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International consortium of geo-scientists, land use planners, forest engineers and computer experts

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Computer Automated Detection and Measurement of Single Trees and Forest Inventory Parameters using Satellite and Airborne Colour Infrared Photos (CIR) and Laser Scanning Systems (LiDAR).

A digital version in print quality can be downloaded from http://landConsult.de/segmentation/download

At landConsult.de we specialize in processing digital aerial and satellite imagery of forest stands. These days the classical image processing methodology has been amended by new ways to analyse Airborne Laser Scanning data and High Resolution Imagery.
We developed an algorithm to identify single trees from colour infrared and high resolution airborne (e.g. Vexel UltraCam) or satellite (Quickbird, Ikonos) imagery. The program generates a shape file (GIS) representing the area and centroid of the detected tree crowns, including the tree height if a surface model is available. The tree height is processed from Laser Scanning (LIDAR) data or photogrammetrically from aerial or satellite (e.g. CartoSat) stereo models.

In addition landConsult and its partners, the University of Freiburg and Cracow, are permanently improving existing methodologies to filter and process huge laser point clouds to automatically measure all laser-represented objects, such as the forest road network, forest stands or single trees. By means of scientifically proven correlations between the number of stems per ha, the crown area and the tree height, the standing stock volume can be assessed. The discrimination of different tree species is being done by a combination of image and LiDAR processing.

Our Service:

Geographical recording (x/y-coordinates) of all dominant and visible sub-dominant trees from aerial imagery and LiDAR or from space (Quickbird).

Calculation of tree height (z-coordinate) of all detected trees.

Visualisation and classification (species, height, density) of all detected trees in a GIS (point shape file).

Classification of forest stands in terms of common features such as vertical and horizontal stand structure, stand density, crown closure, mean stand height, highest trees in a stand, and distribution of tree species.

Assessment of standing stock volume per hectare and per tree species, calculation of single tree volume.

Generation of a high resolution terrain model representing slope, aspect and hidden geo-morphological features covered by vegetation (e.g. ditches, rocks, death wood, etc.).

Automatic detection and classification of roads, logging- and temporary tending lines.

Design of a reliable and cost effective Forest Monitoring System based on Satellite data.

Presentation of results in an Orthophoto Map and GIS, if required with authorised access on a web based system (GIS MapServer or GoogleEarth).

Annex: Figures

Example: Single Tree Detection from Satellite Imagery - <u>Counting Trees from Space</u>

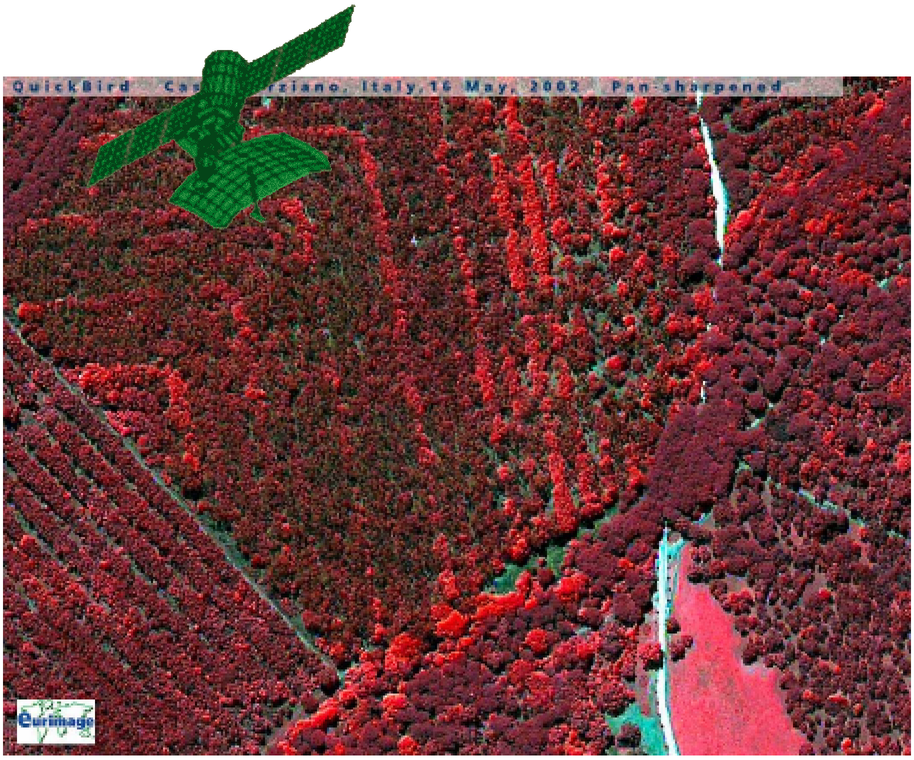


Fig. 1:

Quickbird Satellite Scene of a forested area. Ground resolution ca. 60 cm.

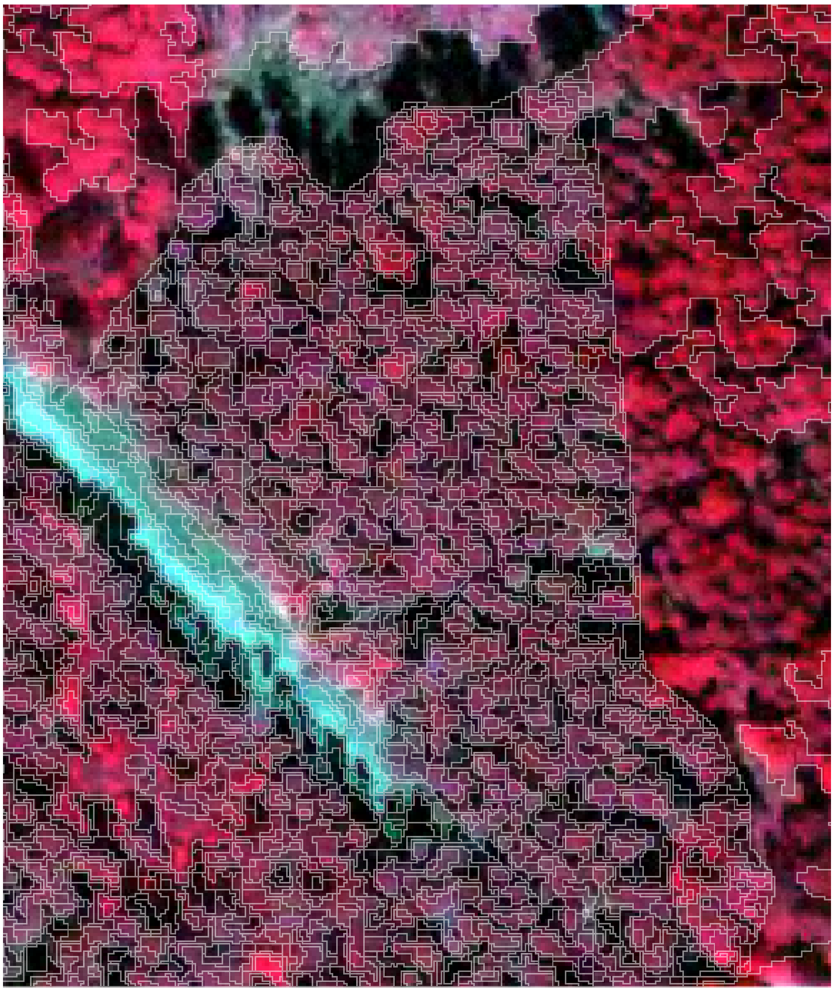


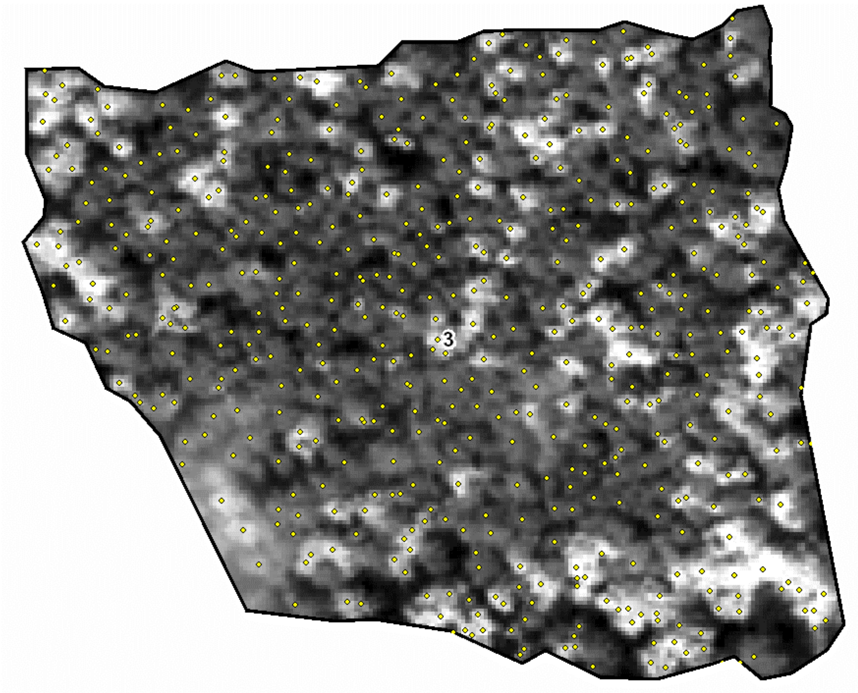
Fig. 2:

Automatic Single Tree Detection on Quickbird Satellite imagery by means of Object Based Image Segmentation (OBIA) with Definiens Developer Software.

<u>Counting Trees from Space</u>

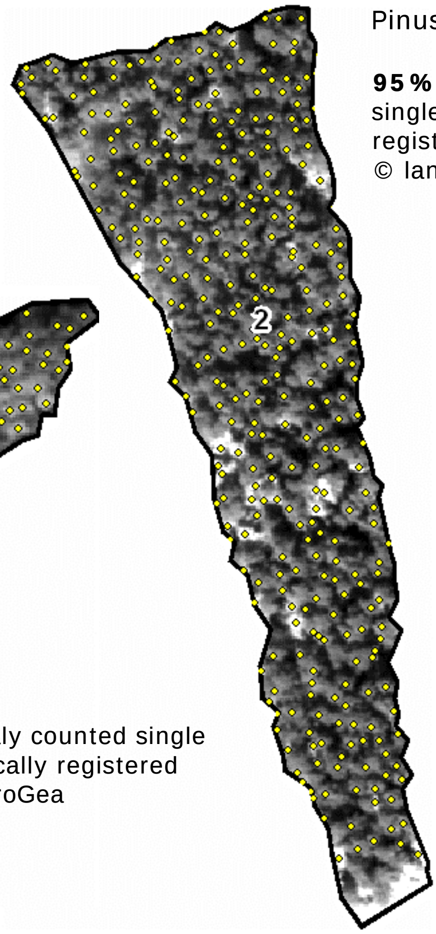
Automatic Single Tree Detection in a Quickbird Satellite Scene (OBIA, Definiens Developer)

Yellow points show recognized crown centres using the automatic OBIA method on the 1e Principal Component of a QuickBird image



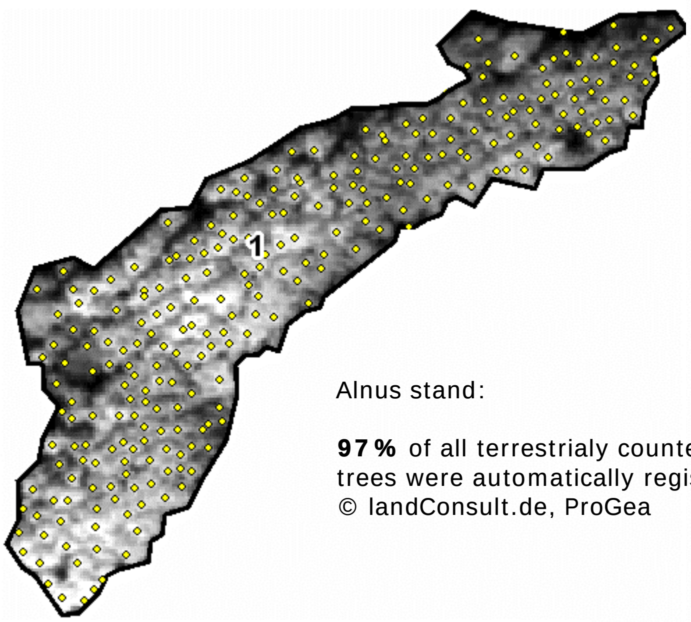
Mixed Pinus / Oak Stand:

92% of all terrestrialy counted single trees were automatically registered



Pinus Stand:

95% of all terrestrialy counted single trees were automatically registered



Alnus stand:

97% of all terrestrialy counted single trees were automatically registered

Example: Processing LiDAR and Color Infrared Aerial Photographs

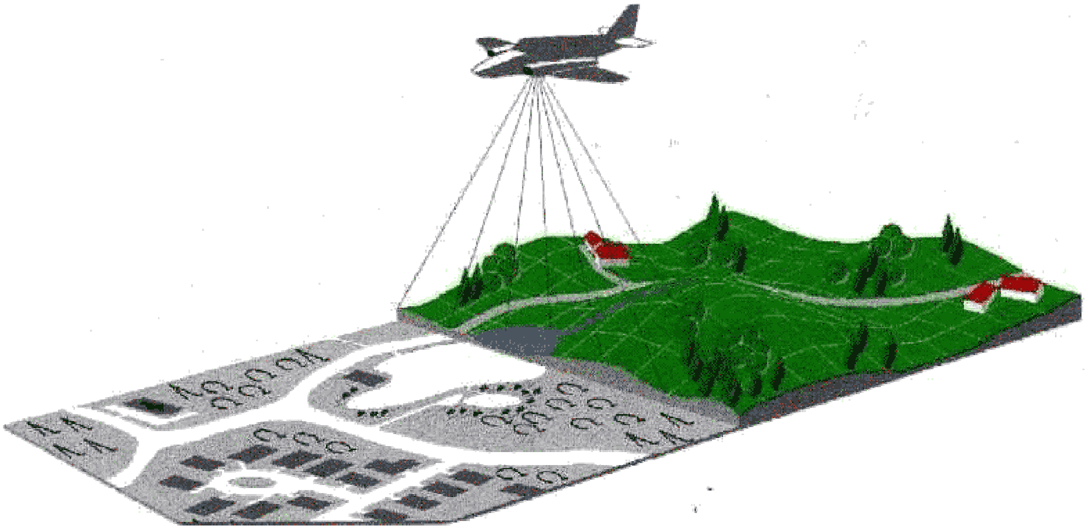


Fig. 6: Scanning the surface to produce height points and color infrared images (processed as true-orthophotos). © TopoSys.

Fig. 7: The terrain model (grey rectangle) generated from the raw LiDAR point data shows hidden structures under the forest cover (green background area). © TopoSys, landConsult.de.

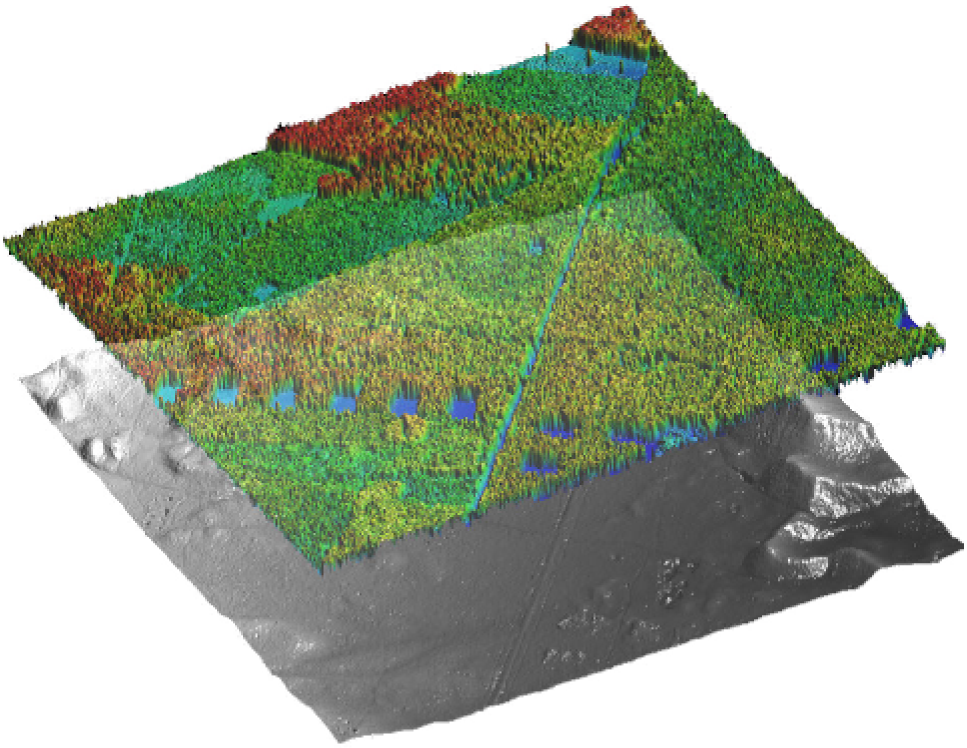


Fig. 8: Processing of surface- and terrain model from LiDAR point cloud. The normalized Surface Model (nDSM) representing the crowns and the tree is the result from the subtraction of the Terrain Model from the Surface Model.

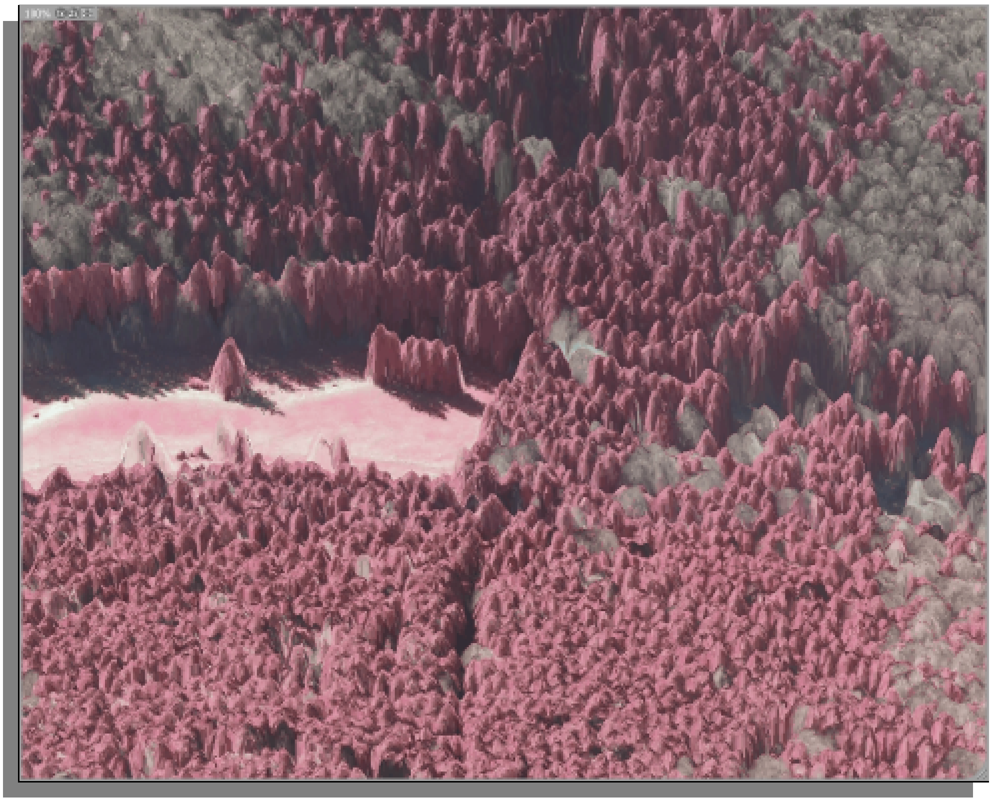


Fig. 9: Overlaying the nDSM with the CIR Data results in a three dimensional and measurable forest model. The photo is taken end of April, hence the chlorophyll activity of the conifers is shown in red, leafless broadleaf trees are grey.

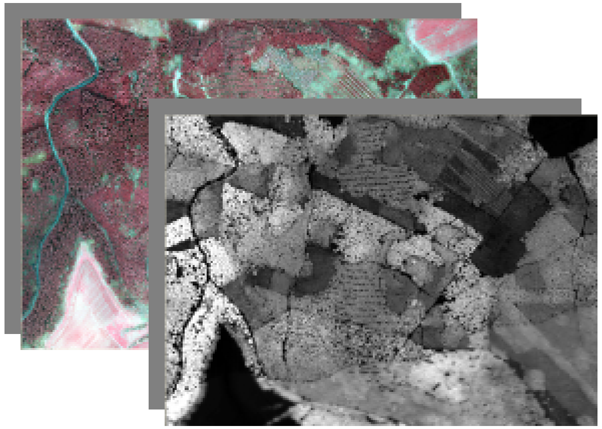


Fig. A1: CIR 8 bit, 0.5 m ground resolution, winter scene (background) and nDSM (front)

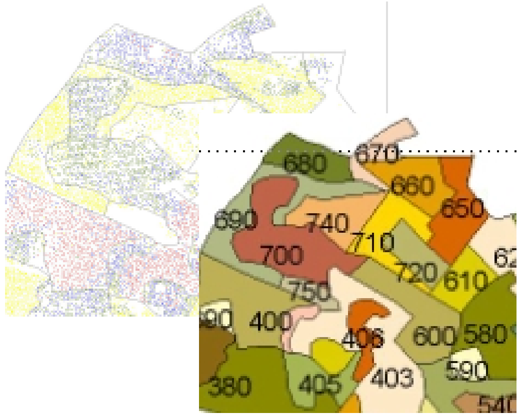


Fig. A2: Detected and height classified trees in the back, semi-automated stand delineation in the front

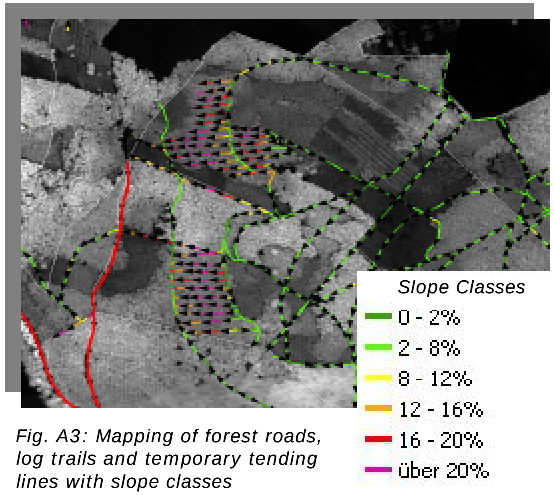


Fig. A3: Mapping of forest roads, log trails and temporary tending lines with slope classes

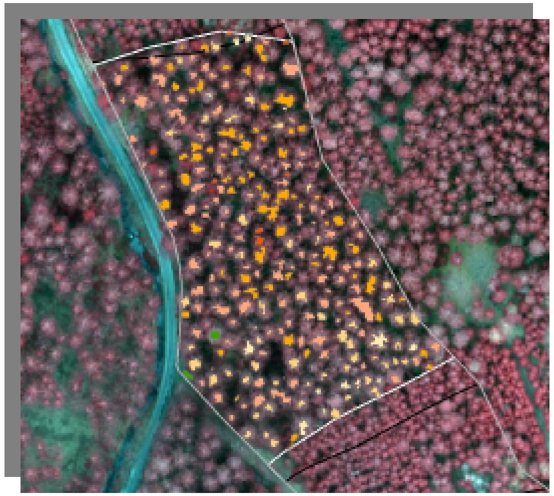


Fig. B1 Crown Centroids with different colours for different chlorophyll activity (NDVI Value)

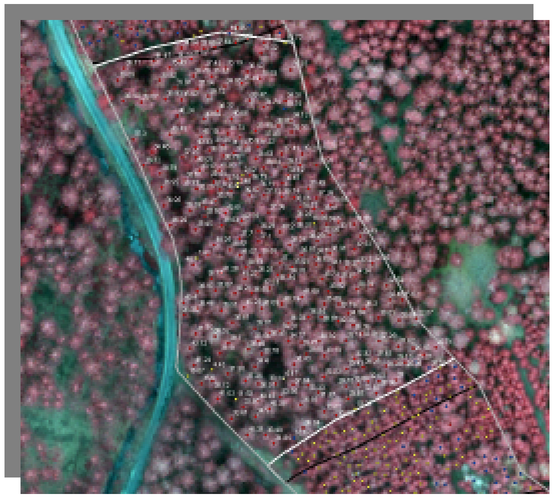


Fig. B2: Trees labeled with tree height

Fig. B3: Trees labeled with tree volume

Example on assessing the stand volume as the sum of individual tree volumes. This approach is practicable in even aged stands. Fig. B1 shows single tree crowns and tree tops detected by the OBIA method. In Fig. B2 each tree top is labeled with the tree height in meter derived from the nDSM. The numbers in Fig. B3 indicate the individual tree volume in cbm as a result of the calculation based on the tree height and certain assumptions on the ratio between tree height and stem diameter (BHD).

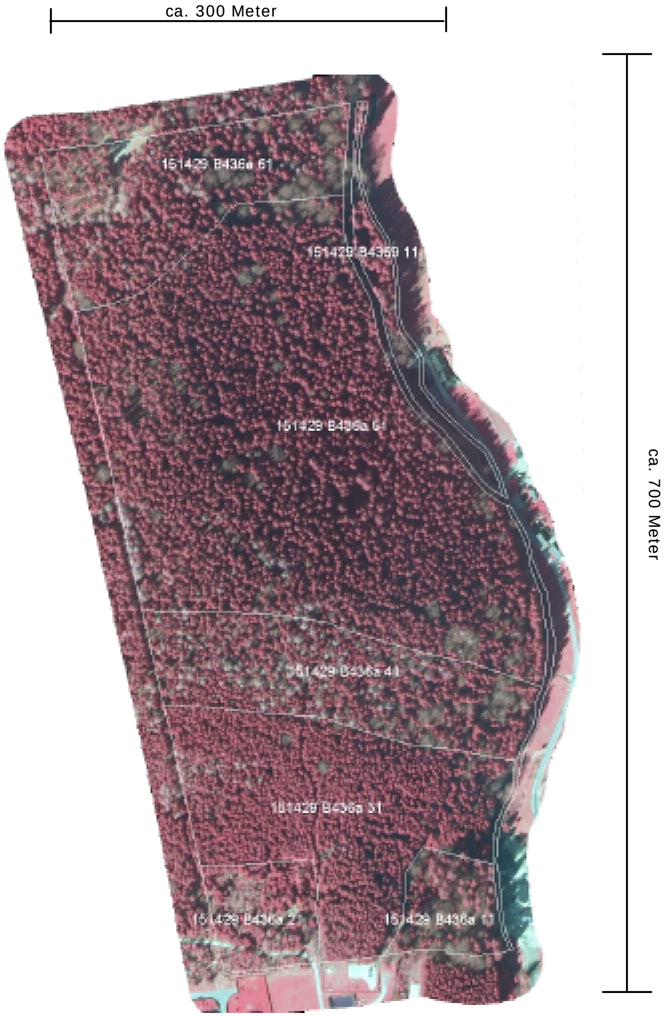


Fig. D1: CIR Mosaic showing the different stands in a 21 hectare small compartment within the 250 ha big test site.

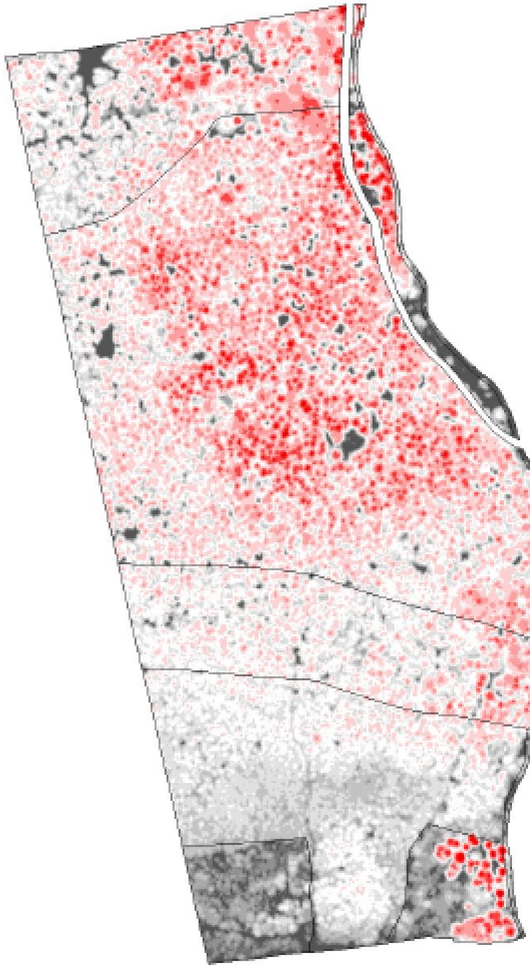


Fig. D2: nDSM created from LiDAR data with ca. 1.4 points per sqm. Red areas are high values representing the biggest trees, white spots are medium high, dark gray and black pixel represent the bare ground.

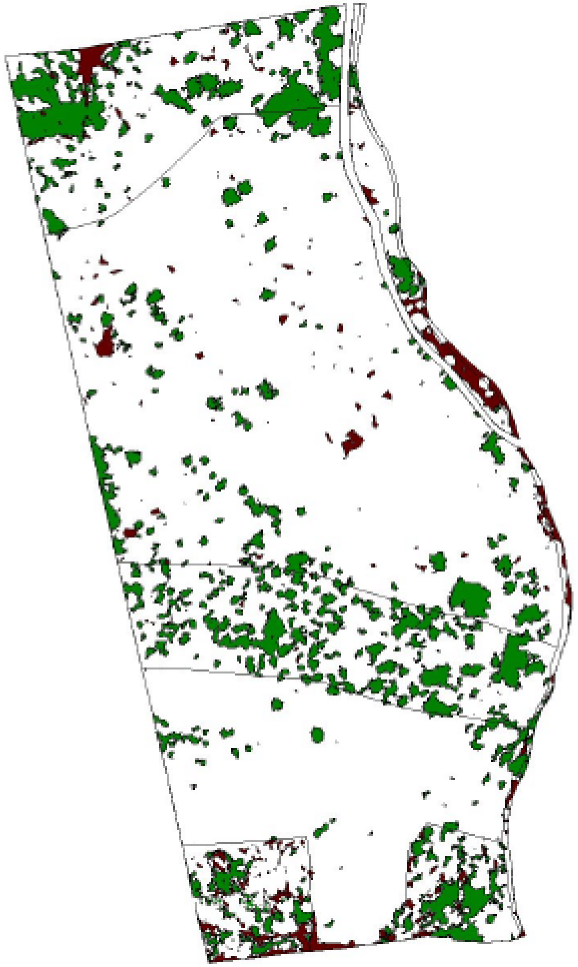


Fig. D3: Areas with deciduous trees (green spots) derived from the CIR information and openings (brown spots) processed from the nDSM data (pixels below 2m).

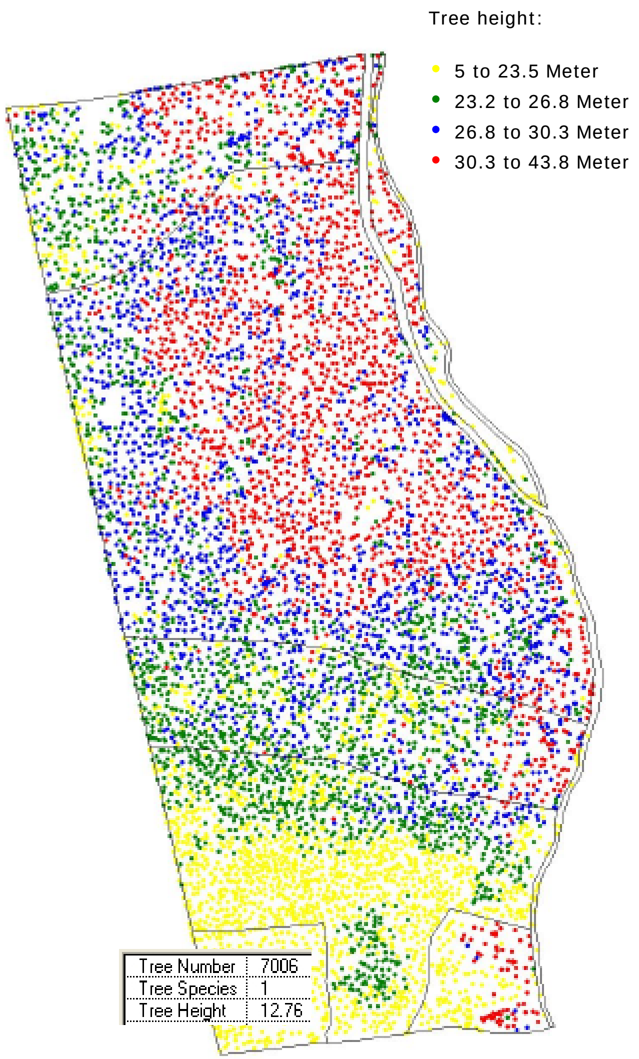


Fig. D4: Individual tree tops and tree height after processing the nDSM with a *local maxima* algorithm. From the individual tree heights, the mean average height of all trees and the maximum height of the hundred highest trees per ha and per stand will be calculated.

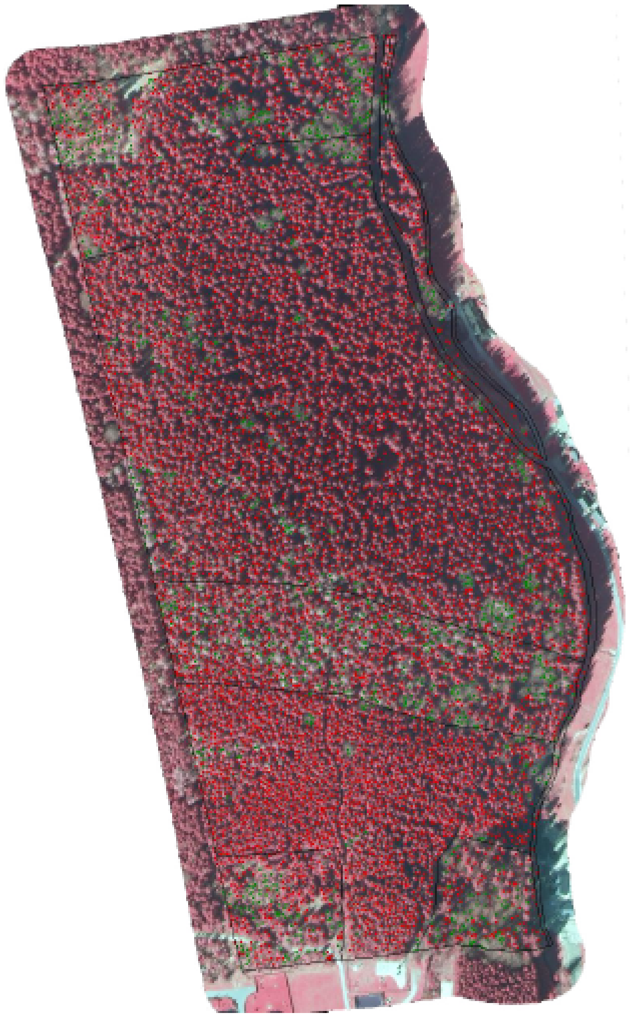
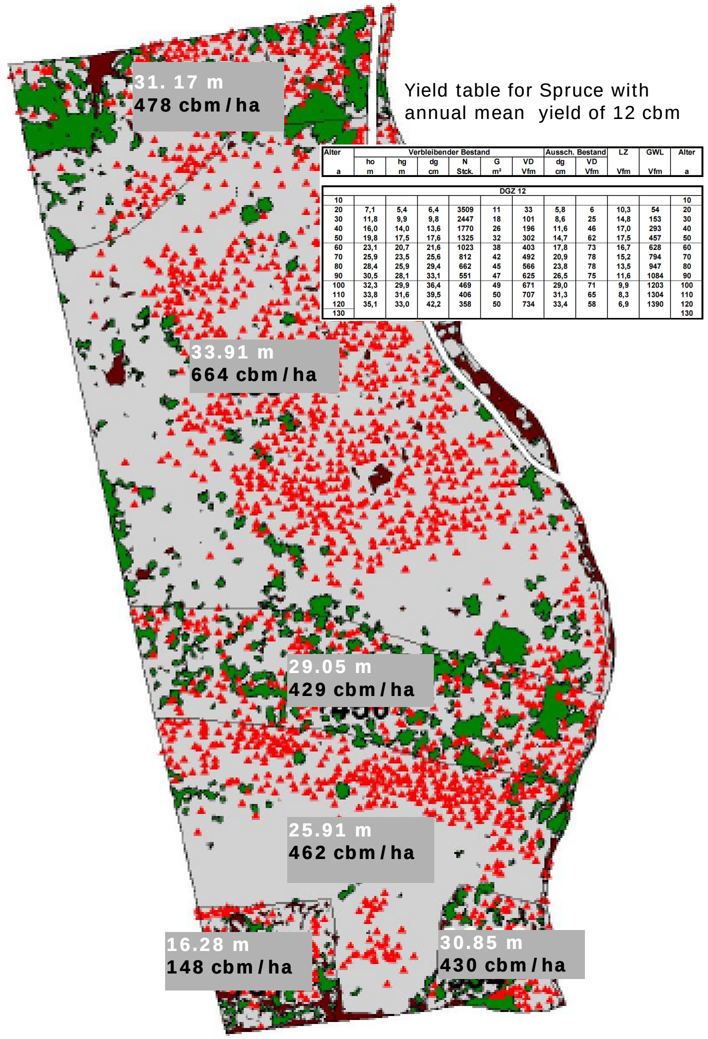


Fig. D5: CIR Mosaic with individual trees (red dots are conifers, green dots are broadleaf trees).



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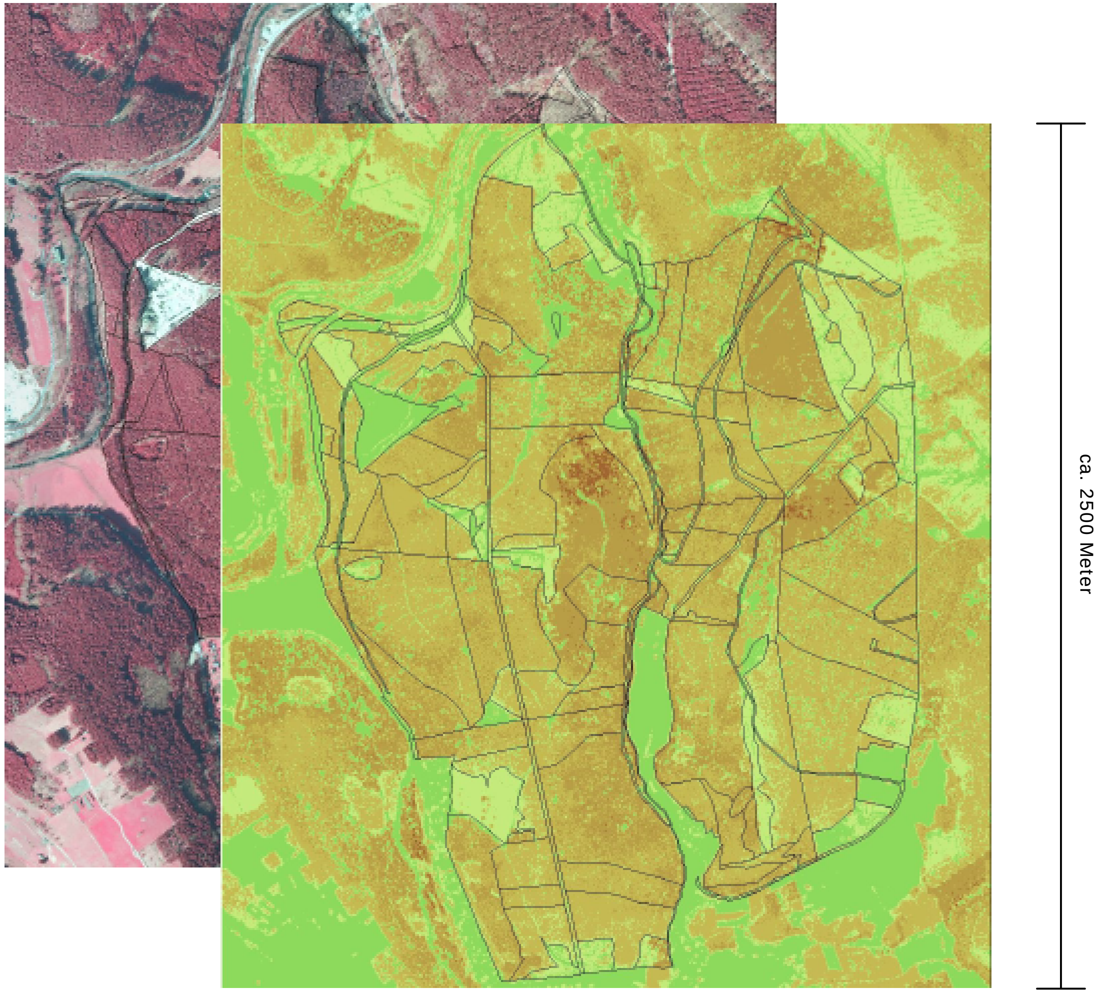
	ho	hg	dg	N	G	VD	dg	VD			
a	m	m	cm	Stck.	m²	Vfm	cm	Vfm	Vfm	Vfm	a
DGZ 12											
10											10
20	7,1	5,4	6,4	3509	11	33	5,8	6	10,3	54	20
30	11,8	9,9	9,8	2447	18	101	8,6	25	14,8	153	30
40	16,0	14,0	13,6	1770	26	196	11,6	46	17,0	293	40
50	19,8	17,5	17,6	1325	32	302	14,7	62	17,5	457	50
60	23,1	20,7	21,6	1023	38	403	17,8	73	16,7	628	60
70	25,9	23,5	25,6	812	42	492	20,9	78	15,2	794	70
80	28,4	25,9	29,4	662	45	566	23,8	78	13,5	947	80
90	30,5	28,1	33,1	551	47	625	26,5	75	11,6	1084	90
100	32,3	29,9	36,4	469	49	671	29,0	71	9,9	1203	100
110	33,8	31,6	39,5	406	50	707	31,3	65	8,3	1304	110
120	35,1	33,0	42,2	358	50	734	33,4	58	6,9	1390	120
130											130

Fig. D6: Map with the calculated conifer wood volume in solid cubic meter of standing crop per ha (cbm/ha, black numbers) and the mean height of the hundred highest conifer trees per ha (in meter, white numbers). The top 100 conifers are represented by the red triangles.

The calculation in Fig. D6 is based on regional yield models (see inserted table in Fig. D6), which are suitable to assess the wood volume and the productive capacity of a stand. The height of the hundred highest trees and the stand age are used to link the yield model to the stand situation on site. The calculation is considering tree species (broadleaf areas are green, areas with conifers are gray) and openings (brown spots).



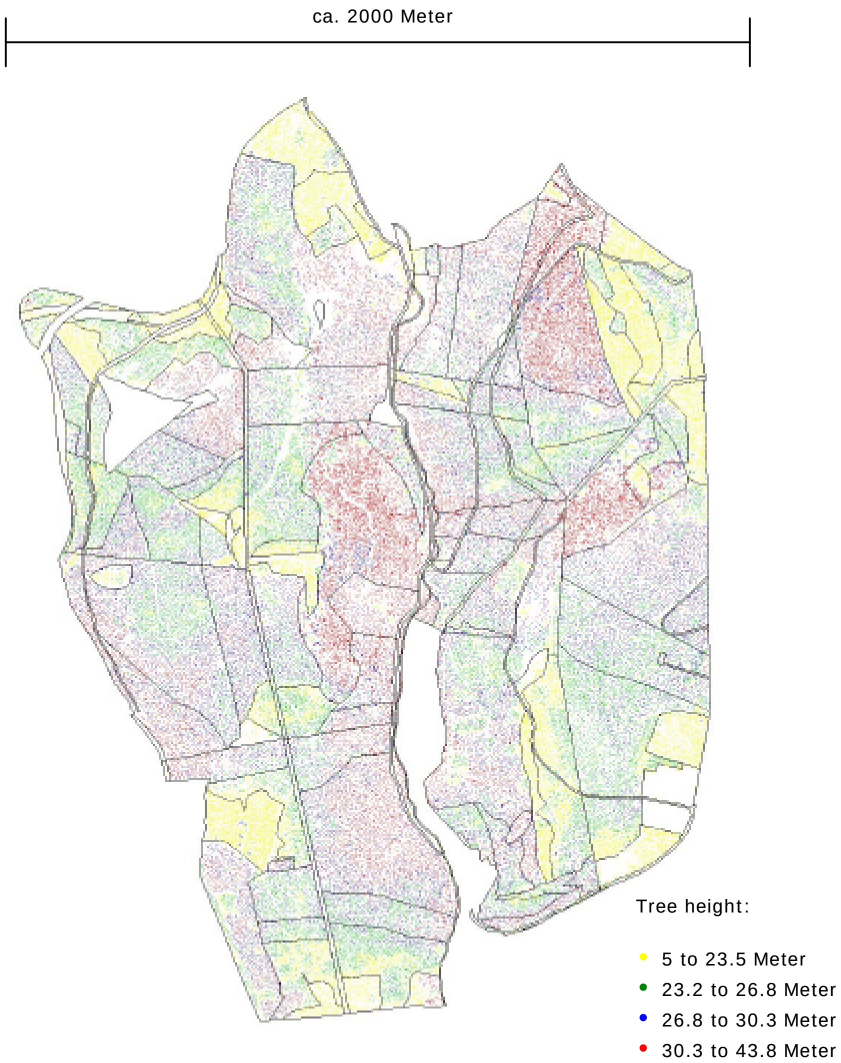


Fig. E1: Standard CIR Ortho Mosaic and LiDAR Data have been processed to assess the wood volume on some 250 ha mixed forests.

Fig. E2: Some 95.000 trees have been automatically detected, classified and height measured. The algorithm used is robust and suitable for processing several thousand hectares.

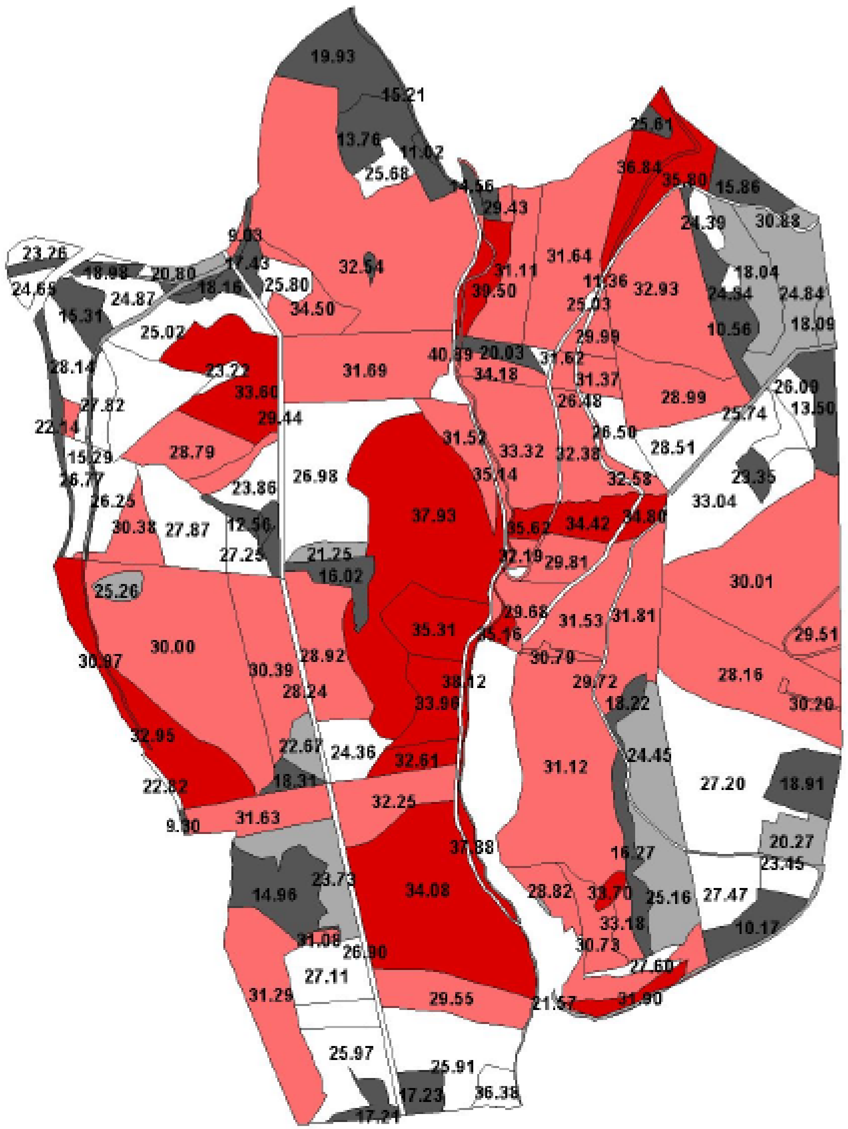


Fig. E3: The mean stand height and the top stand height have been calculated.
On the map the height of the top 100 conifer trees per stand and hectare is indicated by the black numbers (in meter). The colours refer to the mean stand height in meter (dark grey: 5 to 14; grey: 14 - 20, white: 20 – 24; light red: 24 – 28; dark red: 28 – 35).

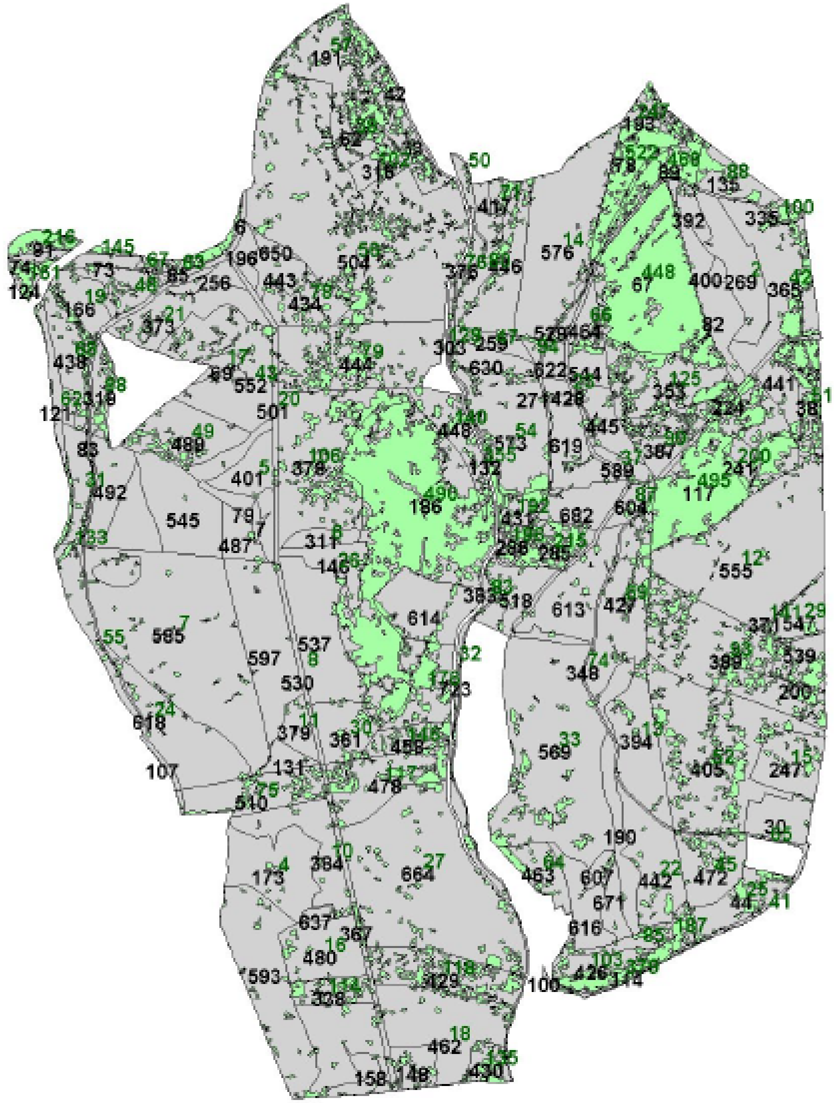


Fig. E4: By means of regional yield models the wood volume for conifer and broadleaf stands have been calculated (the numbers are indicating the standing stock volume for each stand in cbm/ha, black numbers = conifers, green numbers = broadleaf trees).
The percentage of areas with broadleaf (green spots), conifers (gray areas) and openings (black spots) has also been calculated for each stand.

Publications:

- landConsult.de (2007): http://landconsult.de/home/innovation, Work Demos
- Wezyk, P., de Kok, R., Szombara, S., Weidenbach, M., Zajaczkowski, G. (2007): Replacing Sample Plots Forest Inventory by whole Stand Measurements based on LiDAR and Orthophoto. Poster Presentation ForestSat Conference, Montpellier.
- De Kok, R., Wezyk, P. (2006): Process development and sequential image classification for automatic mapping using case studies in forestry. Proceedings of 3D Forestry Conference in Vienna.
- De Kok, R., Wezyk, P. (2005):Automatic Mapping of the Dynamics of Forest Succession on Abandonned Parcels in South Poland. Beitrag zur AGIT Symposium in Salzburg.
- Wezyk, P., de KoK, R., Zajaczkowski, G. (2005): The role of statistical and structural texture analysis in VHR image analysis for forest applications. A case study on Quickbird data in the Niepolomice Forest.
- Thies, M., Koch, B. Spiecker, H., Weinacker, H. (2004): Laser-Scanners for Forest and Landscape Assessment. Proceedings of NatScan Conference, Freiburg im Breisgau, Germany