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USAGE OF GEOPROCESSING SERVICES IN PRECISION FORESTRY FOR WOOD VOLUME CALCULATION AND WIND RISK ASSESSMENT

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Abstract

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This paper outlines the idea of a precision forestry tool for optimizing clearcut size and shape within the process of forest recovery and its publishing in the form of a web processing service for forest owners on the Internet. The designed tool titled COWRAS (Clearcut Optimization and Wind Risk Assessment) is developed for optimization of clearcuts (their location, shape, size, and orientation) with subsequent wind risk assessment. The tool primarily works with airborne LiDAR data previously processed to the form of a digital surface model (DSM) and a digital elevation model (DEM). In the first step, the growing stock on the planned clearcut determined by its location and area in feature class is calculated (by the method of individual tree detection). Subsequently tree heights from canopy height model (CHM) are extracted and then diameters at breast height (DBH) and wood volume using the regressions are calculated. Information about wood volume of each tree in the clearcut is exported and summarized in a table. In the next step, all trees in the clearcut are removed and a new DSM without trees in the clearcut is generated. This canopy model subsequently serves as an input for evaluation of wind risk damage by the MAXTOPEX tool (Mikita *et al.*, 2012). In the final raster, predisposition of uncovered forest stand edges (around the clearcut) to wind risk is calculated based on this analysis. The entire tool works in the background of ArcGIS server as a spatial decision support system for foresters.

Keywords: wind risk, canopy height model, ALS, LiDAR, geoprocessing

INTRODUCTION

The aim of this article is to demonstrate utilization of spatial decision support system for optimization of clearcuts in forestry and its usage in the form of a geoprocessing service. The work is not focused on all aspects of wind risk modeling, it should rather express a concept of precision forestry tool for foresters, that could help them in forest recovery and that should eliminate the risk of wind damages.

Precision forestry is focused on information and supports economical, environmental-friendly, and sustainable decisions by using high-tech sensing and analytical tools. It provides highly repeatable measurements, actions, and processes to initiate, cultivate, and harvest trees, as well as to protect and to enhance riparian zone, wildlife habitat, and other environmental resources. It offers valuable information and linkages among resource managers, environmental communities, manufacturers, and public policy makers (DYCK, 2001).

The ability of forest stands to withstand strong winds is determined by a combination of many factors with variable effects characterized by high heterogeneity in space and time. The stability of forest stands is impacted heavily by the size and frequency of these extremes and topography, due to its influence on the speed and direction of wind circulation, as well as by the overall stability of forest stands as determined by species, age and spatial structure, management methods, and the intensity of management interventions carried out in the recent past (Scott and Mitchell, 2005). Over the last two decades, factors causing occurrence of windthrow have been examined by several authors (e.g. Lohmander and Helles, 1987; Peltola and Kellomäki, 1993; Valinger and Fridman, 1997; Kerzenmacher and Gardiner, 1998; Gardiner and Quine, 2000; Gardiner *et al*., 2008; Byrne and Mitchell, 2007). The finding of most studies has been that the occurrence of windthrow is mostly influenced by forest management (species, age, and spatial structure of forest trees) as well as by topography and overall landscape structure.

In current forest research, many models are known and commonly used to assess the risk of wind to forest stands. These models are based on several approaches:

1) a mechanistic approach in which the main subject of examination is mechanical tree stability,
2) a so-called empirical approach examining the occurrence of windthrow in relation to a combination of natural and forest-management-related factors, or
3) a combination of both aforementioned approaches in the form of so-called mechanistic-empirical models.

In both, mechanistic and empirical modeling, changes in the height of stand edges of adjacent stands resulting from harvesting and the width of such stand edges are considered key factors of windthrow (Peltola *et al*., 1999; Novak *et al*., 2000; Lanquaye and Mitchell, 2005). The limit value for the difference in height between adjacent forest stands is considered to be 10 meters (Blennow and Sallnass, 2004). Furthermore, so-called "FETCH" distances are also important (Burton, 2001). These can be defined as uninterrupted distance without obstacles across which the wind travels before reaching a stand's edge. Differences in height between stands and FETCH distances can be easily expressed using the topographic exposure factor.

Existing surveys show a significant influence of the forest stand edges on the occurrence of windthrow, but automatic identification of the edges themselves, and particularly their orientation toward the direction of the wind, is problematic. Exposure of forest stand edges is not given only by its orientation to wind direction, but also by complex topography of the surrounding terrain, which can be expressed by the aforementioned topographic exposure factor.

Topographic exposure is a topographic characteristic representing a given site's degree of protection by the surrounding landscape. According to Ruel (1995), the topographic exposure in a given site is equal to the sum of all vertical angles to the horizon in 8 basic directions to the cardinal points. By combining topographic exposure with wind direction and speed, we can obtain a site's degree of exposure or protection from a given direction.

Detailed knowledge of topographic exposure is broadly utilized in a number of applications ranging from studying forest wind damage through research on snow storage dynamics to optimization in positioning wind power stations (Lanquaye and Mitchell, 2005; Ruel *et al*., 1997; Scott and Mitchell, 2005). It is, however, applied also in the area of meteorological phenomena modeling (Chapman, 2000), monitoring the impact of wind on railway tracks (Baker, 1985), and many others.

Topographic exposure may be modeled also using the shaded topography (Mikita *et al*., 2012). Calculation of the shaded topography (hillshade) is an integral part of most GIS applications. The hillshading tool creates hypothetical illumination of the topography and, based on the setting of the light source's position, it calculates the illumination level of each pixel relative to its surroundings within the range of 0–255. Parameters of the set-up also include the horizontal angle of illumination direction of in the form of azimuth to the north and the vertical angle from the horizontal plane. The baseline values during normal processing of the shaded topography for DTM presentation are a vertical angle (altitude) of 45° and a horizontal angle of 315° (corresponding to illumination from the northwest) (Mikita *et al*., 2012). According to Boose *et al*. (1994), for the purposes of topographic exposure to wind, it is possible to choose the altitude value of 5° to asses the impact of wind, which partially takes into account the impact of falling winds on leeward slopes of ridges. The result of hillshading determines exposed or covered locations of relief relative to the selected wind direction. The exposure of forest stand edges or their identification itself can be conducted using hillshading in combination with a digital surface model. The highest exposure is at the edges of forest stands oriented into the direction of the wind, which logically form the greatest obstacle for the wind and are the most damaged. What ensues from the comparison of wind direction and DSM is that the exposed stand edges can be regarded as places with values of topographic exposure exceeding 150 and that, on the other hand, the lower values indicate back stand edges (Mikita *et al*., 2012). These results may be multiplied by the occurrence of wind direction interpolated from nearest climatologic stations. Final topographic exposure should express not only impacts of height differences between forest stand heights, but also should include the above mentioned FETCH distances. Higher clearcut length in the direction of prevailing wind speed will increase the level of topographic exposure.

In the Czech Republic, a principle of localization of forest recovery elements (clercuts) perpendicular to the direction of destructive winds has long been applied and various elements of inside spatial arrangement of stands in forest management are also theoretically determined and practically applied to ensure stability of stands against destructive winds (gaps, clearcuts, and wind mantles) (Sequens, 2007). Although these rules are long known, at locating clearcuts it is often very difficult or rather impossible to capture the full impact of both, relief and surrounding vegetation, on subsequent exposure of stand edges created by extraction. Creating a suitable tool for the exposure evaluation of stand edges after extraction is thus in terms of practical forestry one of the key tasks.

Despite the very good results of the above models for the wind risk of forest stands, their application in practical forestry is still rather marginal in view of the quantity of inputs in the form of various data sources. The objective therefore was to develop a relatively simple tool working with basic data sources in the form of DSM and DEM to enable data analysis be performed quickly and repeatedly so that the user did not need to know the principle of computation.

When planning the location of a future clearcut, the overall supply of harvested wood is the essential prerequisite, which in the end affects the size of the clearcut. Basic input data used can be either a forest management plan or the inventory based on ALS data processing in the form of DSM and DEM and subsequently generated CHM.

At present, the highest quality data source for generating DEM and DSM on large areas is the ALS technology. The system of airborne laser scanning (ALS) or generally LIDAR (light detection and ranging) is based on the principle of analyzing laser pulses which are emitted from an aircraft, moving at a certain distance from the scanned object. At the same time, for each laser pulse emitted from a source, its current position in the space is recorded by means of differential GPS and inertial navigation unit (INU). The laser pulse hits an object and is reflected in the form of an echo back to the sensor and the distance it travelled is measured. The pulse is reflected from each surface area of an object, which creates an echo string – from the highest (closest to the sensor) surface area to the lowest one, in order to create a dense field of geographic coordinates in places where laser pulses were reflected from the surface (Baltsavias, 1999).

Laser scanning imposes high demands on processing possibilities of available technology as there is a large amount of data at high accuracy of scanning. The gained data (point cloud) are usually processed by two basic methods: filtration (its task is to separate points corresponding to the required object) and classification (where individual surfaces are separated). These processes may be automatic or semi-automatic; a fully automatic filtration and classification does not always provide the best results. It is used in zonal and global filters while the biggest differences are between types of land cover representing urban area and continuous vegetation (Jacobsen and Lohmann, 2003). In forestry, ALS is used especially for creating CHM and subsequently for forest inventory.

The ALS based forest inventories widely used in forest practice or in forest research are nowadays a so-called individual tree detection (ITD) and area-based approach (ABA). The ALS-based forest inventory methodology based on individual tree detection (ITD) has been widely studied recently, but is not widely used in practice, due to assumed problems related to tree detection under various forest conditions (Falkowski *et al.*, 2008; Kaartinen *et al.*, 2008; Vastaranta *et al.*, 2011). The main problem related to the practical use of ITD is the need for higher ALS points density, which should guarantee higher precision in tree height extraction (Smreček and Danihelová, 2013). The assumed main advantage of ITD is providing true stem distribution series enabling better predictions of timber assortments. Stem distributions are predicted in the ABA causing inaccuracy in timber assortment and forest value estimates (Holopainen *et al.*, 2010). Another advantage of ITD is the reduced amount of expensive fieldwork compared to that which is necessary when applying the ABA approach. The disadvantage of the ITD approach is that suitable models for volume extractions are still missing for conditions of the Czech Republic as well as for Slovakia (Sačkov *et al.*, 2008).

ALS data processing into DSM and DEM, however, requires special software for data processing and knowledge of GIS, which puts great demands on potential users. One option is to implement a tool in the form of a geoprocessing tool. Geoprocessing tools allow exploitation of capabilities and GIS analytical tools using the world wide web. By sharing geoprocessing services, a user can use these tools through both desktop/mobile application, and mainly through a client embedded in a web site easily usable in a web browser. The advantage then is low computational and storage capacity load of the client, since all the capacity needed for the computation of the analysis takes place on the side of a high performance server and the client is then merely transferred the resulting data which can subsequently be visualized and presented in a table. The most commonly used standard for geoprocessing services is Web Processing Service (WPS). WPS is a standard defined by Open Geospatial Consortium (OGC). WPS defines a standardized interface that facilitates publishing of geospatial processes, and discovery of and binding to those processes by clients. Processes include any algorithm, calculation or model that operates on spatially referenced data (OGC, 2006).

The company of ESRI and their extensive system of ArcGIS includes applications for use in a server environment of ArcGIS for Server. This application is responsible for providing GIS services for desktop, mobile, and web clients and provides networking with other ESRI applications as well as other defined standards such as OGC. Since ArcGIS for Server belongs among ArcGIS products, compatibility and easy interconnection with ArcGIS for Desktop is ensured. In this program, a GIS user can model the analytical task of the spatial data sets and, using a visual wizard, he or she can relatively easily publish the service for clients that can begin to use it immediately. ESRI and their system of ArcGIS for Server supports the above mentioned OGC services and standards, but since these are general standards preventing dynamic development on new trends in GIS, ESRI started to create their own services. These services are very similar to services backed by OGC standards, but are modified for better performance, expanding their capabilities and networking with other ESRI products. These services include Map service, Geocode service, Geodata service, Geometry service, Geoprocessing service, Globe Service, Image service, and Search service. As a result, the above listed services can be run on ArcGIS for Server, in addition to which capabilities of OGC standards shall be permitted for clients that can only work with these open standards (ESRI, 2012).

METHODOLOGY

Study Area

The study area includes mixed spruce (*Picea abies* L.) and beech (*Fagus sylvatica* L.) forest stands in the area of the Training Forest Enterprise in Křtiny (TFE) (see Fig. 1). The landscape of sampling plots is characterized by flat ridge with incised ravines in the elevation of about 500 meters above sea level. The research was carried out in a dense forest compartment with tall trees with mean height of more than 30 meters. The selected forest stands were badly damaged by a storm called Antony that occurred here in June 2010. ALS data captured by the discrete return scanner of Leica ALS50-II with a pulse rate of 55 kHz from Leica Geosystems in the summer 2009 were used as a input dataset.

The flight was performed by the GEODIS Brno company at an altitude of 1395 m in clear sky conditions with average density of 4.3 points per square meter. A value of intensity was captured for each one of a maximum of five discrete returns per pulse, average scan density was 4.3 pulses per square-meter and footprint diameters of 0.73 m at nadir.

Data Processing

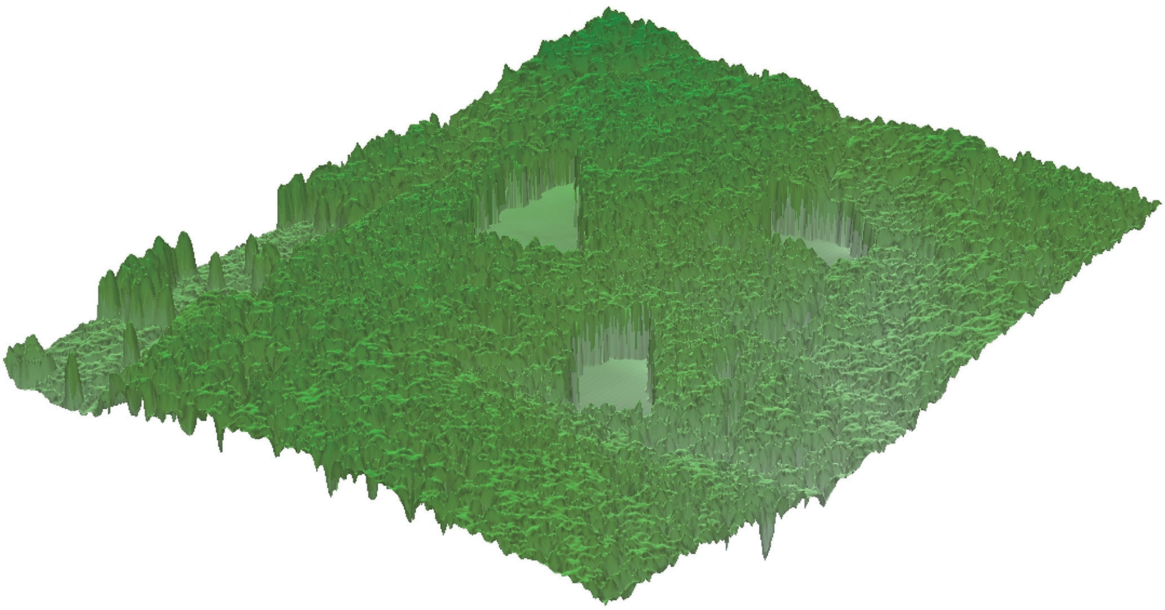
The raw point cloud was processed, filtered, and classified using TerraScan software (Terrasolid, Finland). After the removal of low and air points, discrete returns were classified as ground by using the geometric conditions of maximum terrain slope of 75°, iteration angle of 12° and iteration distance of 2 m. The first return points were automatically classified also in TerraScan software. The final classification results in the LAS files of ground and the first return sets of points were converted in ArcGIS 10.2 by the Create LAS Dataset tool. Interpolation into coherent raster digital surfaces was made by Inverse Distance Weighted Method (IDW) for the first return point cloud and by Natural Neighbor method for the ground point cloud. Finally the DSM and DTM of 0.5 m resolution were obtained.

Terrestrial surveying based on GNSS and total station measurements in 4 sampling plots in an area of 1 hectare proved the quality of DTM and resulted in an observational error of -0.623 ± 0.12 m (Mikita *et al.*, 2013). Therefore this relatively high systematic bias was eliminated by deducting the difference. The reason of this error was either in calibration of GNSS in the airplane or in our GNSS measurement under the forest cover.

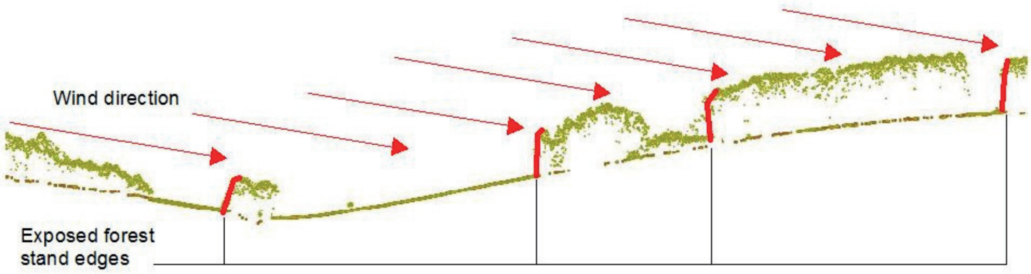
The COWRAS tool combines the previous results of research in the field of wind risk assessment by the MAXTOPEX tool with ALS technology that increases the accuracy of calculation due to higher precision of DSM (Mikita *et al.*, 2012). In the case of the model generated for wind risk assessment at Anthony windstorm in 2011, we used only a simplified DSM created from contour lines combined with tree heights from the Forest Management Plan (FMP) of the TFE. The newly generated model already works with DSM from ALS data and thus enables modeling of wind exposure on the level of individual trees.

The COWRAS tool is based on GIS analysis of ALS data. A pre-processed LiDAR point cloud is used as basic input data subsequently interpolated to the form of digital elevation model and digital surface model. It is necessary to choose (or measure in field using GNSS) a polygon with shape and location of the clearcut as the last input parameter.

1: *Location of TFE Křtiny*



2: *Simulation of clearcuts in DSM*



3: *Calculation of topographic exposure*

On the basis of previous research, computing DSM minus DTM secured an equivalent Canopy Height Model (CHM) subsequently used for individual tree detection. A previous research revealed that the final tree heights from CHM become undervalued. Thus it is necessary to process CHM with filtering. The CHM was smoothed with a Gaussian filter to remove small variations on the crown surface. The degree of smoothness was determined on the basis of the most precise detection of tree heights from ALS in comparison to field measured values (Mikita *et al.*, 2013). In the case of this study, we used the Focal Statistic tool of ArcGIS 10.2 with defined rectangle surrounding of a kernel of 5 × 5 pixels.

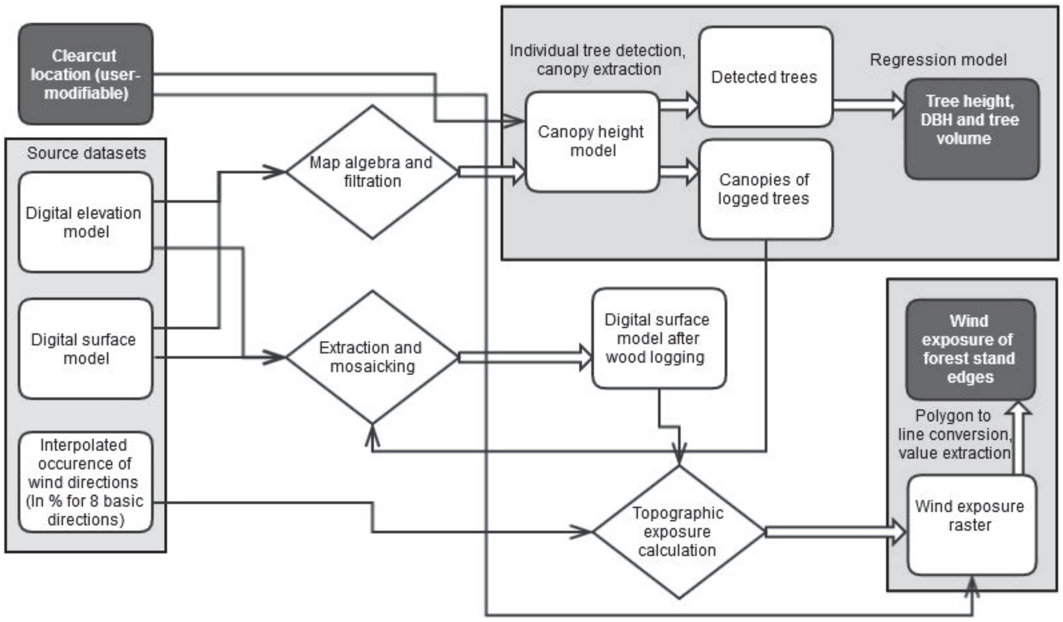
Tree identification was conducted by watershed segmentation and tree tops were identified by finding local maxima. Watershed segmentation determines tree top locations by inverting the CHM and finding local minima as treetops. Heights of the detected trees were extracted from CHM.

In the next step, other tree parameters such as Diameter at Breast Height (DBH) and tree volume were calculated based on regressions created by our own analysis from source data of measured trees (Mikita *et al.*, 2013). Adjusted Michajlov's function was used for DBH calculation. Subsequently, volumes of individual trees based on Slovak tree volume model (Petráš and Pajtík, 1991) were computed (Mikita *et al.*, 2013).

In the next step, in the area where the clearcut is marked using a polygon, extraction is simulated by removing surface of all trees falling into the clearcut (including the treetops detected by inverse basin) and replacing them by DEM (see Fig. 2).

On the basis of this modified DSM, topographic exposure from basic 8 cardinal points is calculated and combined with the prevailing wind direction obtained by interpolating data from climatologic stations (8 continuous rasters for the whole territory of the Czech Republic with the frequency of wind direction within the range of 0–100%). Topographic exposure of a specific direction is then multiplied by the frequency of the wind (e.g. for NE direction azimuth is set to 315° and altitude to 6). Adding topographic exposures from all directions results in the overall exposure of DSM (see Fig. 3).

On the basis of zonal statistics, topographic exposure values of the surrounding of the planned clearcut stand edges are extracted for individual edges of the clearcut and are expressed in a scale from 1 to 5 for each 10-meter section of the stand edge (1 indicates low exposure and 5



4: *Geoprocessing flowchart*

large exposure). Finally, the value of topographic exposure is expressed as a proportion of the sum of total exposure to the total length of the created stand edge. Data processing is shown by a flowchart in Fig. 4.

The entire model is based on a combination of different tools of ArcGIS software and can be easily converted to ArcGIS for Server where all processes are carried out based on the input data through Geoprocessing tools. Then a forester, when planning forest recovery, may determine the desired amount of extraction and consequently the optimum location so as to achieve the smallest possible risk of wind damage only on the basis of FMP.

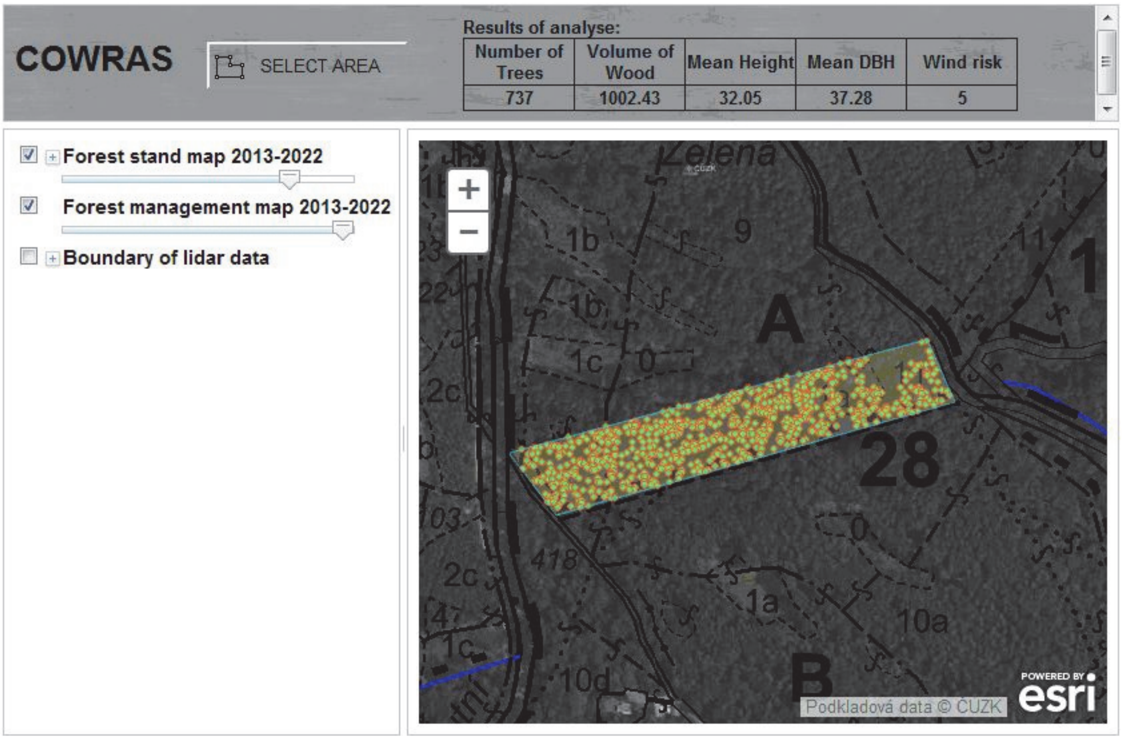
Geoprocessing in ArcGIS for Server

COWRAS tool application consists of three components:

- **Geoprocessing model** (script), or the analytical part of the application, which solves a partial problem. This model processes the input data set, or the polygon specified by the user, and together with static data stored (DTM, DSM) in the geodatabase performs subtasks that lead to the result (output).
- **Geoprocessing service** – a service running on ArcGIS for Server using the above geoprocessing model to calculate the analysis. This service defines the input and output data, where the input in our case is a user-defined polygon and the output are tables showing the total wood mass, mean DBH and mean height of trees as well as wind-related risk index to the surrounding vegetation.
- **Client application** – a web site created in the HTML code using Cascading Style Sheets (CSS) and dynamic part is programmed in JavaScript using libraries of ArcGIS API for JavaScript version 3.7. The application uses a tool bar titled Draw that supports functionality to create new geometries by drawing them: points (POINT or MULTI_POINT), lines (LINE, POLYLINE, or FREEHAND_POLYLINE), polygons (FREEHAND_POLYGON or POLYGON), or rectangles (EXTENT). With the help of that tool, a polygon (planned extraction site) can be drawn in the web mapping application. Once the polygon is completed, this event is captured using a script that sends the selected area to the geoprocessing service and ensures obtaining the result (ESRI, 2012).

For the purposes of better orientation in entering the site, underlying data from WMS of ČÚZK (orthophoto) and WMS (economic map, area of ALS data) are used. Individual legends and layers can then be switched on and off using the TOC widget (Table of Content).

After entering the clearcut using a polygon in the web browser, the entire geoprocessing application will take place on the server (the computation time depends on the size of clearcut, averaging at about 2 minutes) and the user receives back the query as a table with values of the number of trees in the planned clearcut, the total wood volume, mean tree height, and mean DBH. In addition to the table with the parameters of vegetation, a successful computing process is concluded also by depicting the detected tree tops within the planned clearcut. The last information obtained is the topographic exposure of stand edges of the created clearcut (high values indicate high exposure and vice versa) (see Fig. 5). The workable model is available on the address: http://arcgis.mendelu.cz/topex/.



5: *Graphical user interface of the COWRAS tool (with tree parameters and wind risk assessment in the table)*

DISCUSSION

The aim of the paper is not to address all aspects of the wind risk to forest stands, but to introduce a concept of precision forestry tool that would focus on the optimization of the shape and size of clearcuts in forest recovery so as to avoid endangering stand edges by wind and in order the shape and size of the clearcut after extraction created optimal conditions for the growth of newly established stands. The occurrence of destructive winds and their consequences, in spite a high number of studies, are still rather incidental and despite many available models of wind behavior and knowledge of a number of factors that affect the stability of forest stands, it is not possible to predict the resulting impact and damage to forest vegetation. Although previous studies clearly show lower stability of certain tree species (e.g. spruce monocultures) and in case of wrong way of management, as demonstrated by experience, strong winds often damage also theoretically stable vegetation with natural species composition. It is mostly due to the badly designed process of forest recovery which may be one of the major factors that lead to the resulting damage. Inappropriate shape and orientation of clearcuts on the one hand increase the possibility of wind acceleration and hinder the free flow. Although models for evaluating wind risk to forest include more factors and can thus achieve much higher prediction accuracy, they are rarely usable in practical forestry at a specific step of forest recovery due to the amount of input data and the complexity of the computation. Results of the work in the form of a model to optimize the shape and size of clearcuts demonstrate that a combination of modern technology for spatial data collection and processing in GIS allows to simplify and improve processes for planning activities in forestry, because despite the best knowledge of a forester in planning forest recovery, a human being is not able to comprehensively evaluate the effect of environmental factors and their resulting impact. Exposure of the created stand edges can be affected not only by the surrounding landscape, but also by the surrounding vegetation and definitely the right location, orientation, and shape can have the greatest impact on minimizing the damage. Although the model at this point does not include other factors, such as different tree species resistance to wind and soil conditions of the site, in the future these factors as well as specification of species composition in terms of trees or groups of trees shall also be included.

In harmony with previous studies, identification of trees and counting the total harvested wood mass using the ITD achieves relatively good results, nevertheless, use of this method for a particular case is disputable. Although the ITD method compared to ABA allows getting a general idea of the number of trees, according to recent studies ABA achieves more accurate results and has lower requirements on the density of ALS points. Given the currently very little use of forest inventory from ALS data in Central Europe, the results must therefore be taken as indicative only and this area will be further examined. In the future, using the tool in a certain forest unit will always require calibration measurements or creating growth models.

Despite these objections, it may be concluded that the commissioning of COWRAS model in ArcGIS for Server enables practical use of even seemingly complex models for almost everyone and can thus help in practical planning of forest recovery. A fundamental drawback for larger deployment of similar tools of the so-called precision forestry is at the moment both, a certain conservative approach of traditional forestry and also persistent lack of ALS source data. This situation will be partly solved by the availability of data from CZECH OFFICE FOR SURVEYING, MAPPING AND CADASTRE (COSMC), in the near future, however, an overall rather significant reduction of price for ALS data and related higher use of similar tools and applications can be expected, as could be seen in neighboring states. The next logical step for better use is creation of mobile applications, when entering the shape and size of the clearcut will be mediated directly in the field based on GNSS measurements and transferred to the server using data connection and the calculated parameters of the extracted wood mass and wind risk will be returned.

CONCLUSION

Results of this research demonstrate that airborne laser scanning data are a highly suitable source of data for the description of vertical structure of vegetation. DSM from LLS data plays an important role in the final result of analyses in case of both, inventory stock based on ITD as well as computation of the topographic exposure, when it is possible to determine the effect of each individual tree top. Implementation of the tool in ArcGIS for Server allows the use of sophisticated methods and GIS analysis by a normal user as well just via access using a web browser. This eliminates not only the requirements for ability to use certain software, but also the cost of purchasing software and staff training. Based on the analysis repetition, it is possible to choose the most suitable site for planned extraction with regard to the required amount of wood mass harvested with minimizing the risk of damage to surrounding vegetation caused by wind.

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