixel with value 500, will be represented in black and very dark grey colour, and the single outlier pixel with white colour).

Once in the shared disk space, the data are processed to be integrated in the NEWFOR-WebGIS SDI with a highly automated method which loops over all the folder tree-structure which have the partners' data. All spatial-related files (e.g. GeoTIFF and shapefiles) are processed for the following tasks over each file:

- I. read the CRS – coordinate reference system;
- II. define the extents, i.e. the bounding box, in a standard CRS (geographic – WGS84);
- III. calculate the minimum and maximum values for raster data, in order to apply a correct colour scale stretch;
- IV. if not present, create overview-pyramids over raster files for improving loading speed when viewing.

The custom executable was developed in C++ and uses the GDAL/OGR library to extract all the above information from each file and create an index in Mapserver's mapfile format which will be used for visualization and processing. An exception over raster data is when the data are made up of multiple files which mosaic to the whole area. In this case, a VRT format (see GDAL documentation at [http://www.gdal.org/gdal\\_vrttut.html](http://www.gdal.org/gdal_vrttut.html)) was created to index each file in a single reference.

The final result is a spatial data infrastructure with linked datasets with a common structure in Mapserver's mapfile. User interaction via the web-portal allows the server to trigger processing steps which can be easily replicated in innovative modules.

The Mapserver mapfile created as described in the previous section is then used to load all the data in the menu and provide the user with tools to view it and access its data.

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## Critical nodes and future opportunities

**Cons:** the WebGIS needs for continuous maintenance by skilled personnel

**Pros:** very high potential accessibility for end-user; even alone, it can be used as a “training” platform for approaching to the new technologies or for dissemination strategies of information

NEWFOR-WebGIS is a container of data and of tools which improve accessibility and analysis. It adds value to existing data by sharing it with a larger audience, where potential users access data from a single share point, and can load their own data, boosting a collaborative mechanism. Sharing data in an open manner is an aspect that will increase in the future, in many fields of application, and will give in return more possibilities and push towards standardization of formats, avoiding losing information when moving and copying data.

Future development of NEWFOR-WebGIS can be divided in the following streams:

- I. improving data management using a database management systems (DBMS), preferably PostgreSQL enabled with PostGIS spatial library;
- II. leveraging the Open Geospatial Consortium services which are compliant with latest guidelines from the European community (INSPIRE);
- III. adding more advanced catalogue services to follow up on the previous point and allow searching with meta-keywords;
- IV. adding more modules to enhance ETL (extract transform and load) from/to third party software which requires input data from NEWFOR-WebGIS.

The main direction of further development will also depend on feedback from users which will highlight possible improvements of existing functionalities and provide insights for adding functionalities. This process is one of the advantages of a collaborative network which is what the NEWFOR-WebGIS encourages in the first place.

Since the logistic planning strategy of the wood chain from forest to sawmills is based on different steps and tools, the constraint and difficulties are almost the sums of all limitations found earlier in this manual. The lack of an harmonization of the definitions and rules at the Alpine Space is a huge problem, not only among Countries, but even inside national boundaries between different Region. A complete LiDAR data coverage of the Alpine Space along with forest road network databases based on a common classification would greatly boost the use of these new technologies also in the mountains forests.

## The events

In order to show the results of the project and to increase the awareness of potential end users, stakeholders, and all people living in mountain areas of the alpine space, several activities have been carried out during the three years of NEWFOR life. Two main dissemination events, held during 2014, animated the final period, arising people's interest, both from the forestry sector and from the non-technical public: final conferences and NEWFOR Summer School.

One of the final workshops for presenting this manual of good practices was held at BosTer 2014 (<http://www.fieraboster.it/>). For the first year since the establishment of the exhibition, BosTer (acronym for "bosco"-forest and "territorio"-land), the biggest Italian outdoor forestry fair, has been split into two. In addition to the original early fall event located in Oulx (Torino province, North-West Italy) inside a test site of the project (named "Cotolivier"), a further one has been held on the Cansiglio plateau (Treviso province, North-East Italy) during the first week of June. The two weekends gathered approximately 13,000 visitors. Inside both events NEWFOR was there with a stand showing the tools developed, results achieved (forest maps, 3D models,...), and technologies used in the project (LiDAR, UAV, laser rangefinder,...). Hundreds of people stopped by and were directly informed on NEWFOR activities and achievements (Figure 69). From kids to elderly peoples, from local inhabitants to tourists, forest landowners to forest technicians, different categories showed high interest in the project and acquired new information about the application of new technologies in mountain forests.

In addition, more technical events have been organized with the goals of informing forest practitioners, manager,

and local administration. A technical meeting has been held in Trezzo sull'Adda (Milano, Italy), in the framework of "Forestry Edu" events, organized by ERSAF Lombardia. The event, thought as a free formation course for public and private practitioners, has been able to collect more than 70 people, showing that there is a strong willing in understanding the potential of these new technologies.

### NEWFOR Summer School

In July 2014, the NEWFOR Summer School took place in the Italian Alps. Almost 30 people coming from all over Europe (Austria, France, Germany, Italy, Poland, Serbia, Slovakia, Slovenia, Spain and Switzerland) spent a full week to learn about LiDAR technology and its applications in the forestry sector. University students, PhDs and public and private forest practitioners formed the class of the project summer school held in a mountain lodge on Mount Verena (Asiago plateau, Vicenza province), inside a NEWFOR test site ("Verena" study area). It was therefore possible for them to collect field data and then extract the same information from LiDAR data, producing maps of trees and biomass location, forest road network and forest accessibility. The participants, working with the NEWFOR staff, had to deal with the main project topics, such as forest parameters' estimation, harvesting and road planning, for which a final report has been presented. Further experiences included a demonstration of UAV flights, using both a fixed wing and a multirotor (hexacopter), thanks to which has been possible to evaluate differences and applications of this new breakout technology.



Figure 69: NEWFOR stand at the BosTer North-West event in Oulx (Torino, Italy)



Figure 70: Participants and assistants of the NEWFOR Summer School 2014

# Conclusions



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## Recommendations for an efficient mountain forests action plan in the Alpine Space

From the beginning of time, man has modified the environment he lived on and therefore the forest has been one of the key point of land management strategy for developing a sustainable liveable space. The simplest definition of a forest is the following one: a plant community dominated by trees and other woody plants growing relatively close to each other. Traditionally, in mountain areas man has assigned three main functions to forest as 1) the production of timber and (or) other forest products (mushrooms, berries, etc.), 2) protection against natural hazards and 3) watershed protection (soil stabilization, water regulation...). Man has then exploited it regularly by entrusting these specific functions (production, protection, etc).

Nowadays, the term "forest functions" has evolved to the one of ecosystem services provided by forests. Due to the evolution of the human society, these services includes also landscape protection, fauna and flora protection, carbon sequestration, the economic sector including the whole wood supply chain.

Their economic value, the functions they must provide and the management required for maintaining and improving these functions state that forests have to be considered as a real heritage. A heritage is all the property, rights and duty of a person or a system. According to all the services provided, mountain forests are the woody ecosystems for whose heritage aspects are the most pronounced. This notion of heritage is one of the expression of the multi-functionality of these forests. So they should be considered not only as primary production units (timber production and investment income) serving particular interests but as heritage and cultural assets for the human society. So, forest ecosystems serve the interests of the community.

All these functions must be taken into account in the development of adapted forest management, forestry actions and forest policy. But according to its natural dynamics, the forest is changing and only certain stages of development meet the various functions that are expected of it. This inventory determines the first baseline that decision and policy makers have to keep in mind for defining a sustainable and adapted mountain forest action plan:

### People need the forest, and the forest needs our support

The concepts of sustainable development, biodiversity and multi-functionality, have become essential for the management of natural environments. Management is the art of making decisions guided by the pursuit of goals that vary depending on the systems studied. Forest management is therefore all the means and methods used to manage a forest to ensure its ecological balance and allow it to optimize its various functions. Managing mountain forests is significantly more expensive than managing lowland forests. This is mainly due to the constraints generated by the slope and climatic conditions, but also by the ones coming from human implementations and associated activities (i.e. leisure activities that create new constraints on land uses). The main result of all these constraints is the spatially and time limited access to mountain forest resources. Merely to manage mountain forest according to the general principle of sustained yield (to use no more than the forest can produce), is currently no more efficient to sustain all the mountain forest ecosystem services.

In relation with these statements and according to the results gained by the consortium of the project NEWFOR the following 10 baselines for defining an efficient Alpine Space mountain forests action plan should be considered:

1. Mountain forests are multifunctional ecosystems but an efficient and sustainable forest management and land use strategy have to be based on the definition of priority functions. This could only be done if efficient decision support systems (DSS) are developed in order to identify, qualify, quantify and prioritize the different forest ecosystems services.

2. Such a DSS is only a tool, so it is necessary to develop a real governance policy for its uses:
  - a. The DSS and the tools associated have to be developed using geographical information systems in order to provide maps that should be used as negotiation support with the different actors.
  - b. The DSS and the tools associated have to be actors oriented by offering the possibility to each actor to propose its own weighting and set of priorities. The confrontation of each result then will encourage the search for consensus.
3. The prioritization of mountain forest ecosystems services has to be based on the optimization of the natural dynamics of forest stands.
4. If the production function is not sufficient for covering all the management and resources extraction costs then, as preserving and improving the efficiency of mountain forest are key points of public interest, an adapted economic context has to be settled. A specific attention should be paid to the monetisation of ecosystem services.
5. The monetisation of mountain forest ecosystems services can only be done if all the actors are identified and if the public general interest is well defined and displayed. Cost-benefits analysis should be carried on in order to clearly analyse the added value of this "bio-based" land use management. These are the necessary and sufficient conditions for the acceptance by all of this ecosystems services' monetisation. All the users or beneficiaries of these services should be clearly identified and a financial solidarity should be built up in order to help the forest owners and managers to sustainably manage the mountain forest functions of public interest.
6. All the methods and associated tools for defining and prioritizing mountain forest ecosystems services should be harmonized at the Alpine Space scale in order to develop a rational utilisation of forest resources and European funds taking into account the potential benefits and costs of actions. For reaching this goal the development of a global European strategy for providing, producing and disseminating high resolution data consistent with the outcome of the foresters' and more generally users' requirements should be pursued.
7. The access to and mobilization of mountain timber resources should be enhanced in respect to the different mountain forests ecosystems services. This also requires optimising the uses of timber and wood in the local, regional and national economies.
8. According to the specificities of topographic and climate conditions in mountain areas, the preservation and enhancement of the protective role of forest stands against natural risks have to be considered as the key drivers for the development of an efficient action plan for strengthening the liveability of the Alpine Space. This has to be done in consideration to the principle of sustainable production in order to also guarantee the sustainable use of forests as one of the most important reservoir of renewable raw material.
9. The success of all these baselines can only be guaranteed if a public awareness based on an efficient communication strategy is developed. In other terms the forester has to get out of his forest and communicate!
10. The future forest action plan should be built up on the concept that foresters and associated policy have to guarantee and leave a value environmental legacy for future generations.

## Specific and technical recommendation

According to the activities conducted during the three years of the NEWFOR project, recommendations are provided in the next sections of the document. These were formulated from the project's experience in (i) applying new technologies, (ii) testing several tools with data from the Alpine Space region and (iii) using several expert hearings and feedback from stakeholders and potential end-users.

### Forest structure evaluation

#### **UAV flight planning and law limitations**

Many developments in national and European legislation, related to restrictions and permission for UAV surveys, have occurred mainly during the concluding year of the project, through all the Alpine Space region. Some issues are likely to cause confusion or even be a source of problematics in handling data collection through UAV surveys. Detailed information on legislation concerning UAV are provided by the national aviation authorities and mostly also local model aircraft associations. On the website of the European Aviation Safety Agency – EASA – useful links to national UAV regulations can be found (<http://easa.europa.eu/unmanned-aircraft-systems-uas-and-remotely-piloted-aircraft-systems-rpas>). See also the homepage of the "German Speaking Association for Unmanned Aerial Vehicles" ([www.uavdach.org](http://www.uavdach.org)) for news concerning legislation, certification, technologies and actual research in Austria, Switzerland, Germany, Italy and the Netherlands.

Recommendations for a safe and proper data acquisition:

- Follow the national legislation and certification regulations;
- Select the appropriate aircraft for the application purpose (multicopter / fixed wing aircraft). Remember to consider flight time, flight range and visibility of and to the UAV;
- Find an area close to the test-site for starting, piloting and landing. Carefully take into account that the UAV has to be ALWAYS visible from the pilot's position;
- Care for wind and position of the sun which may cause reflection hampering visibility (blinding);
- Use automatic mode only in case you receive enough GNSS-related signals and thus proper positioning at all times;
- Preparing an intelligent flight plan saves battery, flight

time and processing time. Try to hold a constant height above ground and follow a regular flight pattern. Plan a high image overlap in all directions;

For forestry applications it is better to avoid extreme wide-angle lenses due to strong radial distortions.

#### **LiDAR data acquisition**

For forestry related LiDAR data acquisitions the following recommendations are formulated:

- Minimum point density: 4 laser pulses per m<sup>2</sup>;
- At least first and last echoes, beneficial are intermediate echoes or even full-waveforms, even if the latter require skilled personnel for post-processing;
- High positional accuracy: strip differences less than 5 cm; accuracy in XY less than the footprint size;
- Delivering the 3D point clouds and not only derived raster models;
- In addition to the 3D point clouds also the trajectory information should be delivered;
- Detailed information about the coordinate system used as well as other metadata (e.g. date and time of flight, company etc...).

### Forest roads planning and industry connectivity

#### **Nomenclature and definition parameters**

The definition of a common nomenclature and standard technical parameters is definitely the most important goal to achieve within the alpine territory. Indeed, the movement of forest companies among the different countries in the Alpine Space in the last years have become more and more frequent. It is then often necessary to be able to offer to a foreign company a proper planning overview, both for harvesting and later mobilisation.

#### **Forest road data bases**

- Data must be compatible or easily convertible for integration in route guidance system because in the future transport companies will use route guidance systems for navigation and optimization/planning of wood transport.

- Upgrading the data must be done in a collaborative way by the end-users, not only forest management organizations but also transport enterprises and logging companies. Specific procedures must be defined to control the proposed upgrading (new forest roads, temporary obstacles, unpractical section both on public and forest roads).
- The qualification of forest roads should be uniform and consistent and based on European harmonized criteria.
- A good connection between the public road and forest road network need particular attention and post processing data is necessary to make sure that this connection is well established.
- According to the fact that classical field survey (men + GNSS) for forest roads mapping are highly time consuming for a low accuracy results, the research and development action on how to use automatic acquisition of data for forest road qualification (Lidar, embarked equipment in trucks....) should be followed up in order to provide a new and cheaper conventional methods. Public organizations responsible for Geographic Information have also to provide "first level" data and could provide the general frame housing the forest road data.

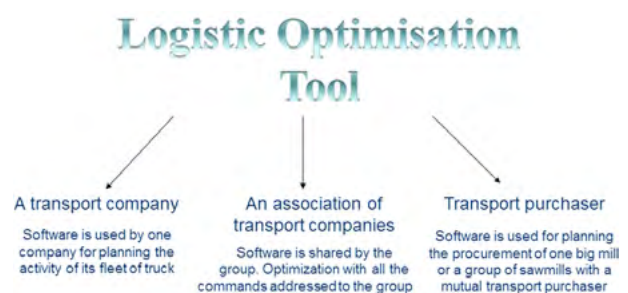
### Transport planning tools

- The specific national regulations must be easily integrated and taken into account in the algorithm used for timber transportation optimization from the forest to the users (e.g. public road network with specific regulations in terms of allowable payload or with particular tax). This research of optimization should of course consider the utilization rate of the trucks fleet but also the cost of transportation, including toll and taxes.
- The softwares which will be developed in the future should be high speed calculator in order than they can quickly propose new options in case of unexpected perturbations and changes (climatic hazards, engine failure on truck or harvesting material in the forest, difficulties on forest roads, and changes in the delivery program of the mills...).

- Transport companies must work in a common way. Optimization is more efficient when possibilities of allocation are higher.
- Back haulage strategy should be taken into account in the optimization tools as it is an important lever to decrease the cost of transport when using non forest-specific truck such as tractor + semi-trailer.
- Transport planning tools must be considered in a global logistic optimization with data exchanges (Electronic Data Interchange) between all the enterprises involved in the supply chain (transport companies, logging companies, sawmills, pulp mills and chipboards mills. The objectives are to have up-to-date data for planning and a good knowledge of the wood stocks all along the supply chain: in the forest, at the roadside, in the factories.

### Organisation

- New organisations must be found for an improved efficiency.
- Transport companies must work in collaboration. Sawmills should also collaborate because optimisation is more efficient when possibilities of allocation are higher.



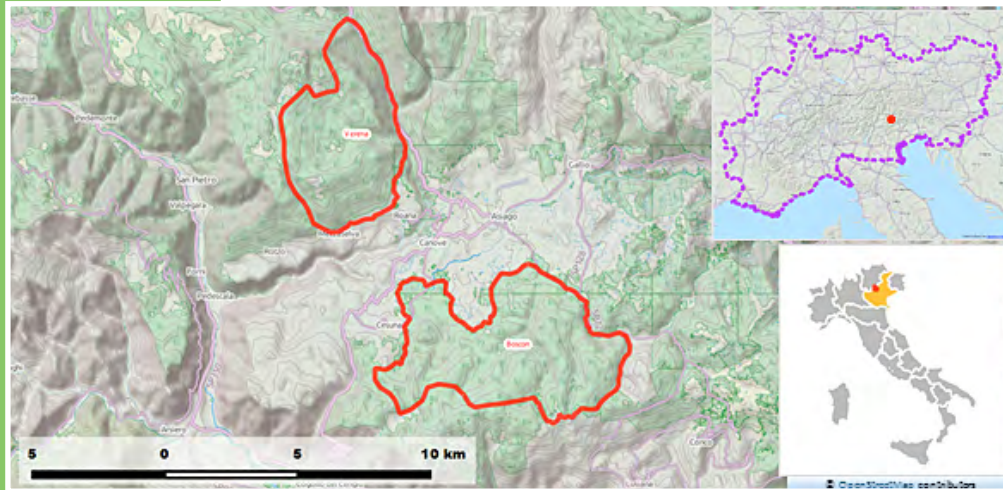
- Transport planning tools must integrate new organisation frameworks.

# Pilot areas





## Asiago plateau



### LOCATION

Asiago, Veneto region

### TEST SITE

Boscon (32 km<sup>2</sup>)

Verena (23 km<sup>2</sup>)

### HEIGHT RANGE

1200 - 1650 m.a.s.l.

### FOREST TYPE

Pure conifer high stands

Mixed high stands

Beech coppices

### REFERENCE PARTNER

University of Padova,  
T.E.S.A.F. Department

The Asiago plateau (Vicenza) is situated in a karstic plain area on the esalpic range of the north-eastern Alps, and these characteristics make it the ideal site for the project purposes.

The test site is divided into two areas: the bigger one, called "Boscon", has an extent of about 32 km<sup>2</sup>, and it's mostly characterised by spruce stands (*Picea abies* (L.) Karst.) (some of them have been planted after World War II), silver fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.), both pure and mixed. In the "Verena" area, approximately 23 km<sup>2</sup> wide, spruce and silver fir stands represent the majority of tree composition, with less than 10% of the extent occupied by beech and larch (*Larix decidua* Mill.).

The structural variability present in the forests of the area is very high, going from evenaged to unevenaged, from high stands to coppices and making this site particularly suitable for the study and development of different methodologies to extract structural parameters through LiDAR. Both areas are identified as productive forests in the management plan and the quite gentle morphology already allows the usage of heavy machinery (harvester, forwarder) and traditional logging systems and cable yarding.

## The Clöise forest reserve

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Within the "Boscon" area, compartments D116 and D117 (approximately 17 ha wide) constitute a special reserve for the study of structural biodiversity and no forest operations are allowed. A specific monitoring permanent plot of 1 hectare size, covered mostly by spruce and silver fir, have been studied as a reference for the LiDAR data acquired for the same area.



## SUMMER SCHOOL

In the period in between the 20-27 July 2014, an international group of 30 students participated to the NEWFOR summer school held close the "Verena" study area.

In one week, the participants have been briefly introduced to the LiDAR usage within a case study, in which different groups had to deal with all the aspects connected to forest structure and road planning.

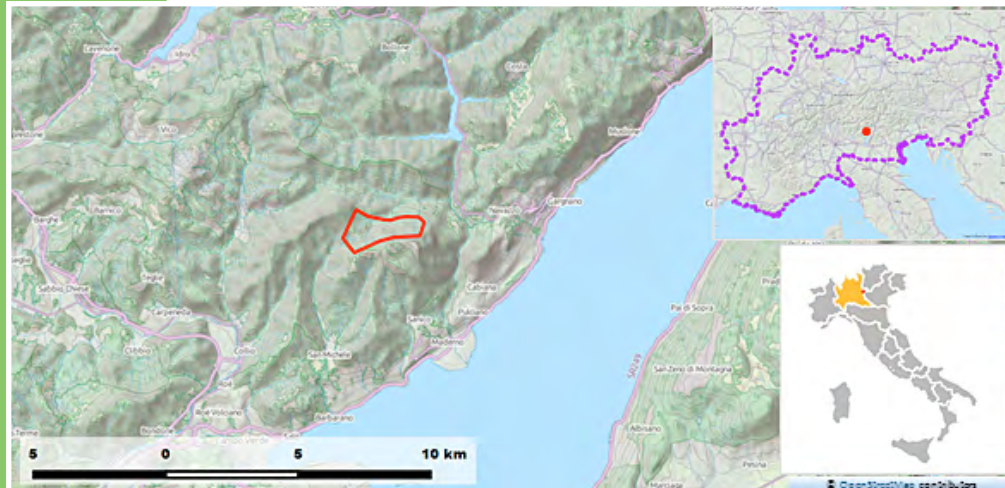
## Logging control through UAV flights

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An experimental flight has been carried on after a planned logging activity, in order to estimate the real timber extraction from the site. The elaboration demonstrated that the usage of Unmanned Aerial Vehicles can provide for quick and cheap surveys, within control or database update activities.



# "Gardesana Occidentale" Regional Forest



## LOCATION

Gardesana Occidentale  
Regional Forest ,  
Lombardia region

## TEST SITE

Archesane valley (2 km<sup>2</sup>)

## HEIGHT RANGE

800 - 1270 m.a.s.l.

## FOREST TYPE

Broadleaf mixed forests  
Broadleaf mixed coppices

## REFERENCE PARTNER

ERSAF Lombardia  
u.o. Innovazione e  
ricerca dei sistemi  
forestali e naturali  
(Gargnano-BS)

The most extended public regional forest of Lombardia is located in the west-side of Garda lake, across the pre-Alps. Gardesana Occidentale Forest, with more than 11.000 ha is a part of Alto Garda Regional Park.

The forest has an average altitude above 600 m.a.s.l., with maximum elevation of 1976 m.a.s.l. (Caplone peak).

The landscape is unique, with striking panorama on the lake and stunning view on forest and rocky slope of valleys.

Broadleaved, coniferous and mixed stands are characterized by the prevalence of black pine, ash, maple, manna ash, oak, beech, scots pine, spruce and mountain pine. On the cliff is common to find a lot of endemic plants.

The main goal of regional forest and park is to protect these flora and the typical mountain fauna, such as: chamois, eagle, capercaillie, black grouse and sporadically bear and lynx.

The test site has an extent of about 2 km<sup>2</sup>, and it's mostly characterised by maple (*Acer pseudoplatanus* L.), ash (*Fraxinus excelsior* L.), hornbeam (*Ostrya carpinifolia*) and beech (*Fagus sylvatica* L.).

The structural and species composition variability of the area is very high, from coppice to high stands and making this site particularly interesting for the study and development of different methodologies to extract structural parameters through LiDAR from broadleaved forest stands.

## Broadleaves forests and LiDAR data

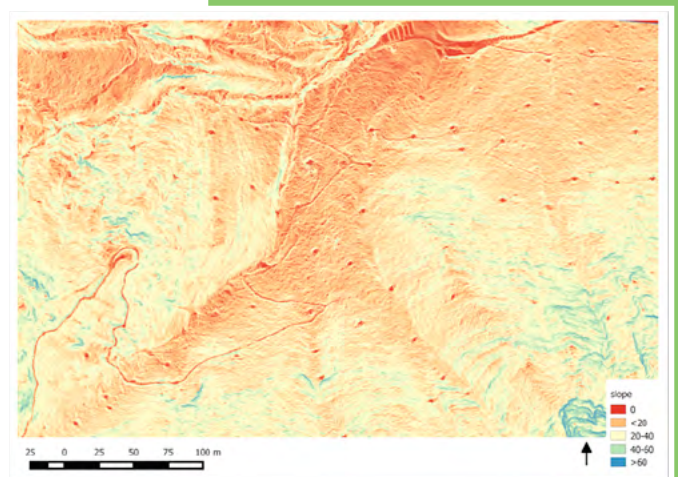
The test site Gardesana was selected to test the LiDAR technology in mixed deciduous forests. The results are obviously worse than the use of the laser scanner on coniferous stands, because the extraction of individual trees from the crown model is more difficult operation. So we decided to collect the parameters to the ground as done in other sites but then applying area-based methodology to extract variables LiDAR. It is however difficult to collect information about the dominated layer of the forest. One solution would be to work directly on the LAS point cloud.



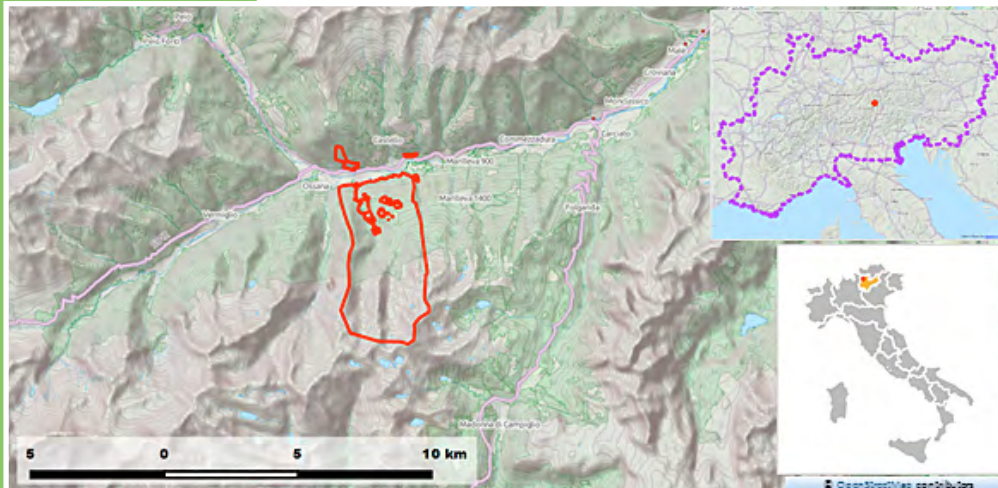
## Charcoal production

Among the different proofs of the past management of the Gardesana area, LiDAR gave the possibility to identify the distribution of the old charcoal production sites.

Indeed, as already demonstrated in many archeological studies, this new technology could be an auxiliary tool to detect the location of historical remnant of human presence. The Digital Terrain Model (DTM) elaborated from the point cloud can give us information about the slope of the terrain. Where the values are very low this underlines flat zones, for example roads, tracks or pastures.



## A.S.U.C. Pellizzano



### LOCATION

Pellizzano – Trentino province

### TEST SITE

Forest property of Pellizzano  
(11,38 km<sup>2</sup>)

### HEIGHT RANGE

930 m – 2767 m.a.s.l.

### FOREST TYPE

Pure or mixed spruce and  
larch stands

natural mixed spruce-fir  
stands

### REFERENCE PARTNER

Forest Service of the  
Autonomous Province  
of Trento

### **The pilot area**

The forest property of the A.S.U.C. (Separate Administration of the Civic Uses) of Pellizzano is located in the Sole Valley in the endalpic range of the central Italian Alps.

It covers a total area of 1.640 hectares, of which 706 hectares are productive forests, 430 ha are non-productive forests, 500 ha are pastures, shrub, rocks and other soil uses.

The exposition is North, on metamorphic and magmatic rocks, with consistent depositi morenici del Quaternario, determining mainly terre brune soils with very high fertility.

Since 1960, the property is managed in accordance with forest management plans of the duration of 10 years, based on forest inventory conducted by traditional callipering; in 2012 a new forest inventory was conducted by sampling plots.

Timber production is very important in Pellizzano, so it was chosen as a pilot area to develop methodologies for extracting structural parameters through Lidar and calculating the distribution of timber volumes at different scale.

### **Productive forest**

Productivity is very high, with an annual increment of 8,5 m<sup>3</sup>/ha on average, reaching 12 m<sup>3</sup>/ha in the best locations. The mean growing stock is about 350 m<sup>3</sup>/ha, but it reaches 500 m<sup>3</sup>/ha in several forest units. Big trees (over 50 cm diameter-DBH) are 62%.

The annual yield is 3.000 m<sup>3</sup>.

## Silvicultural goals

The management target is to produce good quality timber, maintaining and improving the natural regeneration, the diversity in the composition and the structure of the stands, and the timber production capacity. Therefore, clear cutting are generally avoided.

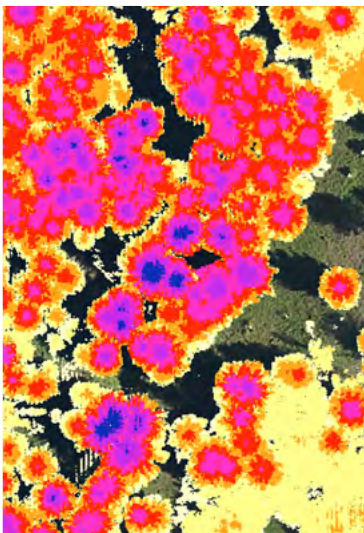
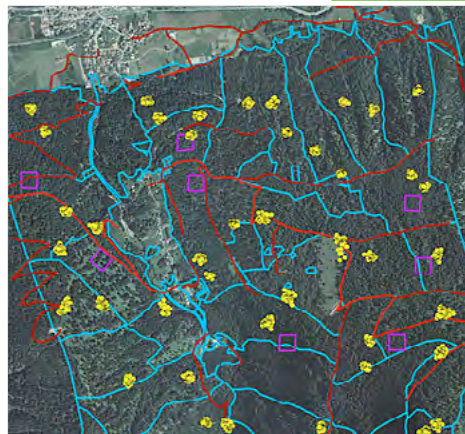
Particular attention is given to the protection of the habitat of capercaille and to the maintenance of landscape and touristic value.



*Silvicultural treatments maintain and improve habitats for Capercaille also in production forest*

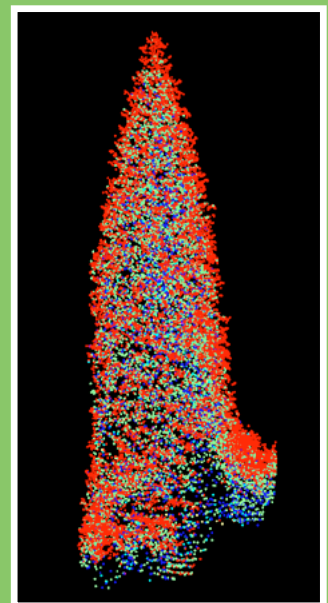
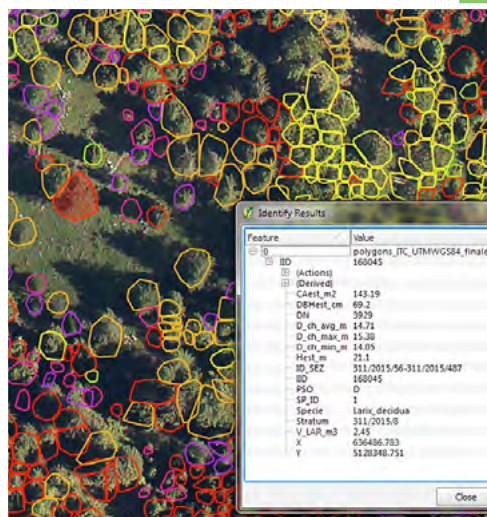
## Testing new technologies and developing methodologies

1. A traditional forest inventory was conducted, based on 368 plots over 10 forest strata
2. About 5000 trees were detected on the field, to measure their position and main parameters.
3. 8 areas of one hectare were totally callipered, to measure the volume by traditional way
4. Inside the 8 areas, 8 circular areas were measured more in deep per single tree
5. A Lidar flight was done over the whole area. Also hyperspectral data and ortophoto images were taken.



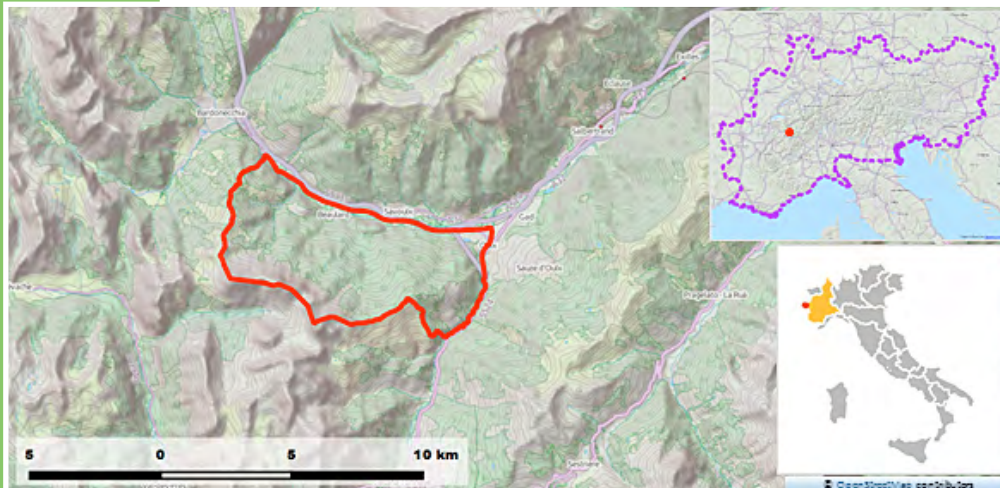
6. Tree crowns were detected; LAS and CHM data were elaborated to find forest parameters such species, diameter and volume of each detected tree

7. Results were compared with field data



*High density point cloud of a subalpine spruce*

## Susa Valley



### LOCATION

Oulx, Piedmont region

### TEST SITE

Cotelivier (39 km<sup>2</sup>)

### HEIGHT RANGE

1050 - 2850 m.a.s.l.

### FOREST TYPE

Pure conifer high stands

Mixed conifer high stands

The Cotelivier study area is about 4000 ha and is located on the right bank of the Upper Susa Valley (Piedmont), between Oulx and Bardonecchia. It's a North facing slope ranging from the montane belt (about 1000 m a.s.l.) up to the treeline (about 2200 m a.s.l.). The forest is composed by *Pinus sylvestris* at lower elevation, *Picea abies* at intermediate elevations and by *Larix decidua* at higher elevations. This tree species variability reflects also a high structural diversity: pine and spruce stands are more homogeneously structured, but larch stands range from sparse wood pasture with few big trees to dense and young stands. Herbs and shrubs are locally abundant when the openness of the stand permits their persistence.

The morphology of the territory in terms of slope and roughness is sometimes very harsh, thus productive forests and protective forests are both present. The more productive and accessible sites has always been characterized by intense forest exploitation, but the topography limited the use of a massive mechanization. The field plots ( $n = 33$ ) are randomly distributed within supposed homogeneous structural types, this stratified sampling design is aimed at cover a high variability in species composition and forest structure.

### REFERENCE PARTNER

University of Torino,  
D.I.S.A.F.A. Department

## Real data - Forest cuts

4 sample plots (about 5000 m<sup>2</sup>) were harvested:

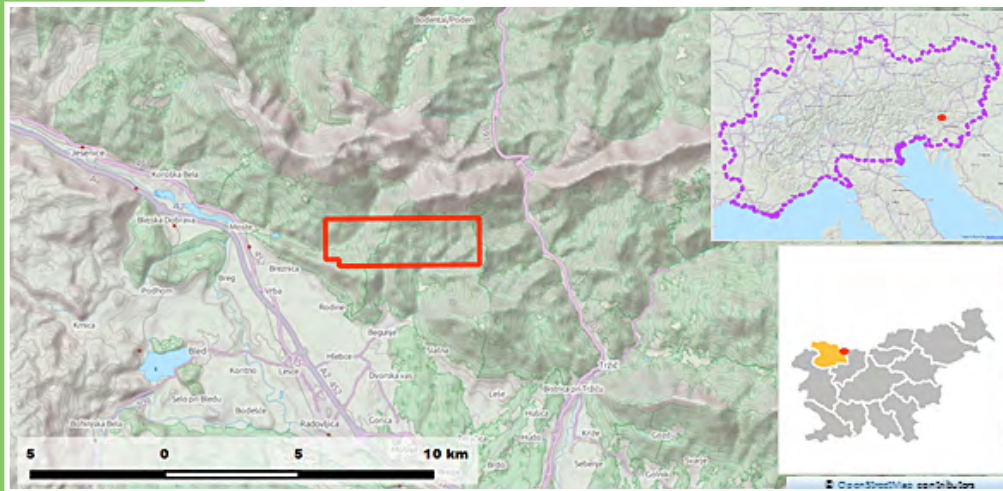
- 1 Larch – clearcut (53 harvested plants)
- 1 Spruce – thinning (26 harvested plants)
- 1 Spruce – thinning (27 harvested plants)
- 1 Spruce + Scots Pine – thinning (31 harvested plants)

All the felled trees were measured to get some “real” data, which have been compared to LiDAR and field data to further evaluate the accuracy of these two different survey approaches.





## Begunjščica



### LOCATION

Slovenia, Gorenjska region

### TEST SITE

Begunjščica (9,79 km<sup>2</sup>)

### HEIGHT RANGE

650 - 1350 m.a.s.l.

### FOREST TYPE

Uneven aged stands  
(in mixed stands conifer  
dominate)

### REFERENCE PARTNER

Slovenian Forest  
Service

The pilot area is located in the northern part of the Gorenjska Region in and around one of the longest mountain ridges in Europe, named Karavanke. This region has relatively high altitudes (its highest peak is 2236 m), rugged terrain, and many mountain backs, ridges and tops which descend into the valley with steep, sometimes precipitous slopes. These slopes are cut by a number of gullies and ravines that end in narrow valleys, through which the water flows into the lowlands in the form of strong, torrential mountain streams.

The predominantly alpine climate has distinctive temperature extremes, an annual amount of precipitation of 1700 – 2500 mm, and has an average yearly temperature of 4 – 6 °C with occasional, stormy winds.

The area is characterized by extreme biodiversity, and has extensive areas in Natura 2000. It also has a number of smaller protected areas and natural values which are eliciting great interest for recreational activities and the development of tourism, also because of the nearby urban and tourist centres. The Karavanke Mountains are depending on the relief conditions, in different degrees exploited for forestry, agriculture (mostly pasture), and as stated earlier, tourism and recreation that is centred around hiking.

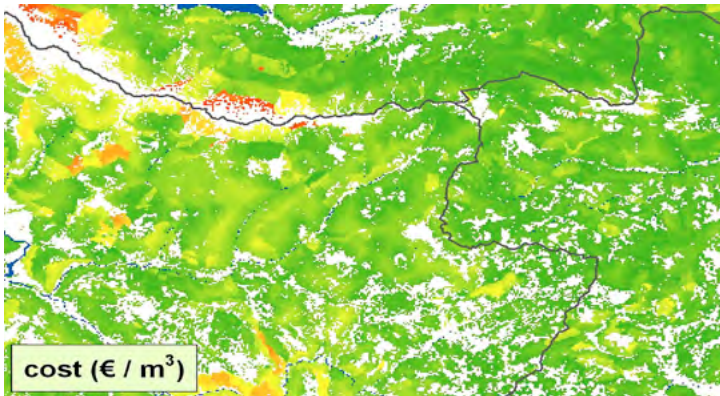
The pilot area extends across two narrow and steep valleys: the Završnica Valley is orientated West to North-East and the one of the Draga Valley is South to North.

## Cost calculating tools

### **SWEIS**

SWEIS is a flexible and adaptable methodology based on:

- 1) the use of geo-reference socio-demographic databases and databases of natural resources which are incorporated into a geographic information system;
- 2) the minimum spatial unit of analysis at the sub-national level;
- 3) a modular, flexible, and open frame which includes information relating to the wood energy from different sources. Due to the high level of detail of the input data, the resolution of the SWEIS output is a 25m cell. The 25m raster data supports a very high spatial detail of analysis, which makes the information adequate for the local operational planning level, and not only for strategic planning. SWEIS also includes data on energy consumption and the possibility of computation of the balance sheet, and displaying the flowing areas of woody biomass to customers – taking into account the cost of cutting and skidding to a truck road.



### **xTi**

xTi is a cost calculating tool developed by the Slovenian Forest Service. It is a tool whose output consists of:

- 1) time consumption, separately for felling and skidding of wood;
- 2) felling and skidding costs for an individual worksite. The tool provides customers with relatively accurate values of harvesting costs which can be used for negotiations with providers of forestry works. Also, the profit from forests can be calculated on the basis of the data output of the tool xTi.

### Slovenia Forest Service

is a public institution, established by the Republic of Slovenia, which performs public forestry service in all Slovenian forests, irrespective of ownership.

At state level it is organized with its central unit in Ljubljana. At regional level in 14 regional units, and at local level it has 69 local units and 396 forest districts. The Slovenia Forest Service also comprises 10 hunting reserves with special purposes.

In 2014 the Slovenia Forest Service celebrated its 20th anniversary.

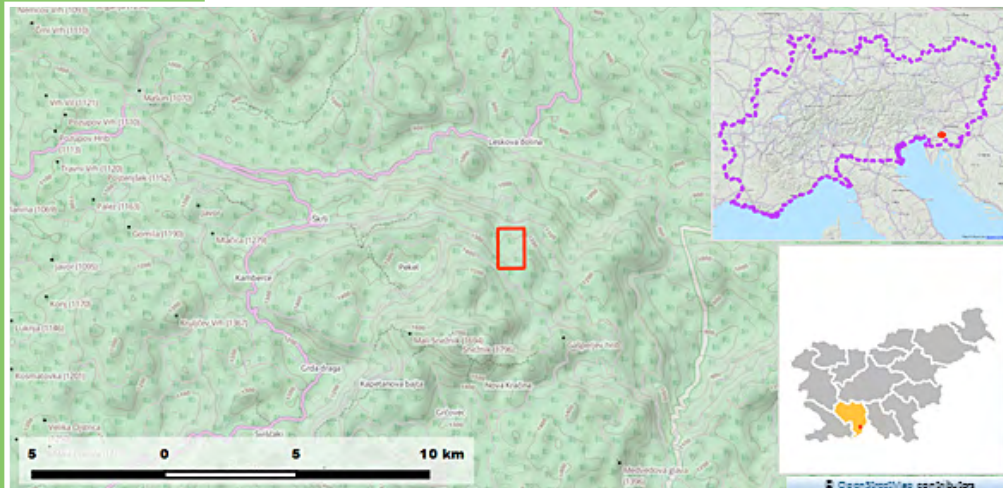
### MISSION

Preservation and close-to-nature development of Slovenian forests and of all their functions for their sustainable and good management and use as well as nature conservation in forest space for the good of present and future generation.



ZAVOD za GOZDOVE  
SLOVENIJE  
Slovenia Forest Service

# Leskova dolina



## LOCATION

Snežnik Mountain

## TEST SITE

Leskova dolina (52 km<sup>2</sup>)

## HEIGHT RANGE

850 - 1650 m.a.s.l.

## FOREST TYPE

Mixed high stands

Beech stands

Spruce stands

## REFERENCE PARTNER

Slovenian Forestry  
Institute

Test site is located in predominantly forested landscape of Leskova dolina in the Dinaric Mountains of southwest Slovenia (center of area approximately located at Longitude = 14.46°, Latitude = 45.62° in WGS84 datum). The karst geology on the site is characterized by numerous sinkholes and limestone outcrops, resulting in very diverse micro-topography. Soils, predominantly Lithosols, Leptosols, Cambisols and Luvisols, are derived from the limestone parent material, and soil depth can vary between 0 and 300 cm, depending on micro topographic position. Precipitation is evenly distributed throughout the year with mean annual precipitation of 2150 mm. Mean temperature is 6.5°C, late spring and early autumn frosts are common.

Forest covers 97.6% of the study area with prevalent vegetation community of Dinaric silver fir–European beech forest (*Omphalodo-Fagetum* s. lat.) with European beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.), and Norway spruce (*Picea abies* (L.) H. Karst.) as the main tree species. Sinkholes shape, size and distribution have significant impact on the forest soil and hydrological characteristics (Vilhar & Simončič, 2012; Vilhar et al., 2005, 2010), and consequently on the tree stand. In such karstic conditions with high number of sinkholes, the forest management needs to be adapted to very rough as well as sensitive terrain.

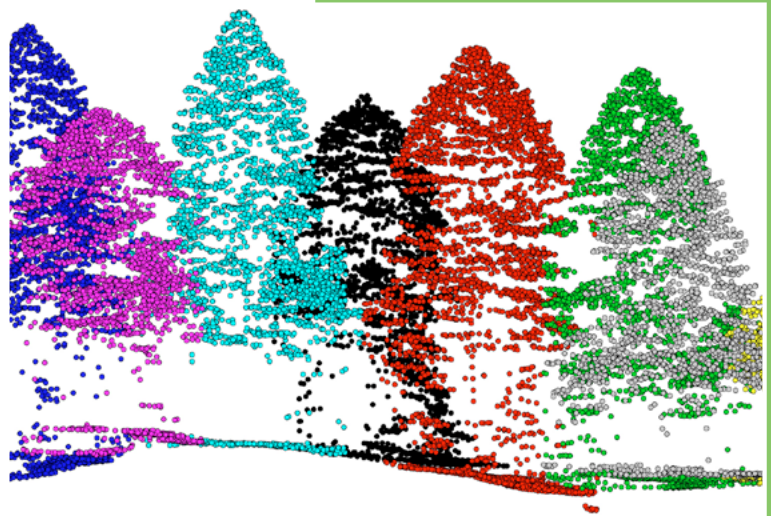
## Ice storm

In the period between 30.1. and 6.2.2014, ice storm disturbed forests on the lower part of the Snežnik Mountain and the Leskova dolina plateau between 850 to 1250 m.a.s.l. Storm killed a significant number of trees, reducing basal area and stand densities. The storms also removed the canopy cover, uprooting of trees were also present. Both abiotic and biotic factors (mountain, slope, tree size, and species) influenced patterns of tree damage and mortality.

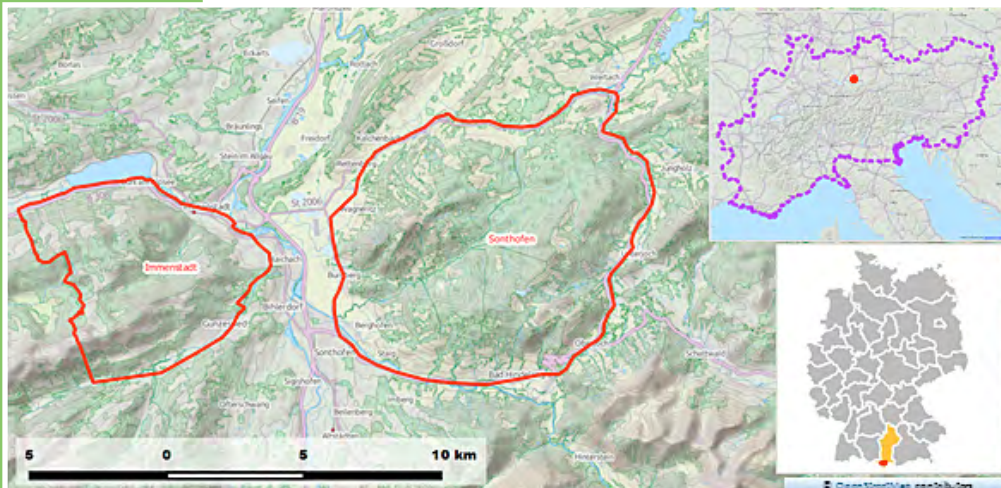


## LiDAR data

Lidar data was acquired by a private company using a Eurocopter EC 120B helicopter between 400 and 600 m relative flight height and a full-waveform laser scanner Riegl LM5600 using 180 kHz frequency of laser impulses. Point density was 30 points/m<sup>2</sup> with an average footprint of 30 cm.



## The "Allgäu" district: Immenstadt and Sonthofen



### LOCATION

Allgäu district, Bavaria

### TEST SITE

Immenstadt (42 km<sup>2</sup>)

Sonthofen (92 km<sup>2</sup>)

### HEIGHT RANGE

700 - 1750 m.a.s.l.

### FOREST TYPE

Pure conifer high stands

Mixed high stands

### REFERENCE PARTNER

*Bavarian Forest Institute,*

*Department of Forest  
Management*

The pilot region consists of two areas located in the most southern part of Bavaria and Germany – the "Allgäu" district near the border to Austria. Both areas lie closely together, divided by the valley of the river "Iller". In the following the both areas are referred to as "Immenstadt" (4200 ha) and "Sonthofen" (9200 ha), named after the both cities situated near by the respective areas.

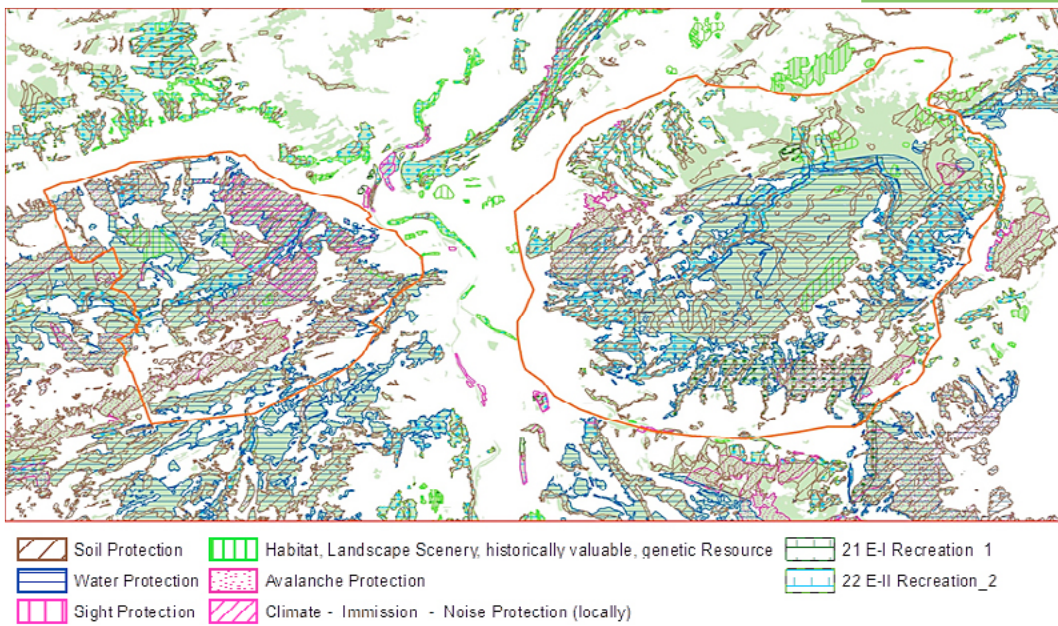
The region is the biggest skiing center in Germany and is highly attractive to visitors and tourists due to the manifold and beautiful landscape scenery of its mountains, lakes and natural monuments. Tourism plays a very important role for this region. Another important economic factor is agriculture dominated by dairy farming. Besides this economy in this region in general is middle-class-oriented with focus on mechanical and electrical engineering and food processing.

Climate in the region is warm temperate and frequently weather is influenced by "Föhn" – a warm mountain wind. The yearly precipitation lies between 900mm and 2.500mm. Due to extensive relief rainfall floods are a common phenomenon in this region.

Natural forest vegetation shows a relatively clear sequence. Beginning in the western part with beech-fir forest communities at about 400m sea level followed by beech-fir-spruce, fir-beech-spruce, spruce-beech-fir and spruce-mountain pine communities in high mountain areas. Above are the alpine natural pastures that climb up to the rock regions.

## Forest functions

Besides the statutory protective functions (fixed by law) forest function plans define forest functions and necessary forest structures more in detail. The figure below shows that practically the whole Immenstadt region and the overwhelming part of the Sonthofen area is covered by one or more of these functions.



All functions as described in the plan can be found in both areas. In many cases forest stands are covered by two or even more overlapping functions. Large parts of both areas are also part of "Landscape protection areas".

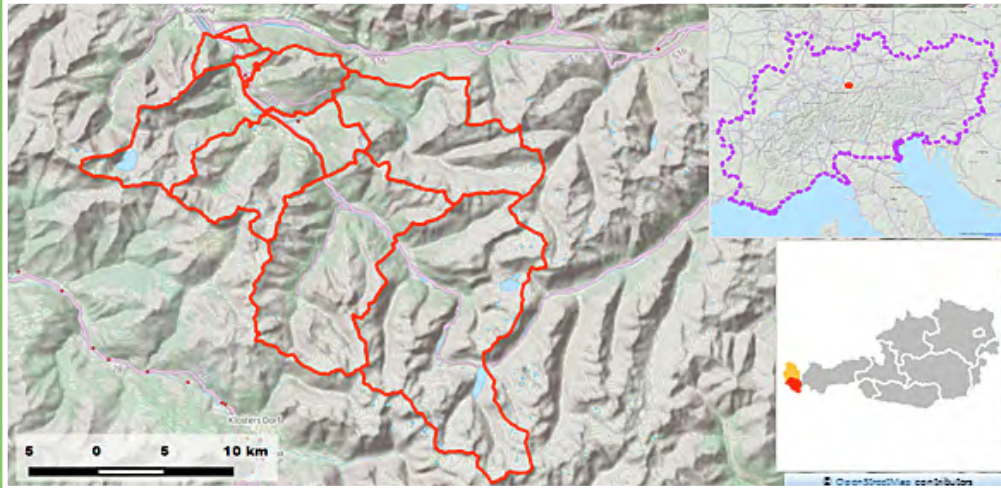
### Available data

During the WINALP project a map of natural forest communities (forest types) for the alpine region was derived by newly developed quite enhanced modeling methods.

Digital terrain models (DTM) with resolution down to 1m were provided by the Bavarian institute of Digitizing, Broadband and Surveying (LVG). For further processing through NEWFOR project partners also ALS raw data were provided by the LVG. The ALS data were obtained from three flight campaigns during the years 2005, 2006 and 2008.

The most precise inventory data were provided by the state forest organization. They were collected from 2010 to 2011 by systematic relascope sampling (200x200m). Data for the municipal forest of Immenstadt are from the year 2004. Inventory sampling was done only within older standings – on an area of roughly 100 ha. Neither coordinates of singular points nor individual stems are known. For further processing data was compiled for the particular standings. As data for the neighborly forests in private ownership were not available, they were calculated on base of the data from the municipal and state forests.

## Montafon Forstfonds



### LOCATION

Montafon, Vorarlberg region

### TEST SITE

Montafon

### HEIGHT RANGE

600—1900 m.a.s.l.

### FOREST TYPE

Pure spruce stands,  
Mixed mountain forest  
Stands with beech, fir and  
spruce

### REFERENCE PARTNER

Stand Montafon Forstfonds  
TU-Wien

The Stand Montafon Forstfonds is an alpine forestry enterprise. It administers and manages about 70% of the forested area (8400 hectares) in the Montafon valley, which is located in the southern part of the Vorarlberg province, the westernmost federal state of Austria. The Stand Montafon Forstfonds belongs to an association of all the municipalities in the Montafon valley.

The Montafon is surrounded by the Silvretta and the Rätikon mountain ranges in the southwest and the Verwall in the northeast. As an alpine valley its altitude ranges from 600 m in the valley floor up to over 3000 m.

The Montafon covers approximately 533 km<sup>2</sup> of which 50% are alpine meadows, 23% are forests, 20% are alpine wasteland and 7% are agricultural and urban land. There are 18.000 inhabitants in ten valley communities, among which Schruns is the main village.

According to the Alpine forest classification the Montafon valley is located in the interalpine spruce/fir area. The forests of the Stand Montafon are to be found to a large extent in predominantly steep terrain at 1200 m above sea level and higher. These forests provide vital protection against avalanches, rockfall, debris flows and landslides to the villages and infrastructural facilities. Besides the essential protective function, the forests in the valley also serve for timber production and play an important role for tourism and recreation, as well as landscape and nature conservation.

## Long-term forest monitoring

The Stand Montafon uses a forest inventory with 500 permanent plots as a basis for long-term forest monitoring system. These plots serve also as a reference data source for many ALS-based studies to assess forest structure of Alpine forests.

The overall goal of the current inventory is to provide the basis for the strategic forest resource planning. To achieve this goal the concept of the remote sensing supported forest inventory is further developed and will be integrated into the operational forest inventory. Therefore, the in-situ measurements are adapted in a way that they can be used in combination with RS data in an optimal way (e.g. use of fixed plot sizes that are fully callipered instead of angle gauge plots). On the other hand, the available administrative units (i.e. forest stands) are in the process of being changed into site-specific units representing different growing conditions. This stratification should be strongly supported by remote sensing data.

### plot 1 (r = 10 m):

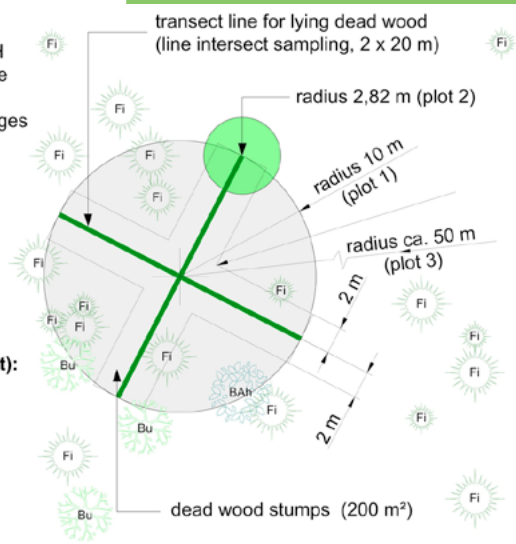
- trees > 10 cm DBH
- Horizontal structure
- layering
- developmental stages
- shrubs
- ground vegetation
- spec. indicators

### plot 2 (r = 2,82 m):

- regeneration
- ungulate damage
- spec. indicators

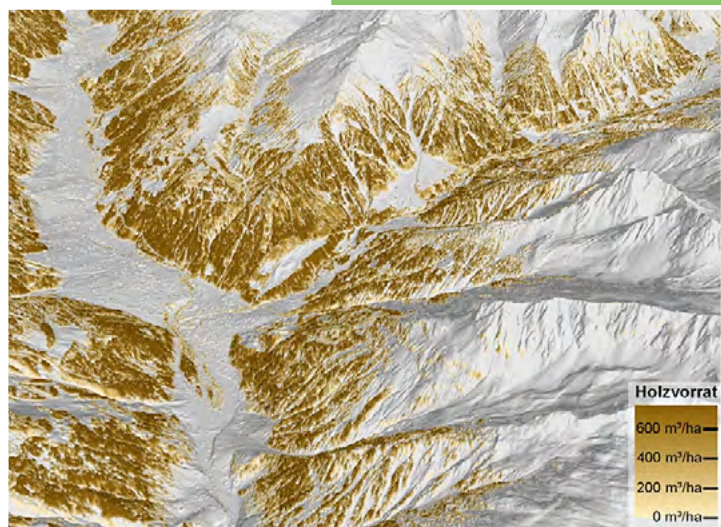
### plot 3 (r = 50 m - sight):

- natural processes
- wood pasture
- brooks, bogs etc.



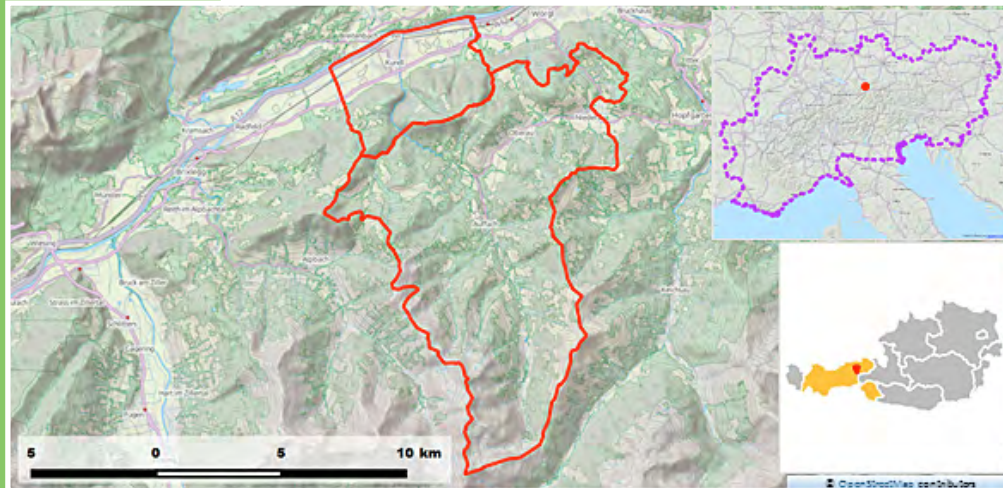
## New volume maps from LiDAR data

For the Montafon region a biomass map was derived from laserscanning data whereas the regression model was calibrated based on a large number of local forest inventory data (approx. 500 sample plots). Based on the operational integration of 3D remote sensing data into the forest inventory it is expected that the number of in-situ measured inventory plots can be reduced to a sparse network of forest inventory plots, which will be used for calibration of the regression models. Due to the decrease of the plot number and the followed decrease of the costs the positional accuracy of the remaining plots will be improved. This, in turn, will provide an appropriate in-situ data set for a combined analysis of 3D remote sensing data.





## Tiroler Unterinntal



### LOCATION

Tiroler Unterinntal, District  
Kufstein

### TEST SITE

Wildschönau (97,4 km<sup>2</sup>)

Kundl (21,9 km<sup>2</sup>)

### HEIGHT RANGE

500 - 2.300 m.a.s.l.

### FOREST TYPE

Spruce - fir - beech stands

Spruce - fir stands

Larch - fir stands

Special sites

### REFERENCE PARTNER

Office of the Tyrolean  
Regional Government,  
Tyrolean Forest Service

For the implementation of the "forest roads – satnav – project" two bordering municipalities in the east of Tyrol named Wildschönau and Kundl had been chosen as pilot areas. Both test sites stand out due to their variety and density of forest roads.

With a surface of about 97 km<sup>2</sup> including 5.170 hectare of forest the Wildschönau is one of the biggest municipalities in Tyrol. More than half of Wildschönau's forest has protective functions. From the annual timber harvest of 35.000 bank meter, 70% of the logging is being realized by cable way. 170.483 running meter forest roads were recorded in the Wildschönau in 2012.

Kundl is with 970 hectare forest in a total area of about 22 km<sup>2</sup> quite smaller than the Wildschönau. Nearly half of its forest has protective functions. In 2011, the annual timber harvest was 2.070 bank meters, 70% of the logging had been realized by cable way. 30.209 running meter forest roads were ascertained in Kundl in 2012. Kundl was selected as pilot area because it is a bordering municipality to Wildschönau. Therefore the connection of the Tyrolean forest road data and public roads could be tested. Furthermore in Kundl there is one of the biggest sawmills in Tyrol. Both pilot areas have about 35 running meter forest roads per hectare (2012).

## Historical wood tracks

Forestry has a special historic importance for the two communities in the Tyrolean test site. Like many other rivers in Tyrol the Wildschönauer Ache was used for log driving, from the densely forested side valley to the Inn valley. The tracks of the historic woodcutters can be followed on a spectacular trail from the Wildschönau through the Kundler Klamm (gorge). Today more than 550 forest owners manage their forests, making wood transport much easier but still challenging.

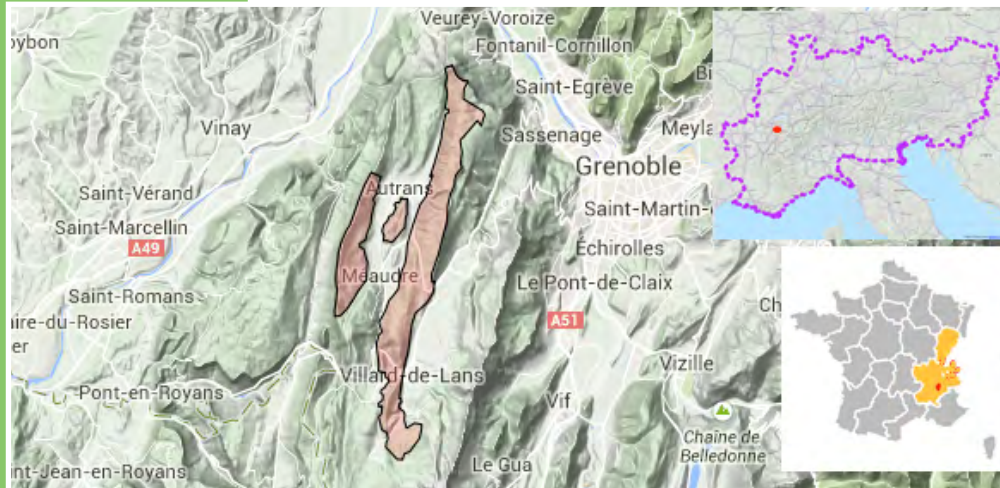


## Getting to a woodpile by using a satnav

When talking about round timber transports in Tyrol one can talk about a sort of unique practice. Local foresters do not only advise private forest owners in respect of logging. To find the most efficient way to get from a public road to a woodpile deep in the woods all timber haulers are being instructed by the local foresters. What if tablets or smartphones could be used for optimizing routes, making optimized freights possible, reducing transport costs? To meet this challenge specific satnav software for wood hauling purposes had to be developed. That needs additional information like streets categories according to their trafficability or turning options for trucks and trailers, to make Tyrolean forest road data usable for route guidance systems. Software's test run had been realised at the Newfor test sites – Wildschönau & Kundl.



# Quatre montagnes



## LOCATION

Isère, région Rhône-Alpes

## TEST SITE

Quatre Montagnes (56 km<sup>2</sup>)

## HEIGHT RANGE

350-2400 m asl

## FOREST TYPE

Pure coniferous stands

Mixed high stands

Mixed stands with coppice

The West and East parts are mainly located on karst soils. The central part (Bois Claret) has better site quality. Western part displays coniferous stands downslope where soil is deeper. Mixed and coppice stands are present on poor quality sites in the upper parts. The central part is constituted of private forests (coniferous plantations). The western displays several forest types, coniferous stands (Norway spruce, silver fir, scots pine), mixed stands and coppice stands on limestone pavement. Forests stands are highly variable due to the topography, geology and silviculture, which makes it a very interesting test site to assess the performance of forest parameter estimation from remote sensing data. The road network is very dense and local practitioners are interested in the comparison of skidder accessibility results and their terrain knowledge.

## REFERENCE PARTNER

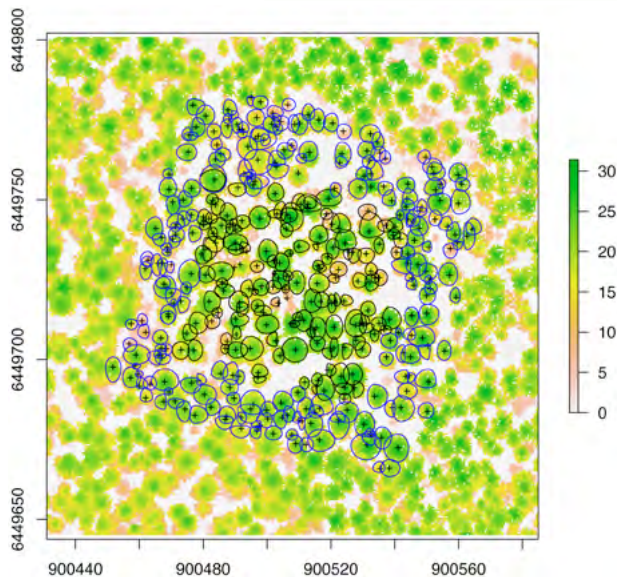
*Irstea Centre de Grenoble,  
UR EMGR*



## New forest maps from LiDAR data...

In the private forests, three marteloscopes of 1 ha surface had been previously implemented for the training of foresters regarding silviculture. Measures on those plots were updated during the Newfor project and used to test single tree detection and species classification from airborne laser scanning and UAV data.

In the whole area, a statistical inventory of 96 forest plots of 15 m radius was implemented in order to calibrate resource estimation models. The resulting resource maps were then transferred to public and private forest managers in the framework of the revision of the Territorial Forest Convention.



La cordelière marteloscope, tree positions and crown limits overlaid on the lidar Canopy Height Model

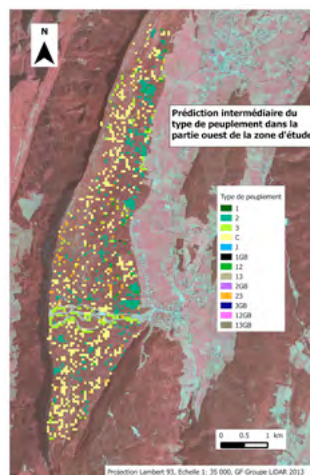
## ... used for communication and management

Field data and resource maps produced in the framework of the project were used by two student groups from AgroParisTech which conducted projects about :

- Forest typology in public forests from remote sensing and field data.
- Private forests in the Bois Claret – under-harvesting and Lidar resource estimation.

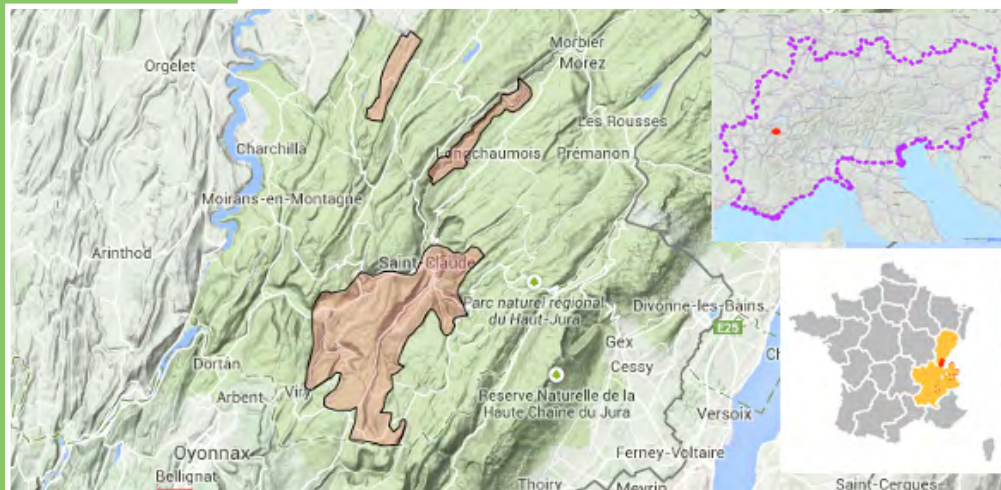


Flyer designed for private foresters



Forest typology in the Méaudre public forest obtained from remote sensing data

## Jura



### LOCATION

Jura, région Franche-Comté

### TEST SITE

Saint Claude (106 km<sup>2</sup>)

Prénoval-Les Piards (9 km<sup>2</sup>)

### HEIGHT RANGE

330-1280 asl

### FOREST TYPE

Mixed high stands

Mixed stands with coppice

Broadleaved high stands or coppice

Coniferous stands

### REFERENCE PARTNER

*Irstea Centre de Grenoble,  
UR EMGR*

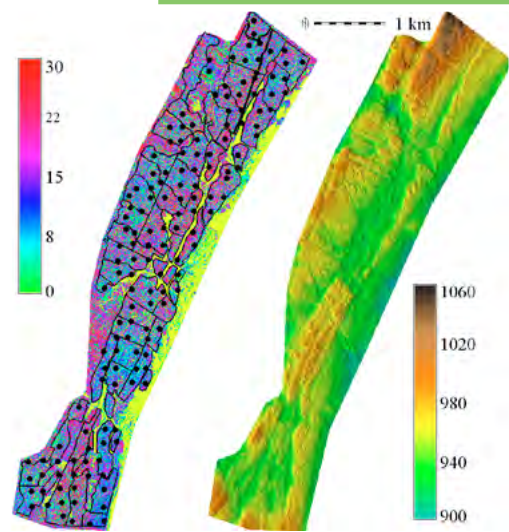
In the Saint Claude area, the topography is highly variable with some steep slopes, and plateaus with high rugosity. This results in highly variable stands, with coppice stands on poor quality sites, mixed and coniferous stands in better sites. This makes it an interesting test site for the assessment of the robustness of resource estimation models. The topography induces high accessibility constraints for some compartments and there is a strong demand for the evaluation of the forest accessibility, including cable yarding potential.

The Prénoval-Les Piards area is a highly documented experimental forest of the French Forest Office. The topography is rather rough. The stands are uneven-aged stands of Norway spruce and silver fir.



## LiDAR maps evaluated at the compartment level

In the experimental forest of Prénovel, compartments have been fully callipered which makes it possible to assess the precision of ressource estimation models at the compartment level. Results show that the basal area and stem density values obtained from airborne laser scanning estimation models have a precision similar to a full-calliper field inventory.



Forest inventory and digital terrain model

## Capercaillie habitat

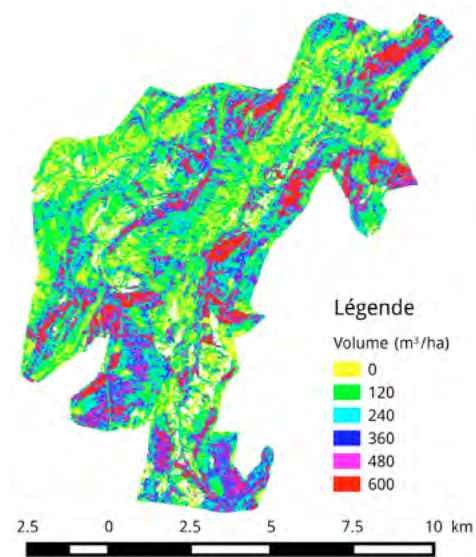
The Jura study area hosts some of the last Capercaillie populations in France. LiDAR data is also a promising tool for the characterisation of bird habitats and optimisation of forest management related to biodiversity protection.



©Claude Lepennec

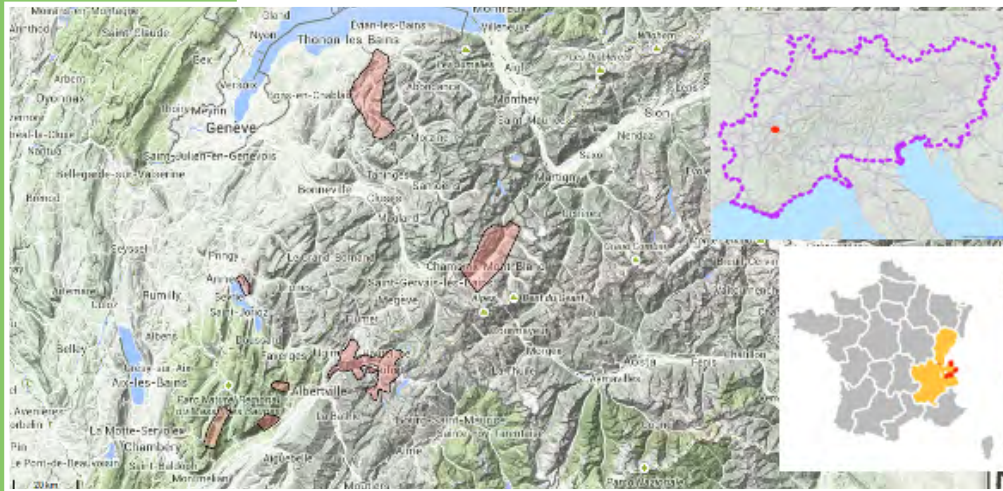
## New forest maps from LiDAR data

In the test site of Saint Claude, 60 plots of 15 m radius were inventoried in order to calibrate ressource estimation models. Resulting maps were transferred to the French Forest Office and private stakeholders.



Volume map

# Savoie and Haute-Savoie



## LOCATION

Savoie and Haute-Savoie,  
région Rhône-Alpes

## TEST SITE

Chablais savoyard (100 km<sup>2</sup>)

Chamonix valley (98 km<sup>2</sup>)

Beaufortain (83 km<sup>2</sup>), Grésy  
(11 km<sup>2</sup>) and Tamié (7 km<sup>2</sup>)

## HEIGHT RANGE

460-2190 m asl

980-2970 m asl

350-2400 m asl

## FOREST TYPE

Pure conifer high stands

Mixed high stands

Broadleaved high stand and  
coppice stands

## REFERENCE PARTNER

Irstea Centre de Grenoble,  
UR EMGR

The Chablais site is mainly located on the communes of Bellevaux, Lullin, Vailly and Reyvroz. Valleys and gentle slopes are mainly occupied by pastures. Forests are generally mixed forests of European beech, silver fir and Norway spruce. Spruce is found at higher altitudes. Some coniferous plantations are present. The southern and eastern part have higher altitudes and steeper slopes.

The bottom of the Chamonix valley is relatively flat and located at 1000 m a.s.l. It is mainly a urban area. Slopes are forested with coniferous trees (mainly Norway spruce) up to the timber line. Stands are mostly uneven-aged, as forests are only extensively managed due to accessibility constraints. The slopes on both sides of the valley are very steep. The road network is not dense and there is a strong will to develop cable yarding.

Grésy: mainly broadleaved stands (various species at low altitude, mainly beech in the upper parts).

Tamié: mainly coniferous and mixed stands.

Beaufortain: some broadleaved and mixed stands downslope, mainly coniferous trees in higher altitudes.

The Grésy and Beaufortain areas display very steep slopes, there is a high demand for the assessment of cable yarding potential.