Single tree detection benchmark report

L. Eysn, J.M. Monnet, M. Dalponte, M. Kobal, M. Pellegrini, E. Lindberg., L. Reolj, D. Mongus, L. Eysn, M. Hollaus

Interreg Alpine Space project - **NEWFOR**

Project number 2-3-2-FR

NEW technologies for a better mountain **FOR**est timber mobilization

Priority axis 2 - Accessibility and Connectivity

Workpackage 4: Forest resources and LiDAR

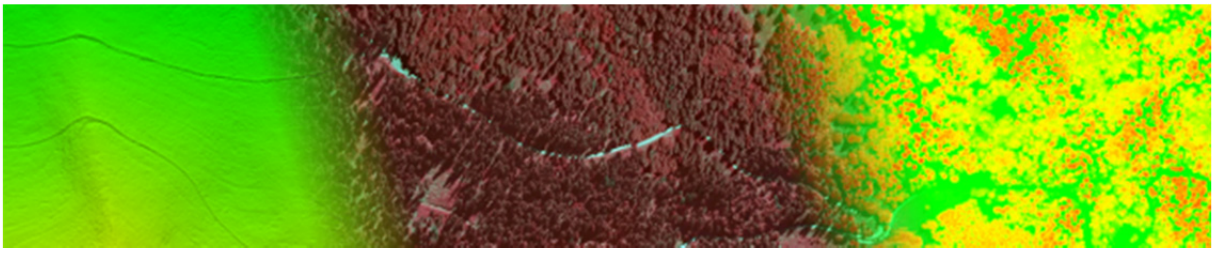
Single tree detection benchmark

Report

Coordinator(s): TUW - Lothar Eysn, TUW - Markus Hollaus

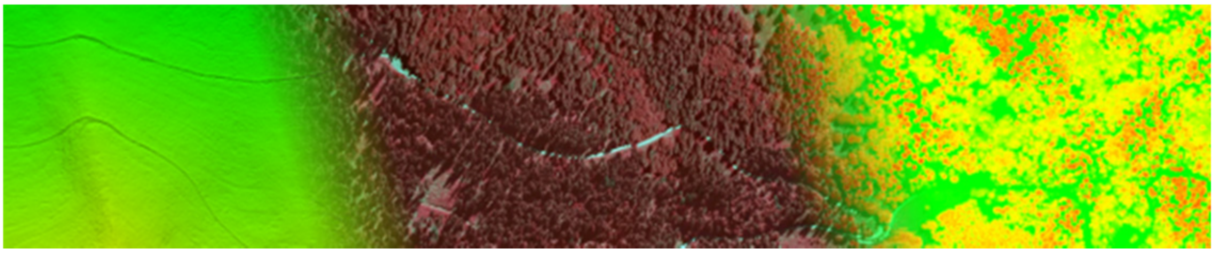
Contributors: PP11 - TUW - Lothar Eysn; LP – IRSTEA - Jean-Matthieu Monnet; PP5 – PAT-SFF - Michele Dalponte; PP7 – SFI – Milan Kobal; PP10 – TESAF - Marco Pellegrini; PP11- TUW – Eva Lindberg; PP12 – SFS – Luka Reolj, Domen Mongus (SFS made the benchmarking in cooperation with the Faculty of Electrical Engineering and Computer Science form the University of Maribor)

Final version 12/11/2014

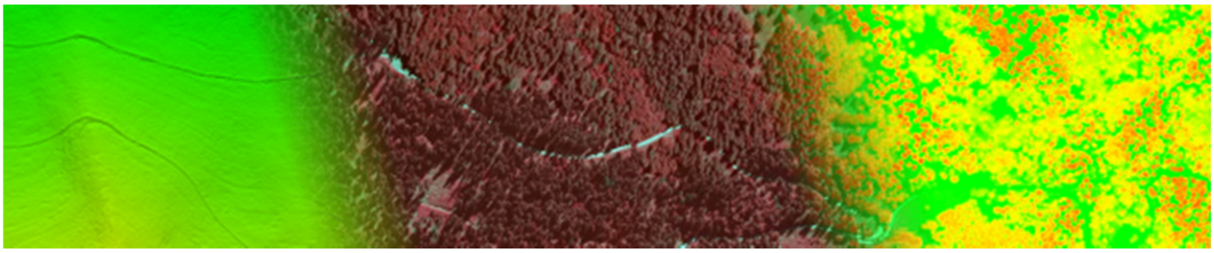


The consortium of the project Interreg Alpine Space NEWFOR

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.



CONTENTS

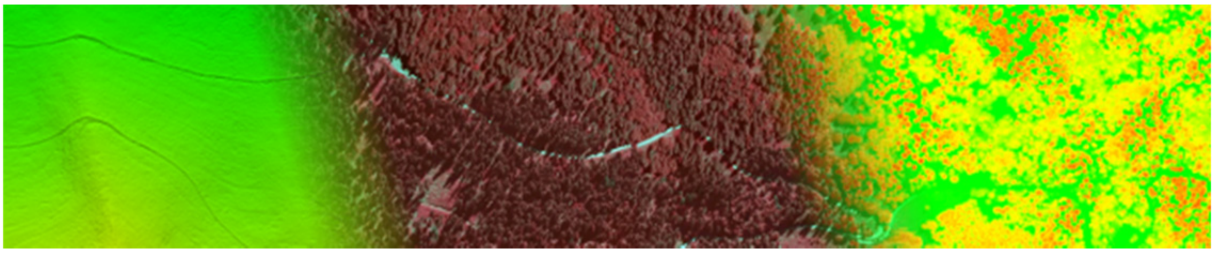


1 ABSTRACT

Large area tasks as for example obtaining information about forested areas are already operational in forest management as the use of remote sensing data and related methods has become a standard. In contrast, terrestrial forest inventories are still obligatory and will probably never be fully replaceable by automatically methods. Data fusion of information obtained from remote sensing data with Inventory data can help to reduce the costs of time consuming inventories and additionally the spatially limited information of the Inventory could be linked to larger areas. The identification of single trees and their parameters is an important task for analysing large forested areas with respect to forest management or harvesting planning. Parameters as for example the spatial distribution of trees, tree heights and stem diameters, the amount of stems per hectare or information about tree crowns as for example a total crown length are of interest. In case of a terrestrial Inventory these parameters are obtained from measurements based on the single tree level. To obtain such detailed information from remotely sensed airborne data many studies on single tree detection were carried out from the research community, resulting in many different algorithms / methods developed in different countries or institutions.

The research project NEWFOR (www.newfor.net) brings together fourteen institutions from six countries within the Alpine Space working in the field of forestry and remote sensing. The project aims at enhancing the wood supply chain within the Alpine Space to improve forest timber evaluation and mobilization using new remote sensing technologies. One objective of the project is to test established as well as new methods that are capable to extract single tree information based on remote sensing data. Therefore a single tree detection benchmark based on airborne laser scanning data was carried out. Eight detection methods were applied to a unique dataset originating from different regions of the Alpine Space covering different study areas, forest types and structures. The evaluation of the different method's detection results was carried out in a clear and reproducible way by automatically matching the results to forest inventory data. Quantitative statistical parameters as for example percentages of correctly matched trees as well as Omission and Commission errors are presented. The benchmarking results are prepared in different Levels of Information, starting with investigations based on study area and detection method. Additionally investigations per forest type and an overall performance of the benchmark are presented. The best matching rate was obtained for single layered coniferous forests. Trees in lower height layers were challenging for all tested methods. The overall performance shows a matching rate of 47 % (Root Mean Square) which is comparable to results of other benchmarks performed in the past.

This study may help to guide the choice of method when performing single tree detection for different forest types in the Alpine Space.



2 A SYNTHETIC OVERVIEW OF THE INTERREG ALPINE SPACE PROJECT NEWFOR

2.1 THE CONTEXT

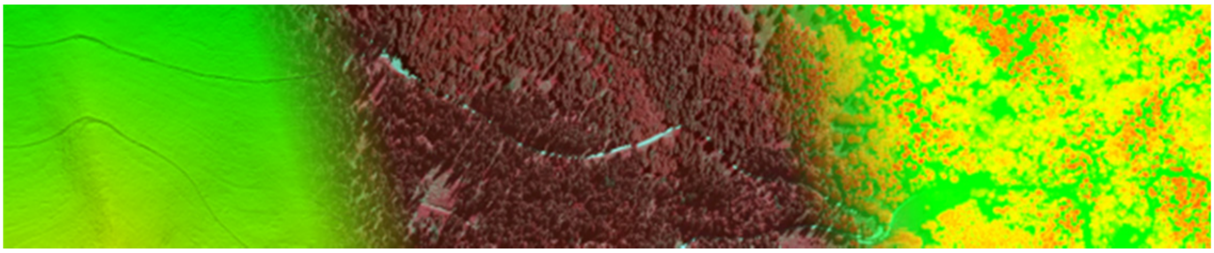
Although forests represent a key resource of mountain environments, their valorization is hampered by accessibility constraints that prevent an efficient mapping, management, harvesting and transport of wood products.

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 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. 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 and modelling tools, 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.

2.2 OBJECTIVES OF THE PROJECT

According to this context and based on the use of new technologies (LiDAR: light detection and ranging, Unmanned Aerial Vehicle,...) for forest and topography characterization, the project NEWFOR is dedicated to enhance and develop tools and adapted policies for decision making in the field of a sustainable and adaptive mountain forest resources management facing the sustainability of mountain forest ecosystems services.



So, the main objective of the NEWFOR project is the improvement of mountain forest accessibility for a better economical efficiency of wood harvesting and transport in a context of sustainable forest management and wood industry in changing climate.

The 14 partners involved in the project consortium tackle this objective within five thematic workpackages (wp):

- Forest resources and LiDAR

Recent developments in LiDAR technology, 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 project aims at testing (e.g. benchmarks) and developing tools that will help forestry end-users to benefit from this technological advance.

- Forest accessibility

After the identification of forest resources, the second step of an efficient forest management is to evaluate the accessibility to these resources. In mountain areas, topography is the main constraint to a technical and economically efficient exploitation. The project demonstrated how to use topographic LiDAR data coupled with geographic information systems (GIS) for an optimal planning of forest harvesting and logging while taking current and scheduled accessibility of forest resources into account.

- Forest and industry connectivity

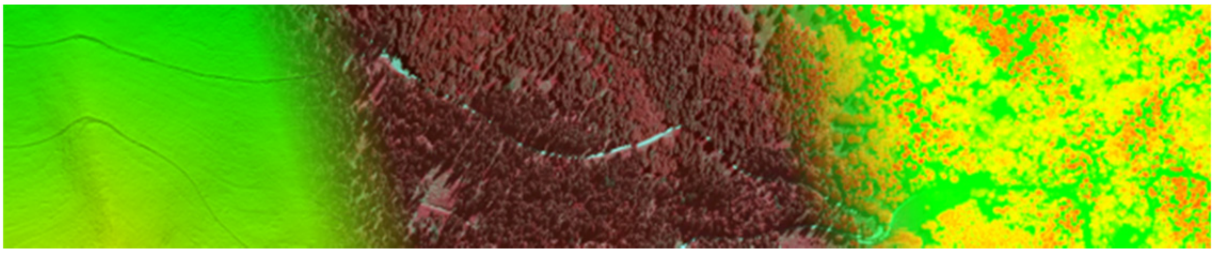
Once the forest resources and accessibility are characterized, then remains the issue of the connectivity between wood piles in the forests and wood yard of mills. This link is often neglected but is crucial for a comprehensive assessment of the wood supply efficiency.

- Costs and benefits evaluation

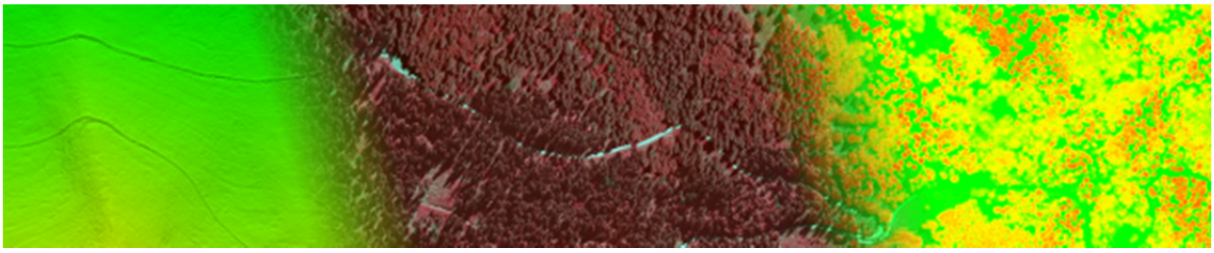
NEWFOR aims at developing decision-making tools dedicated to the definition of strategies for sustainable mountain wood supply chain. To fulfil this objective, tools for identifying forest resources, their accessibility and connectivity to the wood market are first considered separately. In order to achieve the demarche, and to choose the optimal strategy, it is necessary to evaluate the whole workflow from the economical aspect by comparing the costs and benefits of each possible strategy.

- Logistical planning strategy

There is a need to frequently adjust the planning of forest management to new economical evidence as well as to unforeseeable developments. Such an adaptive management needs to



balance ecological, social and economic factors. The final objective was to provide forest managers and decision makers with reliable information for the evaluation of technical and economical conditions for their decision-making on timber supply chain logistical planning and land use strategies.



3 BENCHMARK SINGLE TREE DETECTION

3.1 INTRODUCTION

Terrestrial forest inventories (FI) are a standard in the forestry domain to obtain information about forest stands and trees. FI are time consuming and sampling plot approaches are not designed to create maps.. In contrast, large area tasks as for example harvesting planning or obtaining information for large forest stands are getting more and more operational in the forest management domain as the use of remote sensing data has become a standard in forestry. The parameters obtained in a terrestrial FI are mostly based on the single tree level. To obtain information on the single tree level from remotely sensed airborne data many studies on single tree detection were carried out from the research community resulting in different algorithms / methods. As the project NEWFOR covers partners from the entire Alpine Space, airborne laser scanning data of different forest types and structures from different regions in the Alpine Space are available. In total 21 different study areas in 5 countries of the Alpine Space are available. These unique data are the basis for a benchmark where different methods are tested. The first goal is to test the different single tree detection methods available in the NEWFOR consortium as well as methods which are established at other partners outside of the consortium. The second goal is to prepare the results for a publication in a scientific journal.

3.2 TASK FOR PARTICIPANTS

The task for this benchmark was to detect the positions and heights of trees and optional to extract their diameter at breast height (DBH) and volume of the stem. The detection should be performed fully automatically and should be based on airborne laser scanning (ALS) data (Section 3.4). The input data were anonymized to avoid advantages by knowing the location. The results of the benchmark participants had to be provided in a standardized format (section 3.12.5). A clear and short description of the used algorithm / workflow had to be provided (Section 3.7). Deadline for submitting results was the 6th of April 2014.

Minimum Requirements for the Benchmark:

1. Detection of tree position and tree height
2. Description of the used algorithm/workflow
3. Allocation of the results in the defined output format
4. Information who is responsible for the results (full Affiliation -> will be used in the publication)

Optional Requirements for the Benchmark:

5. Volume per stem (Stemvol.)
6. Diameter at breast height (DBH)
7. Short description how the volume was calculated

3.3 BENCHMARK DATASET

In total 10 pilot areas in 6 countries in the Alpine Space are available inside the NEWFOR consortium (Figure 1). Within these pilot areas 21 different study areas in 5 different countries are investigated in this benchmark (Figure 2). Detailed information about the study areas is given in Section 3.4.

For each study area ALS data and a digital terrain model (DTM) are provided to the benchmark participants. The DTMs are provided as Gtiff with spatial resolutions of 1.0 x 1.0 m or 0.5 x 0.5 m. The ALS data are provided in the LAS format. Detailed information about the ALS data are given in Appendix A in Section 3.12.2.

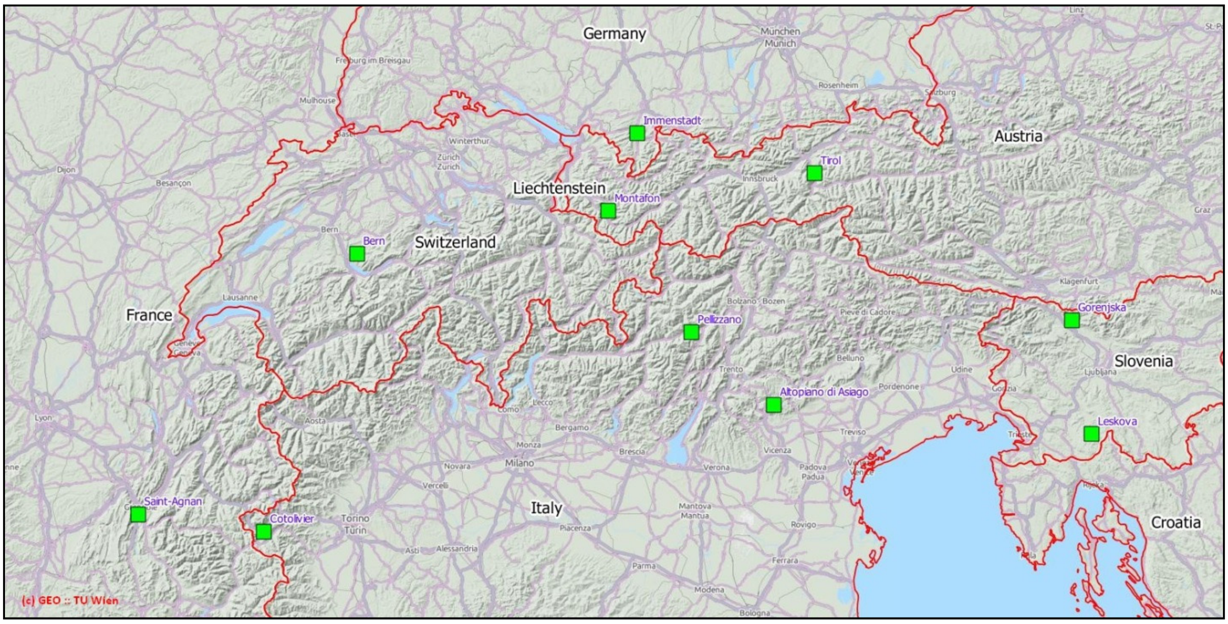


Figure 1: Pilot areas of the NEWFOR project

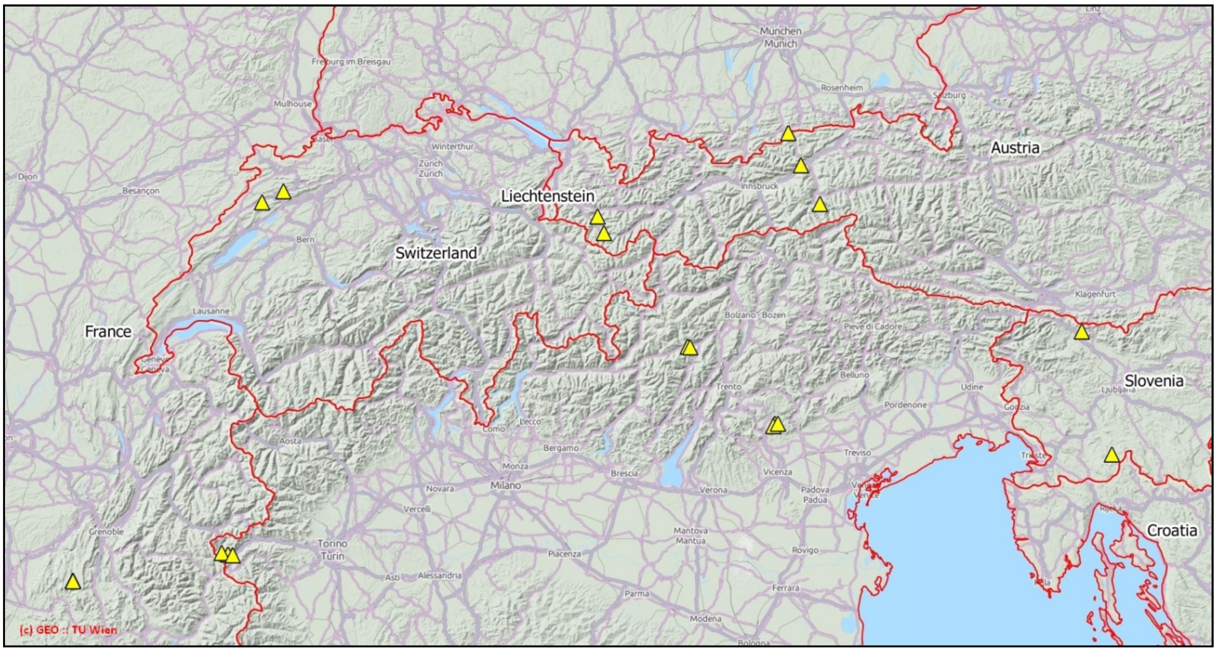


Figure 2: Study areas used for the single tree detection benchmark

3.4 STUDY AREAS

In this section the study areas and available data are presented. Beside the ALS data FI data for each plot are available. Only fully calipered FI plots are used. The ALS data were buffered by 25 m to 50 m around the FI plots to minimize border effects at the FI plot borders when detecting trees based on the ALS data. Condensed information regarding the study areas can be found in Appendix A in section 3.12.

3.4.1 STUDY AREA 01 - SAINT-AGNAN

3.4.1.1 FOREST DESCRIPTION

The local forest consists of an irregular, mixed stand of silver fir (*Abies alba*) and beech (*Picea abies*). Most broadleaved trees are tilted toward downslope. The approximate tree height is 27 m.

3.4.1.2 SITE DESCRIPTION

The site is located in the Vercors mountain in France which is located in the South of Grenoble. The location is on the hillside with west exposition, 32° slope, prone to rockfalls. A road oriented North-South separates the plot in approximately two equal parts. The mean altitude is approximately 1267 meters above sea level. The location of the study area is presented in Figure 3.

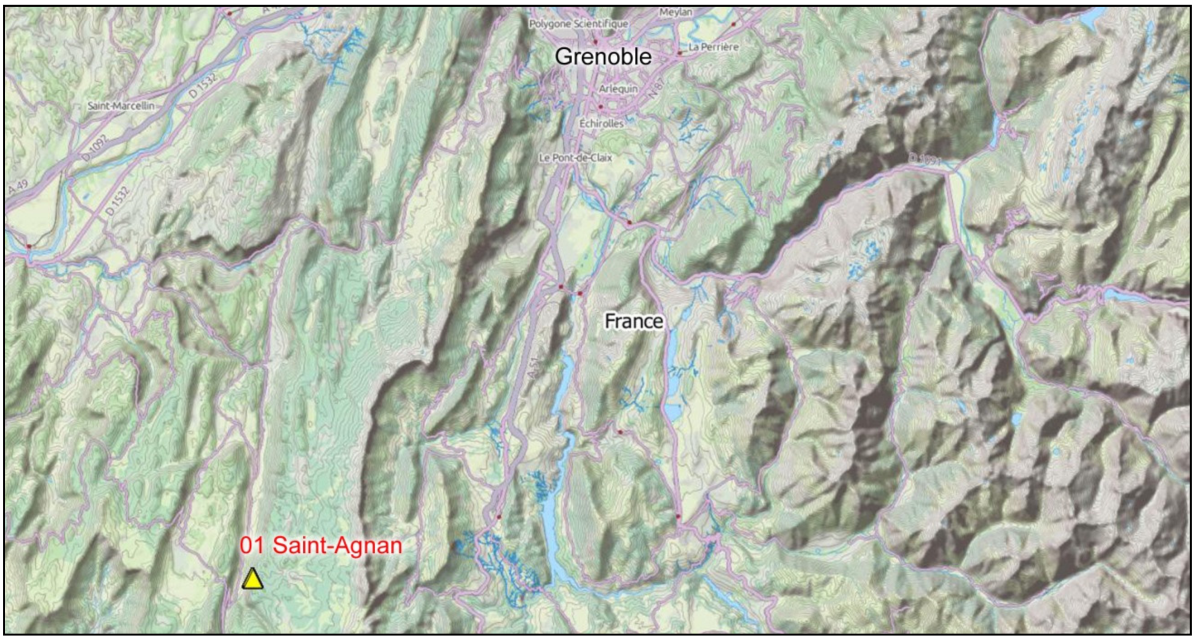


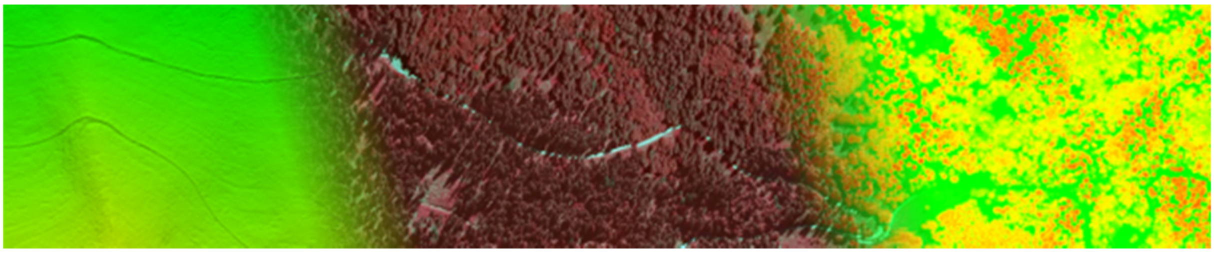
Figure 3: Location of the Study area 01 Saint-Agnan in France.

3.4.1.3 FI DATA

The forest inventory data were acquired in July 2010. The plot size of the rectangular plot is 125 x 80 m which relates to 1 hectare. A differential GPS was used to mark the plot corners and to mark intermediate points. The trees were positioned relatively to the plot corners or markers with a compass, inclinometer and range meter (Vertex III). The tree heights were measured with a Vertex III hypsometer. The calliper threshold was set to 7.5 cm. Dead trees were not measured. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, tree height and tree volume. In July 2013 crown extension measurements in four directions were performed for each tree. The FI data were georeferenced using the coordinate system Lambert93 (EPSG:2154).

3.4.1.4 ALS DATA

The ALS data were acquired on September 21st in 2010 using a Riegl LMS-Q560 scanner. The height above ground was approximately 595 m and flight speed was about 90 knots. The scanner was set to a field of view of 59°, a pulse frequency of 170 kHZ and a scan frequency of 111.4 Hz. The theoretical footprint size on ground was 32 cm. The point density of the dataset is approximately 13 pts / m^2. The ALS data were georeferenced using the coordinate system Lambert93 (EPSG:2154). The ALS data of the study area are presented in Figure 4.



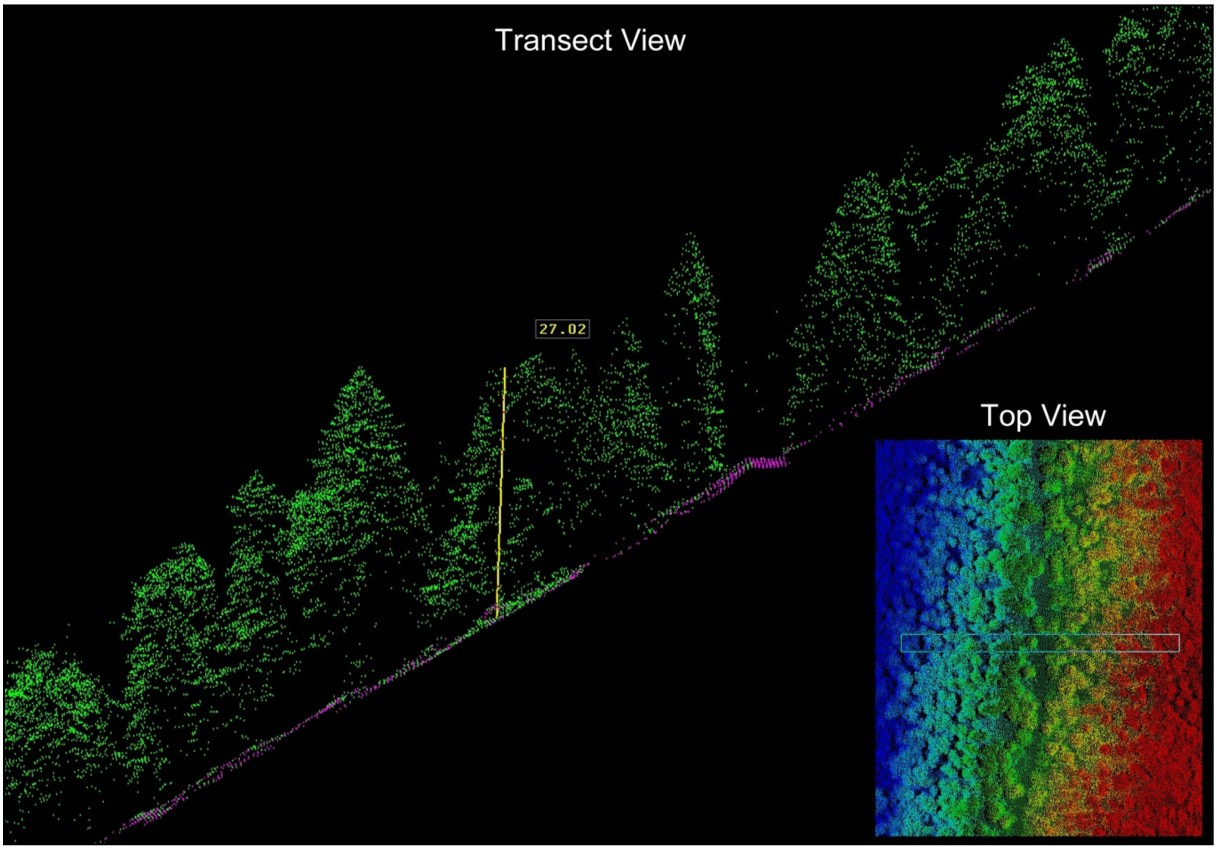


Figure 4: Visualization of the ALS data of study area 01 Saint-Agnan. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.2 STUDY AREA 02 - ACHENKIRCH

3.4.2.1 FOREST DESCRIPTION

The local forest consists of an irregular, mixed stand of acer, beech, spruce and fir. The crown coverage is interpreted as medium. The approximate tree height is 27 meters.

3.4.2.2 SITE DESCRIPTION

The site is located in the Ebenwald area in Tyrol, Austria which is located in the North East of Innsbruck. The location is on the hillside with North East exposition. The mean altitude is approximately 1160 m above sea level. The location of the study area is presented in Figure 5.

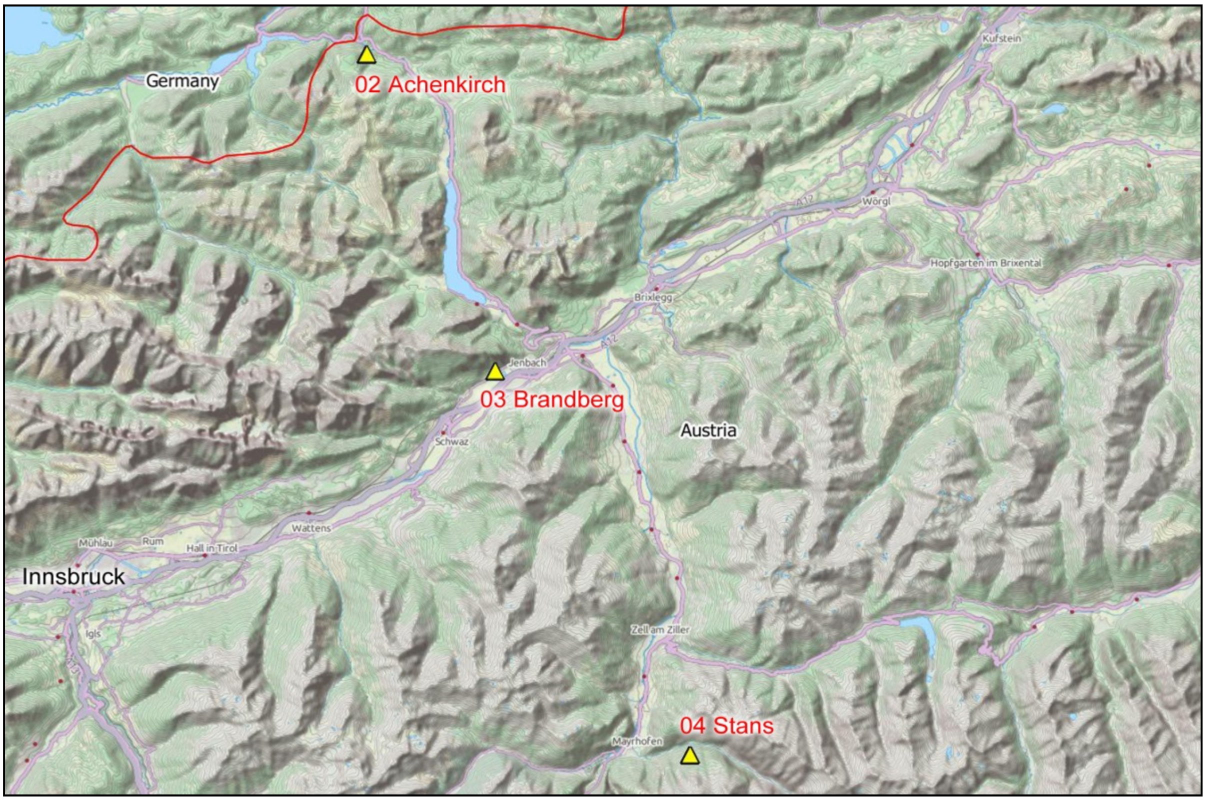


Figure 5: Locations of the Study areas 02 Achenkirch, 03 Brandberg and 04 Stans in Tyrol, Austria.

3.4.2.3 FI DATA

The forest inventory data were acquired in September 2010. The plot size of the circular plot is 3848 m^2 which relates to a radius of 35 m. A differential GPS was used to mark the plot center. The trees were positioned relatively to the plot center with a compass, inclinometer and range meter (Vertex III). The tree heights were measured with a Vertex III hypsometer. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, D03 (diameter at 30% tree height), tree height and height of the crowns starting point. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.2.4 ALS DATA

The ALS data were acquired in 2008 during multiple flight campaigns under leaf-off and leaf-on canopy conditions without snow cover. As laser scanning system the discrete Airborne Laser Terrain Mapper ALTM 3100, manufactured by Optech Inc, was used on a fixed wing aircraft. The data acquisitions were performed in the framework of a commercial terrain-mapping project, fully covering the Federal State of Tyrol. The height above ground was approximately 1200 m. The point density of the dataset is approximately 4 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 6.

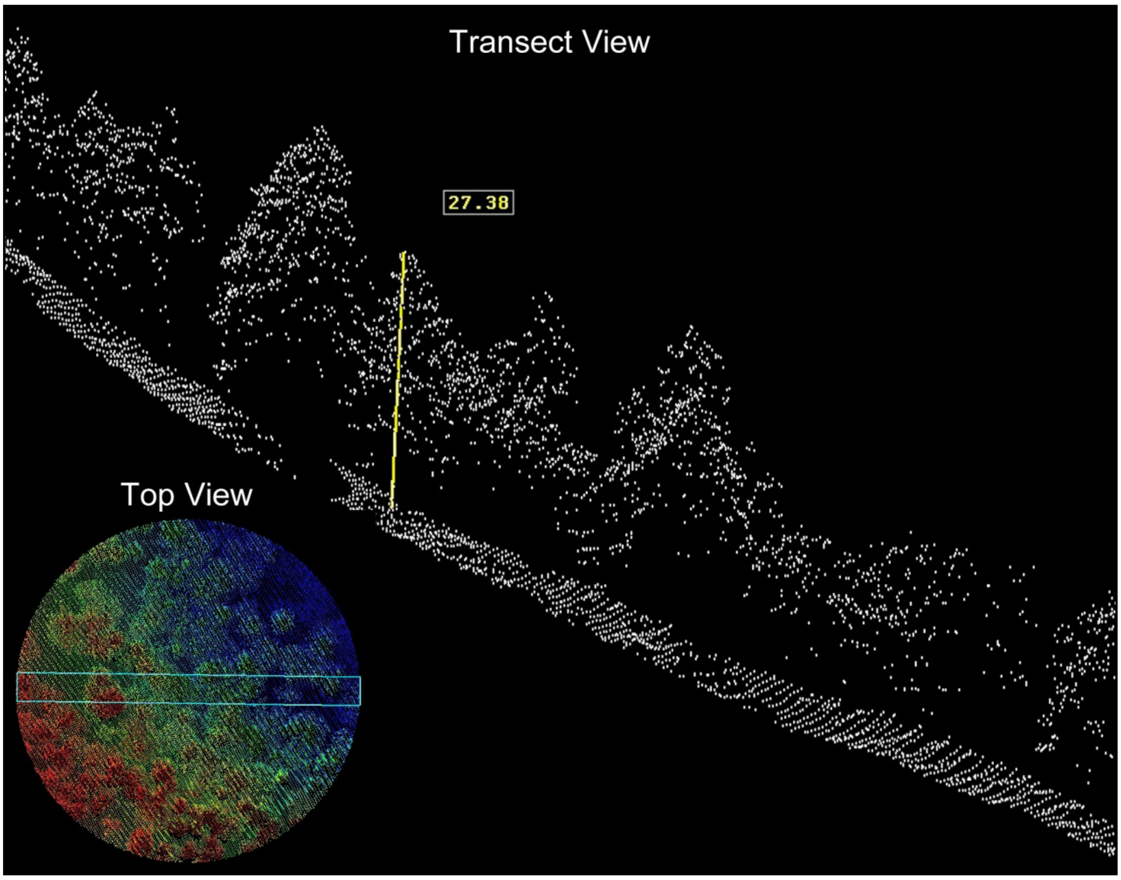


Figure 6: Visualization of the ALS data of study area 02 Achenkirch. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

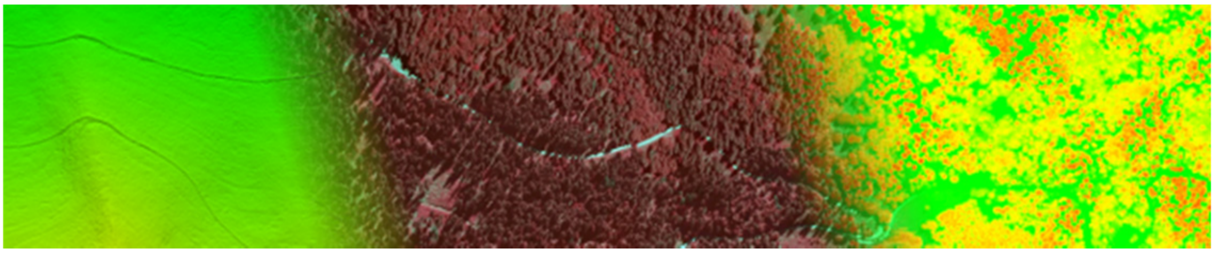
3.4.3 STUDY AREA 03 - BRANDBERG

3.4.3.1 FOREST DESCRIPTION

The local forest consists of an Old spruce stand. The crown coverage is interpreted as dense. The approximate tree height is 42 meters.

3.4.3.2 SITE DESCRIPTION

The site is located in the Inntal in Tyrol, Austria which is located in the East of Innsbruck. The location is on the hillside with exposition to the South. The mean altitude is approximately 1322 meters above sea level. The location of the study area is presented in Figure 5.



3.4.3.3 FI DATA

The forest inventory data were acquired in September 2010. The plot size of the circular plot is 3848 m^2 which relates to a radius of 35 m. A differential GPS was used to mark the plot center. The trees were positioned relatively to the plot center with a compass, inclinometer and range meter (Vertex III). The tree heights were measured with a Vertex III hypsometer. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, D03 (diameter at 30% tree height), tree height and height of the crowns starting point. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.3.4 ALS DATA

The ALS data were acquired in 2008 during multiple flight campaigns under leaf-off and leaf-on canopy conditions without snow cover. As laser scanning system the discrete Airborne Laser Terrain Mapper ALTM 3100, manufactured by Optech Inc, was used on a fixed wing aircraft. The data acquisitions were performed in the framework of a commercial terrain-mapping project, fully covering the Federal State of Tyrol. The height above ground was approximately 1000 m. The point density of the dataset is approximately 5 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 7.

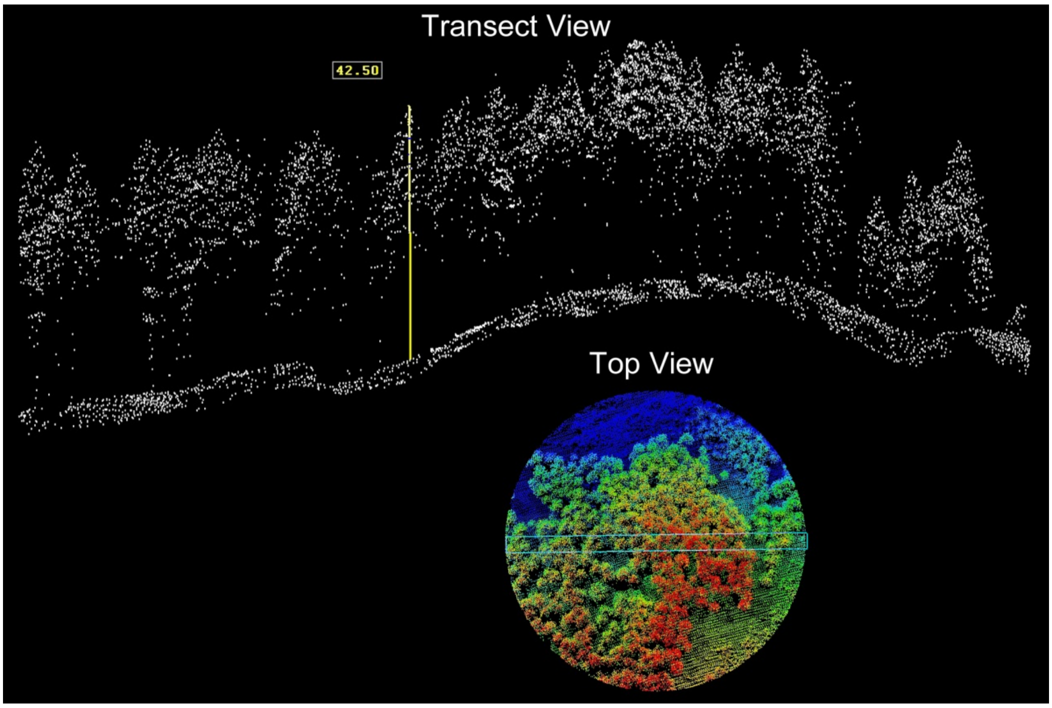


Figure 7: Visualization of the ALS data of study area 03 Brandberg. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.4 STUDY AREA 04 - STANS

3.4.4.1 FOREST DESCRIPTION

The local forest consists of an irregular, mixed stand of acer, beech, spruce, and pine. The crown coverage is interpreted as dense. The approximate tree height is 31 meters.

3.4.4.2 SITE DESCRIPTION

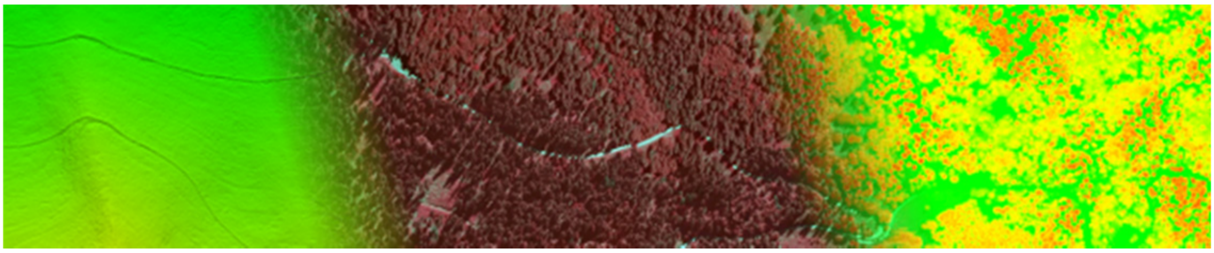
The site is located in the Zillertal in Tyrol, Austria which is located in the South East of Innsbruck. The location is on the hillside with exposition to the North. The mean altitude is approximately 699 meters above sea level. The location of the study area is presented in Figure 5.

3.4.4.3 FI DATA

The forest inventory data were acquired in September 2010. The plot size of the circular plot is 3848 m^2 which relates to a radius of 35 m. A differential GPS was used to mark the plot center. The trees were positioned relatively to the plot center with a compass, inclinometer and range meter (Vertex III). The tree heights were measured with a Vertex III hypsometer. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, D03 (diameter at 30% tree height), tree height and height of the crowns starting point. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.4.4 ALS DATA

The ALS data were acquired in 2008 during multiple flight campaigns under leaf-off and leaf-on canopy conditions without snow cover. As laser scanning system the discrete Airborne Laser Terrain Mapper ALTM 3100, manufactured by Optech Inc, was used on a fixed wing aircraft. The data acquisitions were performed in the framework of a commercial terrain-mapping project, fully covering the Federal State of Tyrol. The height above ground was approximately 800 m. The point density of the dataset is approximately 10 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 8.



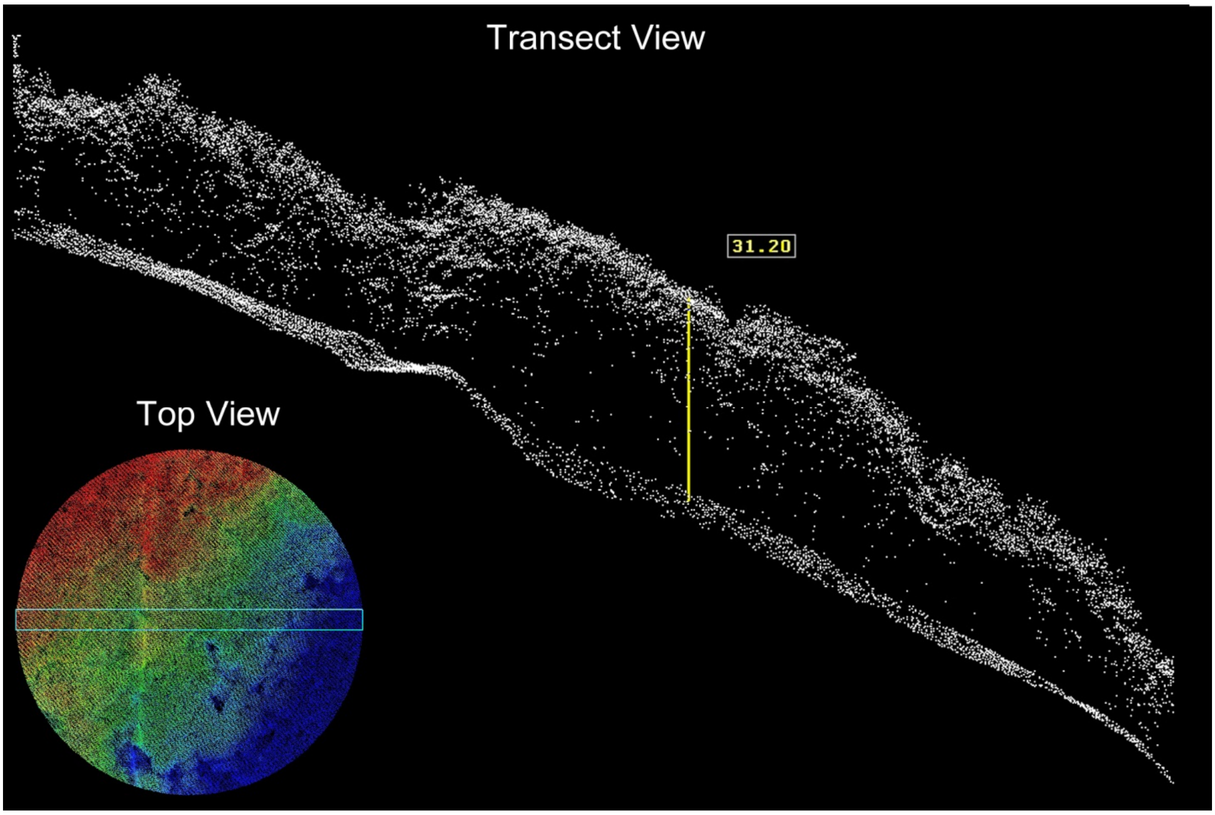


Figure 8: Visualization of the ALS data of study area 04 Stans. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.5 STUDY AREA 05 - PELIZZANO 1

3.4.5.1 FOREST DESCRIPTION

The local forest consists of an irregular spruce pole forest with a very small presence of larix (Larix decidua), fir (Abies alba), and broadleaves (maple, poplar, willow, alder, and birch). The density and the coverage are quite elevated; the vertical structure is a one layered forest. The crown coverage is considered as dense. The approximate tree height is 35 meters.

3.4.5.2 SITE DESCRIPTION

The site is located in the Trento Province in Italy, located to the North West of the city Trento. The location is on the northern mountainside. The altitude of the plot is about 1468 m above sea level. The terrain is smooth and flat; the rock face consists of tonalite with a wet ground. The location of the study area is presented in Figure 9.

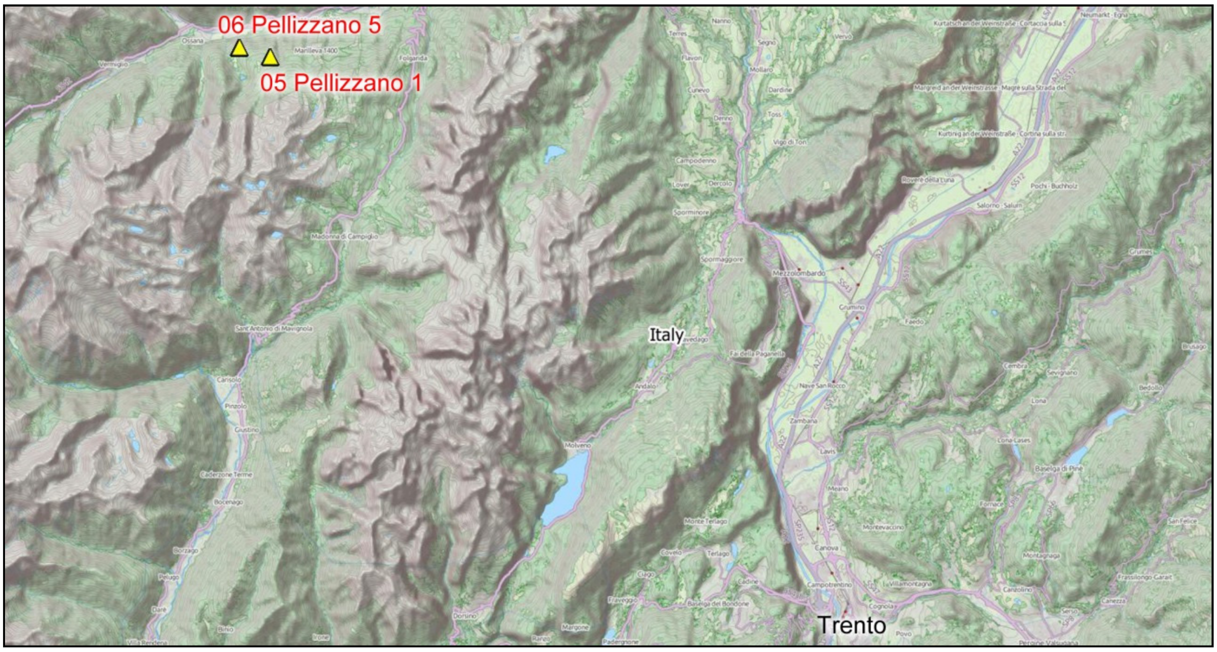


Figure 9: Locations of the Study areas 05 Pellizzano 1 and 06 Pellizzano 5 in the Trento Area, Italy.

3.4.5.3 FI DATA

The forest inventory data were acquired in August 2013. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a Laser rangefinder and a field map software. The tree heights were measured with a Vertex. The caliper threshold was set to 5 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.5.4 ALS DATA

The ALS data were acquired in September 2012 using a Riegl LMS-Q680i scanner. The point density of the dataset is approximately 121 pts / m^2. The sampling density was set to a minimum of 10 pts / m^2 for the first returns. A minimum of 4 returns for each signal were acquired. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 10.

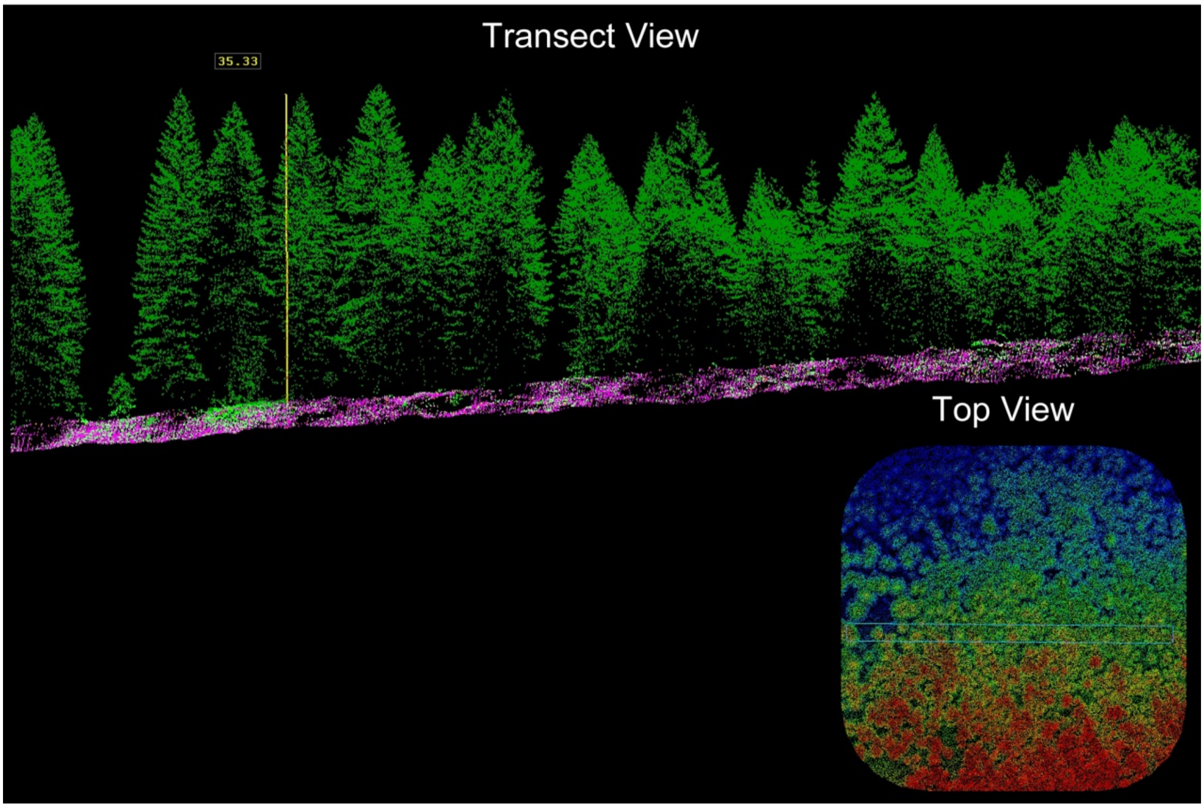


Figure 10: Visualization of the ALS data of study area 05 Pellizzano 1. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

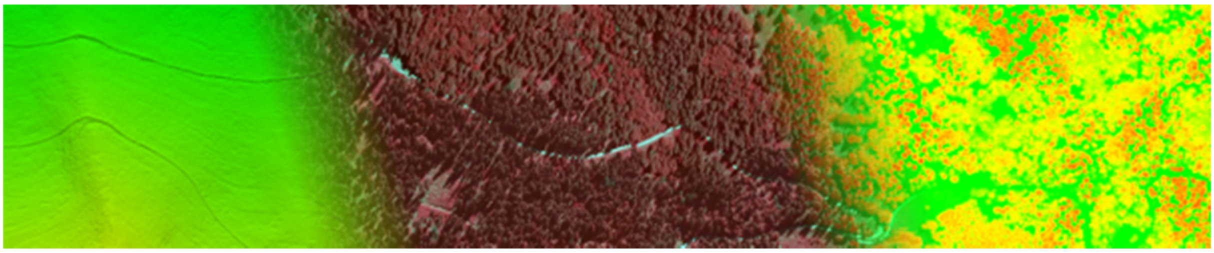
3.4.6 STUDY AREA 06 - PELIZZANO 5

3.4.6.1 FOREST DESCRIPTION

The local forest consists of an irregular, mature larch forest with good presence of spruce wich overlay a younger layer of spruce, fir and poplar. In the South East corner of the study area the stand is fully composed by spruce. The density and the coverage are medium. The vertical structure is a two layered forest. The approximate tree height is 32 meters.

3.4.6.2 SITE DESCRIPTION

The site is located in the Trento Province in Italy, located to the North West of the city Trento. The terrain is quite steep but the South East corner of the study area is flat. The rock face consists of tonalite and the presence of water in the soil is not high. The location of the study area is presented in Figure 9.



3.4.6.3 FI DATA

The forest inventory data were acquired in August 2013. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a Laser rangefinder and a field map software. The tree heights were measured with a Vertex. The caliper threshold was set to 5 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.6.4 ALS DATA

The ALS data were acquired in September 2012 using a Riegl LMS-Q680i scanner. The point density of the dataset is approximately 95 pts / m^2. The sampling density was set to a minimum of 10 pts / m^2 for the first returns. A minimum of 4 returns for each signal were acquired. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 11.

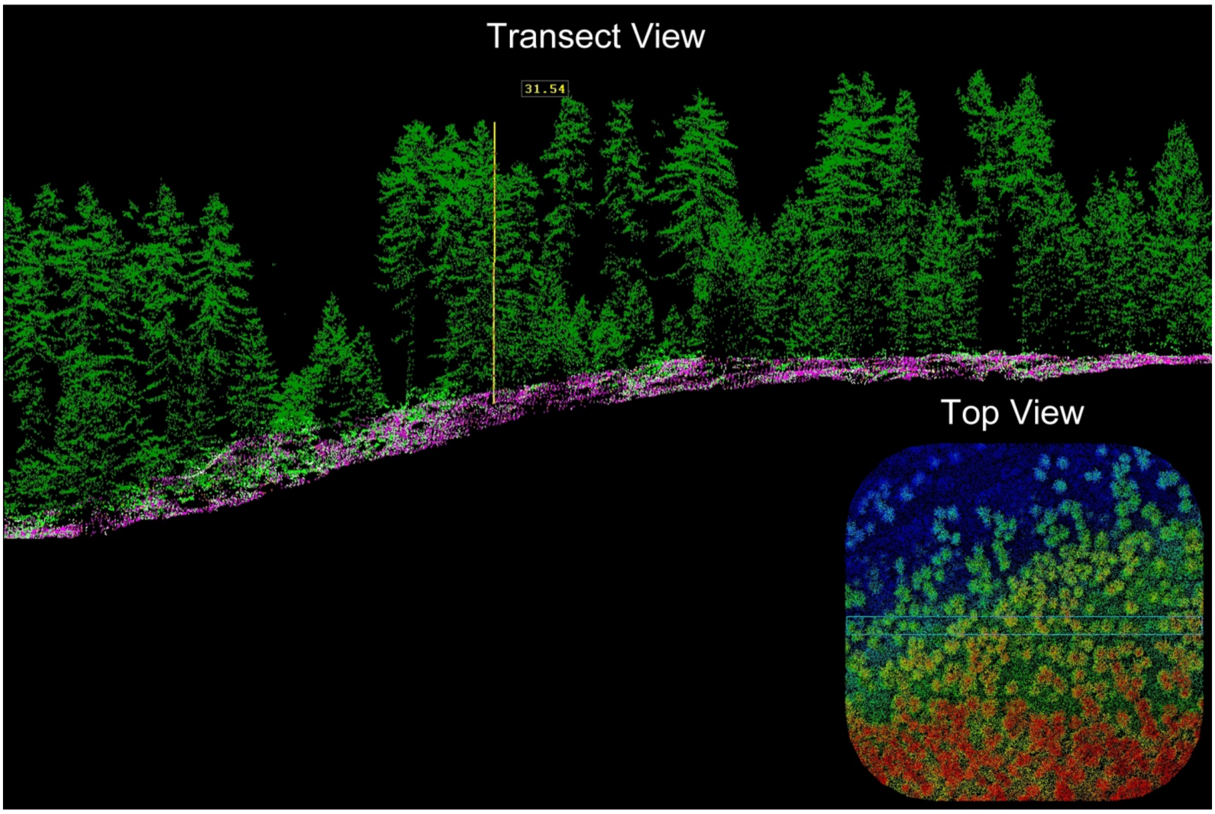
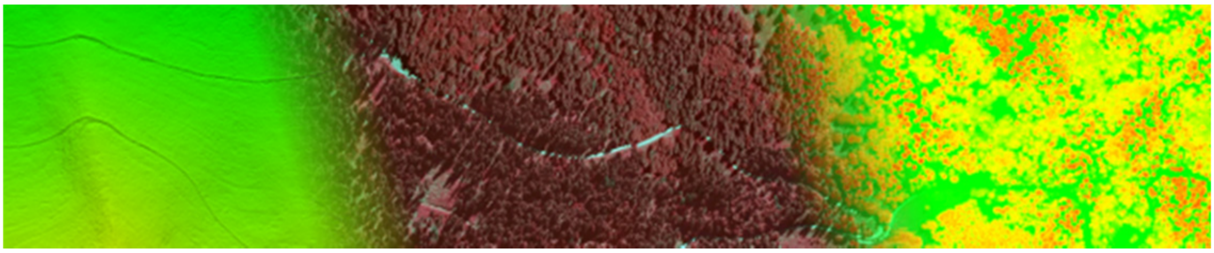


Figure 11: Visualization of the ALS data of study area 06 Pellizzano 5. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.



3.4.7 STUDY AREA 07 - ALTOPIANO DI ASIAGO 22

3.4.7.1 FOREST DESCRIPTION

The local forest consists of a Norway spruce (Picea abies), Silver fir (Abies alba) forest. The forest shows a medium density and coverage. The vertical structure is a one layered forest. The approximate tree height is 25 meters.

3.4.7.2 SITE DESCRIPTION

The site is located in Italy, in the Venetian Pre-Alps North West with respect to the city of Padua. It is located on the East exposition side of a small valley. The ground is smooth and flat; the rock face consists of limestone with a wet ground. The mean altitude is approximately 1153 meters above sea level. The location of the study area is presented in Figure 12.

Figure 12: Locations of the Study areas 07 Altopiano di Asiago 22, 08 Altopiano di Asiago 26 and 09 Altopiano di Asiago 22 in Italy.

3.4.7.3 FI DATA

The forest inventory data were acquired in October 2012. The plot size (circular plot) is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a Laser rangefinder coupled with a decicated system (hardware + software - Field-Map®) for forest mapping. The tree heights were measured with a Vertex. The calliper threshold was set to 5 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.7.4 ALS DATA

The ALS data were acquired in July 2012 under leave on conditions using an Optech ALTM 3100EA scanning system. The average flight altitude was about 420 m above ground. A maximum scan angle of 19° was used. The average point density of the ALS data is 10 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 13.

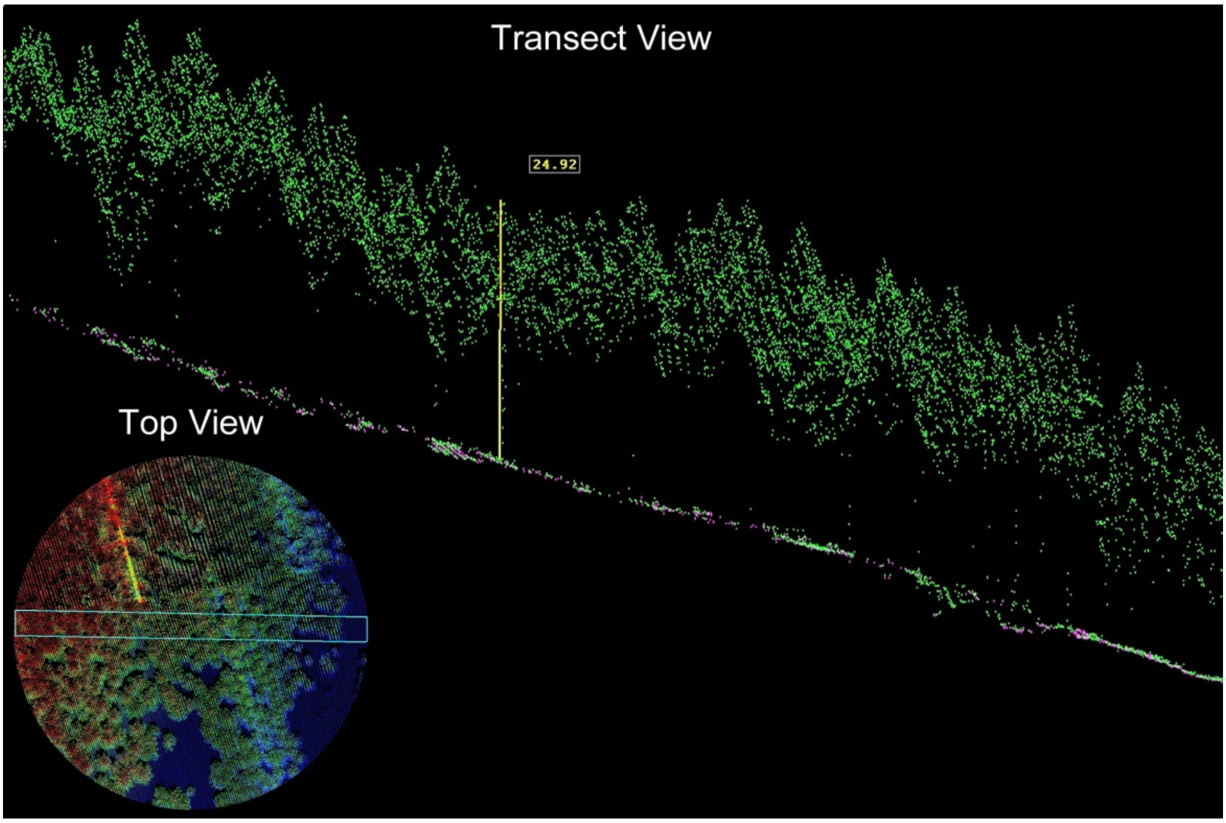
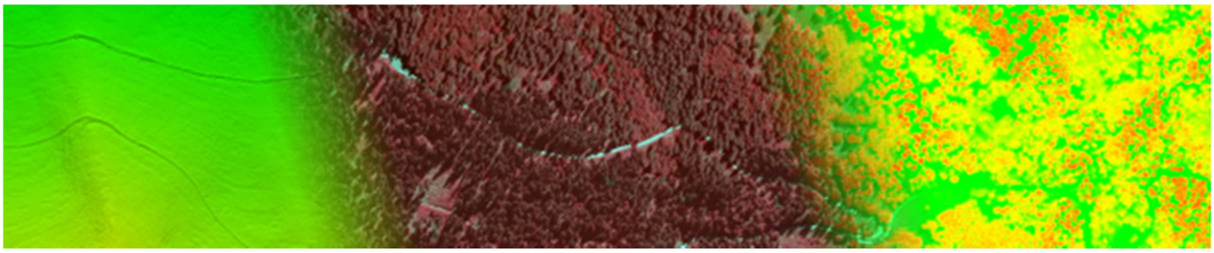


Figure 13: Visualization of the ALS data of study area 07 Altopianao di Asiago 22. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.



3.4.8 STUDY AREA 08 - ALTOPIANO DI ASIAGO 26

3.4.8.1 FOREST DESCRIPTION

The local forest consists of a Norway spruce (Picea abies), Silver fir (Abies alba) and Beech (Fagus sylvatica) mixed forest. The forest shows a medium density and coverage. The vertical structure is a multi layered forest with Fagus present only in the dominated layer. The approximate tree height is 28 meters.

3.4.8.2 SITE DESCRIPTION

The site is located in Italy, in the Venetian Pre-Alps, North West respect to the city of Padua.. It is located on the West exposition side of a small valley. The ground is smooth and flat; the rock face consist of limestone with a wet ground. The mean altitude is approximately 1247 meters above sea level. The location of the study area is presented in Figure 12.

3.4.8.3 FI DATA

The forest inventory data were acquired in October 2012. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a Laser rangefinder coupled with a decicated system (hardware + software - Field-Map®) for forest mapping. The tree heights were measured with a Vertex. The caliper threshold was set to 5 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.8.4 ALS DATA

The ALS data were acquired in July 2012 under leave on conditions using an Optech ALTM 3100EA scanning system. The average flight altitude was about 420 m above ground. A maximum scan angle of 19° was used. The average point density of the ALS data is 11 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 14.

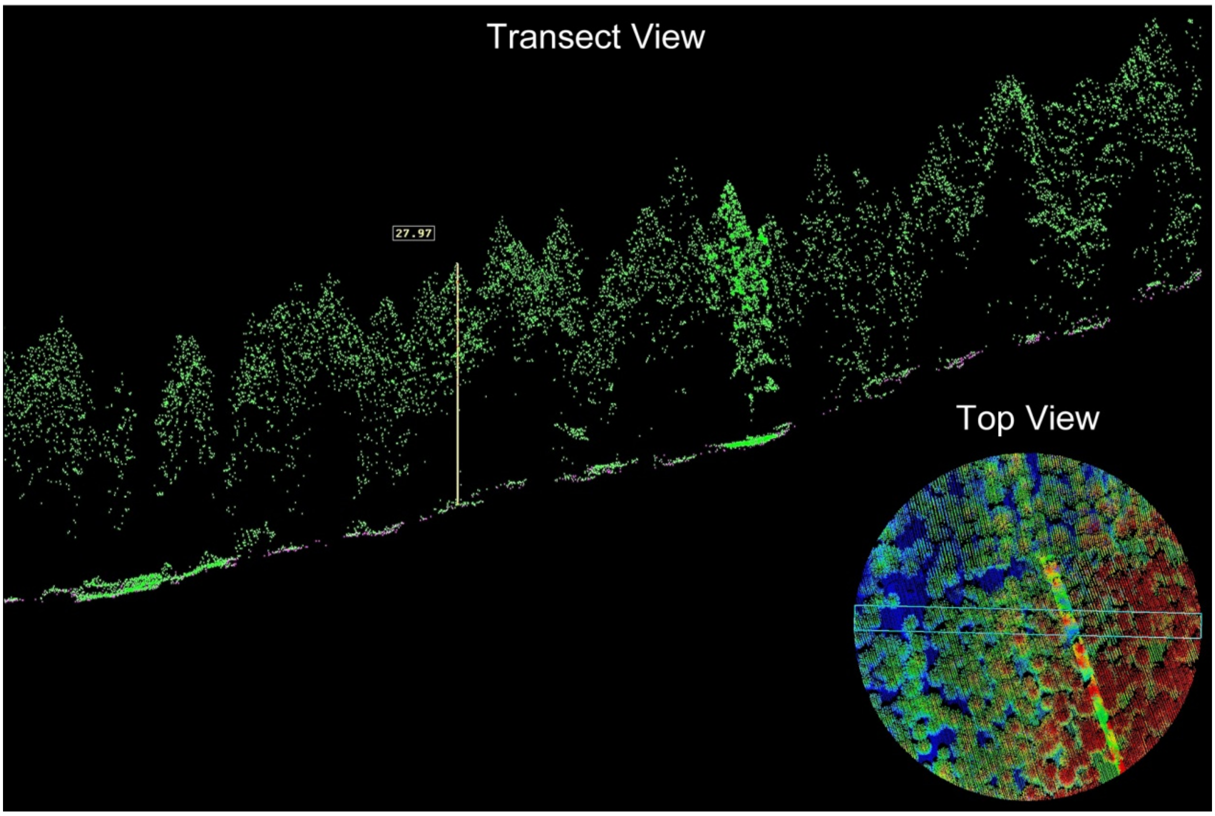


Figure 14: Visualization of the ALS data of study area 08 Altopianao di Asiago 26. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

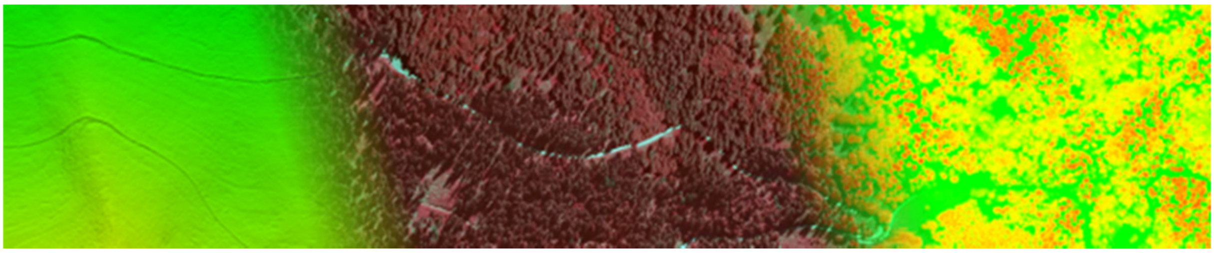
3.4.9 STUDY AREA 09 - ALTOPIANO DI ASIAGO 38

3.4.9.1 FOREST DESCRIPTION

The local forest consists of a Norway spruce (Picea abies), Silver fir (Abies alba) and beech (Fagus sylvatica) mixed forest. The forest shows a high density and coverage. The vertical structure shows a multi layered forest with structure with beech strongly present both in the dominant and in the dominated layer mainly as a coppice stands. The approximate tree height is 17 meters.

3.4.9.2 SITE DESCRIPTION

The site is located in Italy, in the Venetian Pre-Alps, North West respect to the city of Padua.. It is located on the East exposition side of a small valley. The terrain is rough and steep; the rock face consist of limestone. The mean altitude is approximately 1172 meters above sea level. The location of the study area is presented in Figure 12.



3.4.9.3 FI DATA

The forest inventory data were acquired in October 2012. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a Laser rangefinder coupled with a decicated system (hardware + software - Field-Map®) for forest mapping. The tree heights were measured with a Vertex. The caliper threshold was set to 5 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.9.4 ALS DATA

The ALS data were acquired in July 2012 under leave on conditions using an Optech ALTM 3100EA scanning system. The average flight altitude was about 420 m above ground. A maximum scan angle of 19° was used. The average point density of the ALS data is 11 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 15.

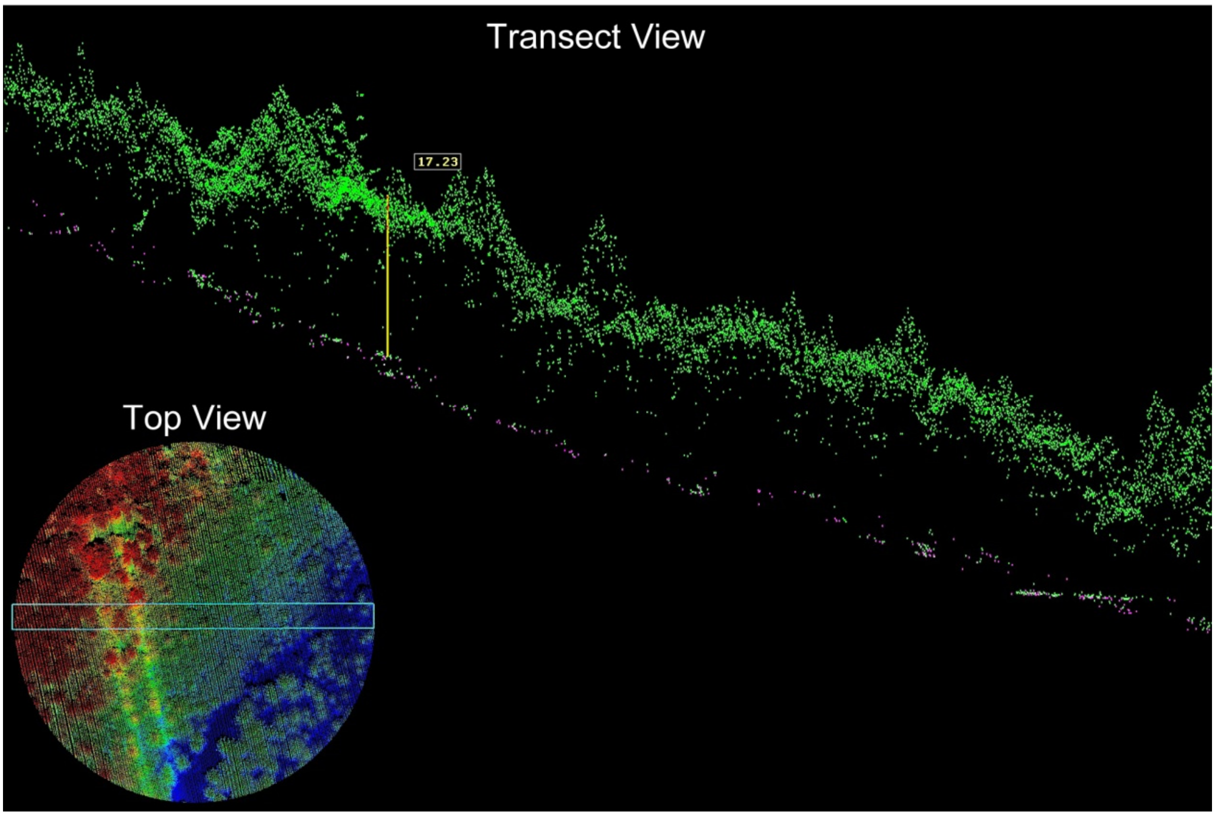
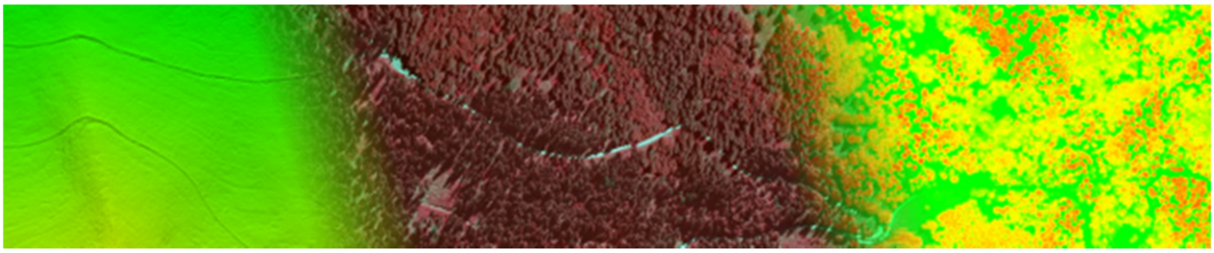


Figure 15: Visualization of the ALS data of study area 09 Altopianao di Asiago 38. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.



3.4.10 STUDY AREA 10 – COTOLIVIER 2

3.4.10.1 FOREST DESCRIPTION

The local forest consists of a scots pine (60%) forest with larch and spruce as additional species. The forest shows a high coverage. The vertical structure shows a single layered forest. The approximate tree height is 22 meters.

3.4.10.2 SITE DESCRIPTION

The site is located in the Piedmont area in Italy, located to the West of the city Turin. The area is facing North East. The terrain shows no particular roughness and a slope of 31°. The mean altitude is approximately 1165 meters above sea level. The location of the study area is presented in Figure 16.

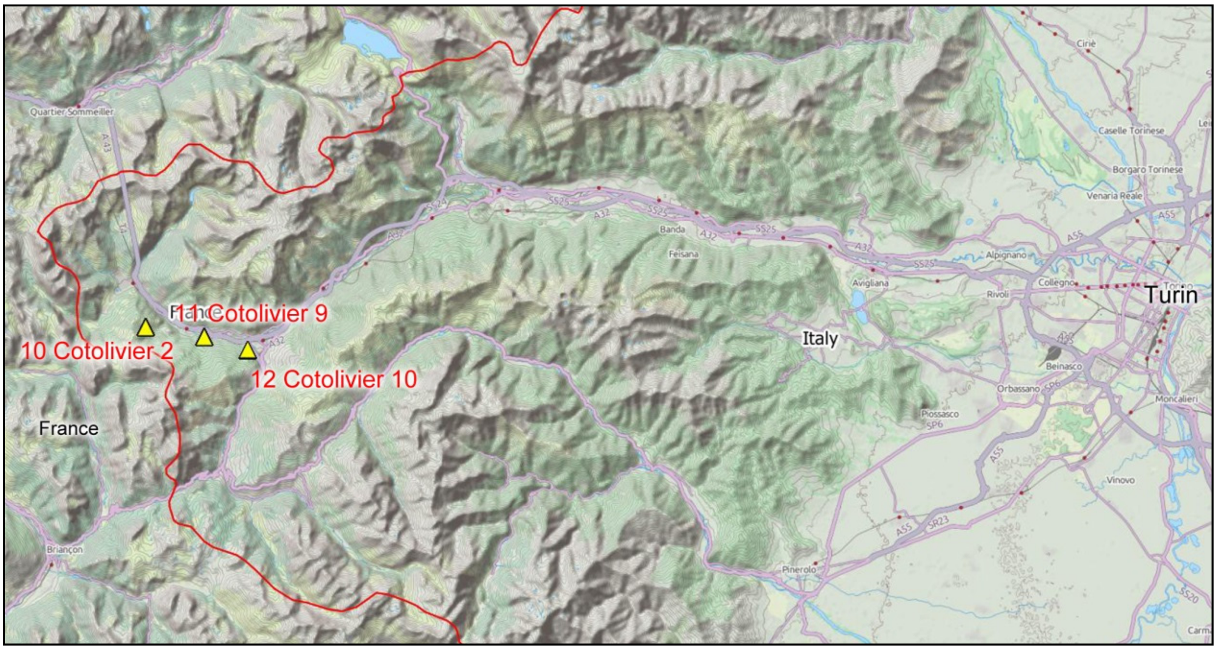


Figure 16: Locations of the Study areas 10 Cotolievier 2, 11 Cotolivier 9 and 12 Cotolivier 10 in the Piedmont area in Italy.

3.4.10.3 FI DATA

The forest inventory data were acquired on 8th and 20th of November 2012. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a TruePulse 360 Laser Rangefinder and a FieldMap system. The tree heights were measured with the TruePulse 360 Laser Rangefinder. The caliper threshold was set to 4 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, crown measures and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.10.4 ALS DATA

The ALS data were acquired in July 2012 under leave on conditions using an Optech ALTM 3100EA scanning system. The average point density of the ALS data is 11 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 17.

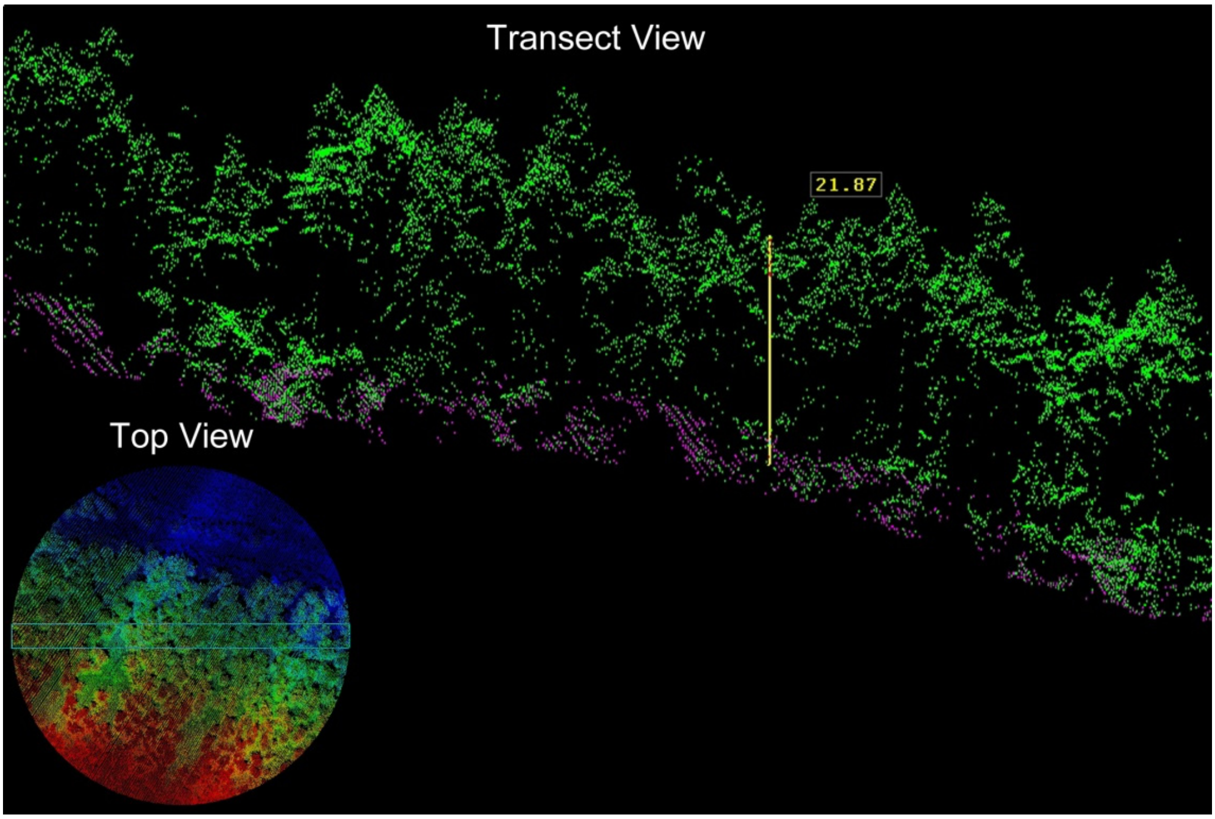


Figure 17: Visualization of the ALS data of study area 10 Cotolivier 2. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.11 STUDY AREA 11 – COTOLIVIER 9

3.4.11.1 FOREST DESCRIPTION

The local forest consists of a larch (80%) forest with maple as additional species. The forest shows low crown coverage (grazed larch wood). The vertical structure shows a dual layered forest. The approximate tree height is 20 meters.

3.4.11.2 SITE DESCRIPTION

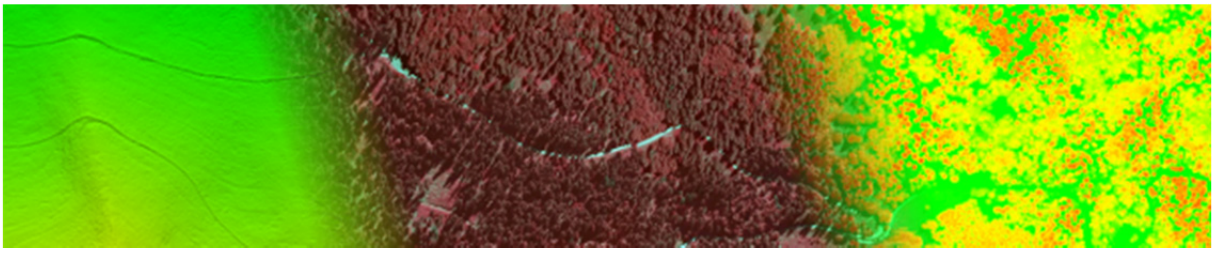
The site is located in the Piedmont area in Italy, located to the West of the city Turin. The area is facing South East. The terrain shows no particular roughness and a slope of 14°. The mean altitude is approximately 1698 meters above sea level. The location of the study area is presented in Figure 16.

3.4.11.3 FI DATA

The forest inventory data were acquired on 19th November 2012. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a TruePulse 360 Laser Rangefinder and a FieldMap system. The tree heights were measured with the TruePulse 360 Laser Rangefinder. The caliper threshold was set to 4 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, crown measures and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.11.4 ALS DATA

The ALS data were acquired in July 2012 under leave on conditions using an Optech ALTM 3100EA scanning system. The average point density of the ALS data is 12 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 18.



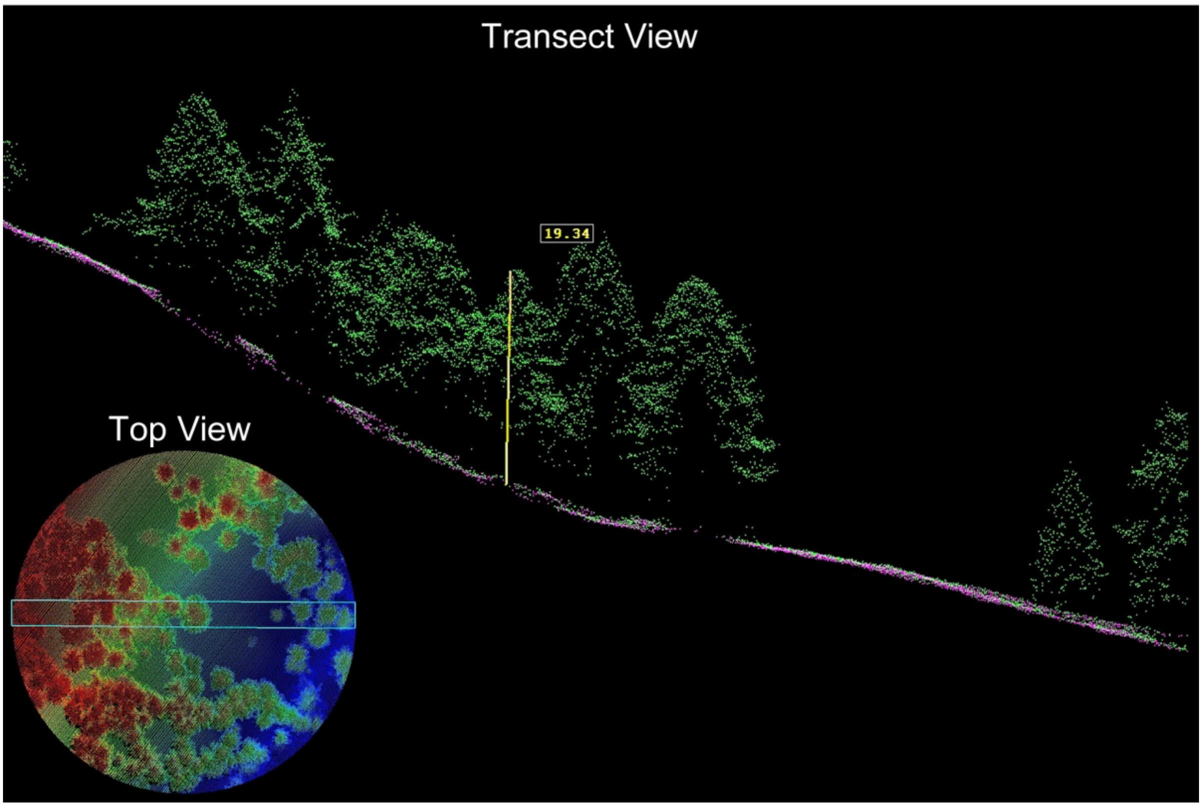


Figure 18: Visualization of the ALS data of study area 11 Cotolivier 9. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

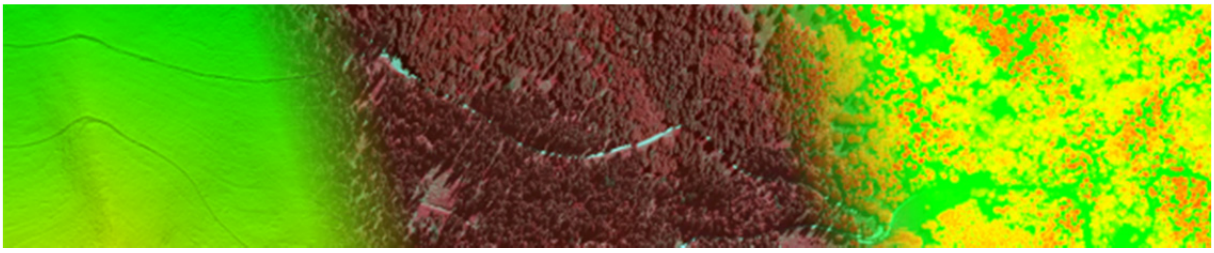
3.4.12 STUDY AREA 12 – COTOLIVIER 10

3.4.12.1 FOREST DESCRIPTION

The local forest consists of a scots pine (55%) forest with larch as co-dominant species. The forest shows a medium crown coverage. The vertical structure shows a mono layered forest. The approximate tree height is 25 meters.

3.4.12.2 SITE DESCRIPTION

The site is located in the Piedmont area in Italy, located to the West of the city Turin. The area is facing North. The terrain shows no particular roughness and a slope of 27°. The mean altitude is approximately 1251 meters above sea level. The location of the study area is presented in Figure 16.



3.4.12.3 FI DATA

The forest inventory data were acquired on 13th June 2013. The plot size of the circular plot is 1257 m^2 which relates to a radius of 20 m. A high precision GPS was used to locate and mark the plot center. The trees were positioned by using a TruePulse 360 Laser Rangefinder and a FieldMap system. The tree heights were measured with the TruePulse 360 Laser Rangefinder. The caliper threshold was set to 4 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, crown measures and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.12.4 ALS DATA

The ALS data were acquired in July 2012 under leave on conditions using an Optech ALTM 3100EA scanning system. The average point density of the ALS data is 11 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 19.

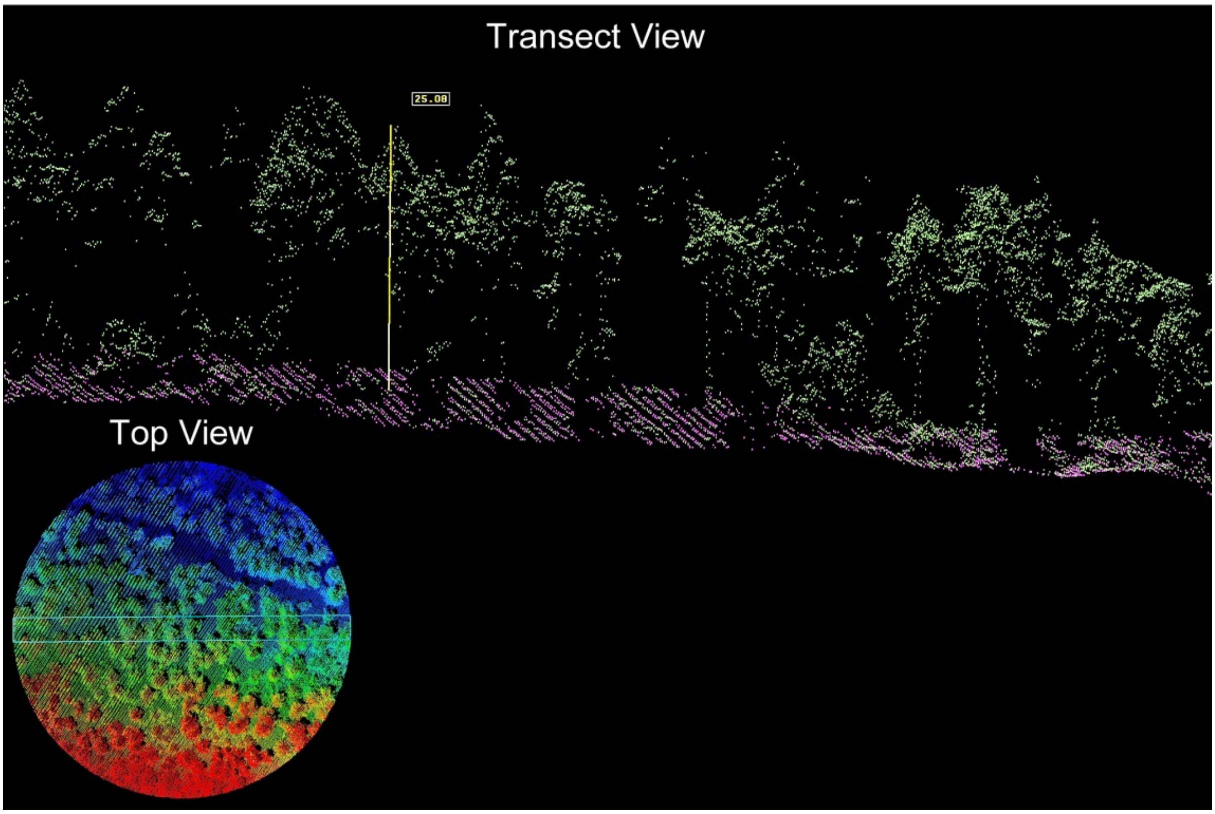
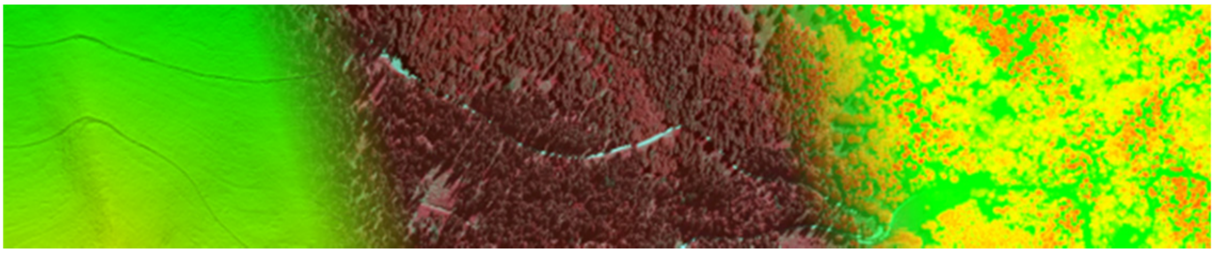


Figure 19: Visualization of the ALS data of study area 12 Cotolivier 10. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.



3.4.13 STUDY AREA 13 – HOLZSCHOPF

3.4.13.1 FOREST DESCRIPTION

The forest of the Holzschopf-Marteloscope consists of old-growth terminal developmental stages with young patches. The natural woodland community corresponds to a subalpine spruce forest on acid soils. Because this forest lies close to the tree line, from time to time avalanches enter the forest and destroy young trees. The average tree volume is 0,98 m^3 which corresponds to an growing stock of 424,16 m^3 per hectare. The forest shows sparse crown coverage. The approximate tree height is 34 meters.

3.4.13.2 SITE DESCRIPTION

The site is located in the Montafon area in Austria, located to the South East of the city Bludenz. The area lies on a North facing slope near the tree line. The mean altitude is approximately 1710 meters above sea level. The location of the study area is presented in Figure 20.

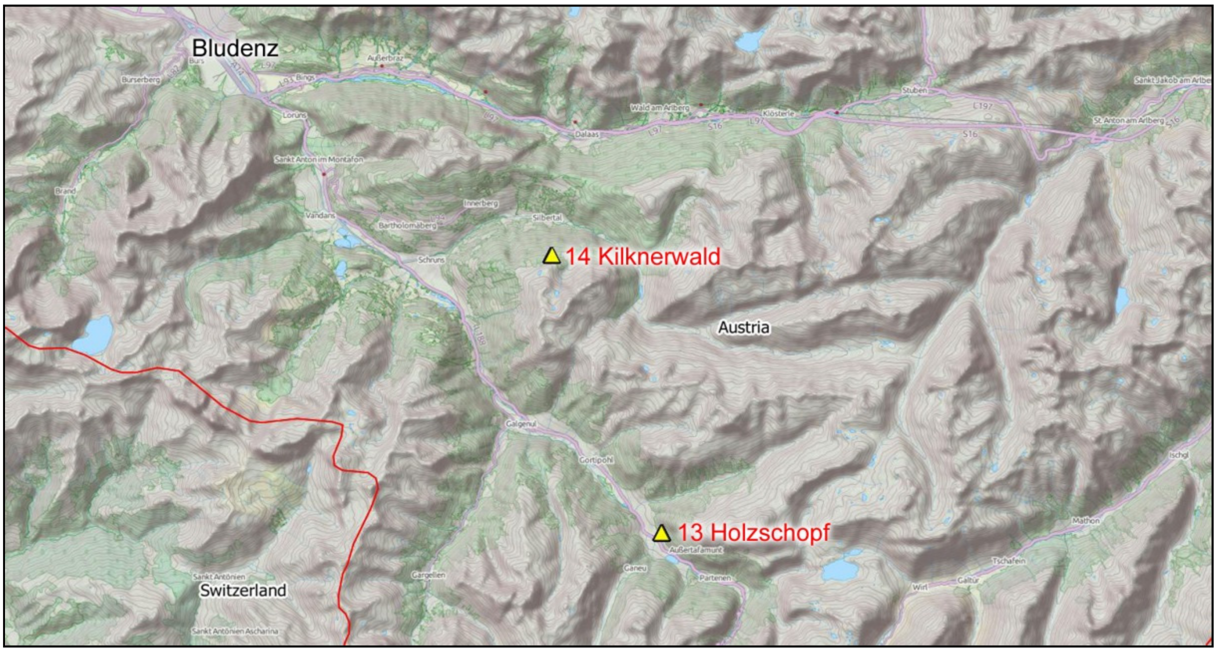
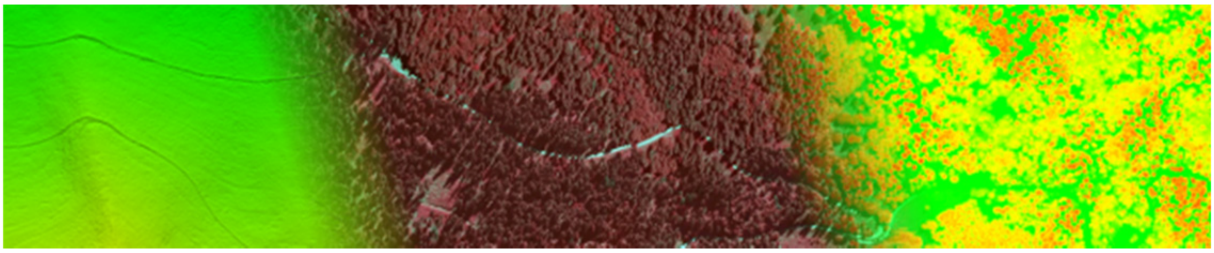


Figure 20: Locations of the Study areas 13 Holzschopf and 14 Kilknerwald in the Montafon area in Austria.

3.4.13.3 FI DATA

The forest inventory data were acquired in June 2009. The plot size of the rectangular plot is 2500 m^2 which relates to a size of 50 x 50 m. A total station was used to locate and mark the plot corners. The tree positions were surveyed by means of compass bearing and distances (Vertex III on tripod). The tree heights were measured with the Vertex III (Handheld). The caliper



threshold was set to 10 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.13.4 ALS DATA

The ALS data were acquired in 2011 during multiple flight campaigns under leaf-off and leaf-on canopy conditions without snow cover. As laser scanning system the discrete Airborne Laser Terrain Mapper ALTM Gemini from Optech Inc. and the full-waveform system Trimble Harrier 56 were used. The data acquisitions were performed in the framework of a commercial terrain-mapping project, fully covering the Federal State of Vorarlberg. The point density of the dataset is approximately 22 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 21.

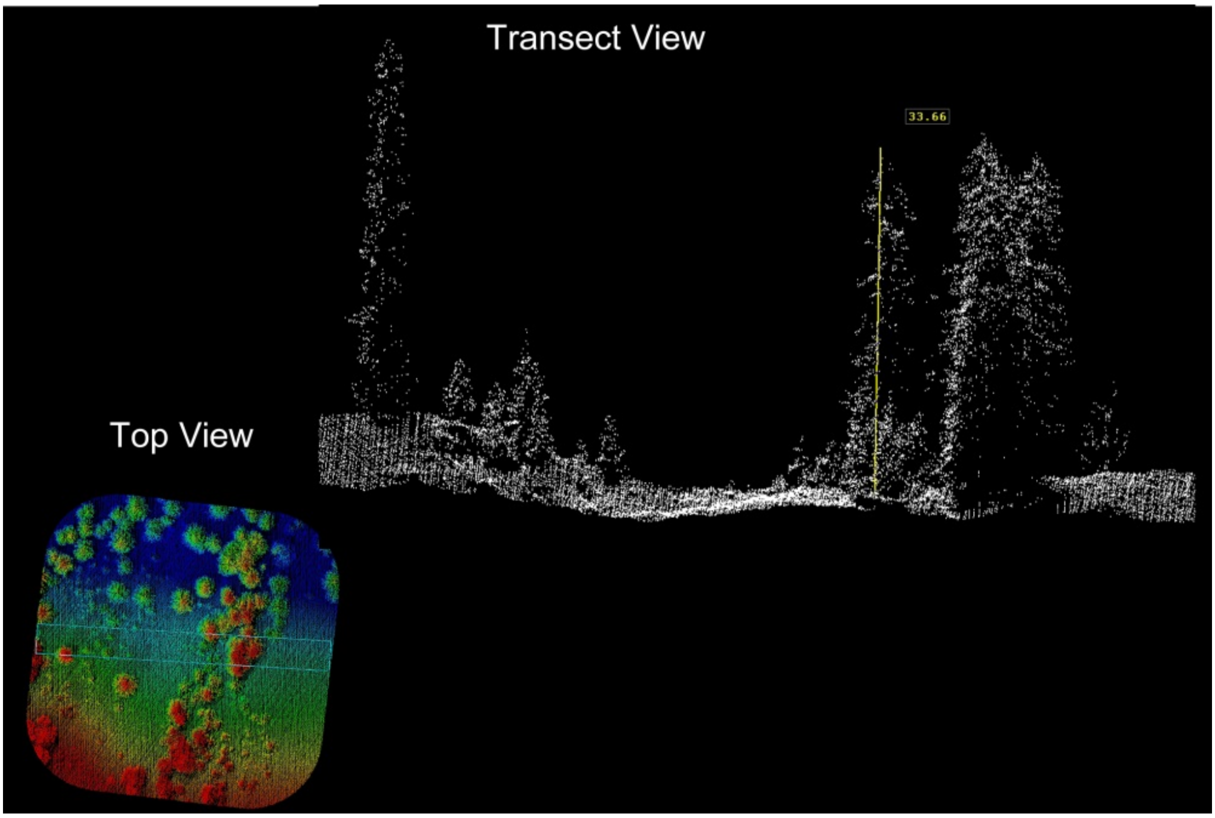


Figure 21: Visualization of the ALS data of study area 13 Holzschopf. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.14 STUDY AREA 14 – KILKNERWALD

3.4.14.1 FOREST DESCRIPTION

The forest in the Kilknerwald-Marteloscope is homogeneously structured. These old spruce stands used to be pastures for sheep and goats in former times. The natural forest community is characterized by a Veronico-Piceetum which usually occurs in high montane to subalpine sites poor in limestone but on not too acid substrates mainly on mica-shists and amphiboltes in the Montafon. There is no shrub-layer and even the herb-layer is not area extensive. The forest shows a dense crown coverage. The approximate tree height is 29 meters.

3.4.14.2 SITE DESCRIPTION

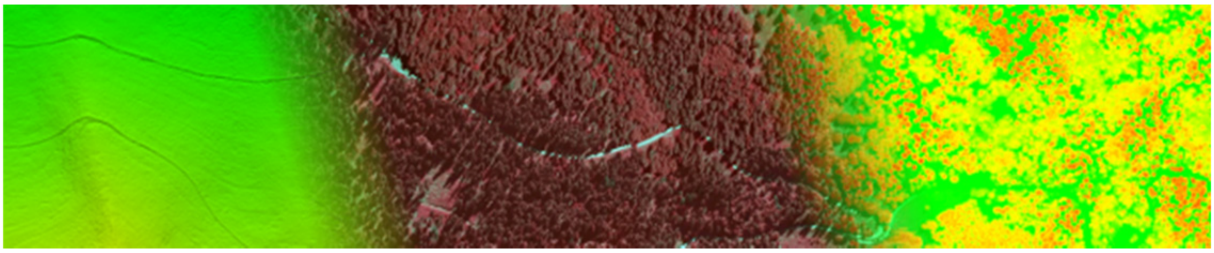
The Kilknerwald-Marteloscope lies on a soth-west-facing foot slope near the village of Gaschurn. The whole forested slope provides essential protection against natural hazards such as landslides, avalanches and rockfall. Above the Marteloscope the area is dominated by steep rugged terrain with rock faces, gullies and torrents. The rock faces and the upper part of the study area consist of hornblende-gneisses and amphibolites. The lower parts consist of mica-schist layers. The Marteloscope itself lies on a more gentle footslope in the transit and ablation area of a rockfall channel. The mean altitude is approximately 1139 meters above sea level. The location of the study area is presented in Figure 20.

3.4.14.3 FI DATA

The forest inventory data were acquired in June 2009. The plot size of the rectangular plot is 2500 m^2 which relates to a size of 50 x 50 m. A total station was used to locate and mark the plot corners. The tree positions were surveyed by means of compass bearing and distances (Vertex III on tripod). The tree heights were measured with the Vertex III (Handheld). The caliper threshold was set to 10 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, and tree height. The FI data were georeferenced using the coordinate system UTM-32N (EPSG:32632).

3.4.14.4 ALS DATA

The ALS data were acquired in 2011 during multiple flight campaigns under leaf-off and leaf-on canopy conditions without snow cover. As laser scanning system the discrete Airborne Laser Terrain Mapper ALTM Gemini from Optech Inc. and the full-waveform system Trimble Harrier 56 were used. The data acquisitions were performed in the framework of a commercial terrain-mapping project, fully covering the Federal State of Vorarlberg. The point density of the dataset is approximately 33 pts / m^2. The ALS data were georeferenced using the coordinate system UTM-32N (EPSG:32632). The ALS data of the study area are presented in Figure 22.



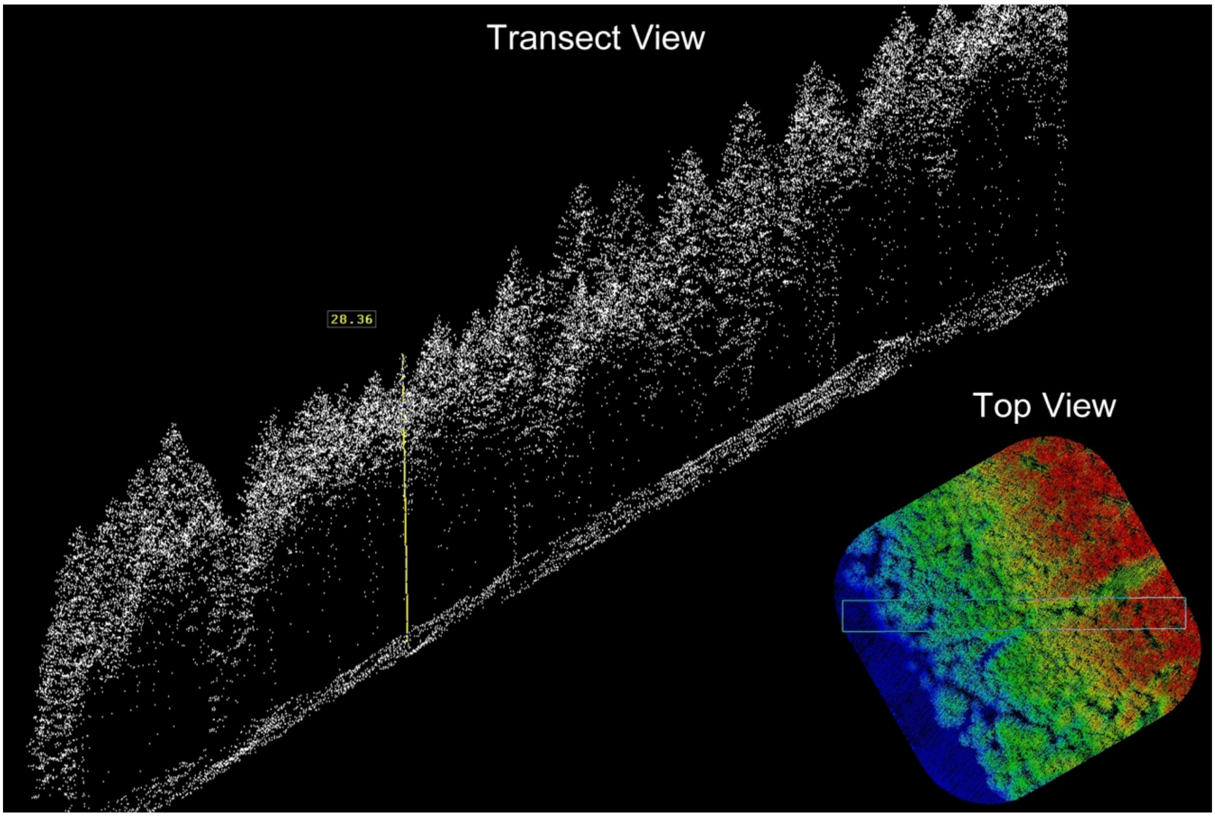


Figure 22: Visualization of the ALS data of study area 14 Kilknerwald. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.15 STUDY AREAS 15, 16, 17 AND 18 – LESKOVA DOLINA 76, 93, 142 AND 150

3.4.15.1 FOREST DESCRIPTION

The prevalent plant community in the study area is the Dinaric silver fir, which is part of the European beech forest community (Omphalodo-Fagetum Mar. 93). The main tree species are silver fir (Abies alba Mill.), Norway spruce (Picea abies Karst.), and European beech (Fagus sylvatica L.). Sycamore (Acer pseudoplatanus L.) and elm (Ulmus glabra Huds.) are also present. Most of the stands are managed with a selection (single-tree or group) system or irregular shelterwood, leading to considerable within-stand variation in tree age and tree species composition. The close-to-nature forest management prevents forest clear cuts or intensive forest shifts. Tree ingrowth largely results from natural processes rather than tree planting. The forest at study area 15 shows a medium crown coverage. The approximate tree height is 30 meters. The forest at study area 16 shows a medium crown coverage. The approximate tree height is 36 meters. The forest at study area 17 shows a dense crown coverage and the vertical structure of the forest is multi layered. The approximate tree height is 26 meters. The forest at study area 18 shows a dense crown coverage and the vertical structure of the forest is multi layered. The approximate tree height is 26 meters.

3.4.15.2 SITE DESCRIPTION

The study site is situated in the predominantly forested Natura 2000 Snežnik area in the South West of Slovenia (Lon. 14°26’E, Lat. 45°35’N). The area is located in the Dinaric Mountains, which range from Slovenia to Monte Negro. The topography of the area is very diverse, with abundant sinkholes typical of high Karst geology with limestone and dolomite as the parent material. Due to the high variability in topography, different pedogenetic associations developed, primarily litosols, rendzic leptosols, cambisols, and luvisols. The soil depth varies between 0 and 300 cm depending on the micro-topographic position, and precipitation is evenly distributed throughout the year, with a mean annual precipitation of 2150 mm. The average mean temperature is 6.5 °C, and late spring and early autumn frosts are common. The mean altitude of all four sites is approximately 870 meters above sea level. The locations of the study areas are presented in Figure 24.

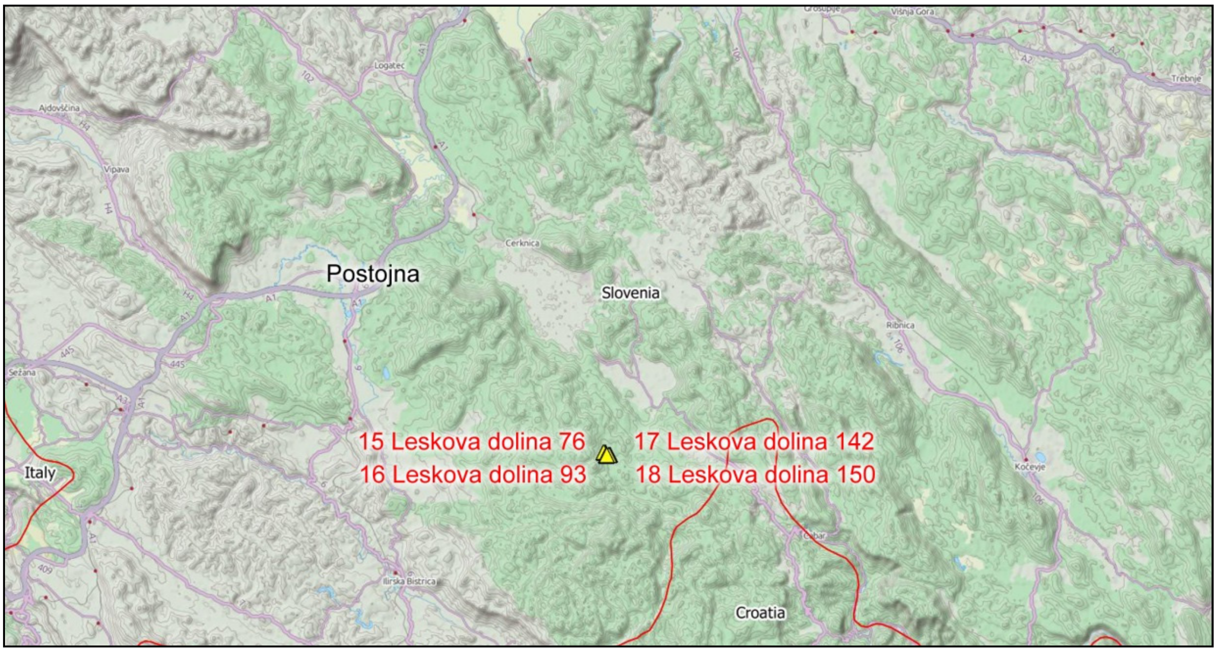
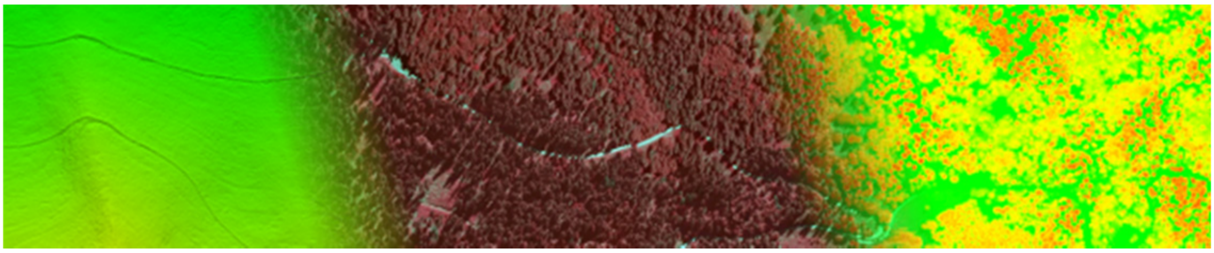


Figure 23: Locations of the Study areas 15 Leskova dolina 76, 16 Leskova dolina 93, 17 Leskova dolina 142 and 18 Leskova dolina 150 in Slovenia.

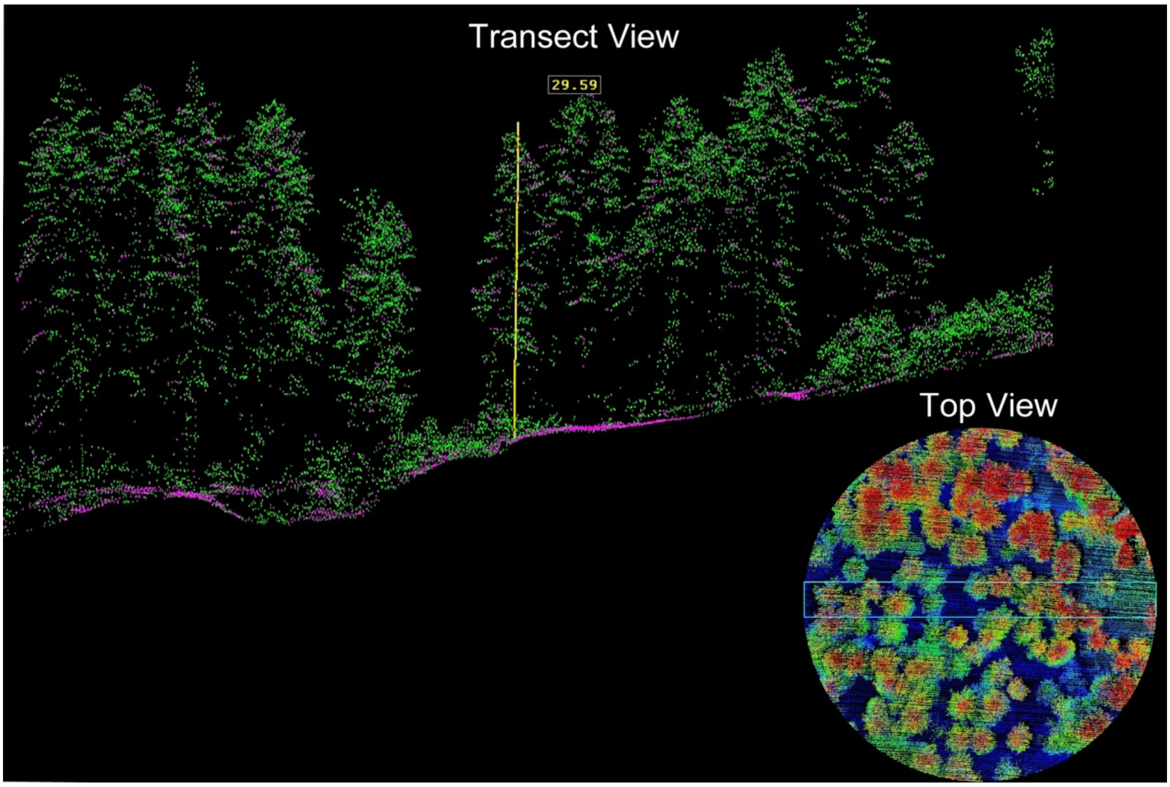


3.4.15.3 FI DATA

The forest inventory data were acquired in November 2008. The plot sizes of the circular plots are 2000 m^2 each. A GPS was used to locate and mark the plot centers. The tree positions were surveyed by means of compass bearing and distances (Vertex IV). The tree heights were measured with the Vertex IV. The caliper threshold was set to 10 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, and tree height. The FI data were georeferenced using the coordinate system Gauss Krüger D48 (EPSG:3912).

3.4.15.4 ALS DATA

The ALS data were acquired on the 9th of October 2009. As laser scanning system the full-waveform system Riegl LM5600, mounted on a helicopter, was used. The point density of the dataset is approximately 30 pts / m^2. The ALS data were georeferenced using the coordinate system Gauss Krüger D48 (EPSG:3912). The ALS data of the study area 15 - Leskova dolina 76 is presented in Figure 24. The ALS data of the study area 16 - Leskova dolina 93 is presented in Figure 25. The ALS data of the study area 17 - Leskova dolina 142 is presented in Figure 26. The ALS data of the study area 18 - Leskova dolina 150 is presented in Figure 27.



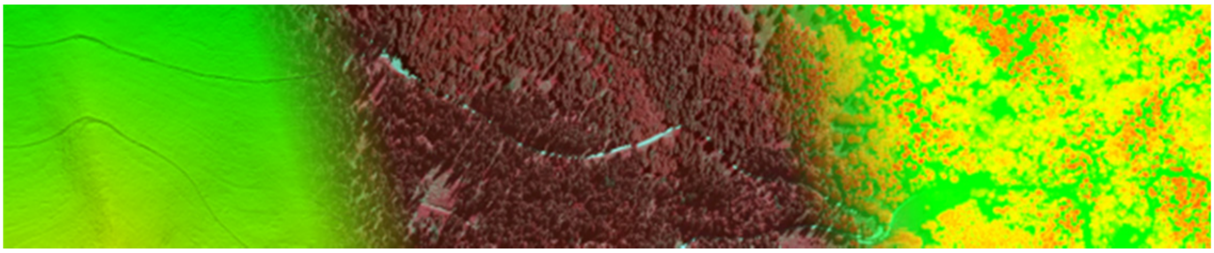


Figure 24: Visualization of the ALS data of study area 15 Leskova dolina 76. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

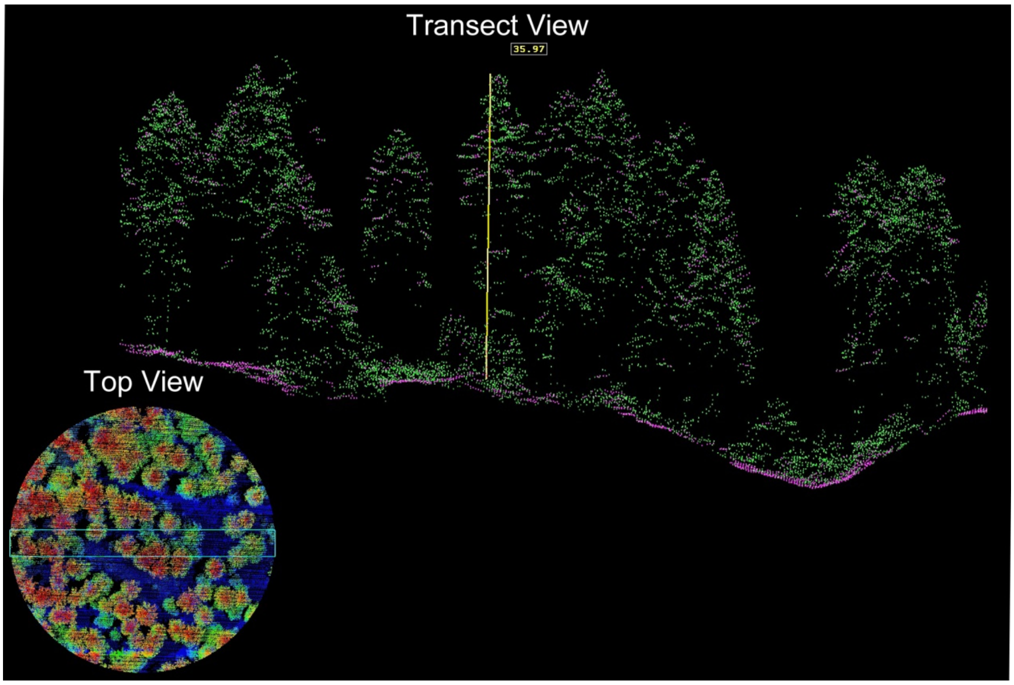


Figure 25: Visualization of the ALS data of study area 16 Leskova dolina 93. The Top view shows a z-colored pointcloud where red indicates higher values and blue colors indicate lower values.

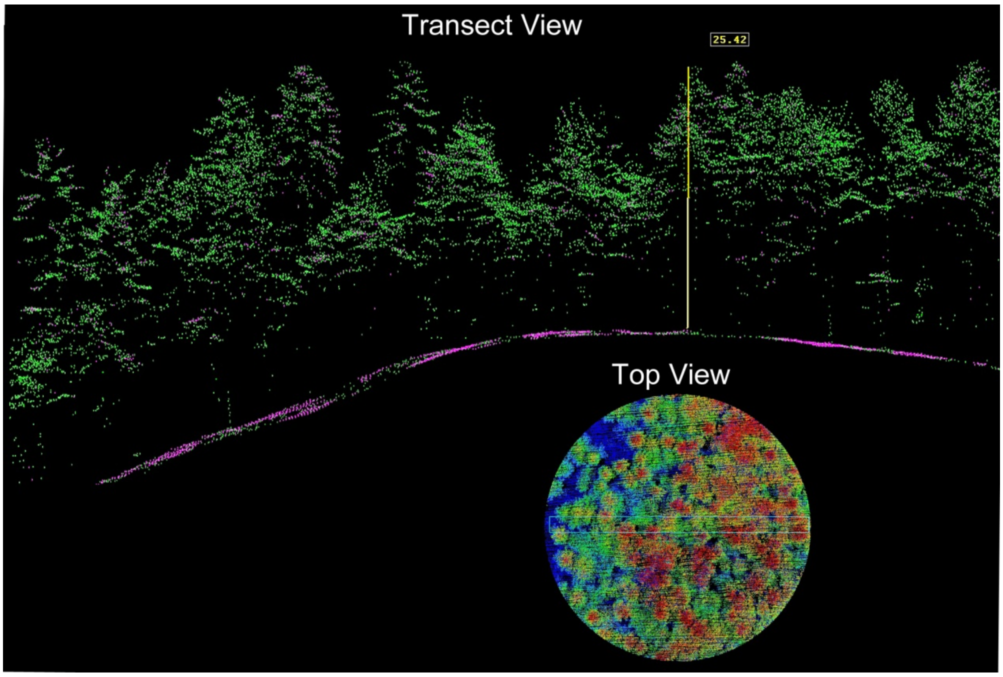
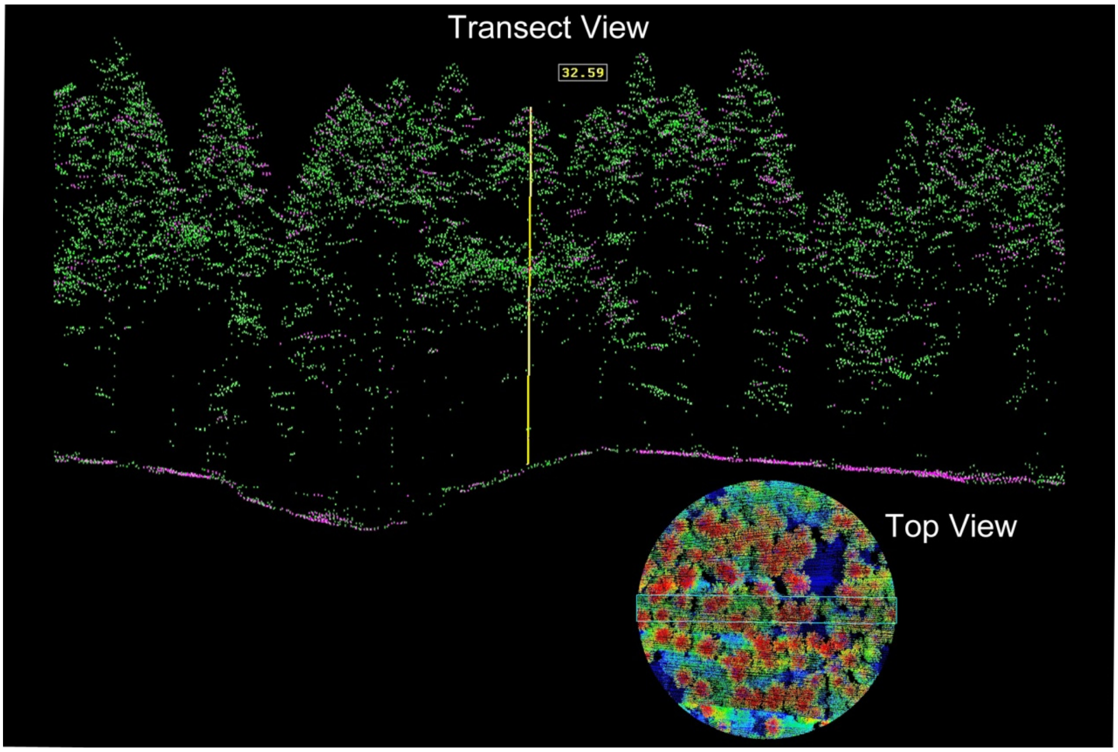


Figure 26: Visualization of the ALS data of study area 17 Leskova dolina 142. The Top view shows a z-colored pointcloud where red indicates higher values and blue colors indicate lower values.



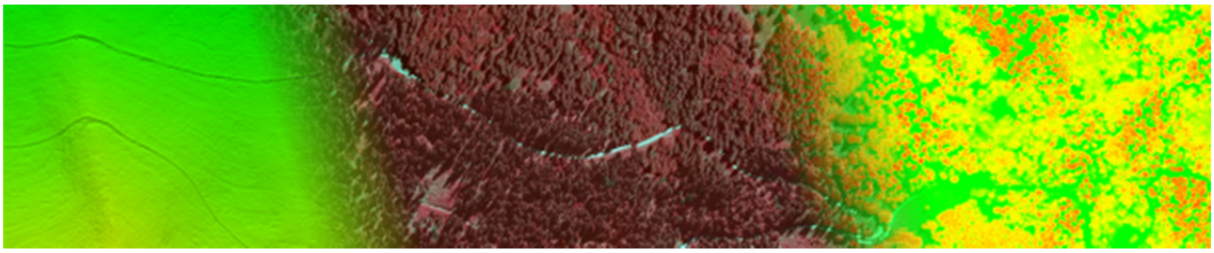


Figure 27: Visualization of the ALS data of study area 18 Leskova dolina 150. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.16 STUDY AREA 19 – BEGUNJŠČICA 9

3.4.16.1 FOREST DESCRIPTION

Forest covers 93% of the test site, with prevailing uneven aged stands, due to small scale parcels and unorganized forest owners. In mixture of stands, conifers dominate. Stands with more than 50% of conifers in stand mixture grow on 59% of study area and only 32% of whole area is overgrown with stands with less than 50 % of conifers in stand mixture. Seedlings are grooving on 2% of whole area. Areas that are not overgrown with forest represent mostly pastures. The main forest community is Abieti-Fagetum prealpinum aceretosum. The forest shows dense crown coverage and the vertical structure of the forest is single layered. The approximate tree height is 34 meters.

3.4.16.2 SITE DESCRIPTION

Test site lies in mountainous landscape with relatively high altitudes (600 – 2000m), rugged terrain, many mountain backs, ridges and tops, which descend to the valley with steep, sometimes precipitous slopes cut by number of gullies and ravines and ending in narrow valleys, by which the water flows into lowlands in form of strong torrential mountain streams. Alpine climate with distinctive temperature extremes is prevailing. Yearly amount of precipitation at site is 1700 – 2500 mm, with average yearly temperature 4 – 6 °C and occasional stormy winds. The mean altitude of all four sites is approximately 1017 meters above sea level. The location of the study area is presented in Figure 28.

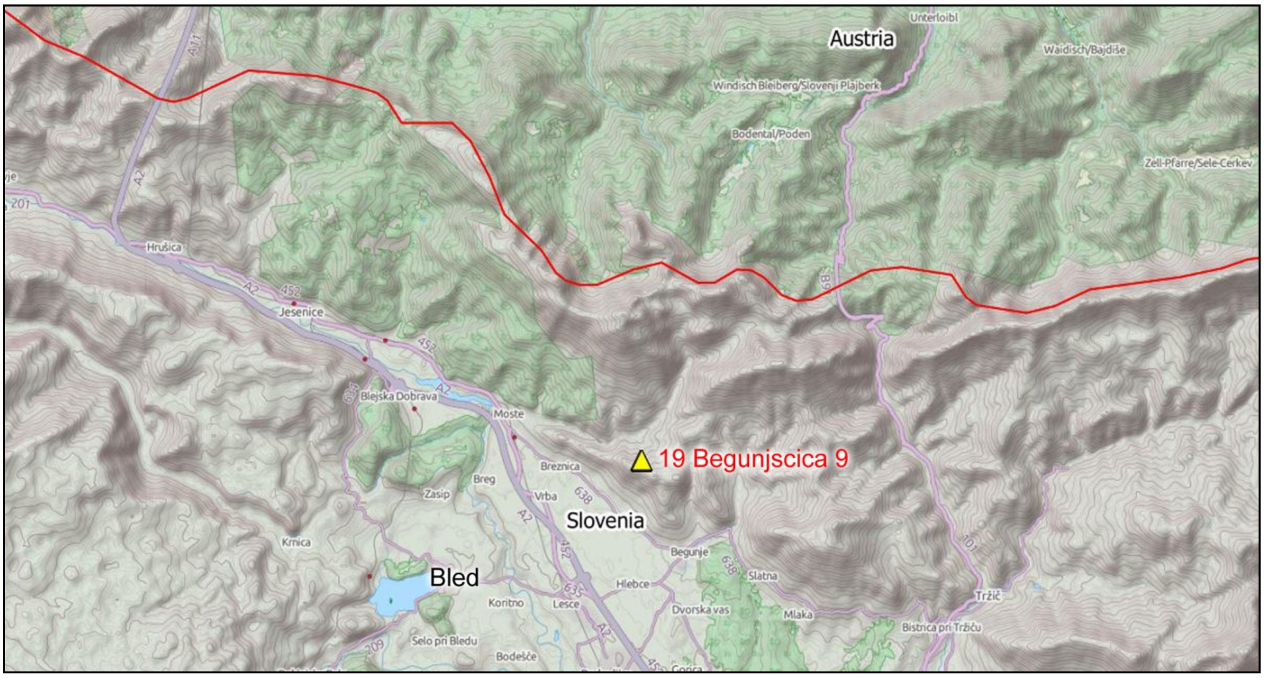


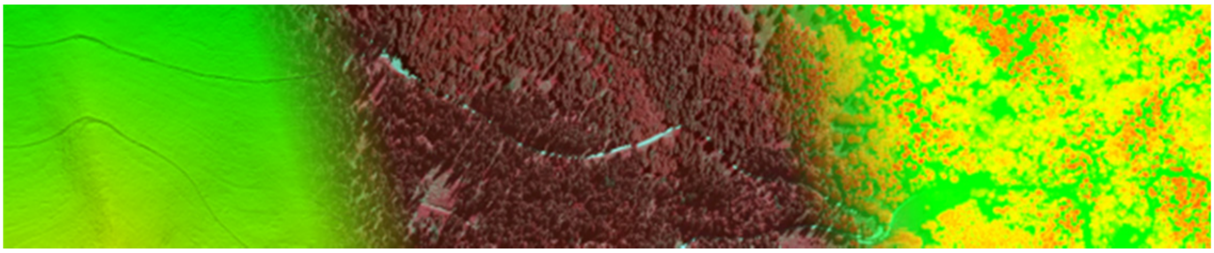
Figure 28: Location of the Study area 19 Begunjščica 9 in the Gorenjska area in Slovenia.

3.4.16.3 FI DATA

The forest inventory data were acquired from June to August 2008. The plot size of the circular plot is 401 m^2 which relates to a radius of 11.3 m. A GPS was used to locate and mark the plot centers. The tree positions were surveyed by means of compass bearing and distances. The tree heights were measured using an inclinometer. The height is calculated based on two measured angles. The caliper threshold was set to 10 cm. The collected attributes are tree number, tree species, coordinates of the tree position, DBH, and tree height. The FI data were georeferenced using the coordinate system WGS84 (EPSG:4329).

3.4.16.4 ALS DATA

The ALS data were acquired in 2007. No information about the laser scanning system is available. The point density of the dataset is approximately 12 pts / m^2. The ALS data were georeferenced using the coordinate system Gauss Krüger D48 (EPSG:3387). The ALS data of the study area 19 is presented in Figure 29.



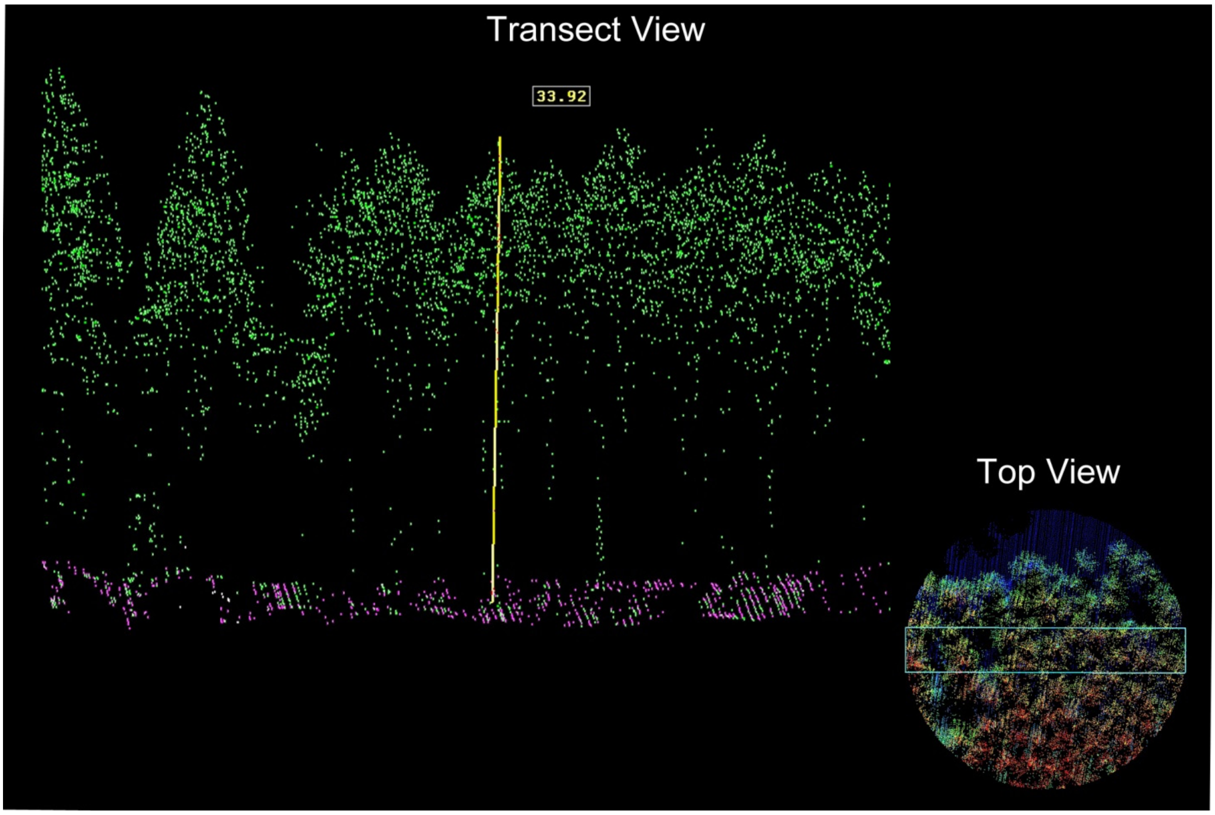


Figure 29: Visualization of the ALS data of study area Study area 19 Begunjščica 9. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.17 STUDY AREA 20 – BERNER JURA 37865

3.4.17.1 FOREST DESCRIPTION

The local forest consists of a spruce and fir stand in an unmanaged forest. The forest shows medium crown coverage and the vertical structure of the forest is multi layered. The approximate tree height is 36 meters.

3.4.17.2 SITE DESCRIPTION

The mean altitude of all four sites is approximately 853 meters above sea level. The location of the study area is presented in Figure 30.

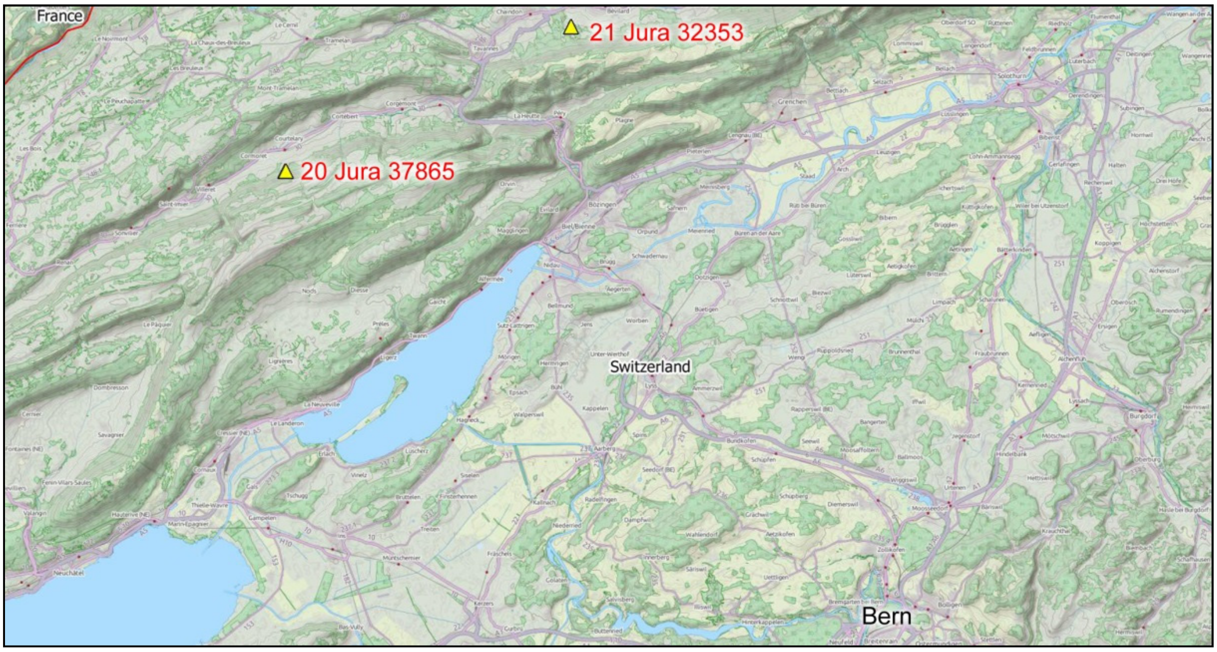


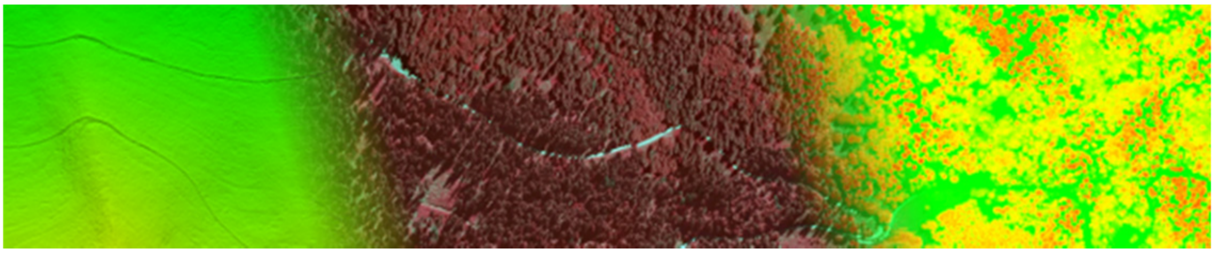
Figure 30: Location of the Study area 20 Berner Jura 37865 and 21 Berner Jura 32353 in the Berner Jura area in Switzerland.

3.4.17.3 FI DATA

The forest inventory data were acquired within the Swiss forest inventory LFI 3 from 2004 to 2006. The collected attributes are tree number, tree species, coordinates of the tree position, and DBH. No tree height information is available. The FI data were georeferenced using the coordinate system CH1903_LN02 (EPSG:21781).

3.4.17.4 ALS DATA

The ALS data were acquired in 2011. No information about the laser scanning system is available. The point density of the dataset is approximately 10 pts / m^2. The ALS data were georeferenced using the coordinate system CH1903_LN02 (EPSG:21781). The ALS data of the study area 19 is presented in Figure 31.



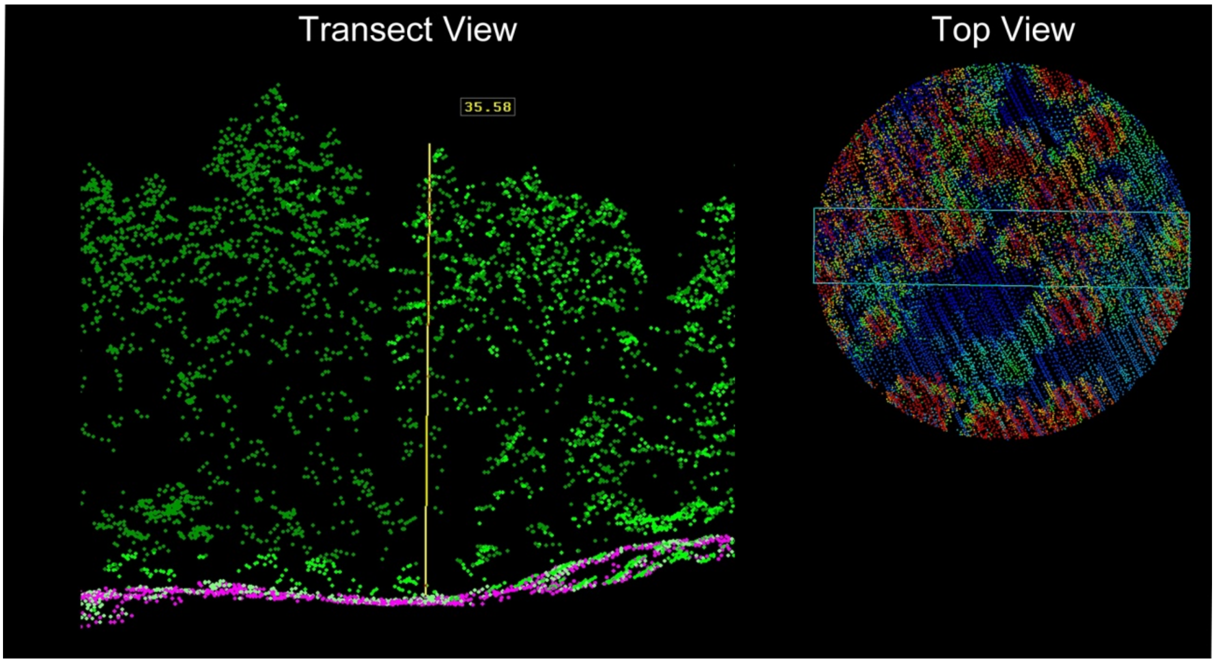


Figure 31: Visualization of the ALS data of study area 20 Berner Jura 37865. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.

3.4.18 STUDY AREA 21 – BERNER JURA 32353

3.4.18.1 FOREST DESCRIPTION

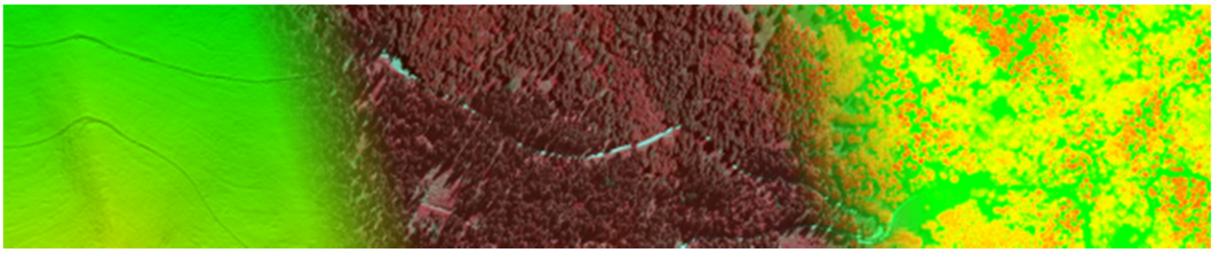
The local forest consists of an old spruce and fir stand in an unmanaged forest. The forest shows a dense crown coverage and the vertical structure of the forest is single layered. The approximate tree height is 36 meters.

3.4.18.2 SITE DESCRIPTION

The mean altitude of all four sites is approximately 825 meters above sea level. The location of the study area is presented in Figure 30.

3.4.18.3 FI DATA

The forest inventory data were acquired within the Swiss forest inventory LFI 3 from 2004 to 2006. The collected attributes are tree number, tree species, coordinates of the tree position, and DBH. No tree height information is available. The FI data were georeferenced using the coordinate system CH1903_LN02 (EPSG:21781).



3.4.18.4 ALS DATA

The ALS data were acquired in 2011. No information about the laser scanning system is available. The point density of the dataset is approximately 5 pts / m². The ALS data were georeferenced using the coordinate system CH1903_LN02 (EPSG:21781). The ALS data of the study area 19 is presented in Figure 29.

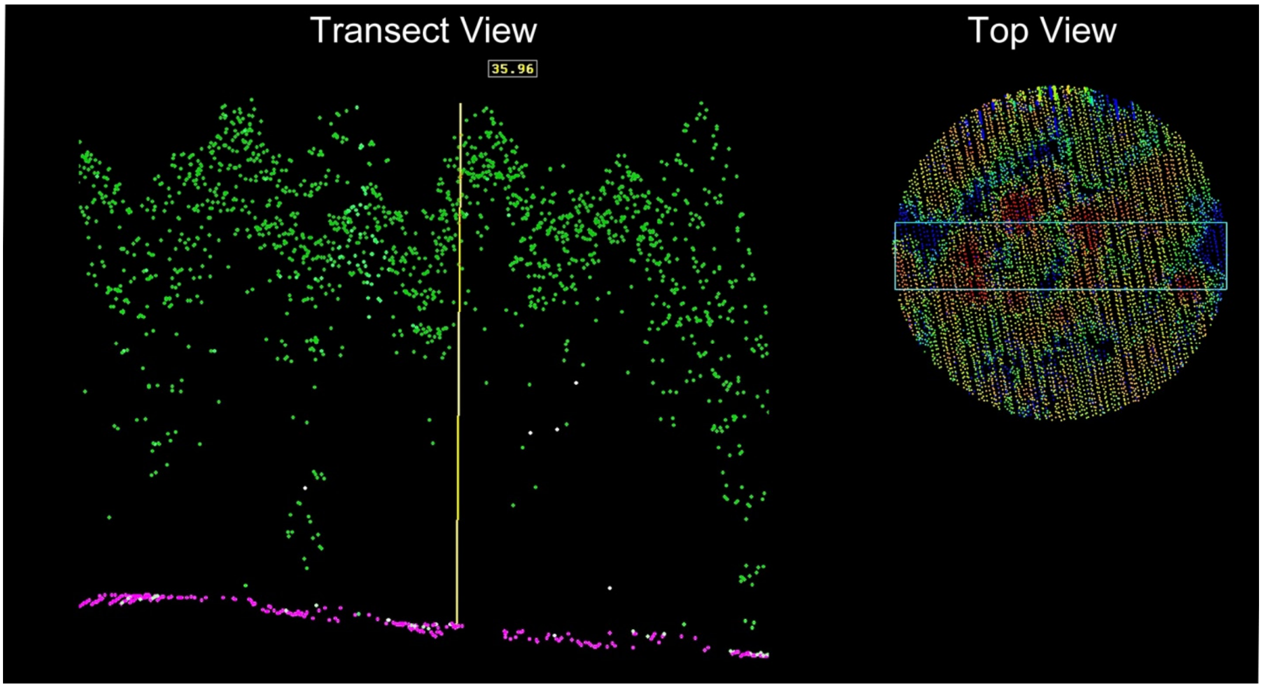
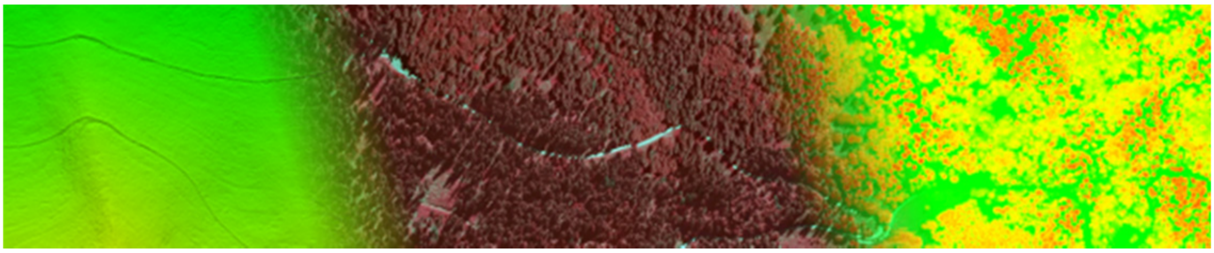


Figure 32: Visualization of the ALS data of study area 21 Berner Jura 32353. The Top view shows a z-colored pointcloud where red colors indicate higher values and blue colors indicate lower values. The transect view shows a 8 m wide transect of the point cloud.



3.5 WORKFLOW OF THE BENCHMARKING PROCESS

The benchmarking process covers seven general steps, starting from a quality check of the input data followed by the detection process of the partners using their methods, the matching process to link the detection results to the ground truth data and finally the investigation of the matching results in different Levels of Detail with corresponding Conclusions. The workflow of the benchmarking process is illustrated in Figure 33.

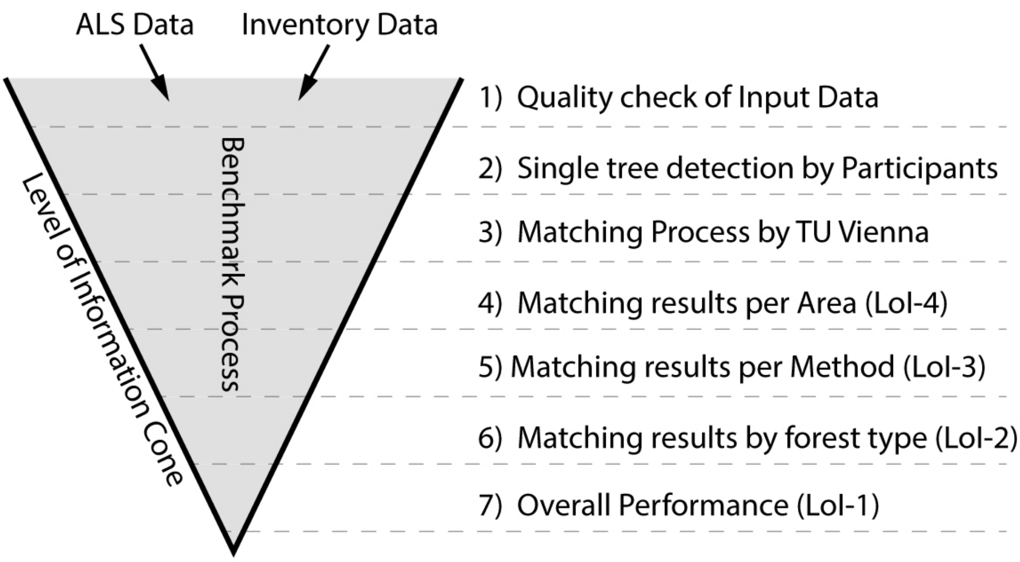


Figure 33: Workflow of the Benchmarking Process

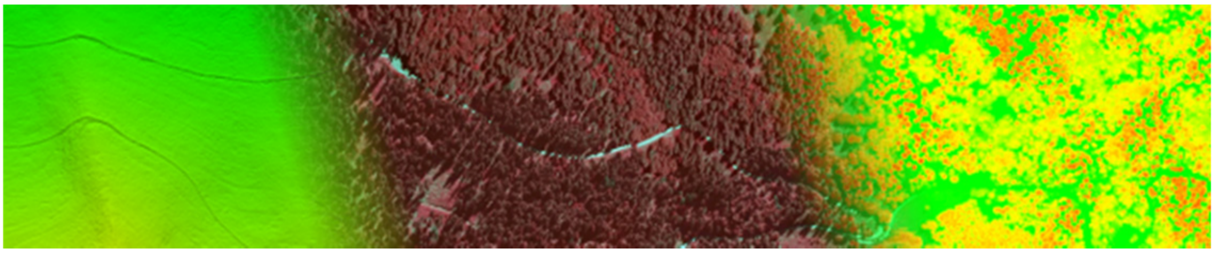
3.6 QUALITY CHECK OF INPUT DATA

Before handing the Input data to the benchmark participants an initial quality check of the input data was carried out. The quality check included a check of the existing ALS data and FI data handed over by the NEWFOR Partners.

3.6.1 QUALITY CHECK OF ALS DATA

For the ALS data two checks were performed:

- visual check for gross errors
- check if the whole Area of Interest plus a specific buffer are covered by ALS data



Additionally a Canopy Height Model was derived by subtracting a surface model from the terrain model. The terrain models were handed over by the NEWFOR Partners. The surface model was derived using the land cover dependent method published by Hollaus et al. (2010).

All investigated study areas were sufficiently covered by ALS data and no gross errors could be found.

3.6.2 QUALITY CHECK OF FI DATA

To be able to treat the quality of the FI data provided by the NEWFOR partners a questionnaire regarding the data was carried out. The partners had to fill a datasheet with information regarding absolute and relative accuracy of the Inventory data as well as general information about the study areas. The detailed results of the questionnaire are presented in Section 3.12.3.

For absolute Georeferencing almost all Partners use a GPS system for surveying the Plot location. The reported horizontal accuracies vary from ± 0.5 m to ± 10.0 m. Most of the plots were coregistered to the Remote Sensing data in a post-processing step. The Registration process was carried out by manually moving the measured tree locations in GIS to obtain an interpretable best fit with the Canopy Height Model. The estimated absolute accuracy after manual coregistration is ± 2.0 m.

For the relative tree measurements inside a plot all partners use compass bearing and tape / electronic ranging for the tree positions and a Vertex system for measuring the tree heights. The reported relative accuracy (accuracy of single tree positions) varies from ± 0.3 m to ± 1.0 m for the horizontal part. For the vertical accuracy a value of ± 1.0 m was reported by all partners.

In total 18 study areas were found to have sufficient quality for being used in the benchmark. The study areas 14, 19 and 20 were excluded from the benchmark as the Inventory data is incomplete in terms of tree heights.

3.7 SINGLE TREE DETECTION BY PARTICIPANTS

In this section different single tree detection methods / algorithms are shorty described. In total eight Methods were applied to the Benchmark dataset. All methods were applied to the complete dataset. In Table 1 an overview of the participating partners and their methods is given. All methods are based on the same input data and automatically detect the positions and heights of single trees. The participants submitted the results in a standardized format described in Section 3.12.5. A contact list of participating partners is given in Section 3.12.4.

Table 1: Overview of Applied Methods

ID	PP	Name	Method	Type	Res.	Kernel
1	LP	Irstea	LM+Filtering	R	0.2	Var.
2	PP5	FEM	LM+Region Growing	R	0.5	5x5
3	PP7	SFI	LM+Multi CHM	R	NA	3x3
4	PP10	TESAF	LM+Watershed	R	0.5	3x3
5	PP11	SLU / TU Wien	Segmentation+Clustering	R+P	0.25	-
6	PP11	TU Wien 3x3	LM3x3	R	1	3x3
7	PP11	TU Wien 5x5	LM5x5	R	1	5x5
8	PP12	SFS	Polyn. Fitting+Watershed	R	0.5 to 1.0	7x7

R…Raster; P...Point Cloud; Res. …Raster Resolution [m]; LM…Moving Window for local Maxima; Kernel in number of pixels.

3.7.1 METHOD LP - IRSTEA, FRANCE

The detection algorithm is based on local maxima filtering of the image of the forest canopy. The input data is the classified ALS point cloud (easting, northing, altitude, classification). The algorithm consists in five sequential steps.

1. Calculation of the raster images (0,2 m resolution) from the point cloud. The DTM is computed by bilinear interpolation of points classified as ground points. The DSM is computed by retaining the highest altitude value of the points located inside each pixel.
2. Non-linear filtering. Void pixels and artefacts in the DSM are removed with a closing filter. A disk of radius 4 pixels is used as structuring element..
3. Lowpass filtering. A smoothing filter with Gaussian kernel of sigma=0,3m of is applied to the DSM.
4. Maxima extraction. A local maxima filtering with sliding, variable window size is applied to output the size of the largest window on which each pixel is local maximum (maxima image).
5. Maxima selection. Pixels that are local maxima are retained only if the value of the corresponding pixel in the canopy height model (CHM) is superior to 7,5m and if their distance to the nearest pixel of equal height (value in the maxima image) is larger than 1m. The CHM is computed as the difference between the non-linear filtered DSM and the DTM.

The remaining maxima are the final tree top candidates. Corresponding coordinates are the pixel centers and heights which are extracted from the CHM.

3.7.2 METHOD PP5 - FEM, ITALY

The method used for the tree crowns delineation exploits both a CHM in raster format, and the ALS point cloud with normalized z. In greater detail the steps of the method are the following:

1. A low-pass (LP) filter is applied to the raster image of the CHM. We used a CHM at 0.5m spatial resolution, and a LP filter with a window of 3x3 pixels;
2. Seed points $S = \{s_1, \dots, s_N\} S = \{s_1, \dots, s_N\}$ are defined. They are defined using a moving window. The central pixel of the moving window is a seed point if it is the highest point inside the window, and if it is higher than a certain threshold. We used a 5 x 5 pixels window, and a threshold of 2.5 m;
3. Initial regions are defined starting from the seed points, and a label map L is defined: $L_{i,j} = k$ if (i, j) is a seed point with index k, otherwise $L_{i,j} = 0$;
4. Regions growths according to the following procedure:
    a. consider a label map point $L_{i,j} \neq 0$ and take its neighbor pixels:
    $\{(i, j-1); (i-1, j); (i, j+1); (i+1, j)\}$;
    b. a neighbor pixel (i', j') is added to the region n if:
    $$\left(dist\left((i', j'), s_n\right) < DistMax\right) \& (CHM(i', j') > (CHM(s_n) * PercThresh)) \& \left(L_{i',j'} \neq 0\right)$$
    with the $PercThresh \in (0; 1)$.
    c. iterate over all the pixels $L_{i,j} \neq 0$, and repeat until no pixels are added to any region;
5. From each region extract the first return ALS points, and apply Otsu thresholding to their normalized heights;
6. Take only the first return ALS points higher than the Otsu threshold and apply a 2D convex hull to these points;
7. The resulting polygons are the final tree crowns.

3.7.3 METHOD PP7 - SFI, SLOVENIA

Method is based on the iterative CHM generation and LM (local maximum) detection within moving window for various CHMs. Method is fully automated and have two following processing of data: a) potential tree identification and b) real tree identification.

Potential tree identification is based on the point cloud PC (*.txt or *.las) and DTM (*.tif, *.img ...):

1. Normalization of point cloud (PC - DTM).

2. CHM creation (95% percentile within raster cell) based on normalized PC (nPC).
3. Local maximum (LM) detection (3 × 3 cells) – maximum defines location of a potential tree.
4. Potential tree's parameters extraction (x, y, height, …).
5. Storing potential tree's parameters in object 'treeList'.
6. Elimination of all points from nPC, which are in upper part of nPC. Upper part is defined with threshold value th1. All points, which are above CHM – th1 are in this step removed.
7. If there are still points in nPC, go to step 2, otherwise stop.

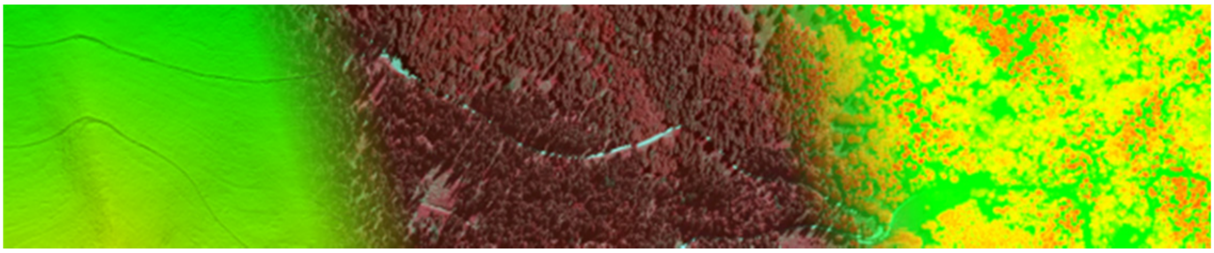
Real tree identification is based on the treeList from step 5 of potential tree identification process:

1. Sorting trees according to their value of height (decreasing).
2. First tree is consider as real tree and is stored into object 'realTreeList'.
3. For all other trees:
    - Checking horizontal distance between selected tree and all real trees, stored in 'realTreeList'. If distance is greater than th2, go further.
    - Checking vertical distance between selected tree and all real trees, stored in 'realTreeList'. If distance is greater than th3, tree is considered as real tree.

Due to threshold values th1, th2 and th3 methods perform better if first threshold values are calibrated! In this case, following values was set: th1 = 0.5, th2 = 2 and th3 = 5.

3.7.4 METHOD PP10 - TESAF, ITALY

The method is fully automated and has been implemented as a string of geoprocessing tools within the software ArcGIS 10.2. Required inputs are the .las dataset and the digital elevation model of the area. The procedure starts generating the DSM and the CHM. The following processing step consists of a CHM surface smoothing using filtering techniques, applying a Gaussian Kernel (3x3) filter. Next process uses focal statistic with a local maximum detection algorithm to locate the top of each tree from the smoothed CHM. Identified trees are then analyzed through a conditional script that consider a minimum distance from the near tree and the relative height in order to identify the probable false positive that are deleted. Remaining single trees are then used as pour point in a watershed algorithm ran on the inverse CHM in order to delineate single tree crowns and generate a polygon features with associated information on canopy area. A first classification into two main groups (conifers, broadleaves) is then done analyzing the mean crown slope within each polygon. Data about trees height, crowns area and species are used into site-specific allometric relation in order to derive expected DBH and then expected volume. These relations can be defined by the user. Final output is thus a point shape file representative of the tree tops, each with associated information about tree height, crown area, expected DBH and expected volume.



Although the procedure does not present novel methodology for tree identification the strength of this approach is the easy applicability due to the implementation in commercial software widely used, and the possibility to directly derive also information about biomass volume.

In the specific case of the benchmarking the DBH of the tress have been calculated applying two general relations (one for the conifers, one for the broadleaves) derived from 2835 model trees surveyed in the field during 2012 within PP10 Test-site. The variable used to predict DBH were Height and Crown Area.

The following calculation of the volume have been done applying the stand volume table used for the Italian National Forest Inventory (Castellani et al., 1984).

3.7.5 METHOD PP11 – SLU, SWEDEN

The delineation was done by segmentation of a correlation surface model followed by ellipsoidal tree model clustering of the ALS data in 3D. The aim of the segmentation was to establish one segment for each tree in the topmost canopy layer. The segmentation method was based on geometric tree crown models and rasters with 0.25 m cells. For each raster cell, an ellipsoid surface was calculated from different generalized ellipsoids. Correlation coefficients were calculated between the height of the ellipsoid surfaces and the height of the ALS data within the horizontal model radius. The correlation surface (CS) was defined as the highest correlation coefficient for each raster cell. The CS was smoothed and delineated with watershed segmentation.

The aim of the clustering was to establish one cluster for each tree in the topmost canopy layer as well as one cluster for each tree below. The algorithm was based on k-means clustering using ellipsoidal tree crown models. The clustering was done in two steps. In the first step, the ALS data were assigned to different clusters based on the Euclidian distance between the ALS data and the cluster centers. In the second step, an ellipsoid surface was fitted to each cluster and the ALS data were re-assigned to the different clusters based on a distance derived from the ellipsoid surface. Two categories of clusters were defined: Fixed clusters corresponding to trees already identified by segmentation of the CS and additional flexible clusters corresponding to trees below the topmost canopy layer.

3.7.6 METHOD PP11 - TU WIEN, AUSTRIA

In a preliminary working process, two base products are calculated from the ALS pointcloud. Beside a digital surface model (DSM), a normalized digitized surface model (nDSM) was derived by subtracting the DSM from the DTM. The nDSM, also known as CHM, is a very suitable product for detecting trees because it directly shows object heights (e.g., tree heights). In order to process the DSM, a land-cover-dependent derivation approach was chosen (Hollaus et al., 2010). This approach makes use of 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 (i.e., moving planes interpolation). The base products derived have a spatial resolution of 1 × 1 m^2 and have been processed consistently for all study areas using the OPALS (OPALS, 2013) software. For the extraction of the trees the positions of single trees have to be determined from the nDSM. This is performed by using a simple local maxima filter based on a circular kernel with a diameter of three pixels (Indicator in the assigned Name is “3x3”). Additionally a second result is generated by applying a circular kernel with a diameter of five pixels (Indicator in the assigned Name is “5x5”). For each detected tree the tree position and height is extracted from the nDSM. Only positions with a tree height greater than 3 m are considered.

3.7.7 METHOD PP12 - SFS, SLOVENIA

The project partner SFS made the benchmarking in cooperation with the Faculty of Electrical Engineering and Computer Science form the University of Maribor.

For the purpose of this study, the input ALS data were first arranged into a grid. While 0.5 m grid resolution was usually used, in cases of datasets with densities below 10 pts / m^2 its resolution was 1.0 m. The height of the grid-cell was defined by the highest points within the cell, while inverse distance weighting interpolation was used for defining the heights of the cells with no contained points. Digital terrain model was then subtracted from the grid and morphological opening and closing were performed in order to remove possible outliers. Best fitted second-degree polynomial was estimated in the 7 x 7 neighbourhood of each grid-cell using least squares method and its factors were used to detect concave neighbourhoods (potential tree-tops). Watershed regions were then estimated based on concave markers and the region-adjacency graph was constructed over the obtained regions. Finally, region merging was then performed based on geometric attributes of the regions (height, area, and shape compactness) with priorities defined by the measured similarity of best fitted polynomials. In all the test-cases, the same attribute-thresholds were used for identifying regions (nodes of the graph) that were merged. They were defined as follows: regions with areas smaller that 5 m^2 or its height smaller than 0.2 m were merged under the conditions that the resulting region after the merging did not exceed 150 m^2 and its compactness did not exceed the value of PI.

3.8 MATCHING PROCESS BY TU VIENNA

The main goal of this benchmark is to test all detection results of the benchmark participants against the FI reference data in a clear and reproducible way. Previous tree detection benchmarks performed an automated matching between the Reference data and the provided detection results (Kaartinen et al., 2012; Vauhkonen et al., 2012). Therefore, also a fully automated matching procedure was established and applied for the NEWFOR single tree detection benchmark.

3.8.1 INPUT DATA

The input data for the automated tree matching are:

1. Resulting single tree data from benchmark participant (shortly defined as “Test”)
2. Forest Inventory data of the study area (shortly defined as “Reference”)
3. Area of Interest of the study area (shortly defined as “AoI”)

3.8.2 IMPLEMENTATION OF THE MATCHING ALGORITHM

The matching of the Test trees to the according Reference trees was implemented in Python (Python-Software-Foundation, 2013). An overview of the workflow is given in Figure 34. Only trees inside the Area of Interest are considered for the check and therefore all input data are filtered using the AoI. Additionally Test trees within a buffer of 5 m around the AoI are considered in the matching procedure. This is necessary to correctly consider trees located closely to the border of the AoI. The value of 5 m was chosen to align with the values chosen in a former single tree detection benchmark published by Kaartinen et al. (2012).

After initial filtering using the AoI information and sorting the Test trees top down the matching procedure is performed in three general steps (Figure 35):

1) Candidate search

For every Test tree the restricted nearest neighboring Reference trees within a defined neighborhood are determined. Ideally the neighborhood is defined by the crown area of the Test tree. As this information is not available circular buffering is used as 2D neighbourhood. The restricted nearest neighbor method introduces a neighborhood criterion ΔD_{2D} and a height criterion ΔH. Both need to be fulfilled to make a tree a candidate for being matched / assigned (Table 2). Additionally already matched candidates are not considered. ΔD_{2D} is implemented by checking the horizontal Distance between Test and Reference tree. ΔH is implemented by checking the height difference between Test and Reference tree. The thresholds of ΔD_{2D} and ΔH vary depending on the tree height of the Test tree. The reason for this variation is the following:

The locations of trees are, in case of a terrestrial survey, measured at the bottom of the stem while most detection methods detect the tree tops. If a tree is tilted or shows a bent stem, the locations of tree top and the bottom of the stem differ. This effect normally increases with increasing tree heights. Therefore with increasing tree heights the ΔD_{2D} criterion is increased up to a value of 5 m. The value of 5 m was chosen to align with the thresholds applied in Kaartinen et al. (2012). Additionally the ΔD_{2D} considers positional errors from the FI survey as well as inaccuracies from the automated tree detection.

The height accuracy of trees measured in a terrestrial forest inventory is believed to be decreasing with increasing tree height. Therefore, when comparing a terrestrially measured tree height to an automatically detected one (which is believed to be more accurate) this effect should be considered. This is accounted for by increasing the ΔH value with increasing tree heights (Table 2).

Table 2: Implemented height and neighbourhood criteria. H_Test is the tree height of a Test tree. ΔH is the height difference between a test and a Reference tree. ΔD_{2D} is the 2D distance between a Test and a Reference tree.

Criterion	Height Test 1	Height Test 2	Distance Test
1	H_Test <= 10 m	$\Delta H < 3$ m	$\Delta D_{2D} < 3$ m
2	10 m < H_Test <= 15 m	$\Delta H < 3$ m	$\Delta D_{2D} < 4$ m
3	15 m < H_Test <= 25 m	$\Delta H < 4$ m	$\Delta D_{2D} < 5$ m
4	H_Test > 25 m	$\Delta H < 5$ m	$\Delta D_{2D} < 5$ m

The thresholds presented in Table 2 were empirically found by testing different settings on a subset of the dataset while visually interpreting the quality of the matching results. The finally found values were applied to all datasets within this benchmark.

2) Candidate voting

Since multiple trees can become candidates in the candidate searching process, the found candidates are ranked depending on their ΔH and ΔD_{2D} value. Starting from the nearest candidate, all other local candidates are tested for a better ΔH. If a Candidate shows a better ΔH and its ΔD_{2D} is at a maximum of 2.5 m greater than the initial candidate's ΔD_{2D}, the candidate becomes the new best voted candidate (Figure 35). The value of 2.5 m (half of the maximum possible ΔD_{2D}) is introduced to spatially limit possible candidate jumps. This feature is helpful if candidates are clustered and the best fitting tree inside this cluster should be found.

3) Candidate testing

Since the tree matching process is more than an isolated problem of matching one Test tree against a group of Reference trees, all other Test trees in the surrounding need to be considered. This is performed by checking the best voted candidate against the surrounding Test trees. If the Test tree from step 1 is the closest tree with the best height difference, these two trees are finally matched.

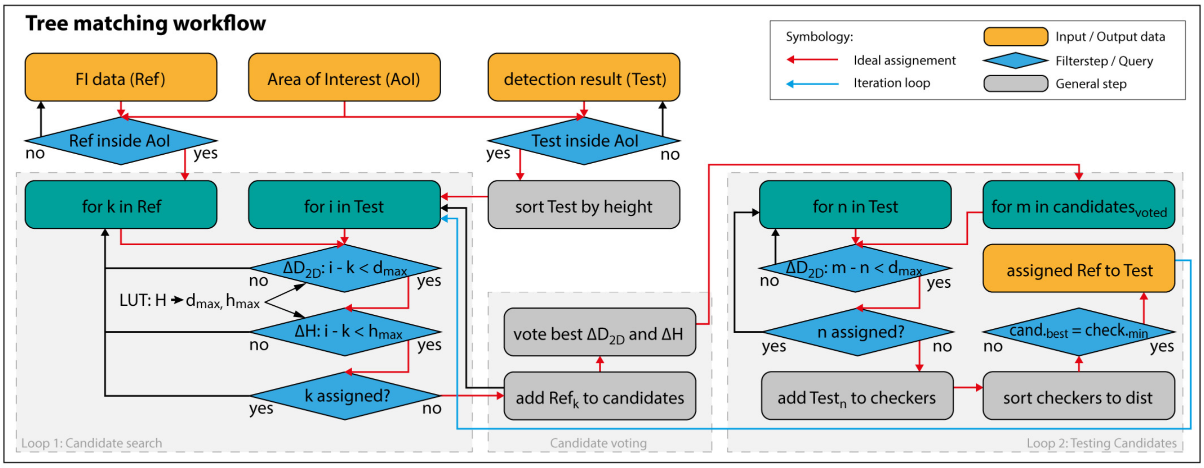


Figure 34: Detailed Workflow for matching Reference and Test data

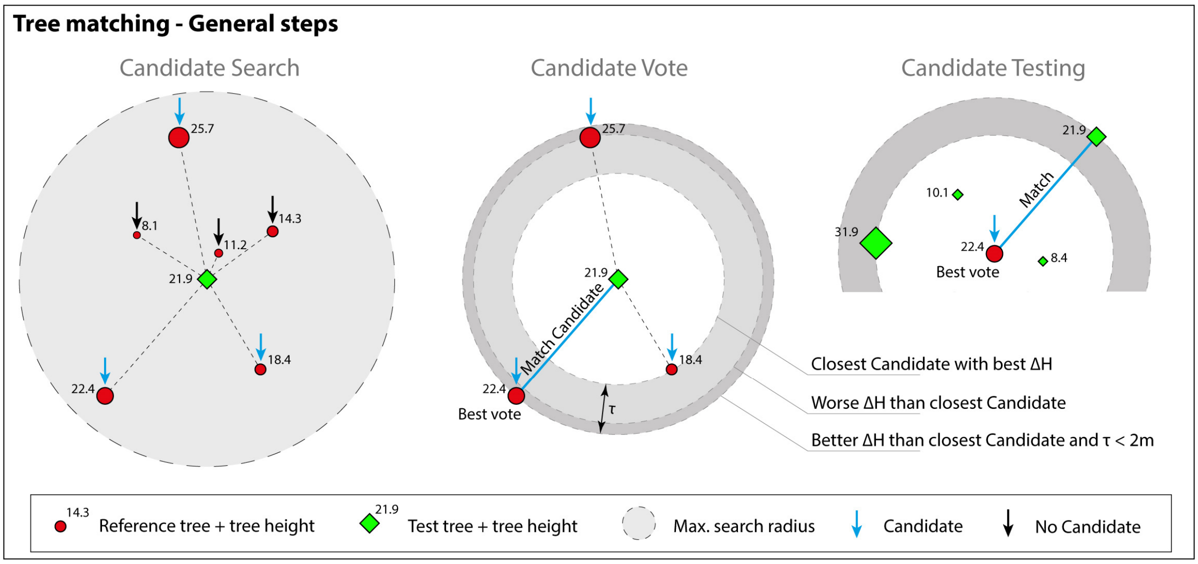


Figure 35: General Steps of the tree matching workflow

The outputs of the matching process are qualitative and quantitative statistical parameters as well as vector layers for being displayed in a GIS system (Figure 36). The following statistical parameters and vector layers are provided:

Parameters per method:

- Extraction rate → Total number or rate of extracted Test trees by a method
- 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_{Mean} → Mean of horizontal matching vectors (2D Vector between Test and Reference)
- V_{Mean} → Mean of tree height differences (ΔH between matched Test and Reference)

Summarizing Parameters (using results of multiple areas or methods):

- RMS_extr → Root Mean Square of Extraction rates
- RMS_ass → Root Mean Square of Matching rates
- RMS_H → Root Mean Square of H_{Mean} values
- RMS_V → Root Mean Square of V_{Mean} values
- RMS_Com → Root Mean Square of Commission values
- RMS_Om → Root Mean Square of Omission values

Vector Layers:

- Reference Trees inside AoI (Shapefile of Type Point)
- Test Trees inside AoI (Shapefile of Type Point)
- 2D matching vectors (Shapefile of Type Line)

3.8.3 VALIDATION OF THE MATCHING PROCESS

The results of the automatically matching are validated by visually interpreting randomly selected matching results in a GIS environment. The output vector layers of the matching process are visualized as an overlay of a Canopy Height Model. An experienced human interpreter classifies the matching results into four classes:

- Correctly Assigned (True Positive)
- Correctly not Assigned (True Negative)
- Wrongly Assigned (False Positive)
- Wrongly not Assigned (False Negative)

Finally an Error matrix and descriptive measures are derived and presented.

3.9 RESULTS

The results of the matching process were aggregated and categorized into four Levels of Information (LoI). LoI-4 enables exploring the detection results on the plot level while LoI-3 gives information on the Method level. LoI-2 shows the results for different forest types. Finally, LoD-1 shows the overall performance of the benchmark. For all LoI 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 Boxplot "Matching Rates" is sorted upwards to the Commission rates. An Example is presented in Figure 36. Additionally for LoI-4 the amount of trees in defined height classes were plotted in separate Barplots. This was performed for the given FI data as well as for the different matching results.

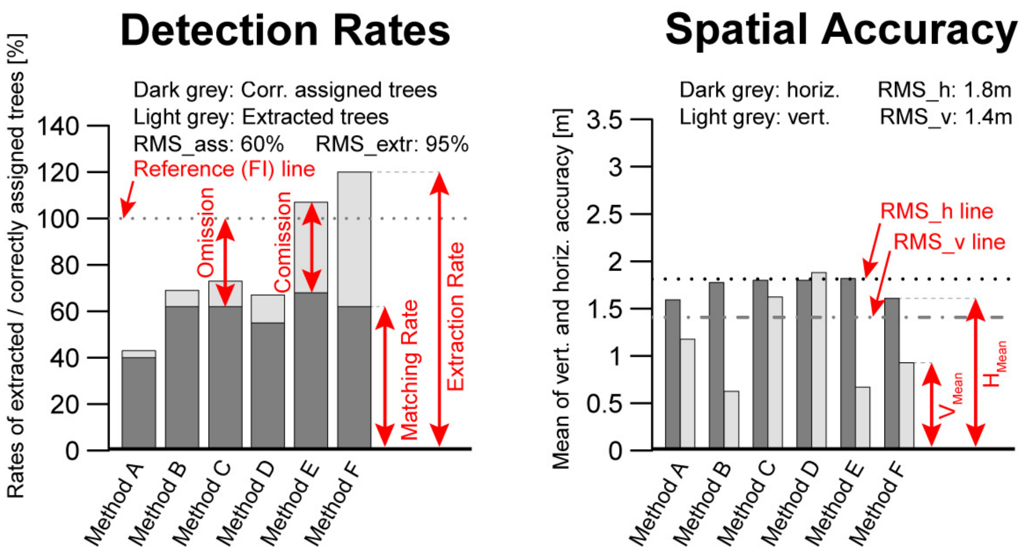
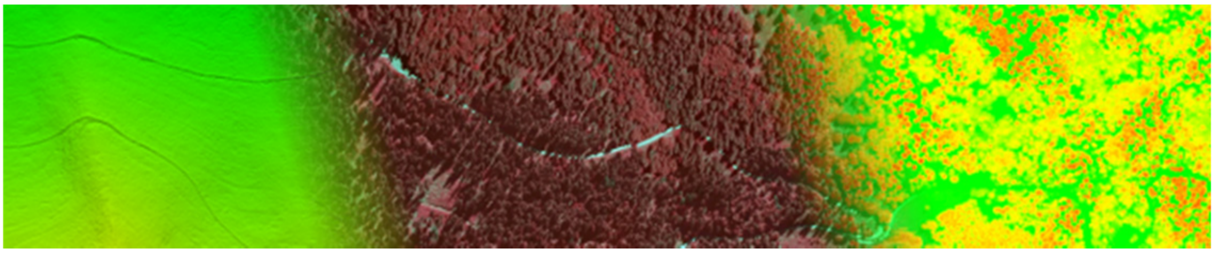


Figure 36: Barplot examples



3.9.1 VALIDATION OF THE MATCHING PROCESS

In total 699 randomly selected test trees were visually interpreted and classified. The resulting error matrix and descriptive measures are presented in

Table 3 and in Figure 38. A GIS visualized matching result example is presented in Figure 37

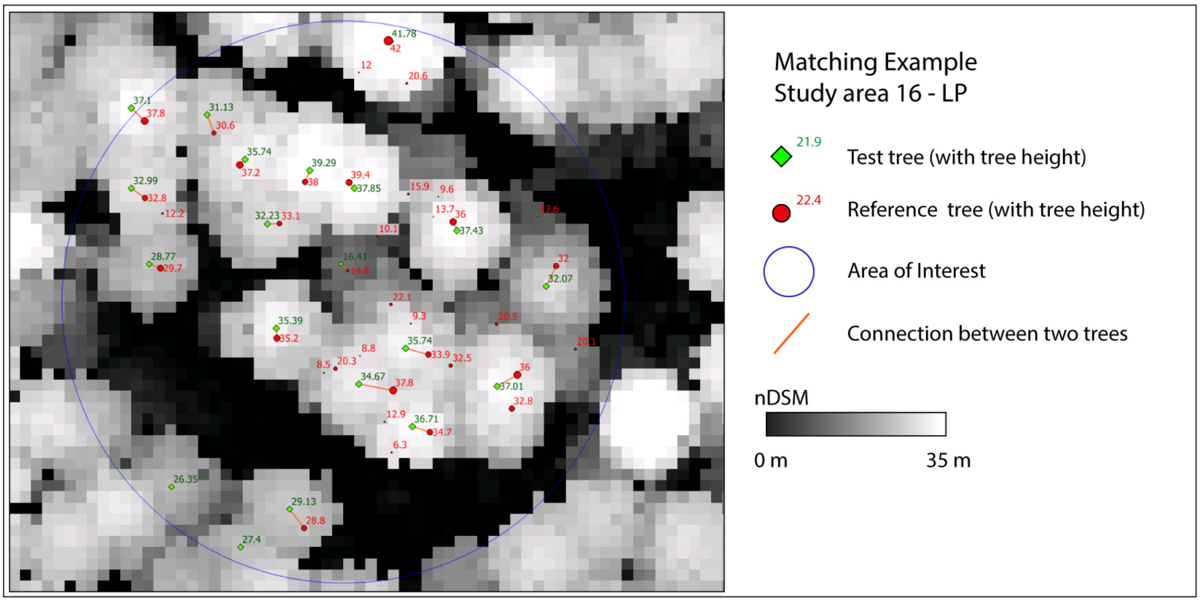


Figure 37: Matching example for study area 16. The Test trees were detected using the method of Partner LP. The detected Test trees (green diamonds), Forest Inventory trees (red circles), Area of Interest (blue circle) and the matched connections (orange lines) are overlaid the height coded Canopy height model.

The manual interpretation of a subset of the matching results shows an Overall Accuracy of 97%. The obtained quality of the matching process was found to be sufficient and the results are operational for further studies.

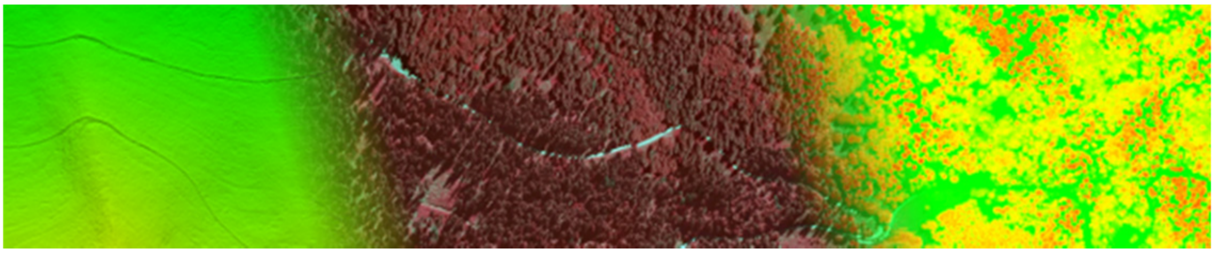


Table 3: Error matrix and descriptive measures for the matching quality check

	Reference – Forest Inventory			
Matching Result	Correct match	Wrong match	*Totals*	User's accuracy
Correct match	307	8	*315*	97%
Wrong match	14	370	*384*	96%
Totals	*321*	*378*	*699*	
Producer's accuracy	96%	98%		
Overall accuracy: 97%		**Kappa: 0.94**		

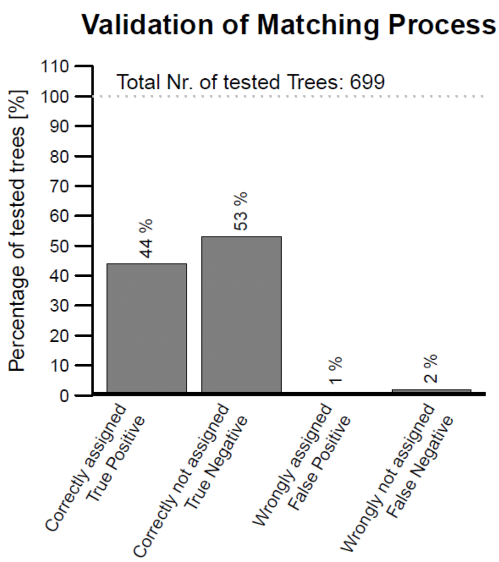


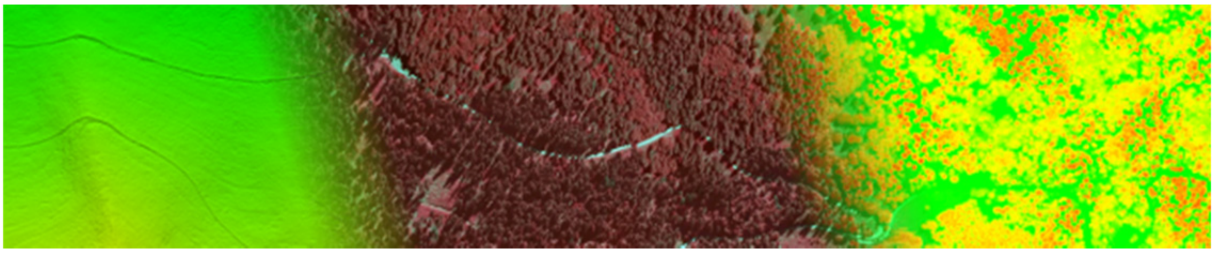
Figure 38: Validation of the matching process

3.9.2 MATCHING RESULTS PER STUDY AREA

The detailed matching results per study area indicate how good the different methods performed on a plot level. A graphical preparation of the study area wise matching results is presented in Appendix B in Section 3.13.1. In Table 4 statistical values (mean values from all methods) are summarized. The highest extraction rate (RMS_extr) with 186 % was found for study area 2 while the lowest rate of 26 % was found for study area 5. For the matching rates (RMS_ass) the highest rate was found with 60 % for study area 3. 18 % was found for study area 5 which marks the lowest matching rate. The highest Commission rate (RMS_Com) with 141 % was found for study area 2. The lowest RMS_Com rate was found for study area 8 with 7 %. The highest Omission rate (RMS_Om) was found for study area 5 with a value of 82 %. The lowest rate was found for study area 21 with a value of 28 %. In the spatial accuracy section the best positional accuracy with a RMS_H of 1.1 m was obtained for study area 7. The best height accuracy with a RMS_V value of 0.2 m was found for study area 17.

Table 4: Summarized matching results per Study Area – Statistical parameters

Plot ID	Nr. Trees FI	RMS_extr.	RMS_ass.	RMS_Com	RMS_Om	RMS_H	RMS_V
1	352	84 %	45 %	45 %	55 %	1.6 m	1.4 m
2	100	186 %	55 %	141 %	46 %	1.9 m	0.7 m
3	122	95 %	60 %	44 %	42 %	1.8 m	1.4 m
4	150	126 %	30 %	99 %	72 %	2.4 m	1.6 m
5	235	26 %	18 %	8 %	82 %	2.1 m	1.2 m
6	47	106 %	56 %	62 %	45 %	1.5 m	1.2 m
7	79	66 %	58 %	11 %	43 %	1.1 m	0.5 m
8	107	38 %	32 %	7 %	69 %	1.6 m	0.3 m
9	169	44 %	31 %	16 %	70 %	1.6 m	0.9 m
10	106	51 %	33 %	19 %	67 %	1.6 m	2.3 m
11	22	127 %	41 %	96 %	60 %	1.6 m	0.4 m
12	49	74 %	54 %	26 %	47 %	1.8 m	1.0 m
13	100	59 %	39 %	24 %	62 %	1.4 m	0.4 m
15	53	111 %	46 %	73 %	55 %	1.6 m	0.3 m
16	37	134 %	53 %	91 %	47 %	1.7 m	0.6 m
17	117	75 %	50 %	30 %	51 %	1.9 m	0.2 m
18	92	76 %	42 %	42 %	59 %	1.5 m	0.3 m
21	17	81 %	72 %	12 %	28 %	1.3 m	1.0 m



3.9.3 MATCHING RESULTS PER METHOD

The detailed matching results per applied detection method indicate how good a method performed in total for all study areas. A graphical preparation of the matching results sorted to detection methods is presented in Appendix B in Section 3.13.2. In Table 5 the statistical values are summarized.

The highest extraction rate (RMS_extr) with 154 % was found for Method Nr.6 (PP11, TU3x3, Austria), while the lowest rate of 51 % was found for Method Nr.1 (LP, Irstea, France).

For the matching rates (RMS_ass) the highest rate was found with 54 % for Method Nr.6. The lowest matching rate was found for Method Nr.7 (PP11, TU5x5, Austria) with 41 %.

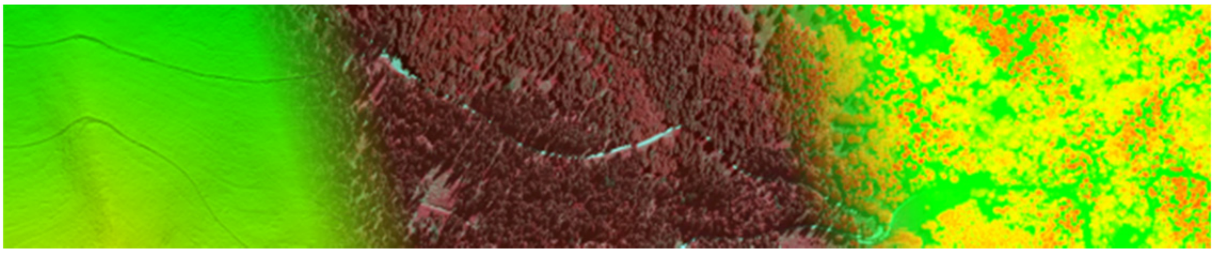
The highest Commission rate (RMS_Com) with 113 % was found for Method Nr.6. The lowest RMS_Com rate was found for Method Nr.1 with 9 %.

The highest Omission rate (RMS_Om) was found for Method Nr.7 with a value of 63 %. The lowest rates were found for Method Nr.5 and Nr.6 with values of 51 %.

In the spatial accuracy section the best positional accuracy with a RMS_H of 1.6 m were obtained for Method Nr.1, Nr.4 and Nr.6. The best height accuracy with a RMS_V value of 0.7 m was found for Method Nr.3 (PP7, SFI, Slovenia).

Table 5: Summarized matching results per Method - Statistical parameters

ID	Method	PP	RMS_extr.	RMS_ass.	RMS_Com	RMS_Om	RMS_H	RMS_V
1	LM+Filtering	LP	51 %	45 %	9 %	59 %	1.6 m	0.9 m
2	LM+Region Growing	PP5	57 %	43 %	20 %	61 %	1.8 m	1.2 m
3	LM+Multi CHM	PP7	101 %	46 %	61 %	57 %	1.7 m	0.7 m
4	LM+Watershed	PP10	86 %	49 %	49 %	55 %	1.6 m	1.1 m
5	Segment.+Clustering	PP11	139 %	53 %	95 %	51 %	1.7 m	1.0 m
6	LM3x3	PP11	154 %	54 %	113 %	51 %	1.6 m	0.9 m
7	LM5x5	PP11	52 %	41 %	16 %	63 %	1.8 m	1.1 m
8	Polyn. Fitting+Watersh.	PP12	54 %	44 %	13 %	59 %	1.8 m	1.1 m



3.9.4 MATCHING RESULTS PER FOREST TYPE

The detailed matching results per forest type indicate how good the methods performed for different forest types. Four forest types were manually classified by interpreting the height distribution of trees in the FI data. The classes are 1) Single Layered Mixed Forest 2) Single Layered Coniferous Forest 3) Multi Layered Mixed Forest and 4) Multi Layered Coniferous Forest. A graphical preparation of the matching results sorted to forest type is presented in Appendix B in Section3.13.3. In Table 6 the statistical values are summarized.

The highest extraction rate (RMS_extr) with 142 % was found for single layered mixed forests (Class 1), while the lowest rate of 55 % was found for multi layered coniferous forests (Class 4).

For the matching rates (RMS_ass) the highest rate was found with 86 % for single layered coniferous forests (Class 2). The lowest matching rate was found for single layered mixed forests (Class 1) with 47 %.

The highest Commission rate (RMS_Com) with 104 % was found for single layered mixed forests (Class 1). The lowest RMS_Com rate was found for multi layered coniferous forests (Class 4) with 22 %.

The highest Omission rate (RMS_Om) was found for Class 3 and Class 4 with a value of 65 %. The lowest rate was found for single layered coniferous forests (Class 2) with a value of 37 %.

In the spatial accuracy section the best positional accuracy with a RMS_H of 1.5 m were obtained for Class 2 and Class 4. The best height accuracy with a RMS_V value of 0.8 m was found for multi layered mixed forests (Class 3).

Table 6: Summarized matching results per forest type - Statistical parameters

Class	Type	Nr. Plots	RMS_extr.	RMS_ass.	RMS_Com	RMS_Om	RMS_H	RMS_V
Class 1	SL / M	4	142 %	47 %	104 %	56 %	1.9 m	0.9 m
Class 2	SL / C	5	86 %	60 %	37 %	42 %	1.5 m	1.1 m
Class 3	ML / M	7	74 %	38 %	45 %	65 %	1.7 m	0.8 m
Class 4	ML / C	2	55 %	35 %	22 %	65 %	1.5 m	1.6 m

3.9.5 OVERALL PERFORMANCE

For the overall performance the matching results of all eight Methods are put together. A graphical preparation of the overall performance is presented in Appendix B in Section 3.13.4.

The overall matching rate RMS_ass shows a value of 47 %. This means that statistically 47 %of all available Reference trees could be successfully matched. For the matching rate RMS_ext a value of 95 % was found. For the Commission error and Omission error a value of 60 % and 57 % was found respectively.

3.10 DISCUSSION

The automatic matching procedure leads to interpreter independent and reproducible results. In contrast to a manual interpretation this method is timesaving. The Validation of the matching procedure shows an Overall Accuracy of 97 %. Accurate georeferencing of the input data is mandatory. Therefore the forest inventory data is ideally acquired by using a survey grade GPS system. A positional check by manually coregistering the inventory data to the remote sensing data in a post-processing step is necessary. A questionnaire regarding spatial accuracy of the inventory showed that these criteria were fulfilled for the given dataset of this benchmark.

Matching Results per Study Area

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 pointcloud can detect more trees than methods that rely on local maximum detection based on a rasterized canopy height model. This finding was also reported in the benchmark study of Kaartinen et al. (2012). The Method of PP11-SLU achieved the highest number of small trees extracted.

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 study area 21 which consists of an old forest stand with high trees and no understory vegetation. The lowest detection result was obtained for study area 5 which consists of 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. Kaartinen and

Hyyppä (2008) concluded in their publication that the laser point density has less impact on the individual tree detection. Therefore the different point densities given in the NEWFOR benchmark should not influence the detection results too much. Study area 05 shows a point density of 121 pts / m^2 and the inventory data shows a high 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 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.

Matching Results per Method

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. In the lower height layers up to 10 m tree height only up to 3% of the extracted trees could be correctly matched. Since the method relies on a rasterized canopy height model and filtering of trees lower than 7.5 m this rather low value was expected. For the spatial accuracy the obtained values for the location are comparable to the results of the other tested methods. For the height component the second best value was achieved with a RMS value of 0.9 m which is comparable to the values obtained for the best models in the benchmark of Kaartinen et al. (2012).

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. In contrast to the method of LP-Irstea trees down to a height of 2.5 m could be detected which might lead to the slightly higher percentage value. However, the method is based on rasterized ALS data and therefore the rather low matching rate in the lower height layers was expected. The spatial accuracy of the method is comparable to the one from LP-Irstea.

High Commission rates in the results of the methods PP7-SFI, PP11-SLU and PP11-TU3x3 indicate that these methods tend to over perform which means they show high commission rates. 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). The small kernel tends to find local irregularities in the canopy height model and since these irregularities can be given even inside a single tree crown the small kernel tends to detect too many potential trees. The result is the highest commission rate within this benchmark. The alternative method of PP11-TU5x5 shows better results in terms of commission rate as the rate of the 5x5 kernel is 7 times lower than the one from the 3x3 kernel. The Methods of PP7-SFI and

PP11-SLU seem to be too sensitive in the detection process and especially the 3D clustering tends to detect multiple trees within a given single tree crown. Beside the fact of high commission rates for these methods 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 PP7-SFI shows the best height accuracy with a RMS value of 0.7m. Both, PP11-TU5x5 and PP7-SFI show the lowest matching rates in the uppermost height layer with trees larger than 20 m. In total the method of PP11-TU5x5 shows comparable results to results of LP-Irstea and is counted as one of the best results within this benchmark.

The method of PP10-TeSAF shows a relatively high matching rate of 49 % (RMS) 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 while up to 40 % (RMS) of the detected trees are sorted to Commission Errors. The rather low matching value can be explained by the methodology of the method itself – it uses a smoothed rasterized canopy model which follows the upper canopy and therefore the detection rate of smaller trees in subdominant layers is believed to be low. In the highest height layer with trees greater than 20 m a matching rate of 76 % (RMS) could be obtained which is on of the highest values in this benchmark for this height class. The spatial accuracy of the method is comparable to the one from LP-Irstea. In general the spatial accuracy of all methods does not differ very much.

The method of PP12-SFS shows a high matching rate of 44 % paired with a low Commission rate of 13 %. 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. Even when 9 % is one of the best results the matching rate in the lower height intervals is low. Like other methods that rely on maximum search in a rasterized canopy height model of the uppermost canopy the low rate can be explained by the methodology.

Matching Results per forest type

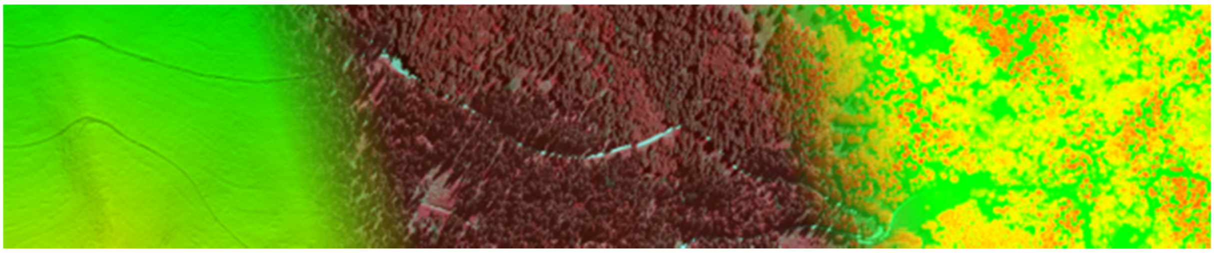
The class of single layered coniferous forests shows the best results of all tested classes as a high matching rate of 60 % combined with a low commission rate of 37 % is given. This result seems feasible as coniferous trees show, in most cases, a clearly defined tree crown shape. This means that the 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. Only a matching rate of up to 38 % (RMS) could be obtained. The commission rate of the multi layered mixed forest is twice as high as the rate found for the multi layered coniferous forest which shows a value of 22 % RMS. 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 higher commission rate for the multi layered mixed forest can be linked to more complex crowns for deciduous trees which results in over performing detection results. The best results for the multi layered coniferous forest were obtained by the methods of PP12-SFS, PP10-TESAF and PP5-FEM. For the multi layered deciduous forest the best results were obtained by PP12-SFS, PP10-TESAF and LP-Irstea.

The single layered mixed forest shows a matching rate of 47 % which is the second best matching rate for the classified results. Unfortunately a very high commission rate of 104 % 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.

<u>Overall Performance</u>

The overall performance brings together all matching results from all tested methods. An overall matching rate of 47 % (RMS) was found. This value aligns with the Benchmark results presented in Kaartinen et al. (2012) as well as with the results for the study areas Germany and Norway in the benchmark published by Vauhkonen et al. (2012). The overall best performing methods are LP-Irstea, PP12-SFS, PP5-FEM and PP11-TU5x5. The other four tested 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. This was also found by Vauhkonen et al. (2012).



3.11 REFERENCES

Castellani, C., Scrinzi, G., Tabacchi, G. and Tosi, V., 1984. *Inventario Forestale Nazionale Italiano (IFNI): tavole di cubatura a doppia entrata*. Ministero dell'Agricoltura e delle Foreste.

Hollaus, M., Mandlburger, G., Pfeifer, N. and Mücke, W., 2010. Land cover dependent derivation of digital surface models from airborne laser scanning data. In: *ISPRS Commission III Symposium PCV2010*, Saint-Mandré, France, pp. 6-6.

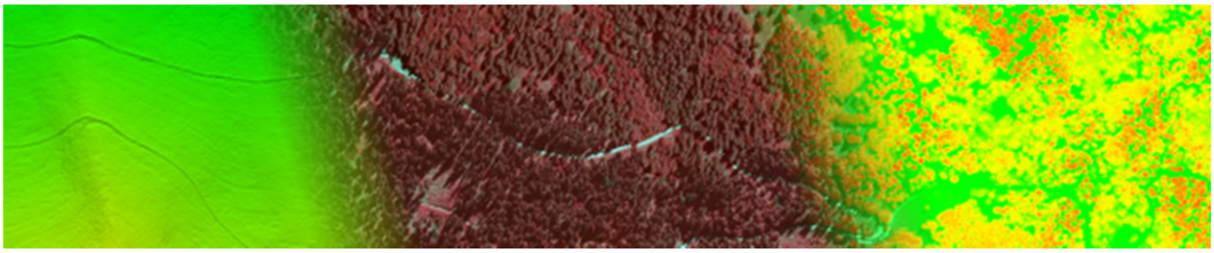
Kaartinen, H. and Hyyppä, J., 2008. EuroSDR/ISPRS Project, Commission II "Tree Extraction"; Final Report, EuroSDR (European Spatial Data Research), Dublin, Ireland.

Kaartinen, H. et al., 2012. An International Comparison of Individual Tree Detection and Extraction Using Airborne Laser Scanning. *Remote Sensing*, 4(4), pp. 950-974.

OPALS, 2013. *Orientation and Processing of Airborne Laser Scanning Data*, http://www.ipf.tuwien.ac.at/opals/, last access: 2013

Python-Software-Foundation, 2013. *Python Language Reference, version 2.7.* , http://www.python.org, last access: 2013

Vauhkonen, J. et al., 2012. Comparative testing of single-tree detection algorithms under different types of forest. *Forestry*, 85(1), pp. 27-40.



3.12 APPENDIX A

3.12.1 NEWFOR PARTNERS LIST

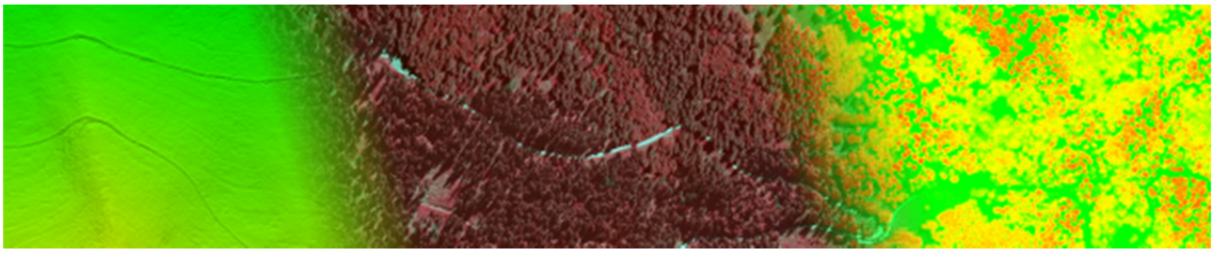
Partner ID	Short Name	Country
LP	IRSTEA	France
PP1	Land Tirol	Austria
PP2	BFW	Austria
PP3	Stand Montafon	Austria
PP4	ERSAF	Italy
PP5	Trento – PAT-SFF	Italy
PP6	FCBA	France
PP7	SFI	Slowenia
PP8	LWF	Germany
PP9	UNITO	Italy
PP10	TESAF	Italy
PP11	TU Wien	Austria
PP12	SFS	Slowenia
PP13	WSL	Switzerland

3.12.2 OVERVIEW OF THE PROVIDED ALS DATA

Study Area	NrOfPoints	Pdens	:Amplitude	EchoNumber	NrOfEchos	Classification
1	535666	12,548	Y	Y	Y	Y
2	48777	4,29	N	N	N	N
3	117456	5,524	N	N	N	N
4	241550	10,548	N	N	N	N
5	4628070	121,449	N	Y	Y	Y
6	3625181	95,124	N	Y	Y	Y
7	157690	10,306	N	Y	Y	Y
8	177692	11,535	N	Y	Y	Y
9	181705	10,752	N	Y	Y	Y
10	171354	11,087	Y	Y	Y	Y
11	180926	11,63	Y	Y	Y	Y
12	163166	10,646	Y	Y	Y	Y
13	212664	22,081	Y	Y	Y	N
14	323269	33,482	Y	Y	Y	N
15	225850	28,256	Y	Y	Y	Y
16	182496	23,281	Y	Y	Y	Y
17	251927	31,507	Y	Y	Y	Y
18	231268	29,223	Y	Y	Y	Y
19	35172	11,732	Y	Y	Y	Y
20	20070	9,887	Y	Y	Y	Y
21	9542	4,761	Y	Y	Y	Y

3.12.3 EXPECTED ACCURACIES OF FOERST INVENTORY DATA

	Absolute Georeferencing				Single tree measurements		
Srudy Area	**Horiz. accuracy**	**Instrument**	**manual coreg.**	**Est. Final accuracy**	**Horiz. accuracy**	**Vert. accuracy**	**Method**
1	± 02.00 m	Trimble Pro XRS	TRUE	± 02.00 m	± 00.50 m	± 01.00 m	Compass, Vertex
2	± 10.00 m	Garmin GPSmap 60CSx	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Compass, Vertex
3	± 10.00 m	Garmin GPSmap 60CSx	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Compass, Vertex
4	± 10.00 m	Garmin GPSmap 60CSx	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Compass, Vertex
5	± 00.50 m	Trimble Juno w. PROXH	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Truepulse, Vertex
6	± 00.50 m	Trimble Juno w. PROXH	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Truepulse, Vertex
7	± 00.50 m	Trimble Juno w. PROXH	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Truepulse, Vertex
8	± 01.00 m	Trimble Juno w. PROXH	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Truepulse, Vertex
9	± 01.00 m	Trimble Juno w. PROXH	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Truepulse, Vertex
10	± 01.50 m	Trimble GeoXM (2005)	FALSE	± 02.00 m	± 00.30 m	± 01.00 m	Truepulse, Vertex
11	± 01.50 m	Trimble GeoXM (2005)	FALSE	± 02.00 m	± 00.30 m	± 01.00 m	Truepulse, Vertex
12	± 01.50 m	Trimble GeoXM (2005)	FALSE	± 02.00 m	± 00.30 m	± 01.00 m	Truepulse, Vertex
13	± 0.25 m	Total Station	TRUE	± 02.00 m	± 01.00 m	± 01.00 m	Tape, Compass, Vertex
14	Plot not used in Benchmark						
15	± 01.00 m	GeoXT	TRUE	± 02.00 m		± 01.00 m	Tape, Compass, Vertex
16	± 01.00 m	GeoXT	TRUE	± 02.00 m		± 01.00 m	Tape, Compass, Vertex
17	± 01.00 m	GeoXT	TRUE	± 02.00 m		± 01.00 m	Tape, Compass, Vertex
18	± 01.00 m	GeoXT	TRUE	± 02.00 m		± 01.00 m	Tape, Compass, Vertex
19	Plot not used in Benchmark						
20	Plot not used in Benchmark						
21	± 10.00 m	Photogrammetric	TRUE	± 02.00 m	± 00.50 m	± 01.00 m	Tape, Compass, Vertex



3.12.4 LIST OF BENCHMARK PARTICIPANTS

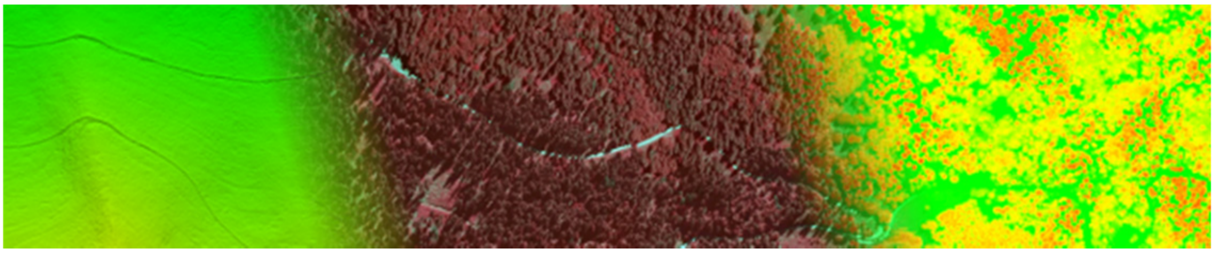
PP ID	Institution	Address	Responsible Person
Result 1			
LP	Irstea UR EMGR	2 rue de la papeterie-BP 76 F-38402 Saint-Martin-d'Hères France	Name: Jean-Matthieu Monnet Mail: jean-matthieu.monnet@irstea.fr Phone: +33-4-76-76-28-06 Fax: +33-4-76-51-38-03
Result 2			
PP5	Department of Sustainable Agro-Ecosystems and Bioresources Research and Innovation Centre Fondazione Edmund Mach	via E. Mach 1 38010 San Michele all'Adige (TN) Italy	Name: Michele Dalponte Mail: michele.dalponte@fmach.it Phone: +39-0461-615596
Result 3			
PP7	Slovenian Forestry Institute Department of Forest Ecology Department for Forest Technique and Economics	Večna pot 2 1000 Ljubljana Slovenia	Name: Milan Kobal Mail: milan.kobal@gozdis.si Name: Nike Krajnc Mail: nike.krajnc@gozdis.si Tel.: +386-1-200 7800 Fax: +386-1-257 3589
Result 4			
PP10	Department of Land, Environment, Agriculture and Forestry University of Padova	Viale dell'Università 16 35020 Legnaro PD Italy	Name: Marco Pellegrini Mail: marco.pellegrini@unipd.it Phone: +39 049 827 2733 Fax: +39 049 827 2774
Result 5			
PP11	Department of Geodesy and Geoinformation Vienna University of Technology Research Group Photogrammetry	Gußhausstraße 27-29 1040 Vienna Austria	Name: Lothar Eysn Mail: Lothar.Eysn@geo.tuwien.ac.at Phone: +43-1-58801-12249 Fax: +43-1-58801-12299
Result 6			
PP11	Department of Geodesy and Geoinformation Vienna University of Technology Research Group Photogrammetry SLU Sweden	Gußhausstraße 27-29 1040 Vienna Austria	Name: Eva Lindberg Mail: Eva.Lindberg@geo.tuwien.ac.at Phone: +46-72-2025729 Fax: +43-1-588-011-2299
Result 7			
P12	Slovenian Forest Service	Večna pot 2 1000 Ljubljana Slovenia	Name: Luka Rebolj Mail: luka.rebolj@zgs.gov.si

3.12.5 MANDATORY OUTPUT FORMAT FOR DETECTION RESULTS

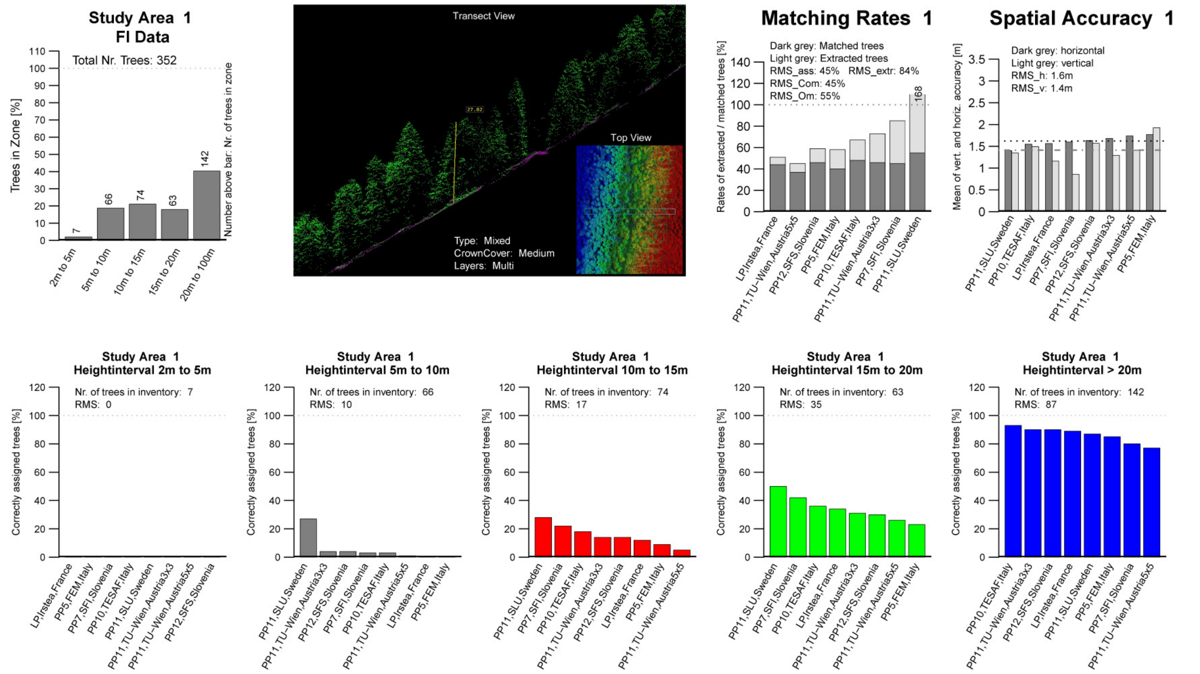
The Output format is mandatory. For every study area an independent file must be generated. If no DBH and Stemvol. information is given the fields are set to zero (0). The resulting file must look like this:

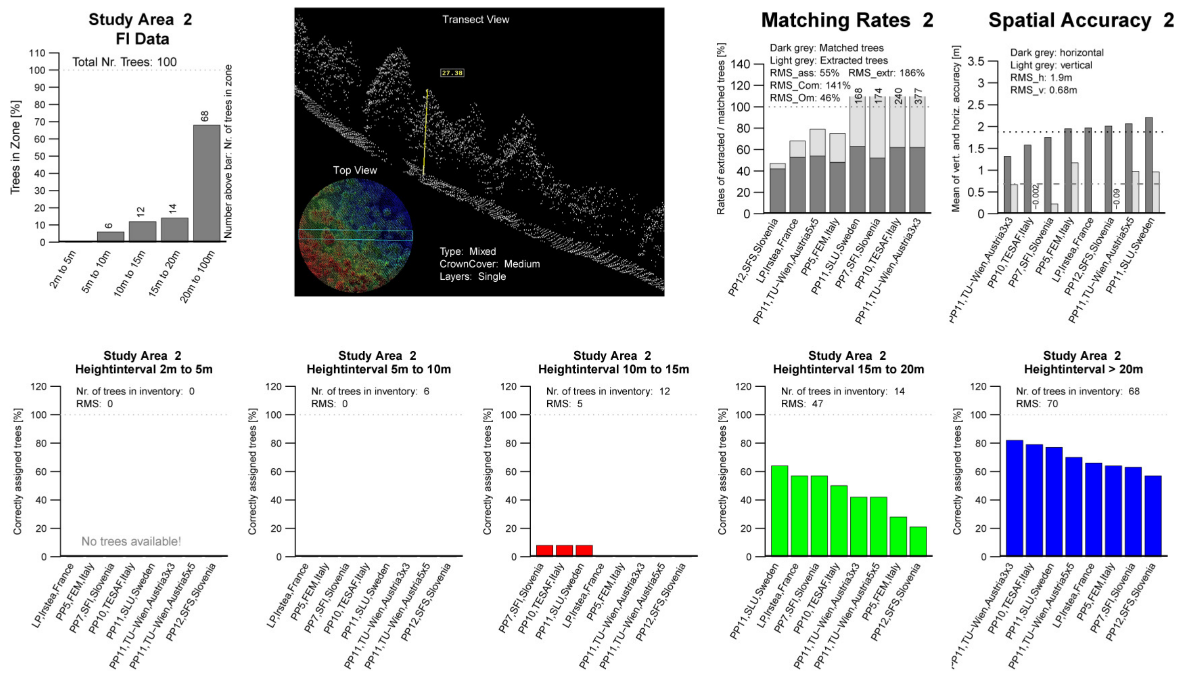
```
#Partner_ID: PP11
#Affiliation: TU-Wien, Austria
#Test Area: 02
#ID;X[m];Y[m];TreeHeight[m];DBH[m];Stemvol[m³]
1;584999.880;228999.547;12.24;0.12;0.883
2;585005.409;229004.776;25.11;0.21;1.696
3;585012.149;229078.642;21.76;0.19;1.543
#END
```

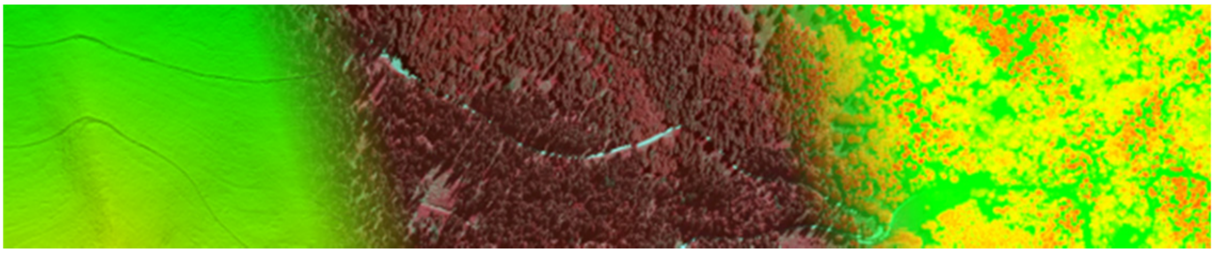
3.13 APPENDIX B

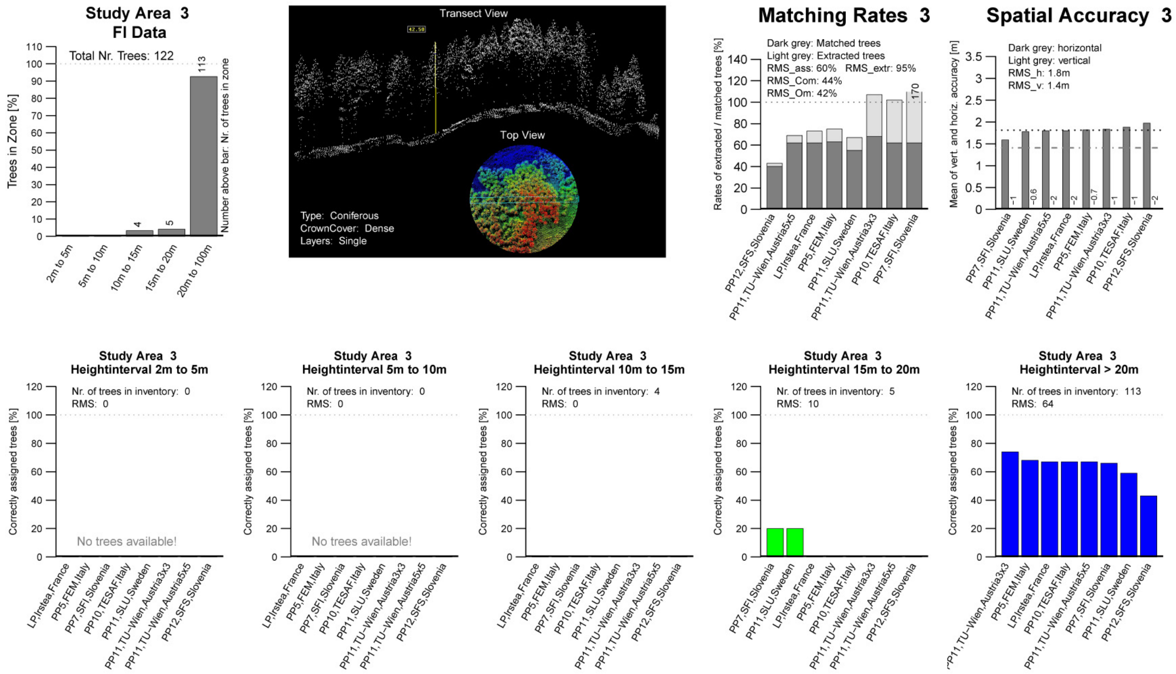


3.13.1 DETAILED MATCHING RESULTS PER STUDY AREA

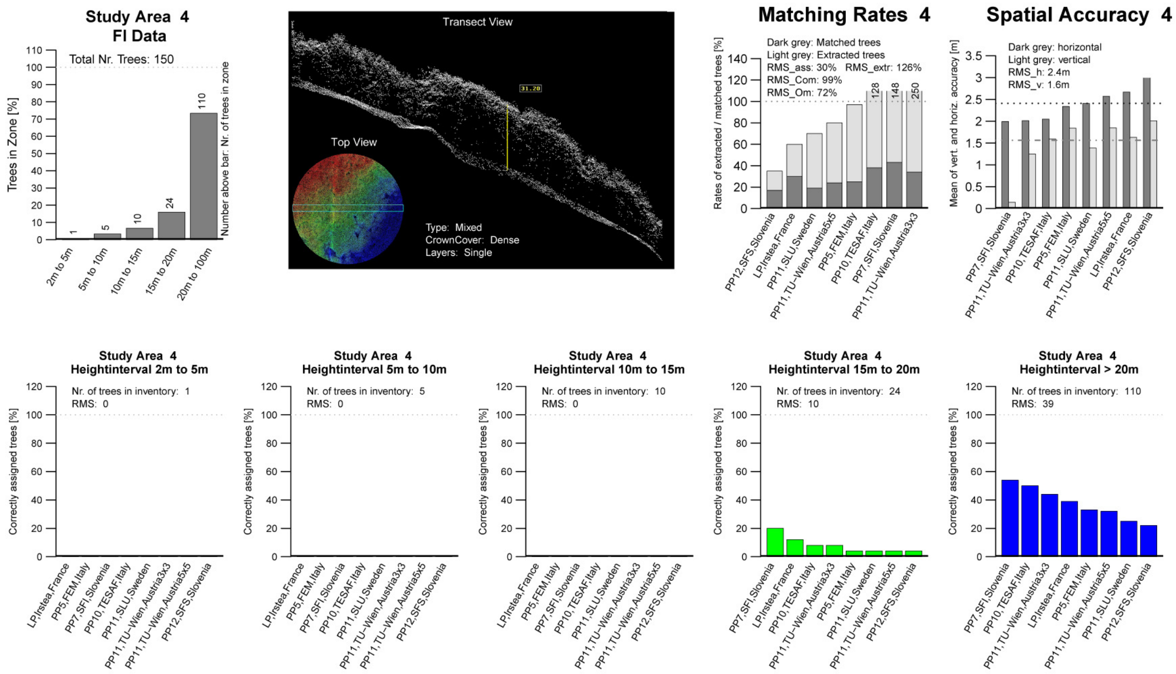




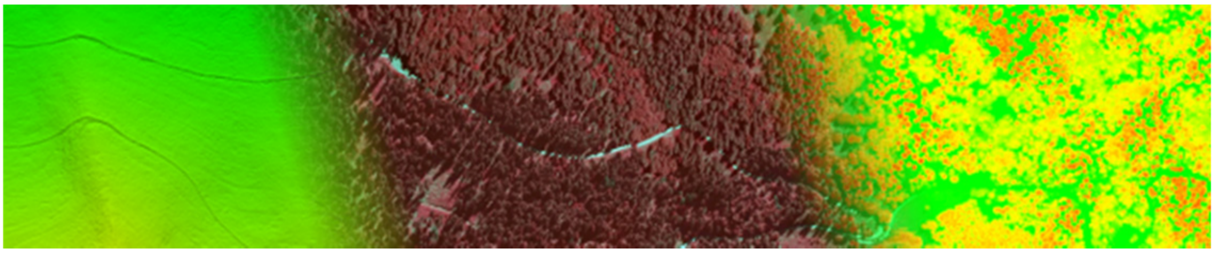


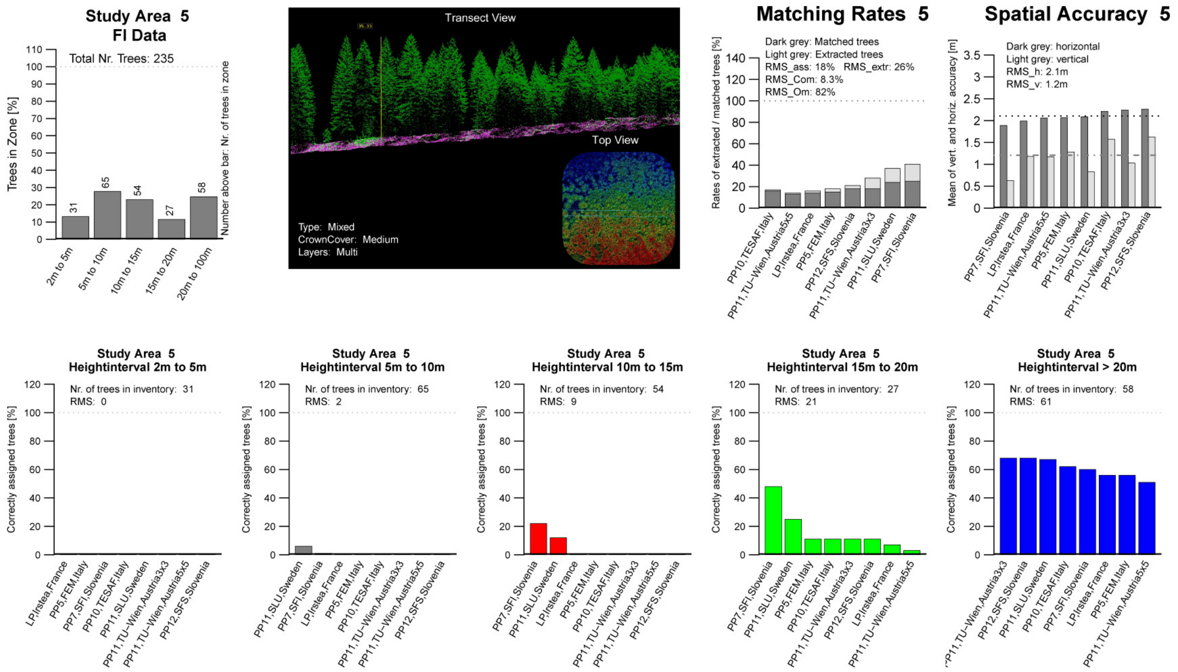


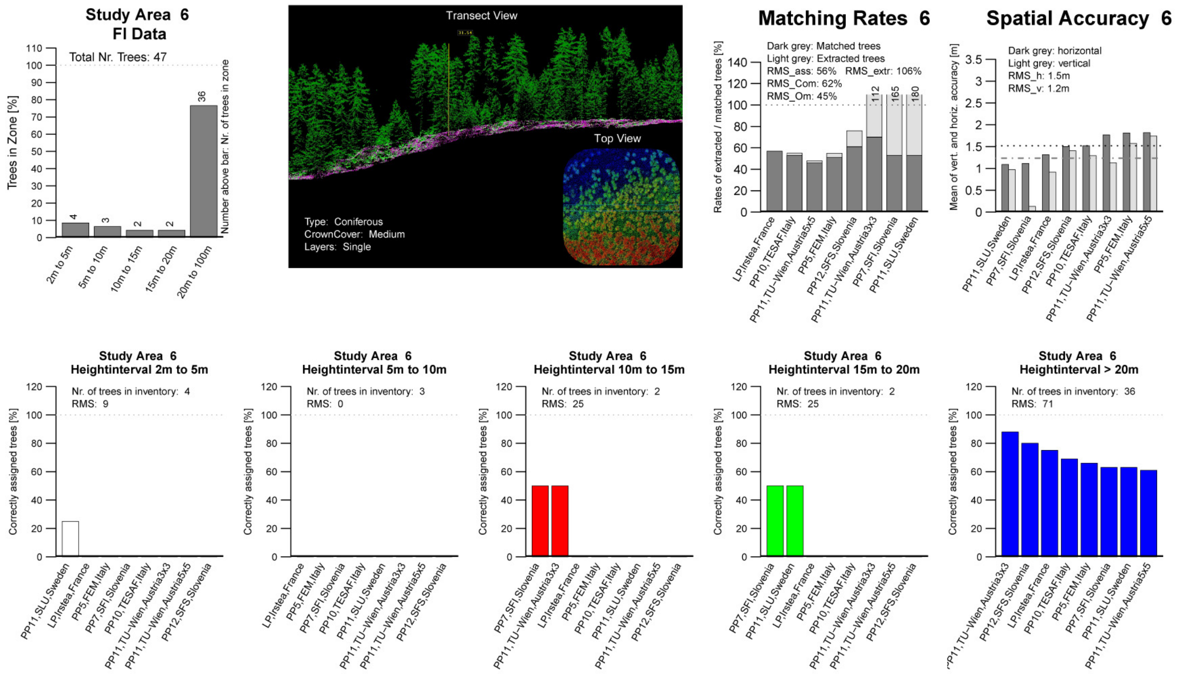
Study Area 3
FI Data
Total Nr. Trees: 122
Transect View
Top View
Type: Coniferous
CrownCover: Dense
Layers: Single
Matching Rates 3
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 60% RMS_extr: 95%
RMS_Com: 44%
RMS_Om: 42%
Spatial Accuracy 3
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.8m
RMS_v: 1.4m
Study Area 3
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 3
Heightinterval 5m to 10m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 3
Heightinterval 10m to 15m
Nr. of trees in inventory: 4
RMS: 0
Study Area 3
Heightinterval 15m to 20m
Nr. of trees in inventory: 5
RMS: 10
Study Area 3
Heightinterval > 20m
Nr. of trees in inventory: 113
RMS: 64

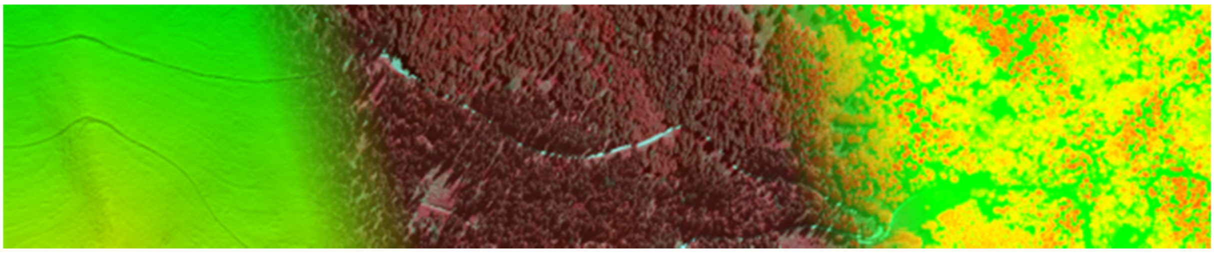


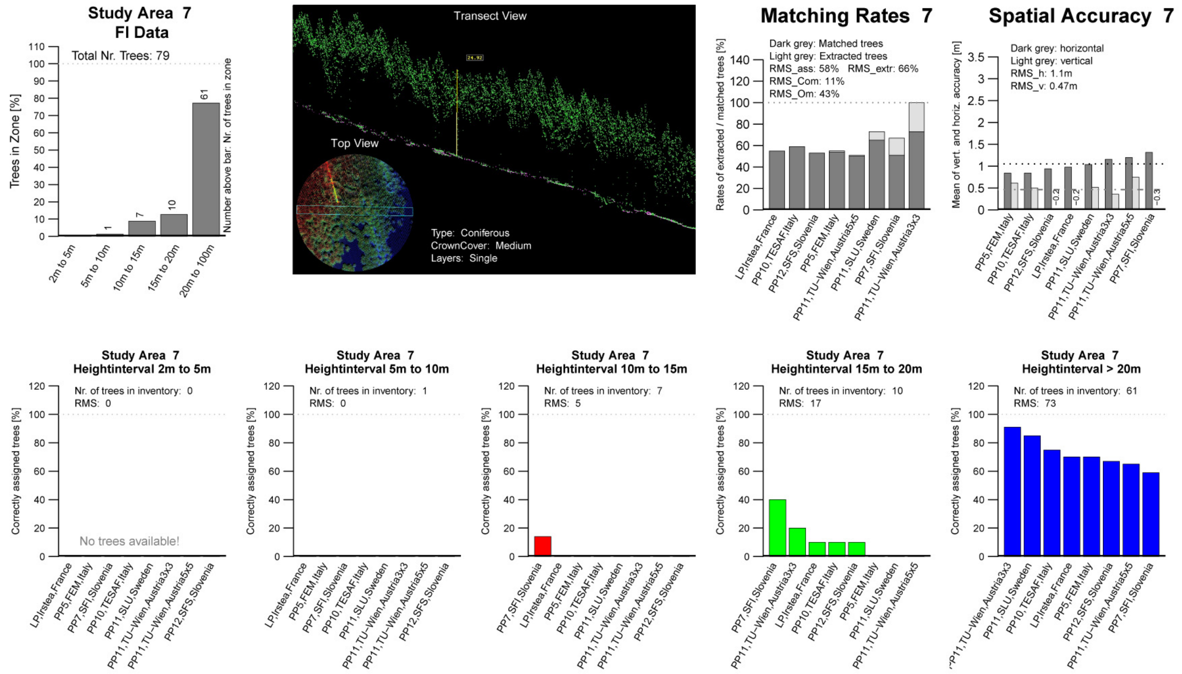
Study Area 4
FI Data
Total Nr. Trees: 150
Transect View
Top View
Type: Mixed
CrownCover: Dense
Layers: Single
Matching Rates 4
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 30% RMS_extr: 126%
RMS_Com: 99%
RMS_Om: 72%
Spatial Accuracy 4
Dark grey: horizontal
Light grey: vertical
RMS_h: 2.4m
RMS_v: 1.6m
Study Area 4
Heightinterval 2m to 5m
Nr. of trees in inventory: 1
RMS: 0
Study Area 4
Heightinterval 5m to 10m
Nr. of trees in inventory: 5
RMS: 0
Study Area 4
Heightinterval 10m to 15m
Nr. of trees in inventory: 10
RMS: 0
Study Area 4
Heightinterval 15m to 20m
Nr. of trees in inventory: 24
RMS: 10
Study Area 4
Heightinterval > 20m
Nr. of trees in inventory: 110
RMS: 39

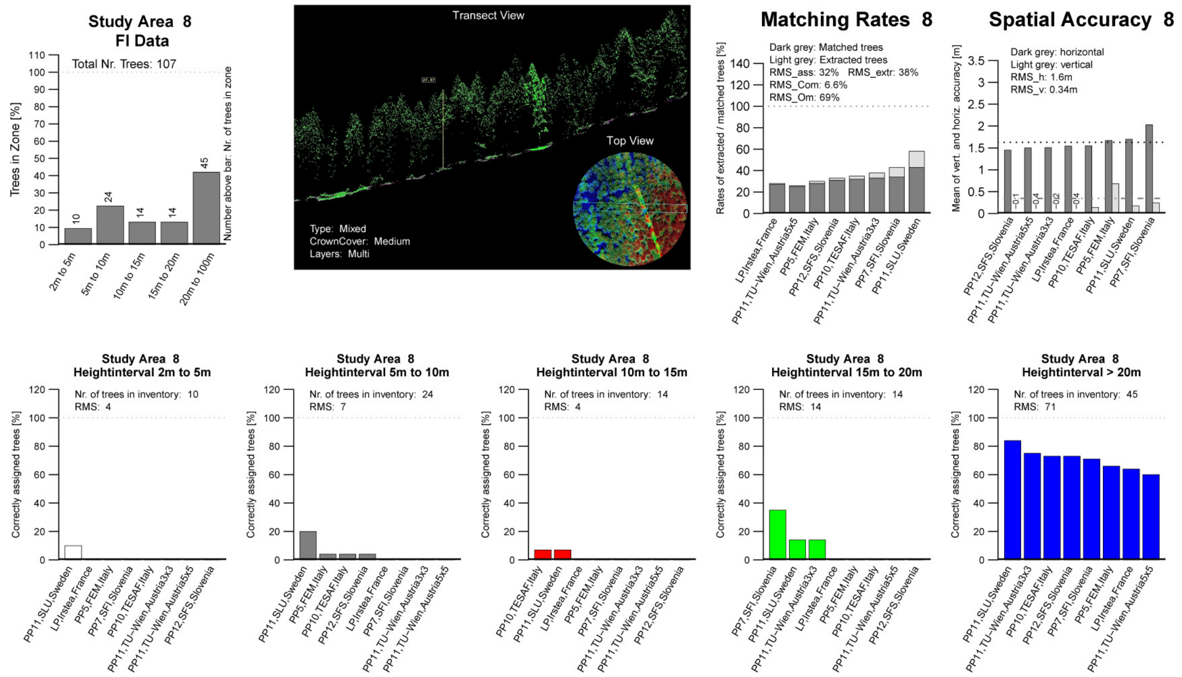


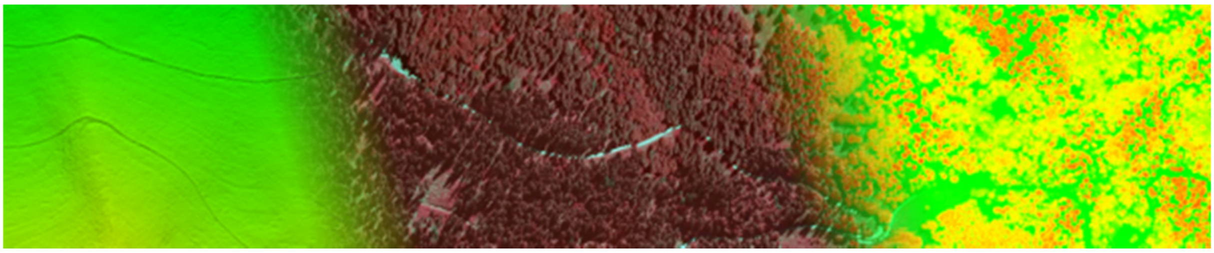

Study Area 5
FI Data
Total Nr. Trees: 235
Trees in Zone [%]
Number above bar: Nr. of trees in zone
31
65
54
27
58
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Medium
Layers: Multi
Matching Rates 5
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 18% RMS_extr: 26%
RMS_Com: 8.3%
RMS_Om: 82%
Rates of extracted / matched trees [%]
Spatial Accuracy 5
Dark grey: horizontal
Light grey: vertical
RMS_h: 2.1m
RMS_v: 1.2m
Mean of vert. and horiz. accuracy [m]
Study Area 5
Heightinterval 2m to 5m
Nr. of trees in inventory: 31
RMS: 0
Study Area 5
Heightinterval 5m to 10m
Nr. of trees in inventory: 65
RMS: 2
Study Area 5
Heightinterval 10m to 15m
Nr. of trees in inventory: 54
RMS: 9
Study Area 5
Heightinterval 15m to 20m
Nr. of trees in inventory: 27
RMS: 21
Study Area 5
Heightinterval > 20m
Nr. of trees in inventory: 58
RMS: 61
Correctly assigned trees [%]

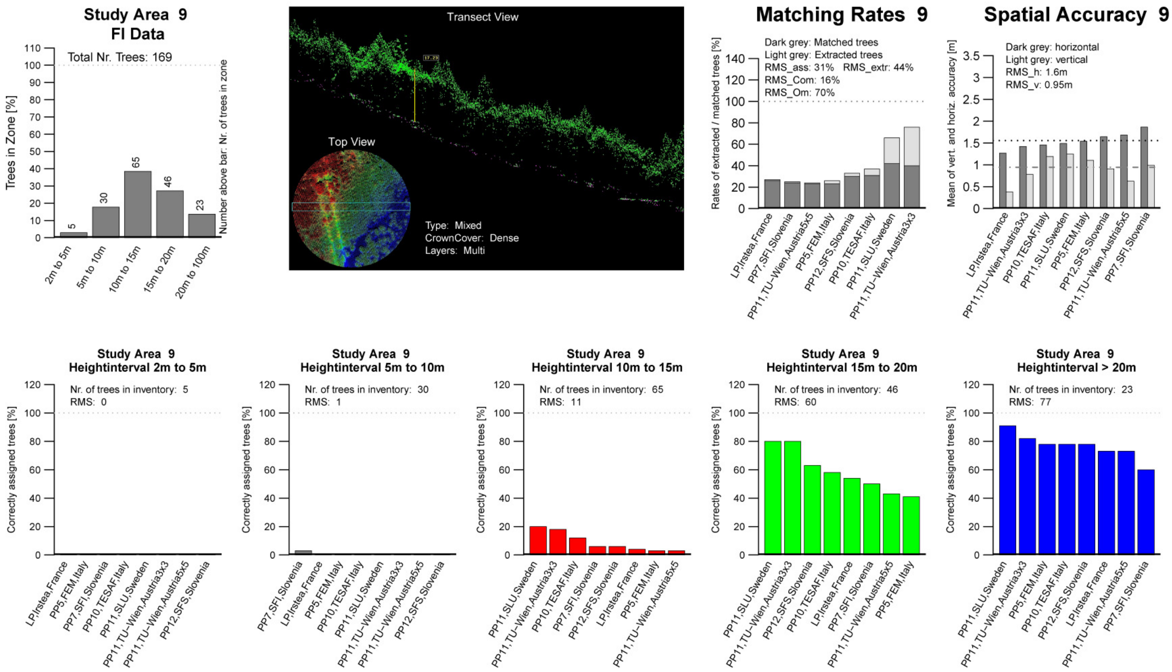

Study Area 6
FI Data
Total Nr. Trees: 47
Trees in Zone [%]
Number above bar: Nr. of trees in zone
4
3
2
2
36
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Coniferous
CrownCover: Medium
Layers: Single
Matching Rates 6
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 56% RMS_extr: 106%
RMS_Com: 62%
RMS_Om: 45%
Rates of extracted / matched trees [%]
Spatial Accuracy 6
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.5m
RMS_v: 1.2m
Mean of vert. and horiz. accuracy [m]
Study Area 6
Heightinterval 2m to 5m
Nr. of trees in inventory: 4
RMS: 9
Study Area 6
Heightinterval 5m to 10m
Nr. of trees in inventory: 3
RMS: 0
Study Area 6
Heightinterval 10m to 15m
Nr. of trees in inventory: 2
RMS: 25
Study Area 6
Heightinterval 15m to 20m
Nr. of trees in inventory: 2
RMS: 25
Study Area 6
Heightinterval > 20m
Nr. of trees in inventory: 36
RMS: 71
Correctly assigned trees [%]

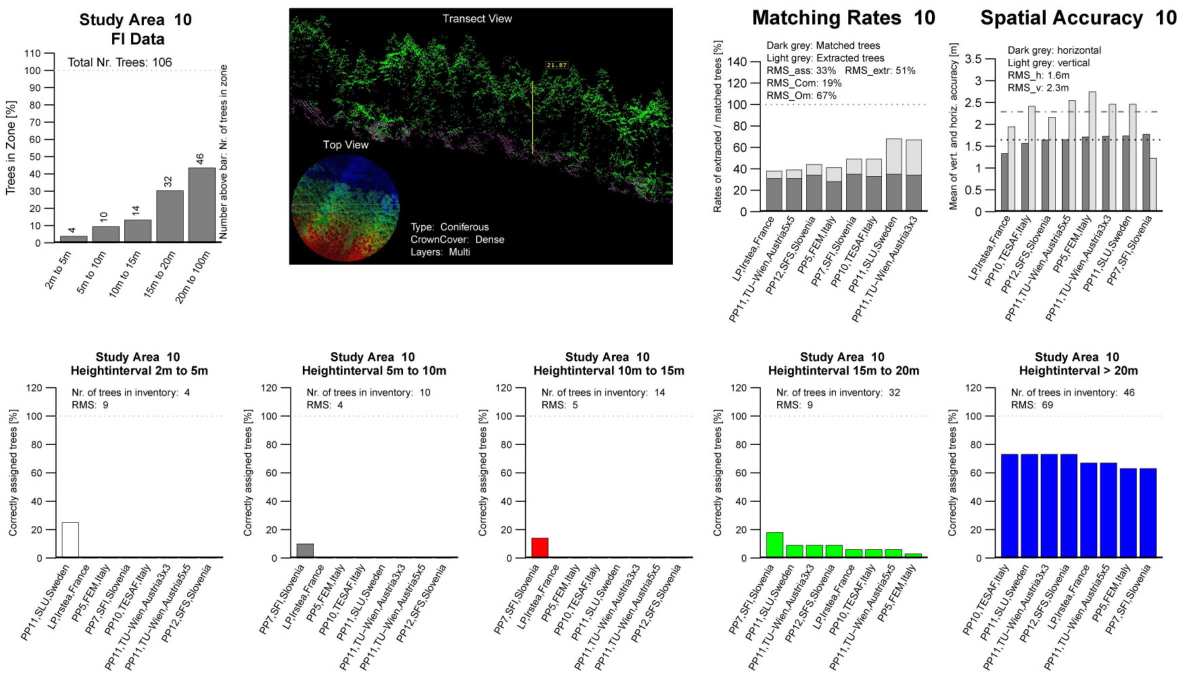


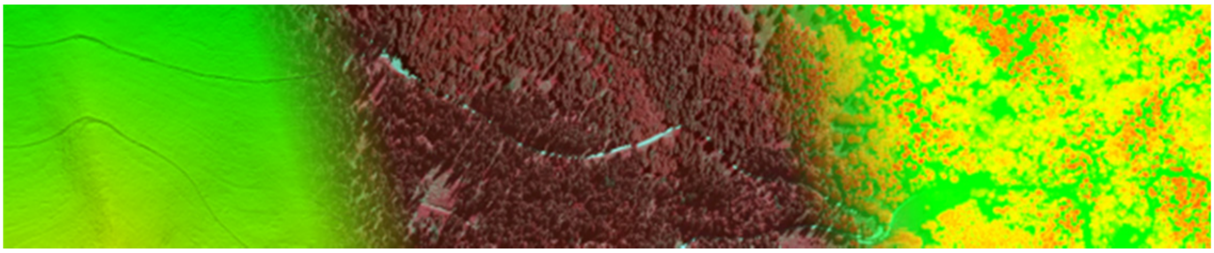

Study Area 7
FI Data
Total Nr. Trees: 79
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Coniferous
CrownCover: Medium
Layers: Single
Matching Rates 7
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 58% RMS_extr: 66%
RMS_Com: 11%
RMS_Om: 43%
Rates of extracted / matched trees [%]
Spatial Accuracy 7
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.1m
RMS_v: 0.47m
Mean of vert. and horiz. accuracy [m]
Study Area 7
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 7
Heightinterval 5m to 10m
Nr. of trees in inventory: 1
RMS: 0
Study Area 7
Heightinterval 10m to 15m
Nr. of trees in inventory: 7
RMS: 5
Study Area 7
Heightinterval 15m to 20m
Nr. of trees in inventory: 10
RMS: 17
Study Area 7
Heightinterval > 20m
Nr. of trees in inventory: 61
RMS: 73
Correctly assigned trees [%]

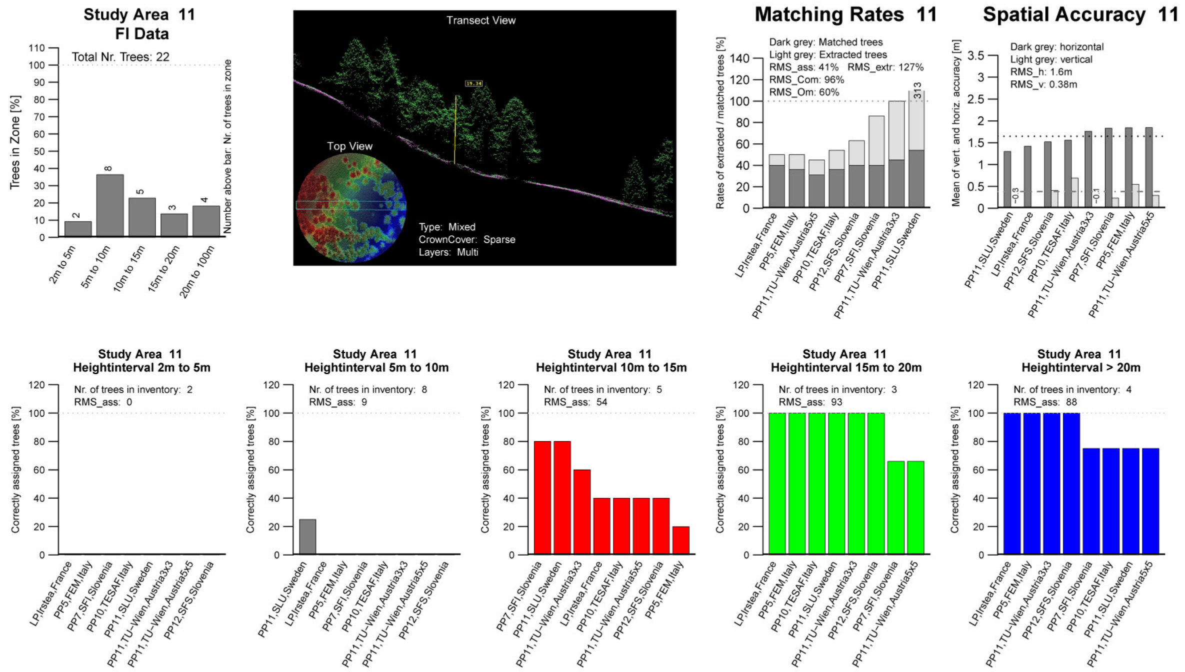

Study Area 8
FI Data
Total Nr. Trees: 107
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Medium
Layers: Multi
Matching Rates 8
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 32% RMS_extr: 38%
RMS_Com: 6.6%
RMS_Om: 69%
Rates of extracted / matched trees [%]
Spatial Accuracy 8
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.6m
RMS_v: 0.34m
Mean of vert. and horiz. accuracy [m]
Study Area 8
Heightinterval 2m to 5m
Nr. of trees in inventory: 10
RMS: 4
Study Area 8
Heightinterval 5m to 10m
Nr. of trees in inventory: 24
RMS: 7
Study Area 8
Heightinterval 10m to 15m
Nr. of trees in inventory: 14
RMS: 4
Study Area 8
Heightinterval 15m to 20m
Nr. of trees in inventory: 14
RMS: 14
Study Area 8
Heightinterval > 20m
Nr. of trees in inventory: 45
RMS: 71
Correctly assigned trees [%]



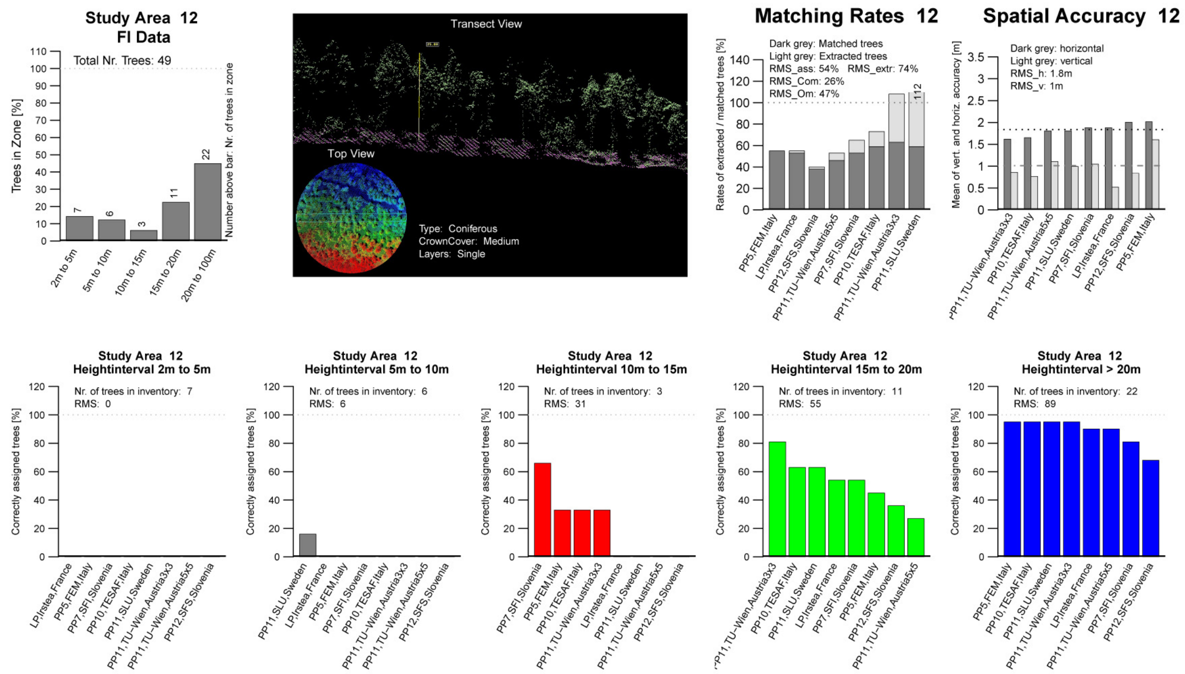

Study Area 9
FI Data
Total Nr. Trees: 169
Trees in Zone [%]
Number above bar: Nr. of trees in zone
5
30
65
46
23
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Dense
Layers: Multi
Matching Rates 9
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 31% RMS_extr: 44%
RMS_Com: 16%
RMS_Om: 70%
Rates of extracted / matched trees [%]
LP,Irstea,France
PP7,SFI,Slovenia
PP11,TU-Wien,Austria5x5
PP5,FEM,Italy
PP12,SFS,Slovenia
PP10,TESAF,Italy
PP11,SLU,Sweden
PP11,TU-Wien,Austria3x3
Spatial Accuracy 9
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.6m
RMS_v: 0.95m
Mean of vert. and horiz. accuracy [m]
Study Area 9
Heightinterval 2m to 5m
Nr. of trees in inventory: 5
RMS: 0
Study Area 9
Heightinterval 5m to 10m
Nr. of trees in inventory: 30
RMS: 1
Study Area 9
Heightinterval 10m to 15m
Nr. of trees in inventory: 65
RMS: 11
Study Area 9
Heightinterval 15m to 20m
Nr. of trees in inventory: 46
RMS: 60
Study Area 9
Heightinterval > 20m
Nr. of trees in inventory: 23
RMS: 77
Correctly assigned trees [%]


Study Area 10
FI Data
Total Nr. Trees: 106
Trees in Zone [%]
Number above bar: Nr. of trees in zone
4
10
14
32
46
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Coniferous
CrownCover: Dense
Layers: Multi
Matching Rates 10
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 33% RMS_extr: 51%
RMS_Com: 19%
RMS_Om: 67%
Rates of extracted / matched trees [%]
Spatial Accuracy 10
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.6m
RMS_v: 2.3m
Mean of vert. and horiz. accuracy [m]
Study Area 10
Heightinterval 2m to 5m
Nr. of trees in inventory: 4
RMS: 9
Study Area 10
Heightinterval 5m to 10m
Nr. of trees in inventory: 10
RMS: 4
Study Area 10
Heightinterval 10m to 15m
Nr. of trees in inventory: 14
RMS: 5
Study Area 10
Heightinterval 15m to 20m
Nr. of trees in inventory: 32
RMS: 9
Study Area 10
Heightinterval > 20m
Nr. of trees in inventory: 46
RMS: 69
Correctly assigned trees [%]

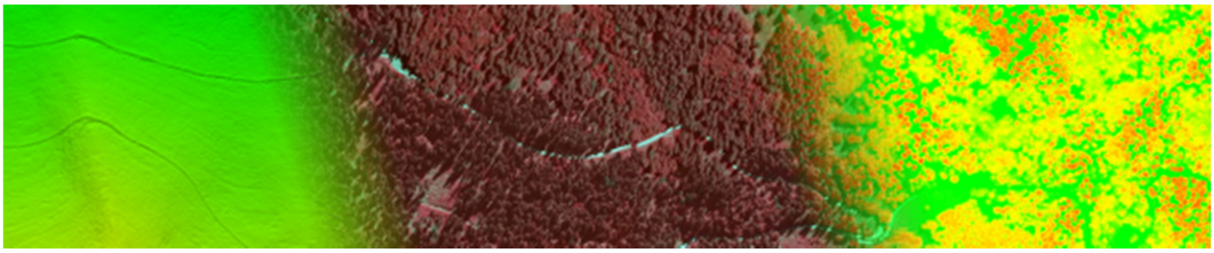


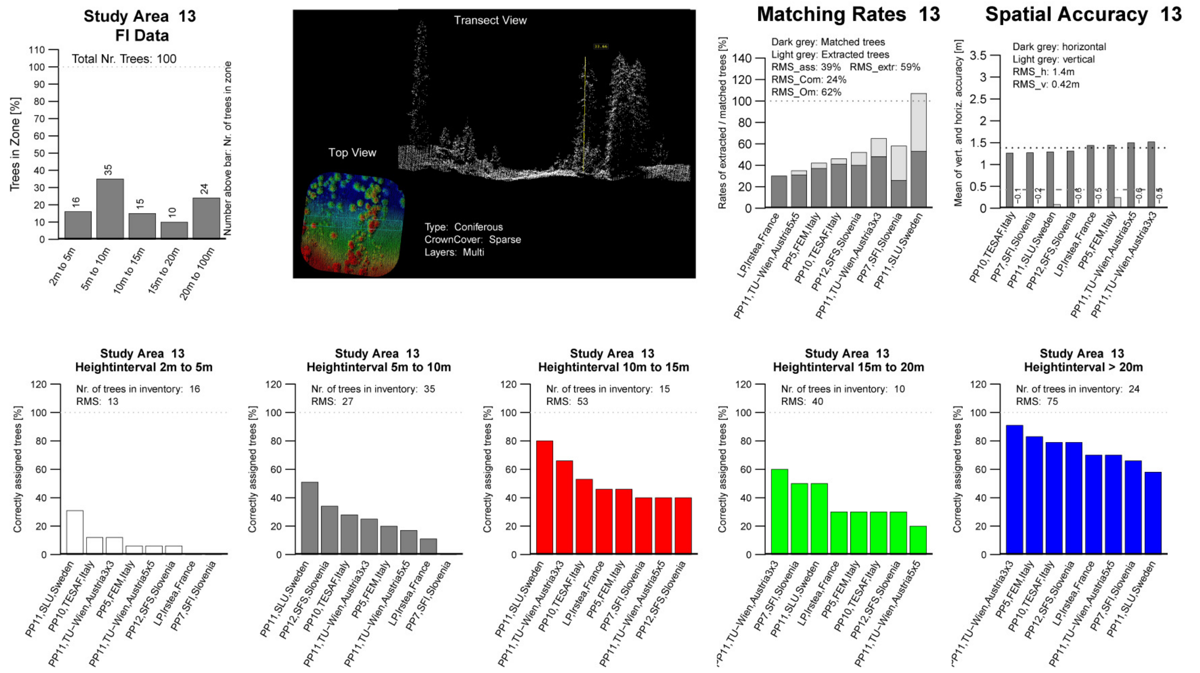


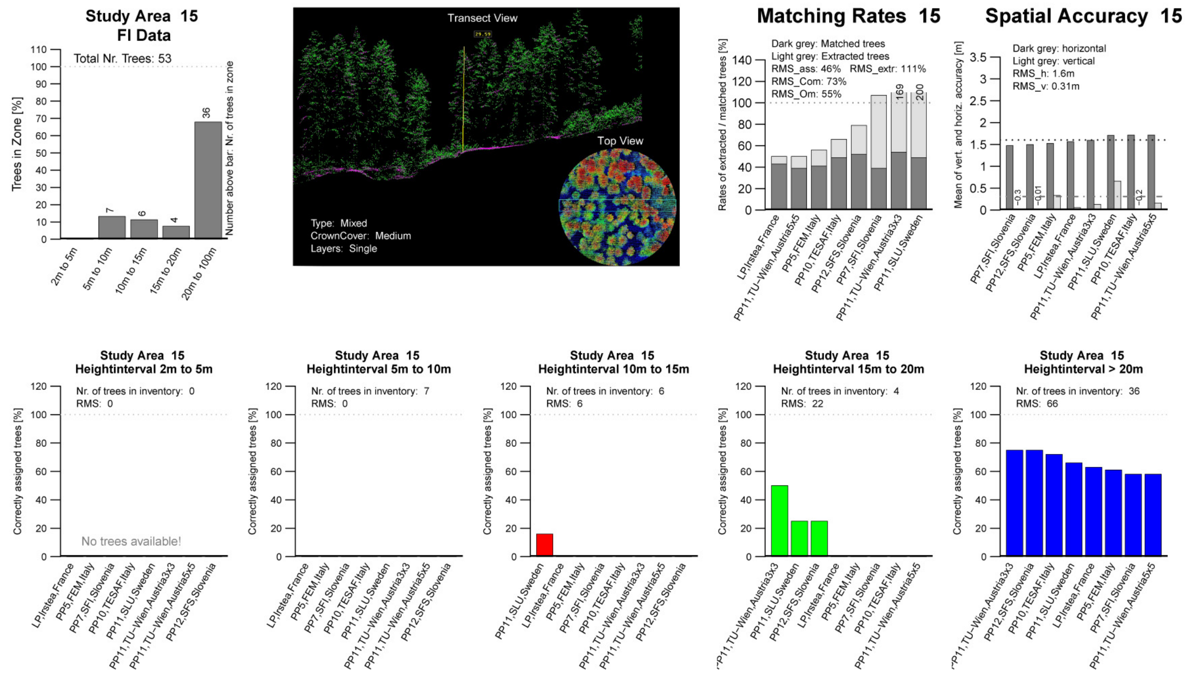
Study Area 11
FI Data
Total Nr. Trees: 22
Trees in Zone [%]
Number above bar: Nr. of trees in zone
Transect View
Top View
Type: Mixed
CrownCover: Sparse
Layers: Multi
Matching Rates 11
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 41% RMS_extr: 127%
RMS_Com: 96%
RMS_Om: 60%
Rates of extracted / matched trees [%]
Spatial Accuracy 11
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.6m
RMS_v: 0.38m
Mean of vert. and horiz. accuracy [m]
Study Area 11
Heightinterval 2m to 5m
Nr. of trees in inventory: 2
RMS_ass: 0
Study Area 11
Heightinterval 5m to 10m
Nr. of trees in inventory: 8
RMS_ass: 9
Study Area 11
Heightinterval 10m to 15m
Nr. of trees in inventory: 5
RMS_ass: 54
Study Area 11
Heightinterval 15m to 20m
Nr. of trees in inventory: 3
RMS_ass: 93
Study Area 11
Heightinterval > 20m
Nr. of trees in inventory: 4
RMS_ass: 88
Correctly assigned trees [%]

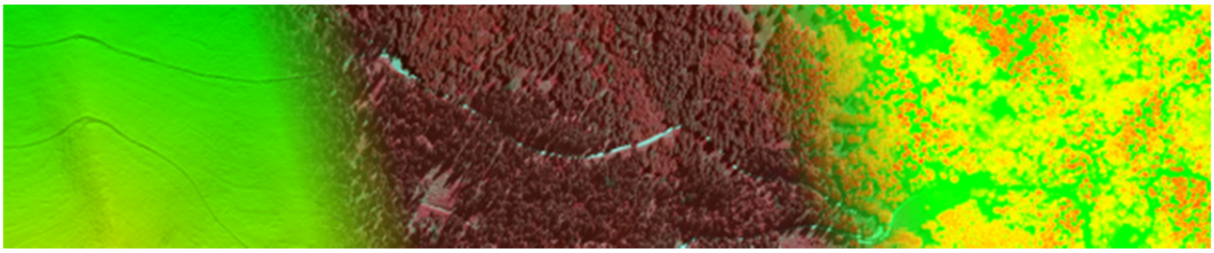


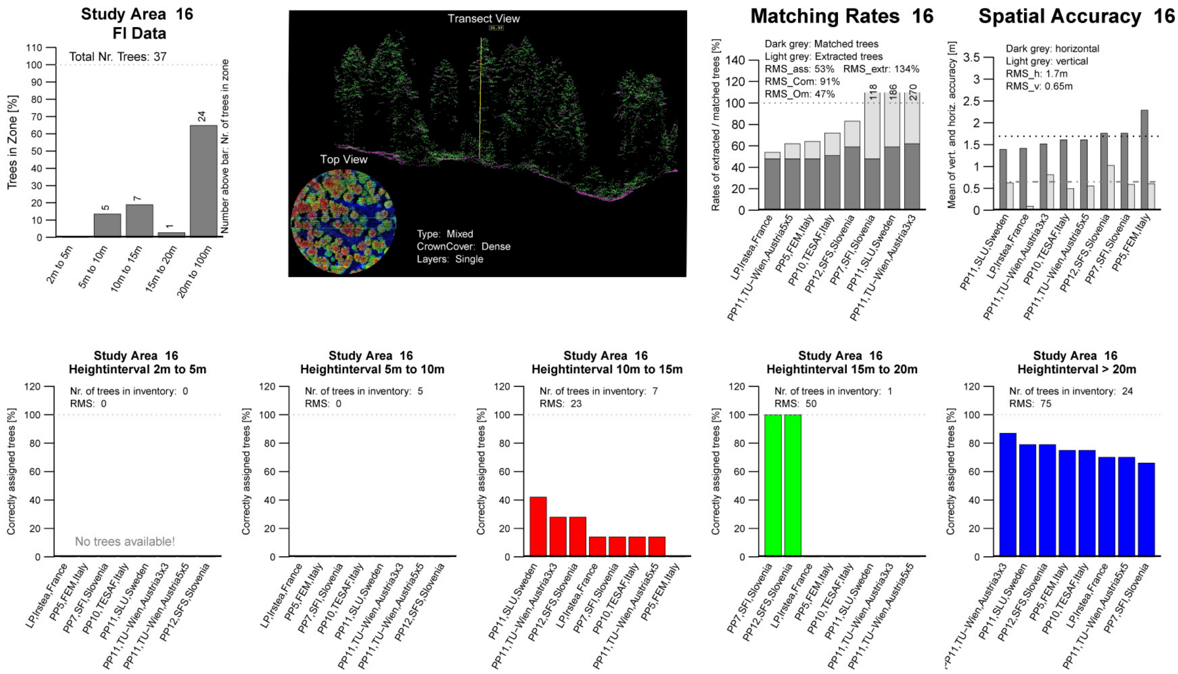
Study Area 12
FI Data
Total Nr. Trees: 49
Trees in Zone [%]
Number above bar: Nr. of trees in zone
Transect View
Top View
Type: Coniferous
CrownCover: Medium
Layers: Single
Matching Rates 12
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 54% RMS_extr: 74%
RMS_Com: 26%
RMS_Om: 47%
Rates of extracted / matched trees [%]
Spatial Accuracy 12
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.8m
RMS_v: 1m
Mean of vert. and horiz. accuracy [m]
Study Area 12
Heightinterval 2m to 5m
Nr. of trees in inventory: 7
RMS: 0
Study Area 12
Heightinterval 5m to 10m
Nr. of trees in inventory: 6
RMS: 6
Study Area 12
Heightinterval 10m to 15m
Nr. of trees in inventory: 3
RMS: 31
Study Area 12
Heightinterval 15m to 20m
Nr. of trees in inventory: 11
RMS: 55
Study Area 12
Heightinterval > 20m
Nr. of trees in inventory: 22
RMS: 89
Correctly assigned trees [%]

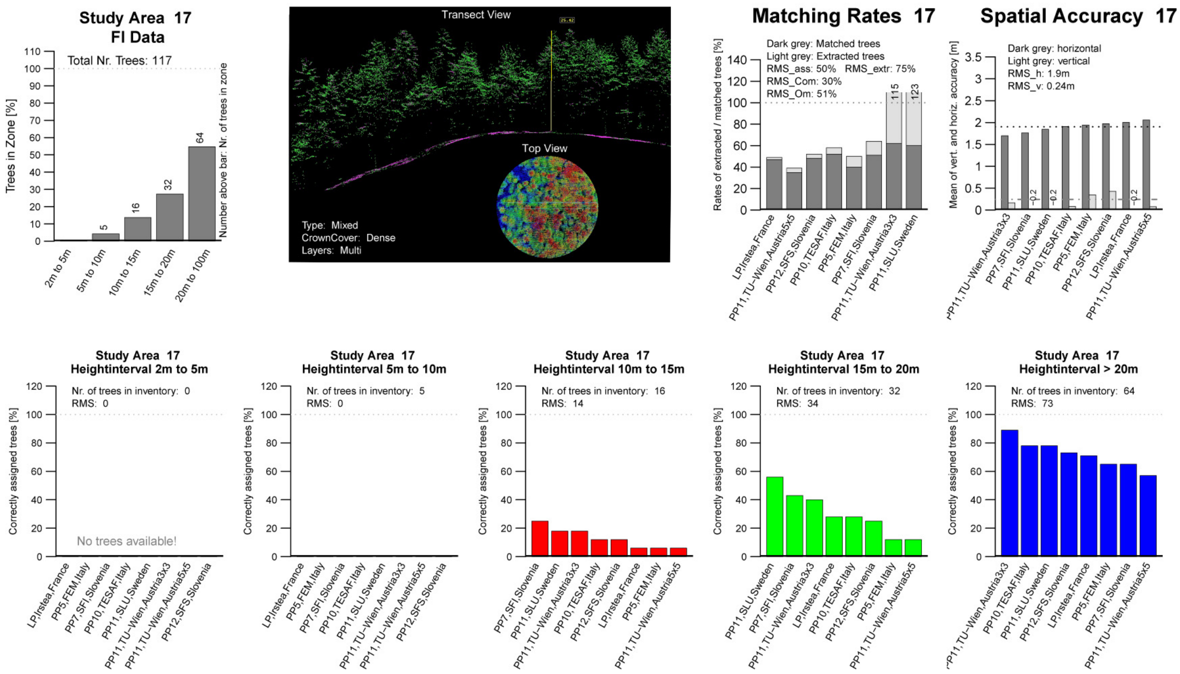


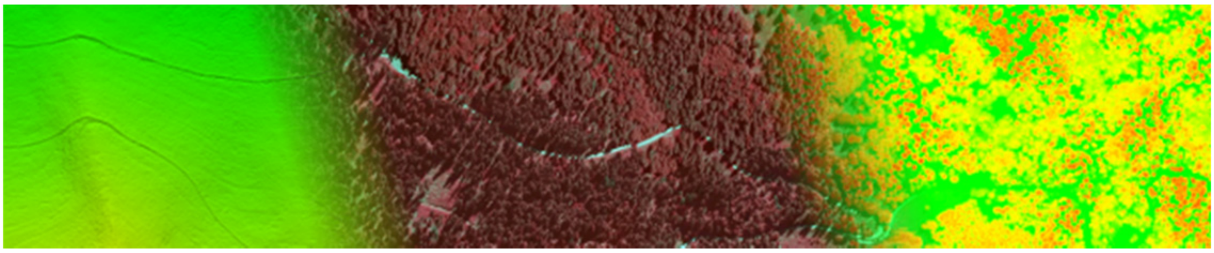

Study Area 13
FI Data
Total Nr. Trees: 100
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Coniferous
CrownCover: Sparse
Layers: Multi
Matching Rates 13
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 39% RMS_extr: 59%
RMS_Com: 24%
RMS_Om: 62%
Rates of extracted / matched trees [%]
Spatial Accuracy 13
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.4m
RMS_v: 0.42m
Mean of vert. and horiz. accuracy [m]
Study Area 13
Heightinterval 2m to 5m
Nr. of trees in inventory: 16
RMS: 13
Study Area 13
Heightinterval 5m to 10m
Nr. of trees in inventory: 35
RMS: 27
Study Area 13
Heightinterval 10m to 15m
Nr. of trees in inventory: 15
RMS: 53
Study Area 13
Heightinterval 15m to 20m
Nr. of trees in inventory: 10
RMS: 40
Study Area 13
Heightinterval > 20m
Nr. of trees in inventory: 24
RMS: 75
Correctly assigned trees [%]

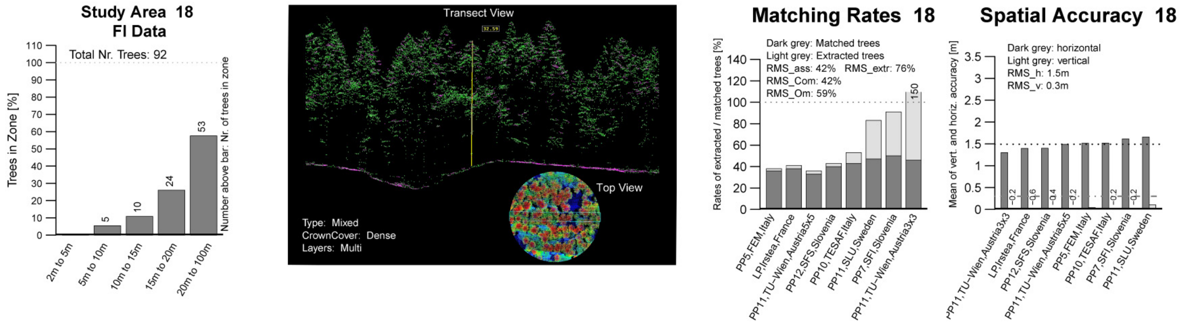

Study Area 15
FI Data
Total Nr. Trees: 53
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Medium
Layers: Single
Matching Rates 15
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 46% RMS_extr: 111%
RMS_Com: 73%
RMS_Om: 55%
Rates of extracted / matched trees [%]
Spatial Accuracy 15
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.6m
RMS_v: 0.31m
Mean of vert. and horiz. accuracy [m]
Study Area 15
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 15
Heightinterval 5m to 10m
Nr. of trees in inventory: 7
RMS: 0
Study Area 15
Heightinterval 10m to 15m
Nr. of trees in inventory: 6
RMS: 6
Study Area 15
Heightinterval 15m to 20m
Nr. of trees in inventory: 4
RMS: 22
Study Area 15
Heightinterval > 20m
Nr. of trees in inventory: 36
RMS: 66
Correctly assigned trees [%]

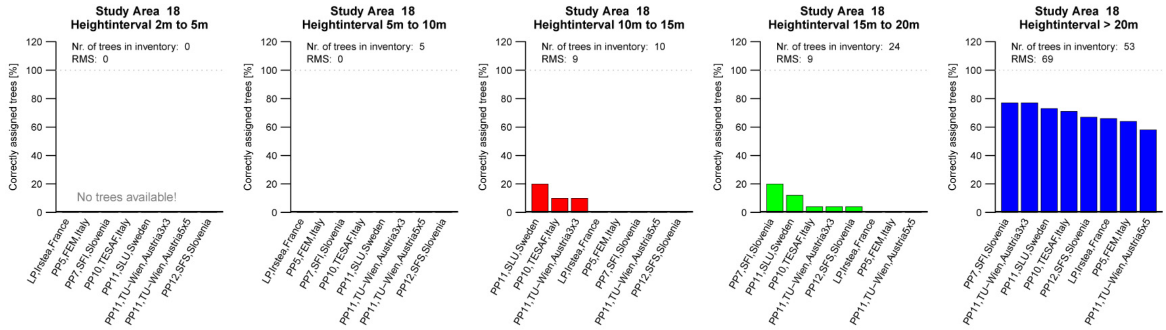


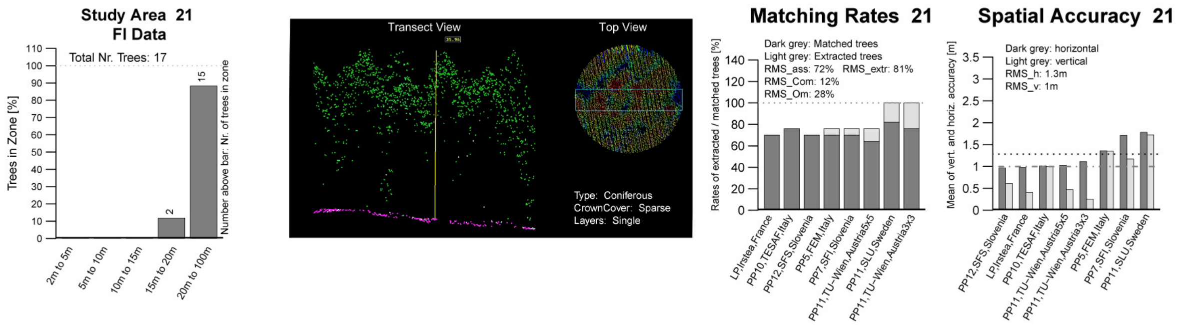

Study Area 16
FI Data
Total Nr. Trees: 37
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Dense
Layers: Single
Matching Rates 16
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 53% RMS_extr: 134%
RMS_Com: 91%
RMS_Om: 47%
Rates of extracted / matched trees [%]
Spatial Accuracy 16
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.7m
RMS_v: 0.65m
Mean of vert. and horiz. accuracy [m]
Study Area 16
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 16
Heightinterval 5m to 10m
Nr. of trees in inventory: 5
RMS: 0
Study Area 16
Heightinterval 10m to 15m
Nr. of trees in inventory: 7
RMS: 23
Study Area 16
Heightinterval 15m to 20m
Nr. of trees in inventory: 1
RMS: 50
Study Area 16
Heightinterval > 20m
Nr. of trees in inventory: 24
RMS: 75
Correctly assigned trees [%]

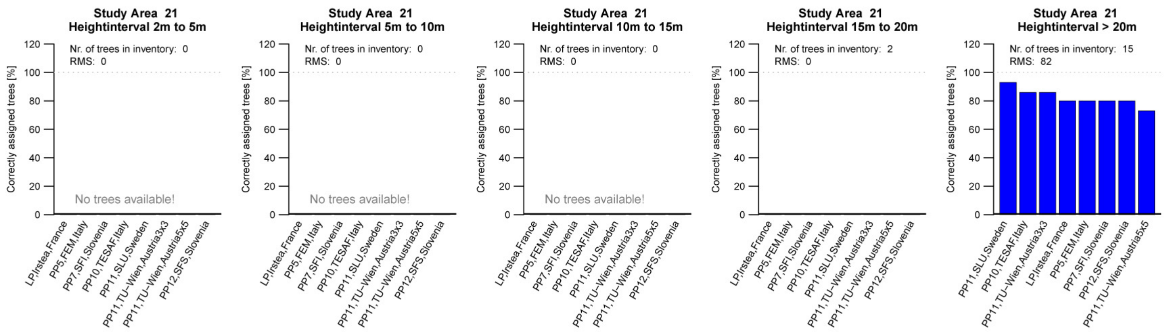

Study Area 17
FI Data
Total Nr. Trees: 117
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Dense
Layers: Multi
Matching Rates 17
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 50% RMS_extr: 75%
RMS_Com: 30%
RMS_Om: 51%
Rates of extracted / matched trees [%]
Spatial Accuracy 17
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.9m
RMS_v: 0.24m
Mean of vert. and horiz. accuracy [m]
Study Area 17
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 17
Heightinterval 5m to 10m
Nr. of trees in inventory: 5
RMS: 0
Study Area 17
Heightinterval 10m to 15m
Nr. of trees in inventory: 16
RMS: 14
Study Area 17
Heightinterval 15m to 20m
Nr. of trees in inventory: 32
RMS: 34
Study Area 17
Heightinterval > 20m
Nr. of trees in inventory: 64
RMS: 73
Correctly assigned trees [%]

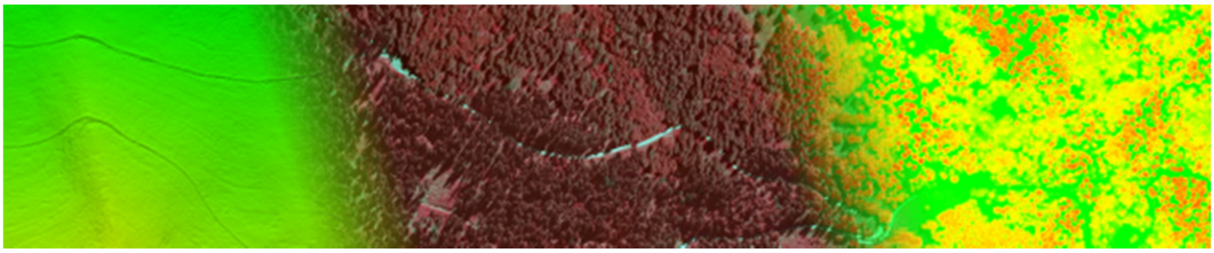



Study Area 18
FI Data
Total Nr. Trees: 92
Trees in Zone [%]
Number above bar: Nr. of trees in zone
2m to 5m
5m to 10m
10m to 15m
15m to 20m
20m to 100m
Transect View
Top View
Type: Mixed
CrownCover: Dense
Layers: Multi
Matching Rates 18
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 42% RMS_extr: 76%
RMS_Com: 42%
RMS_Om: 59%
Rates of extracted / matched trees [%]
Spatial Accuracy 18
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.5m
RMS_v: 0.3m
Mean of vert. and horiz. accuracy [m]

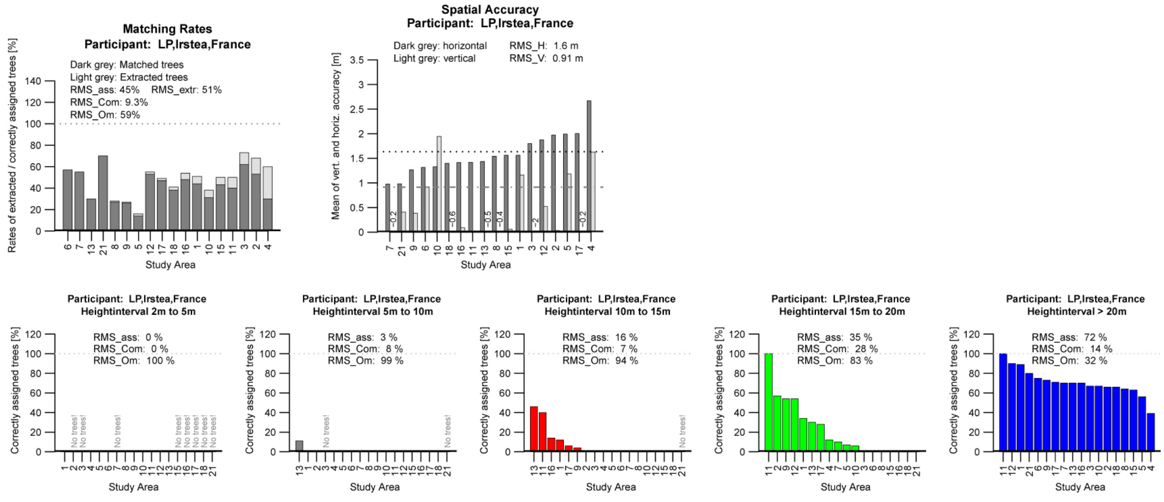

Study Area 18
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 18
Heightinterval 5m to 10m
Nr. of trees in inventory: 5
RMS: 0
Study Area 18
Heightinterval 10m to 15m
Nr. of trees in inventory: 10
RMS: 9
Study Area 18
Heightinterval 15m to 20m
Nr. of trees in inventory: 24
RMS: 9
Study Area 18
Heightinterval > 20m
Nr. of trees in inventory: 53
RMS: 69
Correctly assigned trees [%]

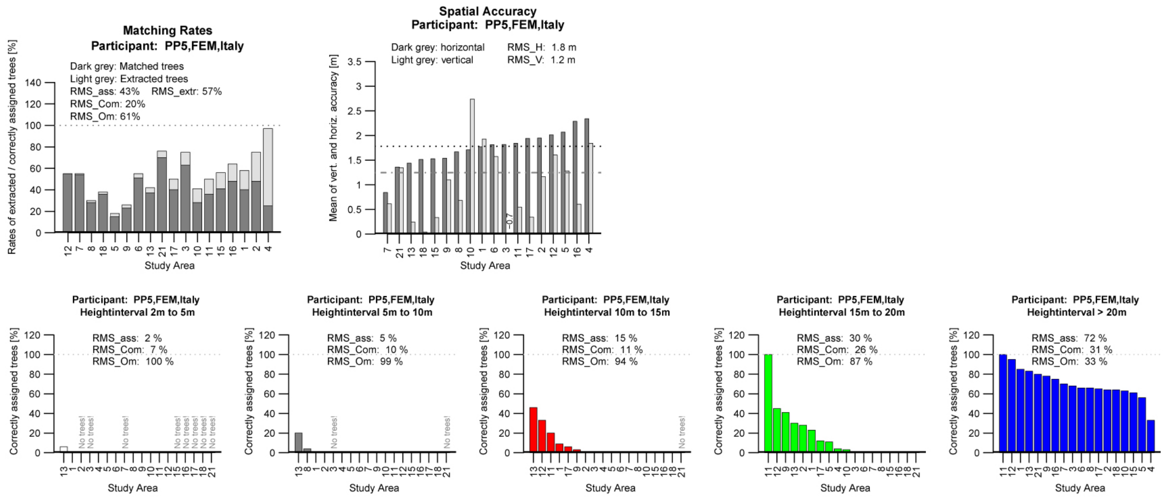

Study Area 21
FI Data
Total Nr. Trees: 17
Trees in Zone [%]
Number above bar: Nr. of trees in zone
Transect View
Top View
Type: Coniferous
CrownCover: Sparse
Layers: Single
Matching Rates 21
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 72% RMS_extr: 81%
RMS_Com: 12%
RMS_Om: 28%
Spatial Accuracy 21
Dark grey: horizontal
Light grey: vertical
RMS_h: 1.3m
RMS_v: 1m

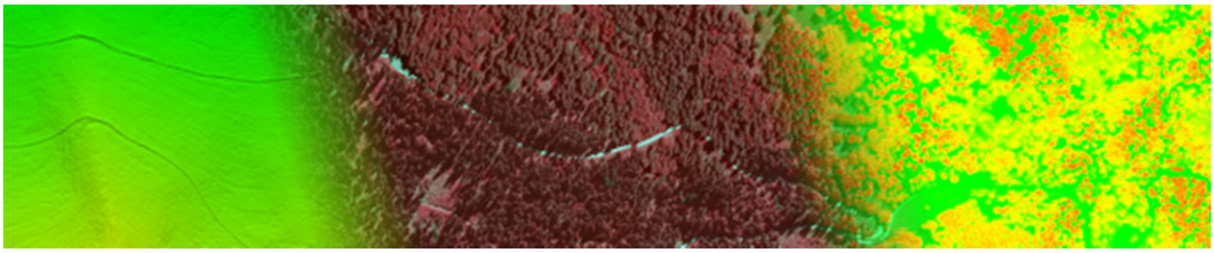

Study Area 21
Heightinterval 2m to 5m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 21
Heightinterval 5m to 10m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 21
Heightinterval 10m to 15m
Nr. of trees in inventory: 0
RMS: 0
No trees available!
Study Area 21
Heightinterval 15m to 20m
Nr. of trees in inventory: 2
RMS: 0
Study Area 21
Heightinterval > 20m
Nr. of trees in inventory: 15
RMS: 82
Correctly assigned trees [%]

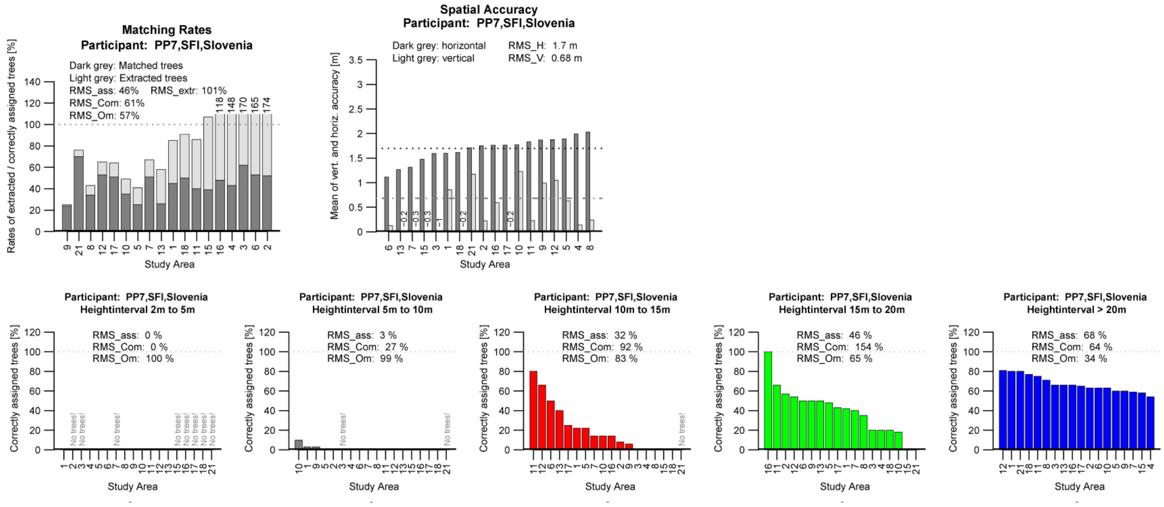


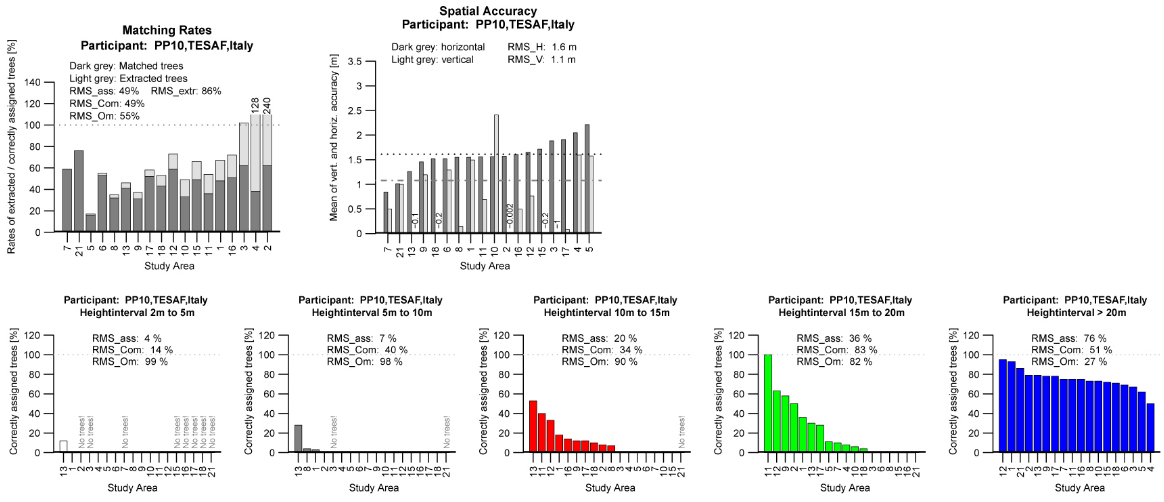
3.13.2 DETAILED MATCHING RESULTS PER METHOD

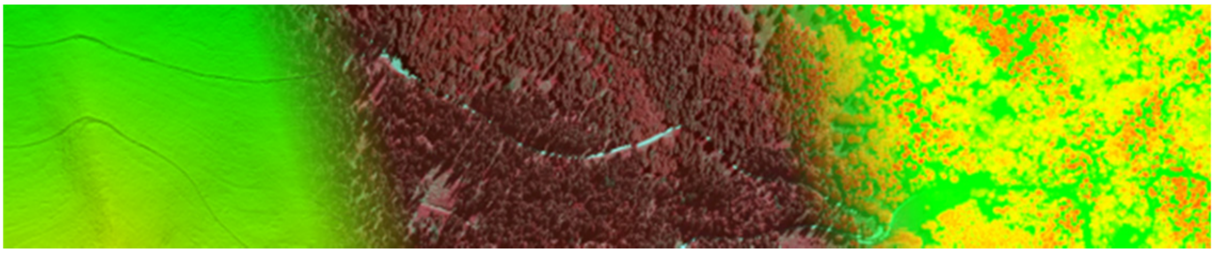


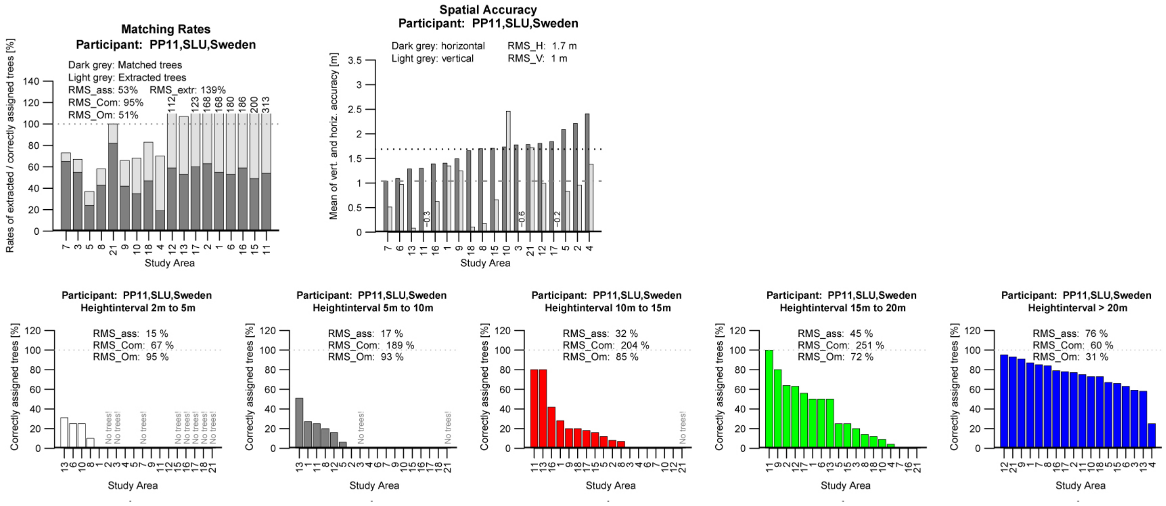




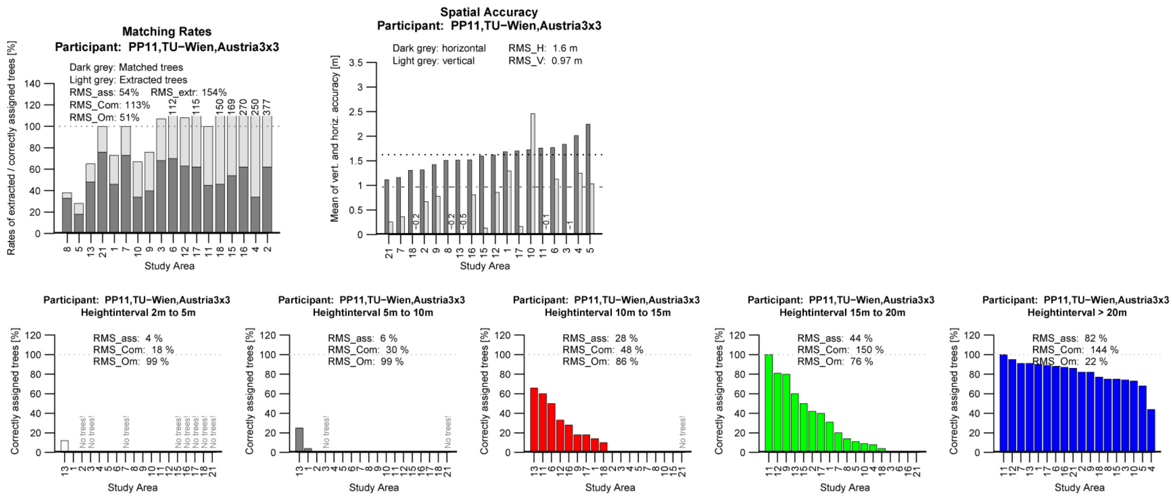

Matching Rates
Participant: PP7,SFI,Slovenia
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 46% RMS_extr: 101%
RMS_Com: 61%
RMS_Om: 57%
Rates of extracted / correctly assigned trees [%]
Study Area
Spatial Accuracy
Participant: PP7,SFI,Slovenia
Dark grey: horizontal
Light grey: vertical
RMS_H: 1.7 m
RMS_V: 0.68 m
Mean of vert. and horiz. accuracy [m]
Study Area
Participant: PP7,SFI,Slovenia
Heightinterval 2m to 5m
RMS_ass: 0 %
RMS_Com: 0 %
RMS_Om: 100 %
Participant: PP7,SFI,Slovenia
Heightinterval 5m to 10m
RMS_ass: 3 %
RMS_Com: 27 %
RMS_Om: 99 %
Participant: PP7,SFI,Slovenia
Heightinterval 10m to 15m
RMS_ass: 32 %
RMS_Com: 92 %
RMS_Om: 83 %
Participant: PP7,SFI,Slovenia
Heightinterval 15m to 20m
RMS_ass: 46 %
RMS_Com: 154 %
RMS_Om: 65 %
Participant: PP7,SFI,Slovenia
Heightinterval > 20m
RMS_ass: 68 %
RMS_Com: 64 %
RMS_Om: 34 %
Correctly assigned trees [%]
Study Area


Matching Rates
Participant: PP10,TESAF,Italy
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 49% RMS_extr: 86%
RMS_Com: 49%
RMS_Om: 55%
Rates of extracted / correctly assigned trees [%]
Study Area
Spatial Accuracy
Participant: PP10,TESAF,Italy
Dark grey: horizontal
Light grey: vertical
RMS_H: 1.6 m
RMS_V: 1.1 m
Mean of vert. and horiz. accuracy [m]
Study Area
Participant: PP10,TESAF,Italy
Heightinterval 2m to 5m
RMS_ass: 4 %
RMS_Com: 14 %
RMS_Om: 99 %
Participant: PP10,TESAF,Italy
Heightinterval 5m to 10m
RMS_ass: 7 %
RMS_Com: 40 %
RMS_Om: 98 %
Participant: PP10,TESAF,Italy
Heightinterval 10m to 15m
RMS_ass: 20 %
RMS_Com: 34 %
RMS_Om: 90 %
Participant: PP10,TESAF,Italy
Heightinterval 15m to 20m
RMS_ass: 36 %
RMS_Com: 83 %
RMS_Om: 82 %
Participant: PP10,TESAF,Italy
Heightinterval > 20m
RMS_ass: 76 %
RMS_Com: 51 %
RMS_Om: 27 %
Correctly assigned trees [%]
Study Area

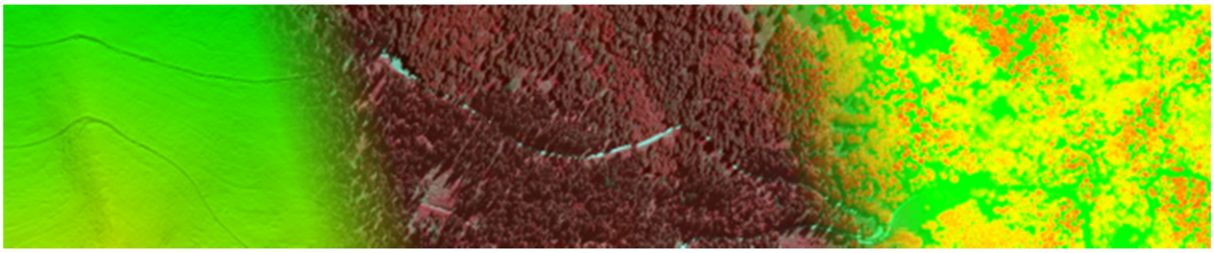


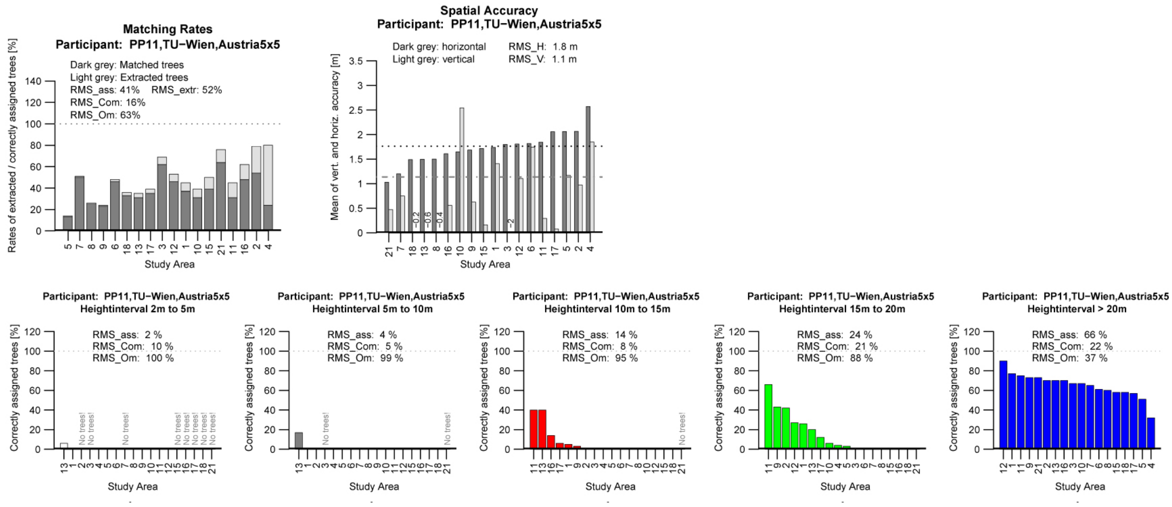


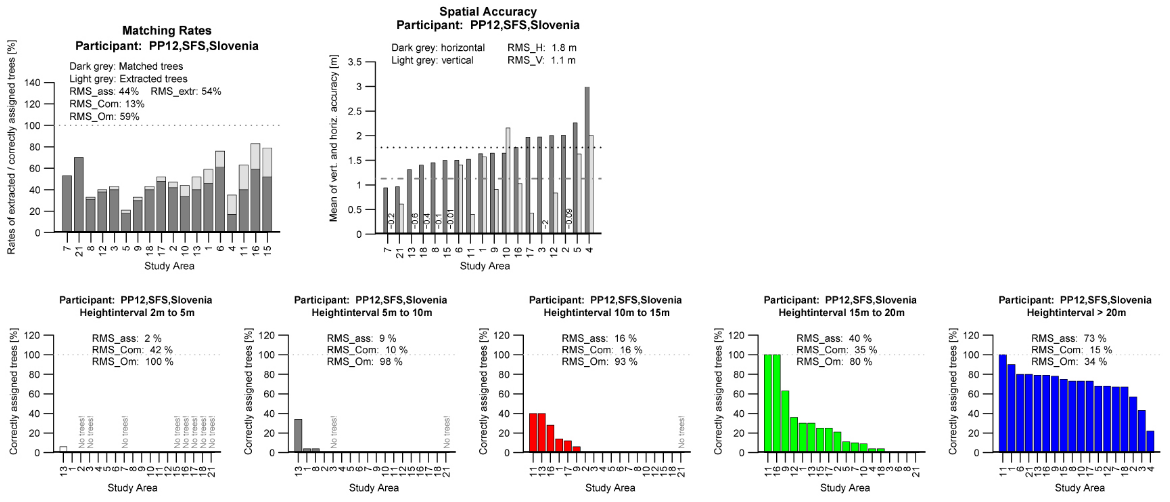
Matching Rates
Participant: PP11,SLU,Sweden
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 53% RMS_extr: 139%
RMS_Com: 95%
RMS_Om: 51%
Rates of extracted / correctly assigned trees [%]
Study Area
Spatial Accuracy
Participant: PP11,SLU,Sweden
Dark grey: horizontal
Light grey: vertical
RMS_H: 1.7 m
RMS_V: 1 m
Mean of vert. and horiz. accuracy [m]
Study Area
Participant: PP11,SLU,Sweden
Heightinterval 2m to 5m
RMS_ass: 15 %
RMS_Com: 67 %
RMS_Om: 95 %
Participant: PP11,SLU,Sweden
Heightinterval 5m to 10m
RMS_ass: 17 %
RMS_Com: 189 %
RMS_Om: 93 %
Participant: PP11,SLU,Sweden
Heightinterval 10m to 15m
RMS_ass: 32 %
RMS_Com: 204 %
RMS_Om: 85 %
Participant: PP11,SLU,Sweden
Heightinterval 15m to 20m
RMS_ass: 45 %
RMS_Com: 251 %
RMS_Om: 72 %
Participant: PP11,SLU,Sweden
Heightinterval > 20m
RMS_ass: 76 %
RMS_Com: 60 %
RMS_Om: 31 %
Correctly assigned trees [%]
Study Area

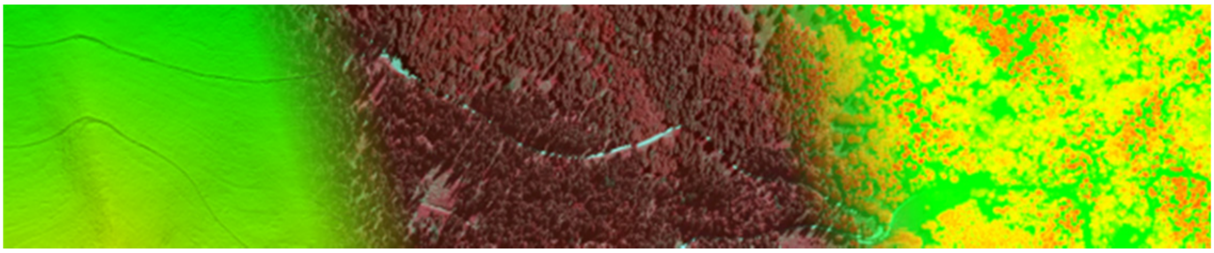


Matching Rates
Participant: PP11,TU−Wien,Austria3x3
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 54% RMS_extr: 154%
RMS_Com: 113%
RMS_Om: 51%
Rates of extracted / correctly assigned trees [%]
Study Area
Spatial Accuracy
Participant: PP11,TU−Wien,Austria3x3
Dark grey: horizontal
Light grey: vertical
RMS_H: 1.6 m
RMS_V: 0.97 m
Mean of vert. and horiz. accuracy [m]
Study Area
Participant: PP11,TU−Wien,Austria3x3
Heightinterval 2m to 5m
RMS_ass: 4 %
RMS_Com: 18 %
RMS_Om: 99 %
Participant: PP11,TU−Wien,Austria3x3
Heightinterval 5m to 10m
RMS_ass: 6 %
RMS_Com: 30 %
RMS_Om: 99 %
Participant: PP11,TU−Wien,Austria3x3
Heightinterval 10m to 15m
RMS_ass: 28 %
RMS_Com: 48 %
RMS_Om: 86 %
Participant: PP11,TU−Wien,Austria3x3
Heightinterval 15m to 20m
RMS_ass: 44 %
RMS_Com: 150 %
RMS_Om: 76 %
Participant: PP11,TU−Wien,Austria3x3
Heightinterval > 20m
RMS_ass: 82 %
RMS_Com: 144 %
RMS_Om: 22 %
Correctly assigned trees [%]
Study Area

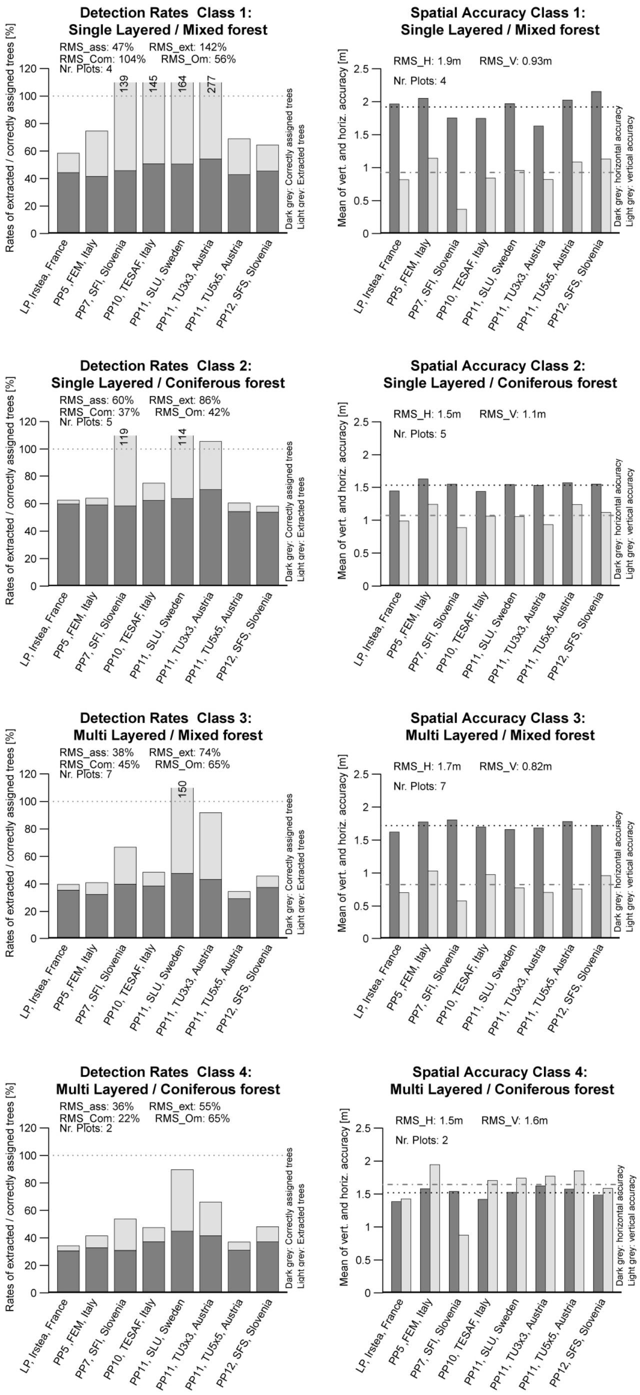



Matching Rates
Participant: PP11,TU−Wien,Austria5x5
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 41% RMS_extr: 52%
RMS_Com: 16%
RMS_Om: 63%
Rates of extracted / correctly assigned trees [%]
Study Area
Spatial Accuracy
Participant: PP11,TU−Wien,Austria5x5
Dark grey: horizontal
Light grey: vertical
RMS_H: 1.8 m
RMS_V: 1.1 m
Mean of vert. and horiz. accuracy [m]
Study Area
Participant: PP11,TU−Wien,Austria5x5
Heightinterval 2m to 5m
RMS_ass: 2 %
RMS_Com: 10 %
RMS_Om: 100 %
Participant: PP11,TU−Wien,Austria5x5
Heightinterval 5m to 10m
RMS_ass: 4 %
RMS_Com: 5 %
RMS_Om: 99 %
Participant: PP11,TU−Wien,Austria5x5
Heightinterval 10m to 15m
RMS_ass: 14 %
RMS_Com: 8 %
RMS_Om: 95 %
Participant: PP11,TU−Wien,Austria5x5
Heightinterval 15m to 20m
RMS_ass: 24 %
RMS_Com: 21 %
RMS_Om: 88 %
Participant: PP11,TU−Wien,Austria5x5
Heightinterval > 20m
RMS_ass: 66 %
RMS_Com: 22 %
RMS_Om: 37 %
Correctly assigned trees [%]
Study Area

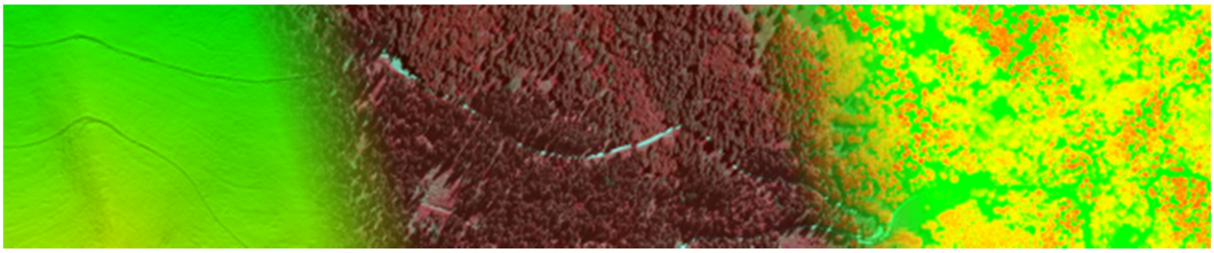

Matching Rates
Participant: PP12,SFS,Slovenia
Dark grey: Matched trees
Light grey: Extracted trees
RMS_ass: 44% RMS_extr: 54%
RMS_Com: 13%
RMS_Om: 59%
Rates of extracted / correctly assigned trees [%]
Study Area
Spatial Accuracy
Participant: PP12,SFS,Slovenia
Dark grey: horizontal
Light grey: vertical
RMS_H: 1.8 m
RMS_V: 1.1 m
Mean of vert. and horiz. accuracy [m]
Study Area
Participant: PP12,SFS,Slovenia
Heightinterval 2m to 5m
RMS_ass: 2 %
RMS_Com: 42 %
RMS_Om: 100 %
Participant: PP12,SFS,Slovenia
Heightinterval 5m to 10m
RMS_ass: 9 %
RMS_Com: 10 %
RMS_Om: 98 %
Participant: PP12,SFS,Slovenia
Heightinterval 10m to 15m
RMS_ass: 16 %
RMS_Com: 16 %
RMS_Om: 93 %
Participant: PP12,SFS,Slovenia
Heightinterval 15m to 20m
RMS_ass: 40 %
RMS_Com: 35 %
RMS_Om: 80 %
Participant: PP12,SFS,Slovenia
Heightinterval > 20m
RMS_ass: 73 %
RMS_Com: 15 %
RMS_Om: 34 %
Correctly assigned trees [%]
Study Area



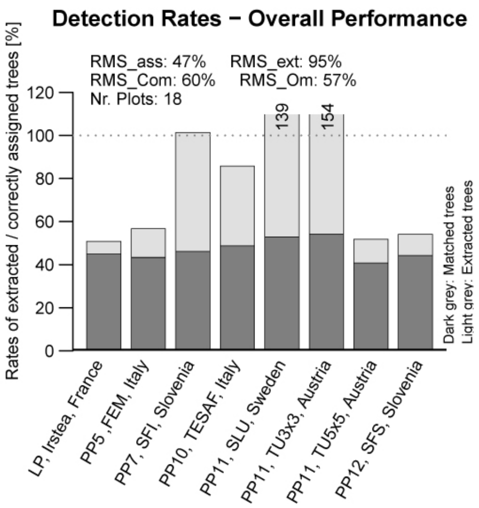
3.13.3 DETAILED MATCHING RESULTS PER FOREST TYPE

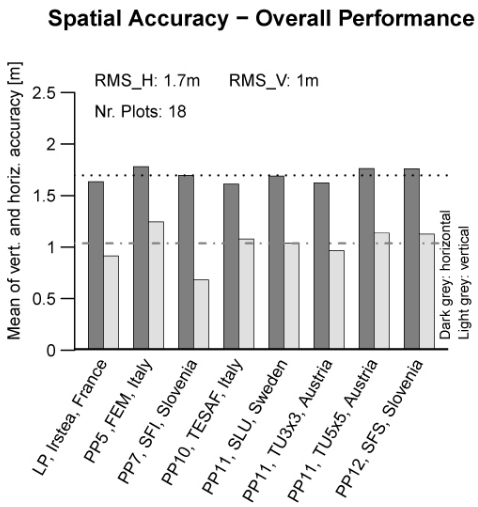


European Territorial Cooperation
Alpine SPACE
EU co-funded
NewFor



3.13.4 OVERALL PERFORMANCE OF MATCHING RESULTS





3.13.5 OVERVIEW STUDY AREAS

ID	Plot Name	Region	Country	PP	Mean Altitude	Approx. Tree Height	FI Acq.	ALS Acq.	Plot Description
1	Saint-Agnan	Rhône-Alpes	France	LP	1267	27	July, 2010	Sept., 2010	Irregular, mixed stand of silver fir and beech. 32° slope, prone to rockfalls. Medium Coverage.
2	Achenkirch	Ebenwald	Austria	PP1	1160	27	Sept. 2010	2008	Irregular, mixed stand of acer, beech, spruce and fir. Medium Coverage.
3	Brandberg	Zillertal	Austria	PP1	1322	42	Sept. 2010	2008	Old spruce stand. Dense Coverage.
4	Stans	Inntal	Austria	PP1	699	31	Sept. 2010	2008	Irregular, mixed stand of acer, beech, spruce, and pine. Dense Coverage.
5	Pellizzano 1	Trento Province	Italy	PP5	1468	35	Aug., 2013	Sept., 2012	Spruce pole forest with a very small presence of larix, fir and broadleaves (maple, poplar, willow, alder, and birch). Dense Coverage.
6	Pellizzano 5	Trento Province	Italy	PP5	1250	32	Aug., 2013	Sept., 2012	Mature larch forest with good presence of spruce wich overlay a younger layer of spruce, fir and poplar. Medium Coverage.
7	Altopiano di Asiago 22	Altop. di Asiago	Italy	PP10	1153	25	Oct., 2012	July, 2012	Norway spruce and silver fir forest. One layered vertical structure. Medium Coverage.
8	Altopiano di Asiago 26	Altop. di Asiago	Italy	PP10	1247	28	Oct., 2012	July, 2012	Norway spruce, silver fir forest and beech mixed forest. Multi-layered vertical structure. Beech in dominant layer only. Medium Coverage.
9	Altopiano di Asiago 38	Altop. di Asiago	Italy	PP10	1172	17	Oct., 2012	July, 2012	Norway spruce, silver fir forest and beech mixed forest. Multi-layered vertical structure. Beech in both layers. Dense Coverage.
10	Cotolivier 2	Piedmont	Italy	PP9	1165	22	Nov., 2012	July, 2012	Stand of scots pine with some larch and spruce. Monolayer. Dense Coverage.
11	Cotolivier 9	Piedmont	Italy	PP9	1698	20	Oct., 2012	July, 2012	Stand of larch with some maple. Multi layered. Sparse Coverage
12	Cotolivier 10	Piedmont	Italy	PP9	1251	25	June, 2012	July, 2012	Stand of scots pine and larch. Monolayer. Medium Coverage.
13	Holzschopf	Montafon	Austria	PP3	1710	34	June, 2009	2011	Subalpine spruce forest on acid soils. Old-growth terminal developmental stages with young patches. Sparse Coverage.
14	Kilknerwald	Montafon	Austria	PP3	1139	29	June, 2009	2011	Old spruce stand. Dense Coverage.
15	Leskova dolina 76	Leskova dolina	Slovenia	PP7	866	30	Nov., 2008	Oct., 2009	The main tree species are silver fir, Norway spruce, and European beech, Sycamore and elm. Medium Coverage.
16	Leskova dolina 93	Leskova dolina	Slovenia	PP7	867	36	Nov., 2008	Oct., 2009	The main tree species are silver fir, Norway spruce, and European beech, Sycamore and elm. Medium Coverage.
17	Leskova dolina 142	Leskova dolina	Slovenia	PP7	872	26	Nov., 2008	Oct., 2009	The main tree species are silver fir, Norway spruce, and European beech, Sycamore and elm. Dense Coverage. Multi Layered.
18	Leskova dolina 150	Leskova dolina	Slovenia	PP7	868	33	Nov., 2008	Oct., 2009	The main tree species are silver fir, Norway spruce, and European beech, Sycamore and elm. Dense Coverage. Multi Layered.
19	Begunjščica 9	Gorenjska	Slovenia	PP12	1017	34	June, 2008	2007	Old spruce stand. Dense Coverage. One Layer.
20	Jura 37865	Berner Jura	Switzerland	PP13	853	36			Spruce and fir stand. Medium Coverage. Multi Layered.
21	Jura 32353	Berner Jura	Switzerland	PP13	825	36			Old Spruce and fir stand. Dense Coverage. Single Layered.