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International consortium of geo-scientists, land use planners, forest engineers and GIS/RS experts

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(A) Technical Proposal for „3D Forest Inventory and Monitoring System“

The following proposal pursues a long-term strategy which delivers immediate results from the **LiDAR based 3D Forest Inventory** and which creates the option for an innovative and **satellite based Forest Monitoring System** at the same time.

The proposed methodological approach is mainly based on other similar projects we conducted in different regions throughout Europe (Black Forest mountain range in Baden-Wuerttemberg, Erzgebirge in Saxony, Ardennes mountain range in Luxembourg, Gorce National Park in Polish Carpathians, see also List of Relevant Projects in the Annex).

Proven algorithms and processing steps may need an adjustment and further development to meet the specific forest condition of the pilot area and finally to deliver the expected results. With respect to that unique situation on-site, we do not propose a solution from the shelf, but our experience and expertise to procure and process the most innovative geodata available to generate forest and stand parameters essential for a sustainable forest management.

Precise 3D Forest Inventory

3D Models

The biomass assessment is primarily based on a digital Crown Height Model (CHM or nDSM for normalised Digital Surface Model) and regional forest growth models and allometric formulas.

The modelling of the crown could be done photogrammetrically by stereo-matching of aerial photos or of stereo satellite imagery, such as Worldview-3, or it could be done with Fullwave Laserdata (LiDAR) recorded from an aircraft (Airborne Laser Scanning – ALS).

The advantage of ALS is the penetration of the laser beams through the canopy down to the ground. Such ground or bare earth points are important to model a representative Digital Elevation Model (DTM). In stereo photos (no matter if airborne or from satellite) the terrain under a dense forest canopy is hardly visible and the few visible points showing roads or openings, are usually not enough to process a representative DTM. But different from the forest ground, the canopy and the vegetation surface is fully visible in stereo imagery, hence aerial and satellite photos are well suited to process a representative Digital Surface Model (DSM).

The crown height, including the height of automatically detected individual trees is the result of the difference between the surface height, represented by the Digital Elevation Model (DSM) and the height of the terrain, given by the Digital Terrain Model (DTM).

That´s why in the beginning a LiDAR survey is essential to get a precise DTM and consequently an accurate Crown Height Model (CHM). But this detailed survey has to be done only once, updates of the CHM can be done later with spectral stereo data.

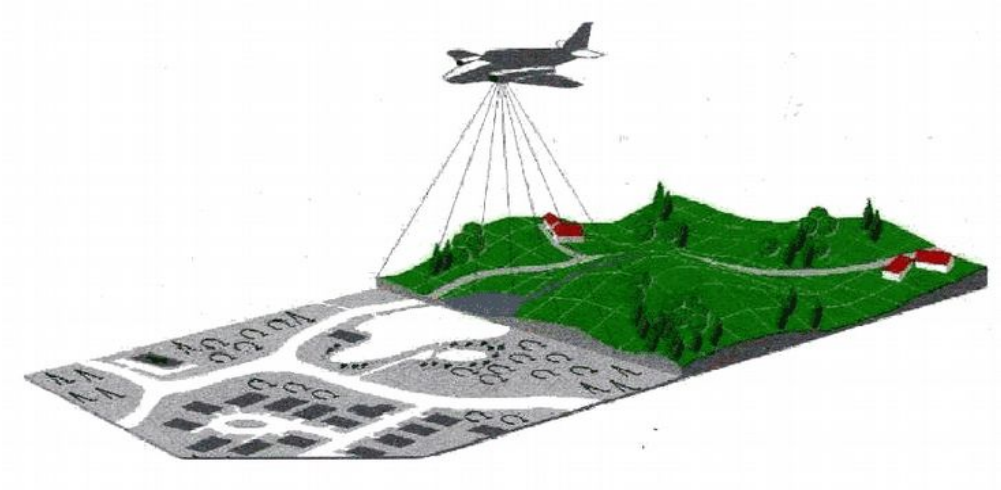


Fig. 1: Scanning the surface to produce height points and color infrared images. © TopoSys.

All three models, DSM, DTM and CHM, are being used for different purposes:

The DSM processed from LiDAR, aerial photos or satellite imagery represents the surface of the vegetation and buildings and their heights above sea level at the time when the data has been recorded. This information is needed to create TrueOrtho Photos, which show 3D Objects in an upright position.

Since the vegetation surface changes with every vegetation period or after any calamities or storm damages, the DSM (and also the CHM) is a permanently changing source of information, which should be update regularly or on demand after natural disasters (the forestal planning cycle of 5 and 10 year is a good regular time period for an update).

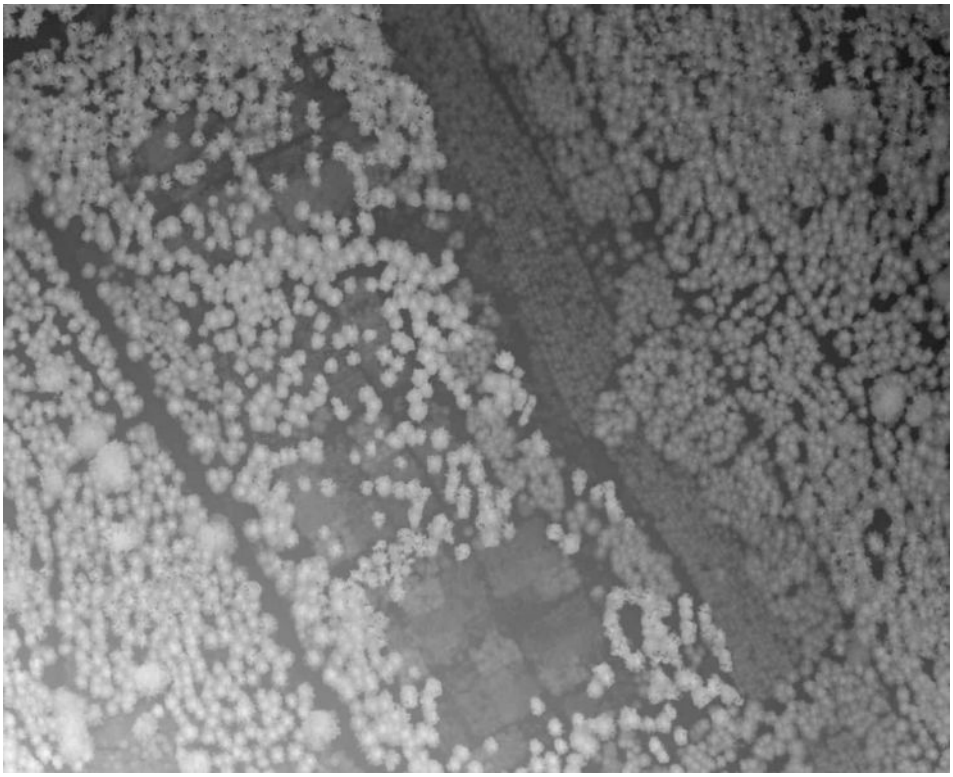


Fig. 2: DSM of forest stands, processed with LiDAR Fullwave data

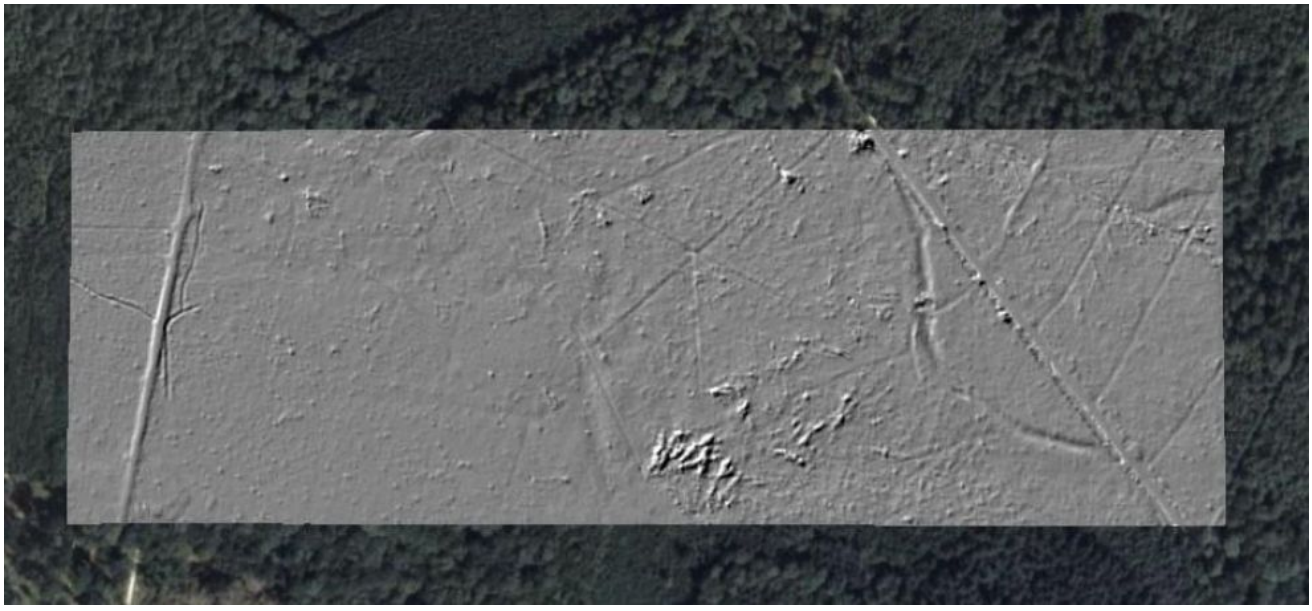


Fig. 3: DTM (grey rectangle) with Orthophoto in the background. Hidden features under the canopy become visible, such as roads and logging lines.

The information of **a DTM** is commonly used to orthorectify and create Orthophotos and to deliver all kind of terrain information. In a LiDAR DTM with 1m grid size you can map primary and secondary forest roads or even logging lines with high accuracy. DTMs are being used to calculate, Slope, Aspect, minimum and maximum sea level of a stand, Wetness, Erosion Risk, Windthrow Risk and many other terrain parameters. Therefore a

LiDAR DTM is a versatile source of information and a valuable investment for the future, because the forest terrain and the DTM normally remain unchanged for a relatively long period.

The **Crown Height Model (CHM)** represents the absolute height of the vegetation surface or the forest canopy. Since it is a product of DSM minus DTM, its accuracy mainly depends on the accuracy of both models and finally of the LiDAR device itself, whose relative height and position accuracy is normally better than +/- 15 cm. In general the LiDAR slightly underestimates the tree heights, because the first echo of the LiDAR beam is rather reflected by the highest branches than by the apical shoot or the top most leaf of a tree.

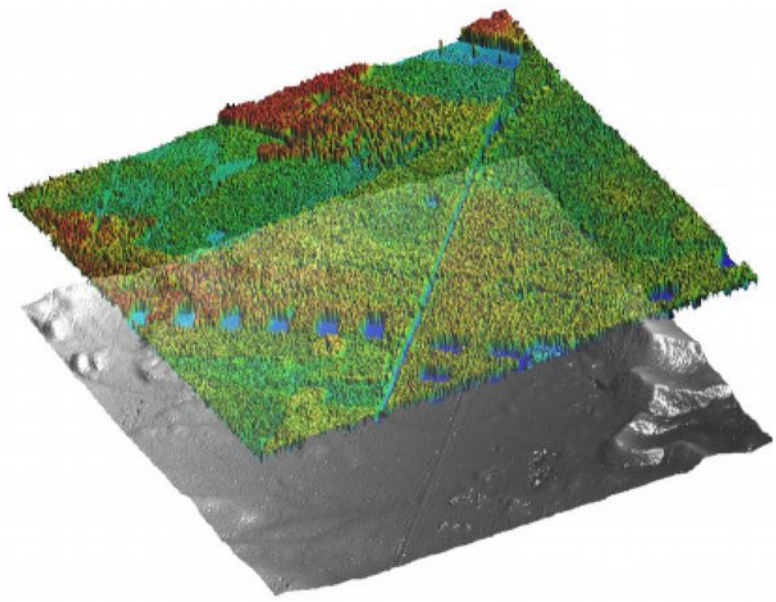


Fig. 4: A CHM with height colors in front of the DTM in grey shades.

The CHM is the source for most of the relevant forest parameters. It is being used to detect individual tree tops or individual shapes of crowns mainly in mature forest stands. It delivers numbers of trees per hectare or per sub-compartment to assess the stand density, top height of e.g. 200 biggest trees per hectare (a number often used for forest taxation) or the medium stand height and others. In older thinning or harvesting stands, the on-site DBH (diameter at breast height) measuring of detected trees, can be used to correlate the CHM height with the DBH to create a detailed DBH distribution and calculate the basal area and assess the biomass.

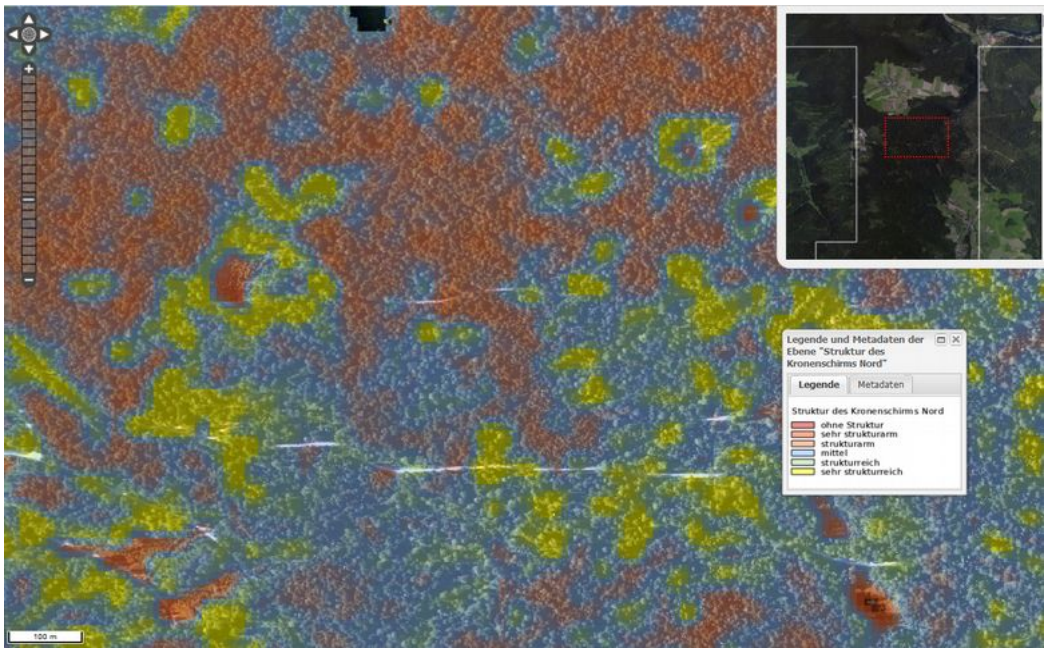


Fig. 5: Forest Structure Map generated from CHM showing areas with an open canopy (yellow) and a closed canopy (red).

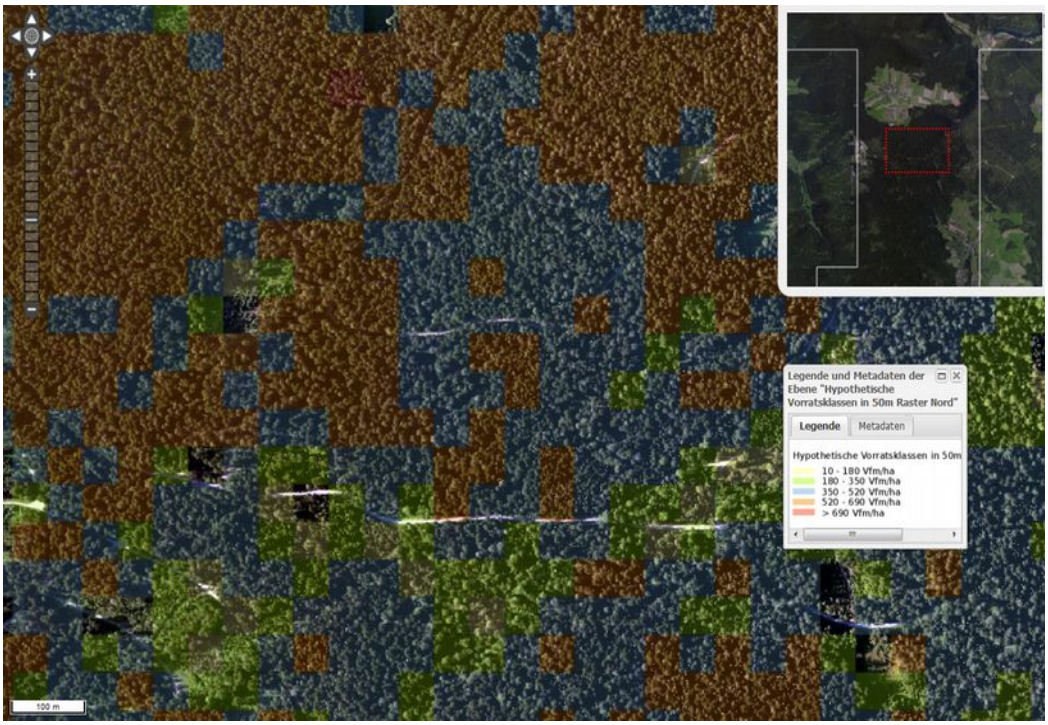


Fig. 6: Biomass Classification based on CHM and 3D Stereomodels in the Black Forest (red = more than 690 cbm/ha, blue = 350 - 520 cbm/ha, green 180 - 350 cbm/ha)

This process could be done on different levels: on sub-compartment or stand level, on an artificial raster (e.g. 50 m grid) over the whole forest in order to disregard the traditional stand borders (see fig. above) or on an individual tree level in mature stands.

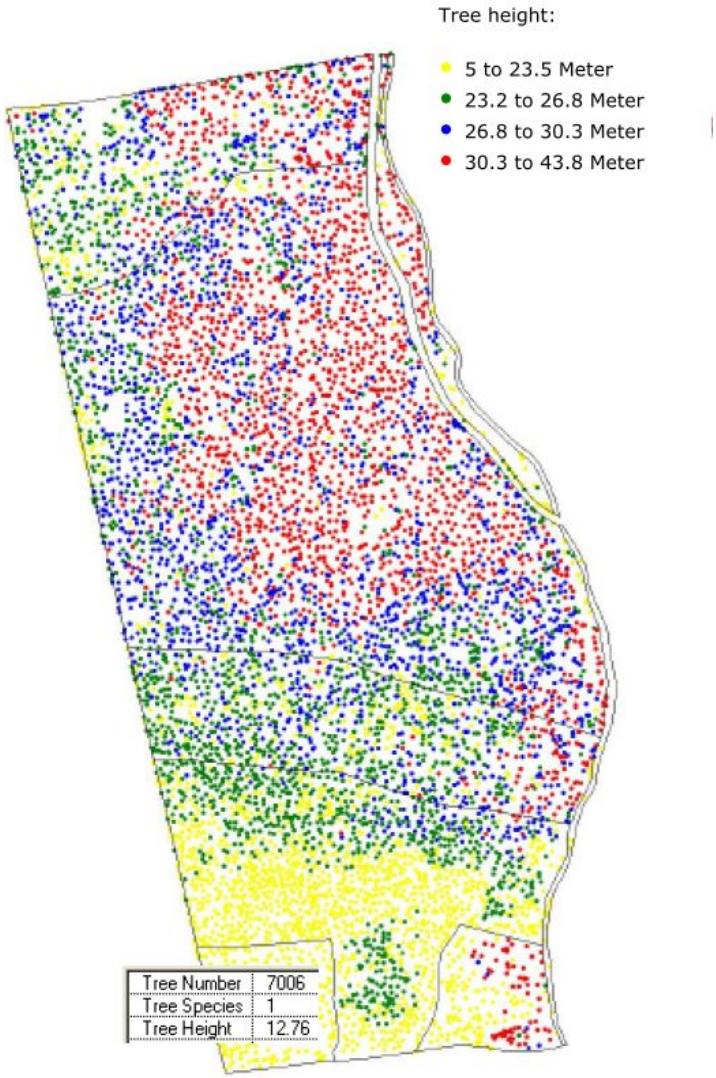


Fig. D4: Individual tree tops and tree height after processing the nDSM wit*local maxima* algorithm. From the individual tree heights, the mean averag height of all trees and the maximum height of the hundred highest trees pe ha and per stand will be calculated.

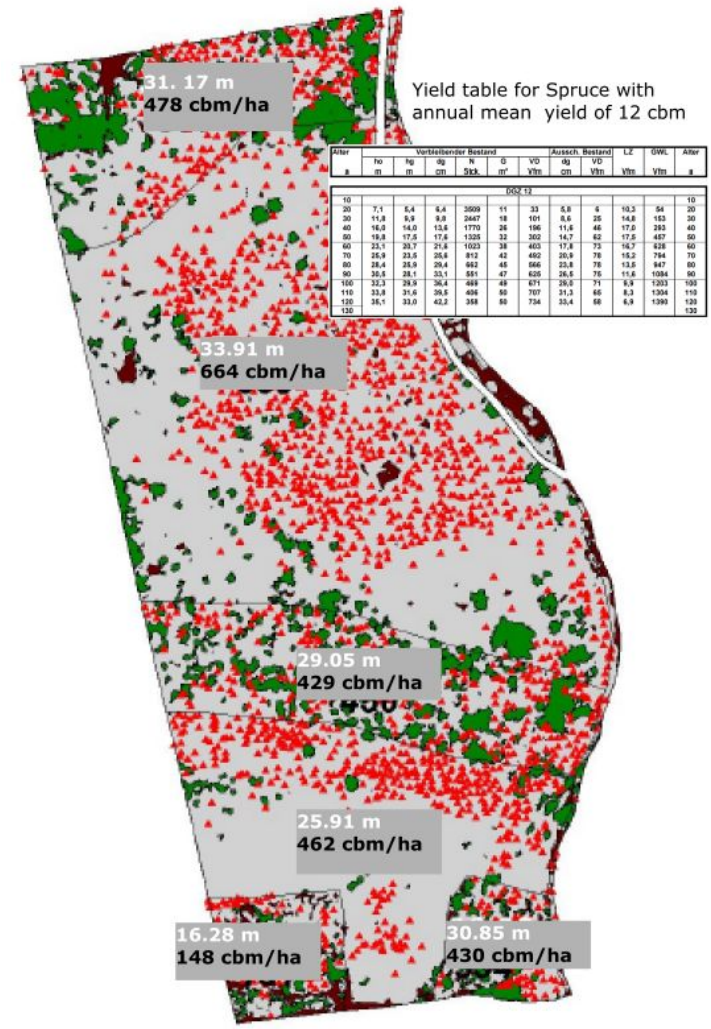


Fig. D6: Map with the calculated conifer wood volume in solid cubic meter of standing crop per ha (cbm/ha, black numbers) and the mean height of the hundred highest conifer trees per ha (in meter, white numbers). The top 100 conifers are represented by the red triangles.

Fig. 7: Individual tree tops, tree heights and wood volume assessment after processing the CHM.

The CHM is also a suitable dataset to measure forest openings, calculate the stocking density, and process the vertical forest structure (see fig. Above).

Further info on the web:

http://landconsult.de/segmentation/download/english_landconsult_LiDAR-CIR_en_feb08_V5_print.pdf

http://landconsult.de/icas08/

Fullwave Laserdata

Fullwave Laserdata are not only the source for the above mentioned models (in general processed from the first and last LiDAR echoes), the Laser point cloud also includes intermediate points reflected from branches and lower vegetation between tree top and ground. Such information can be used to map two-storied stands, natural re-generation or the volume and 3 D shape of individual crowns.

Multi-spectral and Multi-temporal image data

Multi-spectral and Multi-temporal image data is the most efficient source to map tree species, forest health and the forest structure, even more if you can add the height information to the spectral imagery.

We are proposing to use three data sets, namely the aerial photos, taken during the LiDAR survey, (b) the latest Worldview-3 imagery and (c) the latest Sentinel 2a imagery from ESA.

(a) the **aerial photos** will be provided by the company who is recording the LiDAR data. Shooting photos together with the LiDAR data, cost slightly more, but is an important supplement to document the flight and deliver spectral information that best matches to the LiDAR height information. Depending on the contracted survey company the orthophotos have a ground sample distance (GSD) of 9 or 15 cm.

(b) the **worldview-3 imagery** is an interesting option for forest types and health classification. The 8 multi-spectral bands with 1.2 m, and the Panchromatic channel with 30 cm ground resolution of the latest Worldview-3 sensor offer new possibilities for Feature Classification, Change Detection or in detail to map tree species and stand conditions by using different Normalized Difference Index Ratios, such as the NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), NDSI (Normalized Difference Soil Index). In particular the new Red Edge Band plays a significant role in vegetation analysis, because the ratio between Red and Red Edge responds much more sensitive on changes of the forest health than the ratio of the standard NDVI.

Another important advantage is the availability of stereo images of the 30 cm PAN band, which one can use to process a 3D model or satellite based Digital Surface Model (DSM). Such a high resolution DSM is a good way to respond to ongoing vegetation changes, because in combination with the LiDAR DTM you can produce a precise CHM representing the canopy height at the date of the recording. No future and expensive LiDAR survey is needed to update the DSM and CHM.

Such "3D satellite models on demand" could be the backbone of a long-term Forest Monitoring System to survey forest conditions in a precise and efficient way, just by updating your 3D Crown Height Models with actual satellite imagery (the WV3 sensors has an estimated Service Life of 10 to 12 years and its successor, WV4, shall be launched mid 2016).

Since the worldview 3 imagery is also an option to improve the image classification and the results of the basic LiDAR/RGB data analysis, in co-operation with our partners, we can provide Worldview-3 data (archived 30 cm PAN band plus 1,2 m MS bands) for a 25 square kilometre big test area as shown in the following figure, for no extra costs and good enough to demonstrate the suitability of the WV3 data.

Currently the official prices for 1 sqkm (100 ha) of WV3 data, including the 30 cm PAN and the 1.2 m MS bands) range from 24 US$ (archived imagery, minimum order area is 25 sqm) to 34 US$ (for contracting out new imagery, min. order area is 100 sqkm). Please note that the generation of the 3D surface model requires the 30 cm PAN band of two WV3 images (forward and backward).

The average revisit frequency of the WV3 sensor at 40 degree north is < 1 day, and so providing a good chance to get could free images from your forests on time.

More info on WV3 are online at:

https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/worldview-3

(c) **the Sentinel 2a** satellite was launched on 23 June 2015 as one of 7 satellites of the ESA Sentinel campaign with a multi-spectral imager (MSI) on board covering 13 spectral bands (443 nm–2190 nm) with a swath width of 290 km and spatial resolutions of 10 m (4 visible and near-infrared bands), 20 m (6 red-edge/shortwave-infrared bands) and 60 m (3 atmospheric correction bands). Its life cycle is > 7 years.

The download of the Sentinel 2a Level 1 data from ESA is free and due to its short revisiting time of 5 days, there is a high probability of getting cloud free imagery throughout the year. This multi-temporal data shall be used as auxiliary data only, to analyse the different vegetation conditions of all four seasons and so to support the classification of the forest area. And Sentinel-2 can also deliver information for emergency services.

Development and application of local growth models

The application of existing and the development of new allometric formulas and local growth models are necessary for the final biomass assessment. Compared to the traditional approach to measure the DBH and some tree heights from the ground to derive a representative DBH/Height relation, the 3D LiDAR methodology means a total change of that paradigm: now we are able to measure tree heights with very high accuracy and a high degree of completeness, but without being able to measure the DBH at the same time. That´s why the DBH and the basal area must be derived from the parameters we got from the LiDAR/Imagery analysis, primarily from the information in the Crown Height Model.

This approach may also require a field campaign to measure some parameters on-site (ground-truth). For such work and for the necessary expertise in forest modelling we can rely on our local partners on site.

3D Forest Monitoring System

We propose to use the WorldView-3 Stereo Satellite Imagery as the backbone of the proposed Monitoring System, in particular as a precise height information of the crown canopy changing over time. The future processing of DSM's, crown models and biomass assessment from Satellite Imagery within a time interval of every 5 to 10 years is an economical way for a long-term observation system. At the same time this approach also works as a risk assessment and quick response facility in case of natural hazards or calamities.

Contracting out the LiDAR/RGB survey

This is an option, if no updated geodata is available. A clear description of the technical specifications is important and there are two minimum requirements:

(a) The LiDAR point density shall be good enough to accurately represent the ground under a broadleaved forest canopy in summer.

(b) In addition to the LiDAR point cloud, RGB or RGB with NIR band photos shall be taken.

In order to represent the forest terrain under a dense broadleaved canopy in summer, a laser point density of 9 pts and better is recommended.

To achieve this density a low flight altitude is necessary and in case a digital camera is on board at the same time, the photo resolution will also become very detailed.

There are different technical options, such as planning two LiDAR flights, each with < 9pts/m^2 to achieve 18 pts/m^2 in total and to fly the camera separately from the LiDAR sensor on a higher altitude. A LiDAR flight in April (leaf-off situation with no snow on the ground) is also an option to get a good DTM with a density of < 9pts/m^2 on one LiDAR flight.

All such technical details must be considered in your time planning and shall be discussed with the selected LiDAR company again in time.

It is advisable that you contract the LiDAR Survey directly in order to become the legal owner of the data.

From our experience it's very critical to use a qualified contractor to make sure the optimum quality of data is being obtained and delivered on time. All other project activities depend on that data and therefore we recommend to assess also the companies' reputation and experience and not only the price.

For instance, an economical option could be to procure 9 pts/m^2 LiDAR data (on flight with leaf-on summer conditions) without aerial photos but instead combine the LiDAR data with a new WV3 imagery.

Existing LiDAR Data

Often there are official LiDAR data and aerial photographs available from other public projects. In some regions of Europe and the U.S. such data is even freely available.

Such data might be a good opportunity to demonstrate the processing of a Crown Height Model and the biomass assessment without the need to procure new LiDAR data.

Alternative sources of DTMs

DTMs generated photogrammetrically from Aerial Photos or from the Worldview 3 Stereo Imagery, both with a resolution of 30 cm and better or from analogue stereo-photos – once used to map the isolines in the Topographical Map 1:25.000 (and now available as a 10 m DTM) - deliver comparable results on open terrain. But the accuracy of such a DTM covered with forests depends very much on the visibility of the ground under a dense forest canopy in the stereo-photo. And in general it is not comparable to a Laser DTM.

Another alternative would be the NextMap DTM10 model, generated from an airborne Radar Sensor, but again, the accuracy of forested areas is uncertain. The price for a 400 sqkm big area is 1200 €.

Other free sources such as the SRTM (Radar Mission of Space Shuttle 2003) or ASTER (spectral satellite sensor) DEMs with a resolution of 25 – 30 m are representing the vegetation and man-made surface and not the ground, they are good for analysis on a large scale, but not suitable to map forest heights on a detailed level.

Data Management

The detailed LiDAR data provides the base for a "Precise 3D Forest Inventory" and is the reference data for the satellite based "3D Forest Monitoring System". The products generated from it are maps in all scales and databases with relevant geo- and forest information, needed for an operational and sustainable forest management.

All information (tree and stand heights, tree species and tree distribution, vertical and horizontal forest structure, forest roads and/or logging lines, slope and aspect, wetness or

wind throw risk, etc.) and all datasets are stored in standardised OGC compatible formats, such as GeoTiff, Shape or LAS. Upon request we are also addressing other formats or databases operated by the customer.

The results from that process can be held in all GIS - or for a more flexible and mobile usage - also in a WebGIS such as http://3dgis.landconsult.de. With this WebClient Application you can print PDF maps of all sites of interest, e.g. in a 1:10.000 scale or even in 1:2.500, such as those demo maps which you can open from http://3dgis.landconsult.de.

The WebClient is just another User Interface on the Internet, more important is the Server Technology behind it, providing Web Mapping Services (WMS), Web Feature Services (WFS), Web Coverage Service (WCS) and others. The server streams the data to different devices, such as your ArcGIS software on your desktop or any other app on your smart phone or tablet.

If you are interested in such a service, we propose to use our landConsult´s QGIS Server running in one of the most modern data centres of Europe in Strasbourg.

(B) Typical offer for 3D Forest Inventory and Monitoring System

Pos.	Service	Amount in € (net)
1	Support and advice to select the best company for the LiDAR/RGBI survey of the Pilot Area. Discuss and plan the project in detail with your responsible staff (expected results, accuracy, time frame, field work, etc.).	
2	Pre-processing of the LiDAR point cloud and RGBI images to generate and analyse DTM, DSM and Crown Height Model (CHM) Processing of a high resolution terrain model representing slope, aspect and hidden geo-morphological features covered by vegetation, such as roads, logging- and temporary tending lines, erosion gullys, ditches, rocks, lying dead wood. Geographical recording (x/y-coordinates) of all dominant and visible sub-dominant trees from LiDAR and aerial or Worldview-3 imagery. 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). Mapping of forest openings and classification of forest stands or sub-compartments in terms of common features such as stand structure, stand density, crown closure, mean stand height, or distribution of tree species. Assessment of biomass (standing stock volume per hectare and per tree species). Optional: manual editing of existing sub-compartment or stand borders to adjust them to the detected trees and height information of the CHM and to improve statistical accuracy of stand analysis.	
3	Optional: Object Based Image Processing of Worldview 3 imagery using the 30 cm PAN and the 1.2 m multi-spectral bands (vegetation indices such as NDVI, PCA and other ratios) to map different structural forest parameters.	
4	Optional: Stereo-Matching of the Worldview-3, 30 cm PAN Channel to generate a precise photogrammetric 3D model based on satellite imagery only.	
5	Provision and Object Based Image Processing of Sentinel 2a Imagery from European Space Agency using the 10 m multi-spectral bands as auxiliary data.	
6	Co-operation with local forestry experts on-site to develop and apply the allometric growth models and to assess the wood volume by means of forestry parameters generated from LiDAR and spectral data.	

Pos.	Service	Amount in € (net)
7	Delivering forest inventory results in OGC compliant data formats and as a QGIS project. Optional: Presentation of results in a password protected WebGIS Application (QGIS WebClient) on the Internet including comprehensive WMS/WFS/WCS support of our QGIS Server.	
	TOTAL (excl. VAT)	

(C) Annex:

C 1: Company Profile, Key Personnel and Publications

Online Resources

Webpage: http://landconsult.de

Presentations: http://landconsult.de/segmentation/download/

Project List: http://landconsult.de/markus/bibliography.htm

CVs Weidenbach and de Kok: http://landconsult.de/home/cv/

LinkedIn Profile M. Weidenbach:

https://www.linkedin.com/in/markus-weidenbach-039792a

LinkedIn Profile landConsult.de: https://www.linkedin.com/company/landconsult-de

Envromental Experts: http://www.environmental-expert.com/companies/landconsult-de-environmental-planning-and-consulting-10751

Company Profile and Key Experts

landConsult is a consultancy group founded in 2001 and focused on Forestry and Land Use Planning, Geographic Information Management and Remote Sensing. We are working internationally with completed projects in Poland, Romania, Bulgaria, Turkey, Albania, South Africa, Nepal, Mongolia and Germany.

The office of landConsult.de is located in Buehl, Federal State of Baden-Wuerttemberg, Germany. It is equipped with the latest RS/GIS hard- and software and currently the landConsult group is staffed with more than 20 RS and GIS experts with an academic education.

LandConsult.de is specialised and interested in practical and operational RS solutions for precision forestry based on individually detected trees from LiDAR and high resolution spectral aerial and satellite imagery (aerial sensors, Worldview-3, Pleiades). We are advanced in stereo-matching and Object Based Image Analysis (OBIA) and see a possible benefit for the customer by delivering precise forest information in different scales. We are addressing regional forest administrations as well as community and private forests with less than 5000 ha.

Dr. Markus Weidenbach, owner of landConsult.de and responsible for the project, holds a doctoral degree in Forest Sciences. He graduated from the University of Munich in 1999 with a PhD Thesis about "Geographical Information Systems and New Digital Media in Land Use Planning".

He is executive member of the forest land owner association northern Black Forest, member of the Baden-Württemberg Forestry Board (Forstkammer) and the German Forestry Society (Deutscher Forstverein).

Dr. Weidenbach has long-standing professional experience in Geographic Information Management (including GIS, Remote Sensing, LiDAR and Photogrammetry), in forest management and inventory, regional and land use planning, public administration, international research, project management and in public planning mediation including profound knowledge in ecology, forest sciences and planning methods. He was team leader and short-term expert in several EU funded projects in eastern Europe.

Since 2001 he is managing director of landConsult.de and responsible for all landConsult.de projects, such as forest inventories by means of multi-spectral and stereo

satellite data, laser scanning data, CIR (True-) Orthophotos or supporting activities to the Global Forest Information System (GFIS) and others.

Dr. Weidenbach started the development of 3D forest and crown models from LiDAR data when he was a scientific partner of the research project "MatchWood - Optimizing the Forestry - Wood Chain to Strengthen Sustainable Forest Management", lead by the University of Freiburg from 2006 -08 (http://www.matchwood.uni-freiburg.de/). The project developed practical applications of the latest Airborne Laser Scanning (ALS), Remote Sensing and GIS technology for forestry.

Since 2007 landConsult is offering a digital 3D forest mapping and inventory service mainly based on laser scanning data and Color-Infrared Imagery (see http://landconsult.de) using official LiDAR and geodata from the regional survey authorities. Since 2011 such precise 3D crown models are being processed not only with LiDAR data but also with permanently updated aerial stereo-images commonly available from the official survey authorities.

For the technological development of such new photogrammetrical 3D Forest and Crown Models made from ordinary digital aerial photos, landConsult.de had been awarded with the innovation prize of the Ministry of economics of Baden-Württemberg in 2011.

Dr. Ing. Roeland de Kok is landConsult´s senior expert for Remote Sensing and Geospatial Analysis. In the project he is responsible for the processing of the Sentinel, Worldview and aerial imagery. Dr. de Kok holds a doctoral degree in Forest Sciences, studied at the University in Wageningen, the ITC in Enschede and graduated from the University of Munich with a PhD Thesis about automated mapping techniques. He is a renown expert in Object Based Image Analysis and the e.cognition software suite.

Both CVs can be downloaded from http://landconsult.de/home/cv/

landConsult´s customers and partners

(c) contracting authority

- PC Consulting Österreichische Bundesforste AG, Purkersdorf, Austria (c),
- UNIQUE Landuse and Forestry GmbH, Freiburg, Germany (c)
- South African Pulp and Paper Industries, Pietermaritzburg, South Africa (c)
- Joanneum Research GmbH, Graz, Austria (c)
- Waternet / Sector Onderzoek & Projecten, Amsterdam, Netherlands (c)
- CSIR Satellite Applications Centre, Pretoria, South Africa (c)
- European Commission, Joint Research Centre, Italy (c)
- Staatsforstbetrieb Sachsenforst, Pirna, Germany (c)
- Albert-Ludwigs-University, Institute for Remote Sensing and Landscape Information Systems, Freiburg i. Br., Germany (c)
- Montgomery Watson Harza (MWH), La Hulpe / Brussels, Belgium (c)
- Balkan Software Consult srl, Bucharest, Romania
- Ministry of Agriculture, Forests and Rural Development, Bucharest, Romania
- ROMSILVA, State Forest Administration, Bucharest, Romania
- Ministry of Agriculture and Forestry, Sofia, Bulgaria
- Ministry of Regional Development and Public Works, Sofia, Bulgaria
- BELDA Ltd., Ankara, Turkey
- State Planning Organization, Ankara, Turkey
- Ministry of Agriculture and Forestry, Ankara, Turkey
- Ministry of Environment, Ankara, Turkey
- Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany (c)
- ProGea Consulting, Cracow, Poland (c)
- Ministry of Environment, Warsaw, Poland

- Bayerisches Staatsministerium für Umwelt, Gesundheit und Verbraucherschutz, Munich,Germany
- AGL Arbeitsgruppe für Landnutzungsplanung, Institut für ökologische Forschung, Etting-Polling, Germany (c)
- Black Forest Nature Park Administration, Seebach, Germany
- International Union of Forest Research Organisation (IUFRO), Vienna, Austria (c)
- Food and Agricultural Organisation of the UN (FAO), Rome, Italy
- Ministry of Environment, Tirana, Albania
- StoraEnso Forestry Consulting, Helsinki, Finland (c)
- Bayerisches Staatsministerium für Landwirtschaft und Forsten, Munich, Germany
- Centro de Investigación y Extensión Forestal Andino Patagónico CIEFAP, Esquel, Argentina
- Ludwig-Maximilians-University (LMU), Institute for Landscape Planning and Nature Conservation, Munich, Germany (c)

Works relevant to the proposal

- REDD+ National Forest Inventory Project in Mongolia. Key expertise for Database (PostgreSQL and PostGIS) and Forest Atlas (QGIS WebClient) development (2015)
- 3D Forest Inventory based on LiDAR data and aerial stereo-photos (DMC and Ultracam) of 18.500 ha in the Black Forest mountain range in Baden-Württemberg, Germany to assess the wood volume in privately owned and community forests. Project funded by EU, national and private funds (2014).
- Assessment of Forest Cover Change in Gorce National Park (Poland) Using a GEOBIA Approach of CIR Aerial Orthophotos and nDSM Derived from Aerial Stereo Photos (2014).
- Photogrammetric Development and Application of 3D Tree Crown Models processed from digital Aerial Imagery. Awarded Innovation Project in co-operation with Joanneum Research Institute in Graz, co-financed by landConsult.de and the Ministry of Economics Baden-Württemberg (2011).
- contracted by the State Forest Administration Sachsenforst, Pirna, Germany (2007 - 2012)
  Processing Color-Infrared Orthophotos and Airborne Laser Scanning Data to retrieve forest information on different test sites in Saxony (2007).
  Measuring individual crown parameters on forest research plots from Fullwave Laser (2011).
  Measuring individual crown parameters on forest research plots from Aerial Stereomodels, low density Airborne Laser data and Terrestrial Laser Scanning (2012).
- 3D Forest Inventory of some 12.000 ha of private forests in Luxembourg (Ardennes mountain range) based on LiDAR DTM and aerial stereo models (2012).
- Processing of Quickbird Satellite Imagery to automatically detect and map individual trees and stand openings on 6.400 ha of eucalyptus and pinus plantations. Contracted by South African Pulp and Paper Industries (2008)
- "MatchWood - Optimizing the Forestry - Wood Chain to Strengthen Sustainable Forest Management". Practical applications of the latest Laser Scanning (LiDAR), RS and GIS technology for forestry in Germany. Contracted by the University of Freiburg, Institute for Remote Sensing and Landscape Information Systems, Germany (2006 – 08)
- Technical Assistance to the Ministry of Agriculture, Forests and Rural Development and ROMSILVA in Bucharest and the Ministry of Agriculture and Forestry and the Ministry of Regional Development and Public Works in Sofia. Procurement of GIS, outdoor devices and machinery for nature protection and forest authorities and Promotion of Sustainable Development and Conservation of Biodiversity in the Bulgarian-Romanian Cross Border Region (2005 - 06).

Publications relevant to the proposal

(online on http://landconsult.de/markus/bibliography.htm)

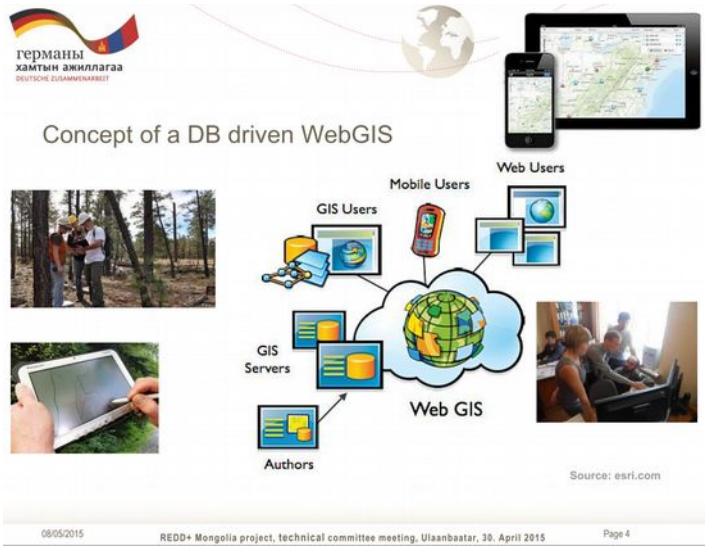
- WEIDENBACH, M. 2015: 3D Forestinventur im Nordschwarzwald (3D Forest Inventory in the Black Forest).. In: AFZ - Der Wald 23/2015, S. 48 - 52.
- WEZYK, P., HAWRYLO, P., JANUS, B., WEIDENBACH, M., 2014: Assessment of Forest Cover Change in Gorce National Park (Poland) Using a GEOBIA Approach of CIR Aerial Orthophotos and nDSM Derived from Aerial Stereo Photos. Forestry: An International Journal of Forest Research. Paper Submitted. [Presentation at IUFRO Conference on Forest Change 2014 in Munich].
- TOMPALSKI, P., WEZYK, P., WEIDENBACH, M., de KOK, R., HAWRYLO, P., 2014: A Comparison of LiDAR and Image-derived Canopy Height Models for Individual Tree Crown Segmentation with Object Based Image Analysis. 5th Geobia Conference Thessaloniki. Publ. in South-Eastern European Journal of Earth Observation and Geomatics, Vol 3, No 2.
- WEIDENBACH, M., WEZYK, P., HOFFMANN, M., MARTENS, S., TOMPALSKI, P. 2012: Processing of LiDAR and digital Aerial Images to detect and measure individual crown parameters on selected forest research stands in Saxonia. Erfassung von Einzelbaumparametern mit Airborne-Laser-Scanning-Daten. Allgemeine Deutsche Forstzeitschrift – AFZ, publication in press.
- WEIDENBACH, M., GUTJAHR, H., SCHARDT, M. 2011: Photogrammetric Development and Application of 3D Tree Crown Models processed from ordinary digital Aerial Imagery. Awarded Innovation Project in co-operation with Joanneum Research Institute in Graz, co-financed by landConsult.de and the Ministry of Economics Baden-Württemberg. Work Report.
- WEIDENBACH, M., DE KOK, R. 2008: Large Scale Forest Taxation based on Single Tree Measurements using Airborne Laser Scanning Data and Spectral Information from Quickbird Satellite Imagery and Digital Orthophotos. Paper presented at ICAS Conference: "Sustainable Forest Management in a Changing Environment Context". Bucharest 2008
- WEIDENBACH, M., DE KOK, R. 2008: Developing Strategies for Large Scale Forest Inventories Combining LiDAR Data, Satellite Imagery and Regional Yield Models. Poster presented on the SilviLaser 2008 conference in Edinburgh
- DE KOK, R. and TASDEMIR, K., 2011: Analysis of high-resolution remote sensing imagery with textures derived from single pixel objects. SPIE Remote Sensing Conference 8181, Earth Resources and Environmental Remote Sensing/GIS Applications, 19-22 September, Prague2011.
- DE KOK, R., 2010:: An object based approach on the detection of landscape features in the Czech Republic. Geomatics in support of the Common Agricultural Policy Proceedings of the 16th GeoCAP Annual Conference, 2010. Centro Congressi Giovanni XXIII, Bergamo 24th-26th November 2010
- DE KOK, R., WEZYK, P., WEIDENBACH, M., 2008: The Role of Edge Objects in Full Autonomous Image interpretation. Paper presented at the international GEOBIA conference 2008 in Calgary, Canada
- WEIDENBACH, M., KOCH, B., WEINACKER, H., BALIC, N., STRAUB, C., WANG, Y. 2006: Stakeholder and User Participation to develop LiDAR and Internet based forest information exchange platform. Beteiligung der MatchWood Praxispartner an der Entwicklung eines Verfahrens zur Laser gestützten Erfassung und zum Internet basierten Austausch forstwirtschaftlicher Inventur- und Planungsdaten
- WEZYK, P., DE KOK, R., ZAJACZKOWSKI, G. 2004:. 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. Angewandte Geoinformatik 2004. Herbert Wichmann Verlag. Heidelberg. ISBN 3-87907406-2, 770-775.

C 2: LandConsult Reference sheets:

REDD+ Mongolia

Assignment Name: REDD+ compatible National Forest Inventory in Mongolia, Database Development and Reporting (MRV, M/I, NFI)		**Approx. value of the Contract (in current US$ or Euro):** 2.5 Mio. EUR
Country: Mongolia **Location within Country:**		**Duration of Assignment (months):** 12
Name of Client: Österreichische Bundesforset (ÖBF) in cooperation with local authoities and German GIZ		**Total No. of Staff-months of the assignment provided by your firm:** **2** ppm
Address: Pummergasse 10-12 3002 Purkersdorf Österreich		**Approx. Value of the Services provided by your firm under the contract (in current US$ or Euro):** 20000 EUR
Start Date (Month/Year): 12/2014	**Completion Date: (Month/Year):** 11/2015	**No. of man-months of professional staff provided by associated consultants:**
Name of Associated Consultants if any: Dan Altrell (ÖBF)		**Name of Senior Professional Staff of Your Firm Involved and Functions Performed (indicate most significant profiles such as Project Director/Coordinator, Team Leader):** Dr. Markus Weidenbach – Technical Adviser – 2014-2015

Narrative Description of Project:



The purpose of this assignment was to provide expertise for the Database and WebGIS programming to support the analysis of the National Forest Inventory and the reporting to the UNFCCC. Different DBs for NFI processing and MRV and M/I activities , including Safeguards has been proposed and installed. The goal was to combine Postgres and PostGIS components with the QGIS Server to develop a seamless work environment for the local staff in Ulaanbaatar and a Forest Atlas Online application to be used for the information of all stakeholders on different information levels.

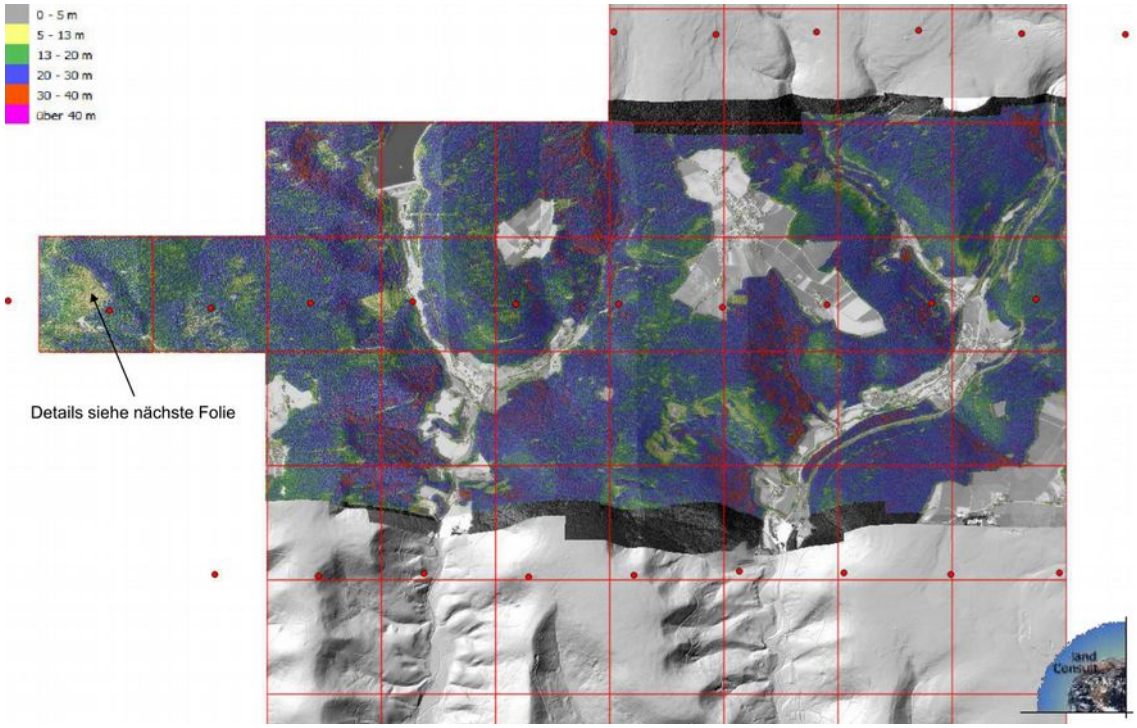
Description of Actual Services provided by Your Staff within the Assignment:
landConsult.de was fully responsible for the contract management with ÖBF, and the implementation of the proposed system on the server in Ulaanbaatar. And the reporting to the ÖBF, the GIZ and the local authorities.

3D Forest Inventory Black Forest, Germany

Assignment Name: 3D Forest Inventory in the Northern Black Forest	**Approx. value of the Contract (in current US$ or Euro):** 60.000 EUR
Country: Germany **Location within Country: Northern Black Forest**	**Duration of Assignment (months):** 12
Name of Client: Waldbesitzerverein Nordschwarzwad e.V.	**Total No. of Staff-months of the assignment provided by your firm:** **5** ppm
Address: Forstweg 8 72297 Seewald-Göttelfingen	**Approx. Value of the Services provided by your firm under the contract (in current US$ or Euro):** 18.000 EUR
Start Date (Month/Year): 12/2013 — **Completion Date: (Month/Year):** 12/2014	**No. of man-months of professional staff provided by associated consultants:**
Name of Associated Consultants if any: H. Gutjahr, Joanneum Research Graz, Austria B. Wippel, UNIQUE Landuse GmbH, Freiburg, Germany	**Name of Senior Professional Staff of Your Firm Involved and Functions Performed (indicate most significant profiles such as Project Director/Coordinator, Team Leader):** Dr. Markus Weidenbach – Project Leader

Narrative Description of Project:

This projects demonstrates the latest photogrammetrical technology in forestal remote sensing on large scale. By means of Laser terrain modells and stereo-matched aerial photographs a total of more than 2.5 Mio individual trees had been precisely located and automatically measured. This 3D information is being used to assess many relevant forest parameters such as wood volume, mean height, crown closure, tree species and others.



The 3D data analysis iof the aerial imagery is based on the award winning stereo-matching technology developed by landConsult.de and Joanneum Research mbH in 2011.

In order to present the results of this 3D Forest Inventory a WebGIS has been programmed, which is accessible to all stakeholders and forest land owners.

The project was co-funded by the European Commission and the Federal State of Baden-Wuerttemberg, Germany.

Results are online under http://3dgis.landconsult.de

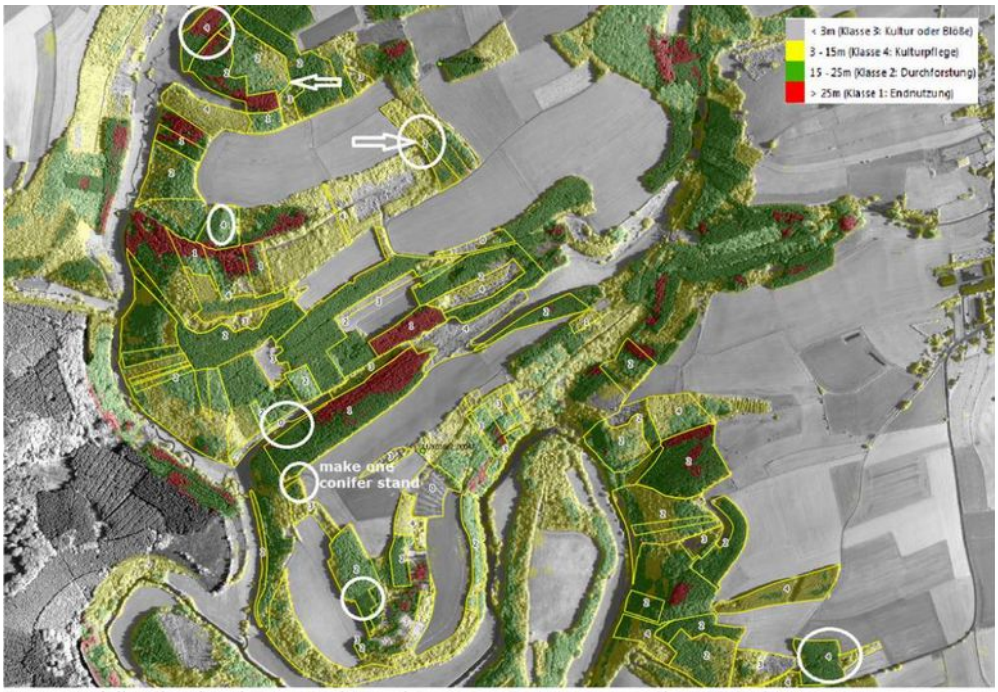
Description of Actual Services provided by Your Staff within the Assignment:

Contracted by the main beneficiary, the Forest Owner Association, landConsult.de was fully responsible for the development of the project idea, the proposal and the overall project planning and management.

Semi-automatic 3D Forest Inventory Luxembourg

Assignment Name: Mapping of Private Forest Land by means of Aerial Stereo-photo modells and Digital Elevation Modells	**Approx. value of the Contract (in current US$ or Euro):**
Country: Germany **Location within Country: North Luxembourg**	**Duration of Assignment (months):** 5
Name of Client: UNIQUE Forestry and Landuse GmbH	**Total No. of Staff-months of the assignment provided by your firm:** **5** ppm
Address: Schnewlinstraße 12, **79000 Freiburg**	**Approx. Value of the Services provided by your firm under the contract (in current US$ or Euro):** 24.000 EUR
Start Date (Month/Year): 07/2012 — **Completion Date: (Month/Year):** 11/2012	**No. of man-months of professional staff provided by associated consultants:**
Name of Associated Consultants if any: P. Wezyk, ProGea Consulting, Krakow, Poland	**Name of Senior Professional Staff of Your Firm Involved and Functions Performed (indicate most significant profiles such as Project Director/Coordinator, Team Leader):** Dr. Markus Weidenbach – Project Leader

Narrative Description of Project:



Crown Modell with colored Tree Heights and Digitizing Comments on 16bit NIR Ortho

Digital aerial photographs were processed by means of specific stero-matching, photogrammetrical algorithms, developed to detect and measure individual trees. In combination with a precise digital elevation model, individual tree heights and tree species were classified and used to delineate homogenous forest stands, roads and openings.

Completed by a terrestrial sample plot inventory, the digital forest maps were the basis for the final Forest Taxation.

An illustrated summary is available online under http://landconsult.de/segmentation/download/lux2013.pdf

Description of Actual Services provided by Your Staff within the Assignment:
landConsult.de was fully responsible for the processing of the entire northern part of Luxembourg, including the classification of the stands and mapping of other forest relevant features.

Airborne and Terrestrial Laser Technology for Forest Inventory

Assignment Name: Processing of Airborne Laser data (ALS), terrestrial Laserdata (TLS) and aerial stereo-photos to measure forest research stands of the Saxony Forest Administration.	**Approx. value of the Contract (in current US$ or Euro):**
Country: Germany **Location within Country: Saxony**	**Duration of Assignment (months):** between 2007 and 2013
Name of Client: Staatsbetrieb Sachsenforst	**Total No. of Staff-months of the assignment provided by your firm:** **6** ppm
Address: **Pirna bei Dresden** **Germany**	**Approx. Value of the Services provided by your firm under the contract (in current US$ or Euro):** 50.000 EUR
Start Date (Month/Year): 2007 — **Completion Date: (Month/Year):** 2013	**No. of man-months of professional staff provided by associated consultants:**
Name of Associated Consultants if any: Dr. Piotr Wezyk, ProGea Consulting, Krakow, Poland	**Name of Senior Professional Staff of Your Firm:** Dr. Markus Weidenbach – Project Leader Dr. Roeland de Kok, Technical Expert RS and OBIA

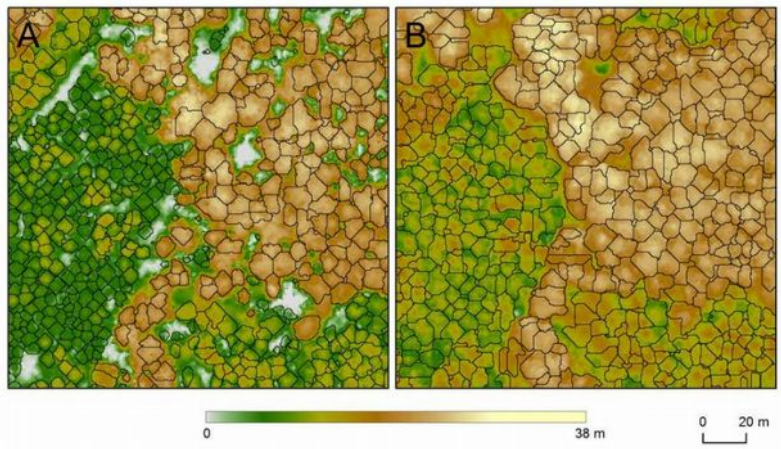
Narrative Description of Project:

Between 2007 and 2013 landConsult.de completed 3 different projects for the state forest administration in Saxony to demonstrate the power of Laser Technology and compare its crown models with photogrammetrically processed crown models of aerial photographs.

Different Airborne Laser (ALS) sensors have been tested and also Terrestrial Laserdata (TLS) were aquired with the latest 3D Laser devices.

With this technology the trees of all forest research sites in Saxony had been measured. As a result some 20 different tree crown parameters (such as the crown height, crown volume, different crown radii etc.) were automatically processed.

For the same are aerial photos were processed and terrestrial laser data was recorded and compared with the ALS data.



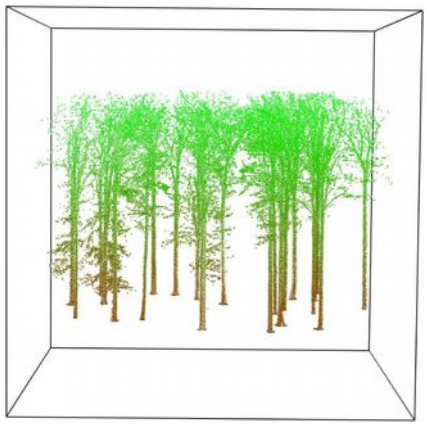


Figure . Tree crown delineation result on one of 200 x 200 m sample plots. A – CHM based on ALS LiDAR data. B – CHM based on SGM on aerial stereopairs.

There is a presentation, held at the University in Dresden with the main results, is online at:
http://landconsult.de/segmentation/download/tharandt_present_04Feb13_v7_web.pdf

Another presentation, held at GEOBIA Conference 2014 at the University in Thessaloniki is focusing on the OBIA (Object Based Image Analysis) of this approach. The extended abstract is available at
http://landconsult.de/segmentation/download/GEOBIA_2014_extended_abstract.pdf

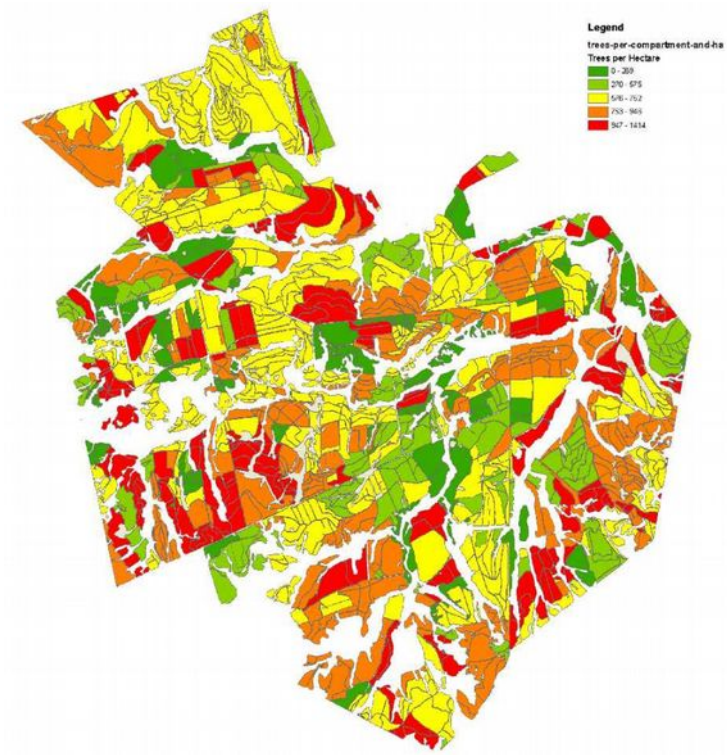
The powerpoint is available at http://landconsult.de/segmentation/download/GEOBIA_2014.pdf

Description of Actual Services provided by Your Staff within the Assignment:
landConsult.de was fully responsible for the contract management and the project planning and delivery of the results . The data processing was supported by staff from ProGea.pl

Satellite Based Forest Inventory in South Africa

Assignment Name: Satellite Based Forest Inventory of Pinus Spec. and Eucalyptus Spec. plantations I South Africa	**Approx. value of the Contract (in current US$ or Euro):** 8.000 €
Country: Germany **Location within Country: South Africa**	**Duration of Assignment (months):** 2
Name of Client: South African Pulp and Paper Industries	**Total No. of Staff-months of the assignment provided by your firm:** **2** ppm
Address: **Pietermaritzburg** **South Africa**	**Approx. Value of the Services provided by your firm under the contract (in current US$ or Euro):** 8.000 EUR
Start Date (Month/Year): 07/2012 / **Completion Date: (Month/Year):** 11/2012	**No. of man-months of professional staff provided by associated consultants:**
Name of Associated Consultants if any:	**Name of Senior Professional Staff of Your Firm Involved and Functions Performed (indicate most significant profiles such as Project Director/Coordinator, Team Leader):** Dr. Markus Weidenbach – Project Leader Dr. Roeland de Kok, technical expert (OBIA and RS)

Narrative Description of Project:



The project area covers some 4.800 ha of a Pinus spec., Eucalyptus spec. and Acacia spec. plantations in South Africa. The topography is hilly with some riparian vegetation between the plantations. The total processing area depended on the shape of the Quickbird imagery which is about 6.400 ha. The entire plantation is divided in 464 compartments which are often composed of several polygons, i.e. parts of plantations on different locations belonging to one compartment.

Throughout the entire Quickbird Mosaic some 3.5 Mio. trees have been automatically detected and registered in the attached MS Access database and in different shape files

The Quickbird Mosaic could be successfully processed and trees in all age classes and species groups could be automatically detected. An illustrated summary is available online under

http://landconsult.de/southafrica08/sa-webreport.pdf

Description of Actual Services provided by Your Staff within the Assignment:
landConsult.de was fully responsible for the satellite data acquisition, the processing of the entire area and the presentation of the results.