

## IDENTIFICATION OF WET AREAS IN FOREST BY USING LIDAR BASED DEM

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Water tends to flow and accumulate in response to topographical characteristics of local area and gravitational potential energy. Remote sensing data like LiDAR (*Light detecting and ranging*) or satellite data can be used to identify local depressions where wet areas may occur. The aim of this study was to evaluate methods that can be used to identify wet areas, to determine correlation between topography of the area and forest regeneration and to prepare proposals for forest management that could be usable in Latvia. Study area includes fertile forest land on wet mineral soils and drained mineral soils with planted spruce (*Picea abies*) and available LiDAR data. Map examples have been made to demonstrate methodology which allows to identify depressions with potentially hindered run-off. *Fill sinks* algorithm has shown best results in identifying wet areas and correlation with wet areas that were detected in field studies is 62%. TWI index is not suitable for this study because of relatively flat area. Result of this study reveals that wet areas have significant effect on tree species. In depressions, despite the fact that there has been planted spruce, main species are birch (*Betula pendula*) and black alder (*Alnus glutinosa*). Wet areas have significant effect on tree height.

*Keywords: Depressions, fill sink, GIS.*

### INTRODUCTION

Poorly drained and wet soils are challenge in forestry, agronomy and similar fields (McNabb *et al*, 2001). Wet areas are important for various habitats, biodiversity and for water exchange and chemical processes (Detenbeck *et al*, 1999), thereby it is important for sustainable forest management to know exact locations of those areas (Moore *et al*, 1991). Information about wet areas helps to improve land management and to avoid operational incidents like rutting and soil compaction (Curzon *et al*, 2013), and their associated environmental and financial costs (Christensen *et al*, 1996). Riparian buffers can be used to protect surface waters from harm by harvesting and have become the norm in freshwater ecosystem protection in Northamerica (Richardson, 2012)

Surface topography is important for hydrological processes and different topographical indices are in use to describe spatial distribution of soil moisture. Groundwater flow often coincides with slope of the hill. Groundwater flow direction is important for soil forming processes (Burt *et al*, 1985; Zinko *et al*, 2005). Stream network extraction from DEM (digital elevation model) is common practice for surface water flow modelling, which in combination with Depth-to-Water mapping can be used in determination of wet areas (Ågren, 2015).

Topographical wetness index (TWI) is developed by (Beven *et al*, 1979). It represents catchment topography by means of a topographic index,  $\ln(\alpha/\tan\beta)$ ;  $\alpha$  is the area draining through a grid square per unit length of contour and  $\tan\beta$  is the average outflow gradient from the square. TWI can be used to describe spatial distribution of hydrological and chemical processes (Robson *et al*, 1992), biological processes (White *et al*, 1994), vegetation (Moore *et al*, 1993) and forest stand vitality (Holmgren, 1994).

Surface topography is also important for soil pH (Högberg *et al*, 1990). Soil moisture and pH are important indicators that affects spatial distribution and diversity of vascular plants in Nordic boreal forests (Sørensen *et al*, 2006; Zinko *et al*, 2005) in their study by using TWI explains 52% of plant species diversity variation in forest stands with relatively high soil pH and 30% of variation in forest stands with relatively low soil pH. Geographic Information Systems (GIS) software has become important processing tool in several fields. Fill sinks is an algorithm that is often used in hydrological modelling to discern flow direction. Fill sinks algorithm 'fills' depressions in digital elevation model (DEM)

to correctly calculate flow direction, otherwise streams would flow into depressions and never flow further (Jenkins *et al*, 2006). In this study to fill depressions we use method that is proposed by Wang and Liu, which uses concept of spill elevation (Wang *et al*, 2006). After filling depressions in DEM and further processing data it is possible to get spatial information about depressions. Information about depressions is useful in managerial decision making processes.

Maps of wet areas are already in use in Sweden, where soil damage (rutting, soil compacting) by logging process is halved since methodology is transferred to practice. Information about wet areas is mostly used in heavy forest machinery routing. One of most successful commercial tools is software program Best Way, which is developed by Sweden forestry research institute Skogforsk (Johansson, 2015).

## MATERIALS AND METHODS

### Sample plot empirical survey

To verify modelled data, 30 sample plots have been made in young forest stands on wet mineral soils and drained mineral soils (Figure 1). Total area of 85 ha has been studied both in depressions and control points. Sample plots have been placed in depressions which are at least 250 m<sup>2</sup> large and data about tree species, diameter and height were collected. Results were compared with existing database tree parameters. Empirically borders of depressions were tracked by plant species in ground vegetation. Only in 2 sample plots plant species that are common in wet areas were not detected. Borders of depressions were tracked by using Garmin eTrex 30 GPS receiver.

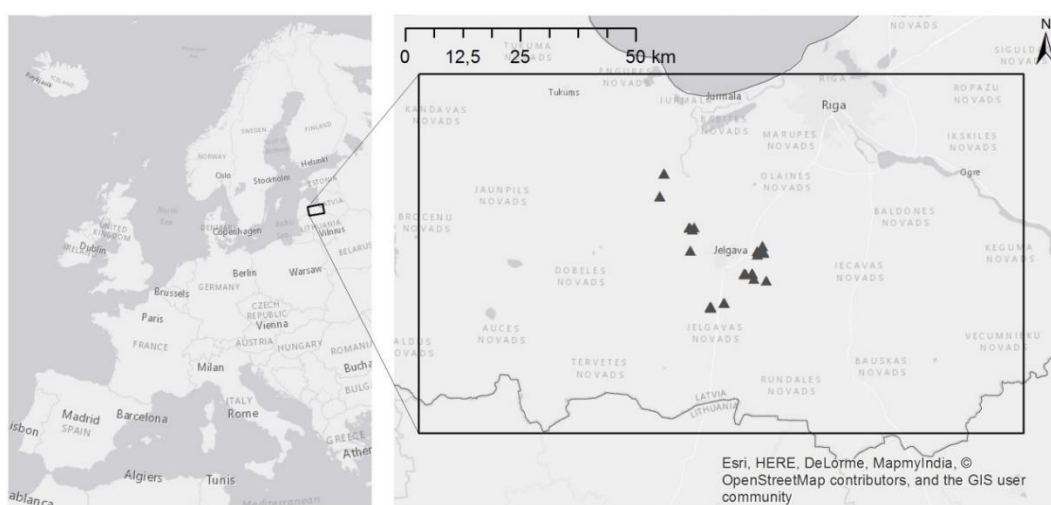


Figure 1. Location of sample plots

### Remote sensing

Two algorithms were used to identify depressions in DEM's. DEM's were generated from LiDAR data with average ground point cloud density at least 4 p/m<sup>2</sup>. Raster cell size were 2\*2 meters. For TWI index algorithm to work correctly it is necessary to correct DEM with Fill sinks tool. After correcting DEM's, flow direction, flow accumulation and slope were calculated. TWI were calculated by formula 1:

$$\ln('FLOWACC' * 900 / \tan('SLOPE')), \quad (1)$$

Other approach was fill sinks method, where, filled (modified) DEM were subtracted from original DEM. In resulting raster, values that were below 0 indicated depressions with potentially hindered runoff. For this method to work correctly it is necessary that sample plot areas are not on edge areas of DEM, because algorithm may 'think' that runoff may happen over the edges of DEM. To avoid this problem, it is necessary to merge neighbouring raster mosaics. Before running this algorithm, it is advisable to check DEM for bridges, culverts, dams or similar objects, that in processing may block water runoff in places where it should not do it. If necessary, DEM should be corrected. After processing DEM, depressions were transformed to vector files and area and shape of them were calculated.

## RESULTS AND DISCUSSION

### Comparison of forest inventory in depressions and control sample plots

There is significant difference in results from survey and database in tree height and diameter, but not in growing stock. There is significant difference in tree (spruce) height between depression and control sample plots (Figure 2). Difference in tree species between depression and control sample plots are substantial – in depressions it's common that spruce is replaced by birch and black alder. Spruce population in depressions on average are 42 % down comparing by control sample plots (Figure 3).

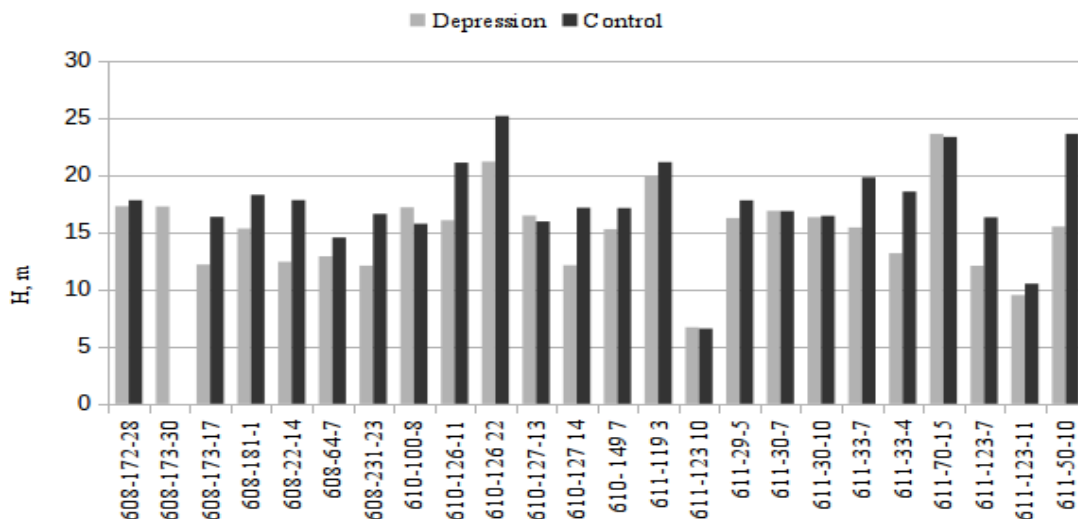


Figure 2. Differences in tree height between depression and control sample plots

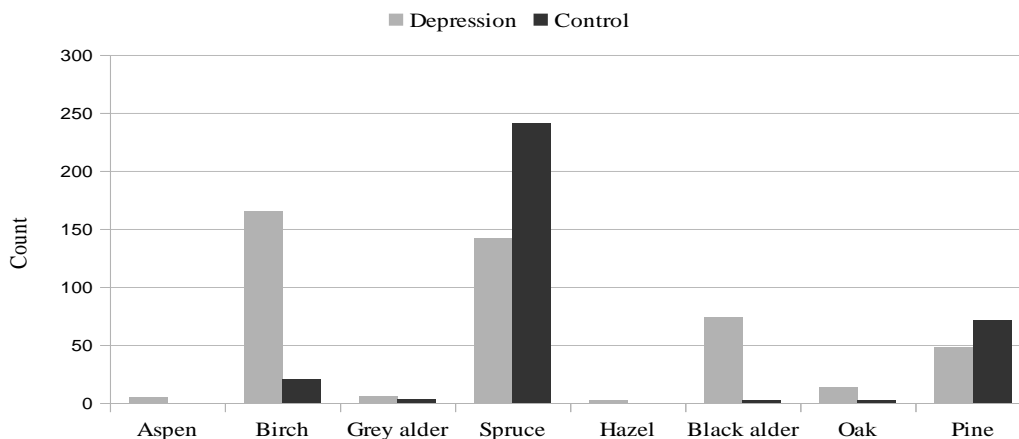


Figure 3. Common tree species in depression and control sample plots

**Analysis of remote sensing options in depression identification.**

Depression identification using DEM's made from LiDAR data is examined in different papers and is characterized as perspective. In this study, by processing LiDAR data, 29 depressions were selected and only 2 of them were not found in field works. By changing parameters of depression characteristics (area, depth) in processing and filtering data it is possible to get different depression characteristics. DEM data should be corrected to better represent natural water flow. Bridges, culverts and dams in LiDAR data are blocking modelled water flow, while in nature water may flow freely through these structures. Further study is needed to evaluate best parameters.

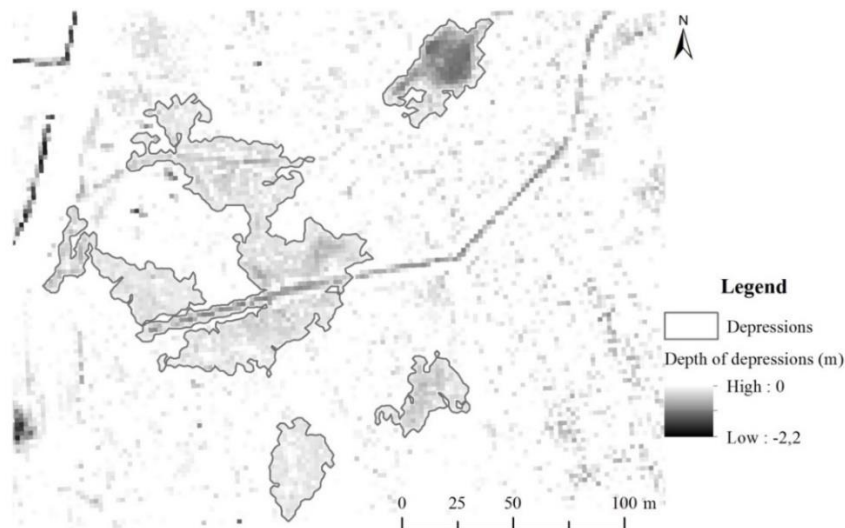


Figure 4. Example of map of wet areas

Example of wet area data is shown in Figure 4. In this area are couple of large depressions with probably hindered water runoff. In forest management this data can help in decision making for drainage system development. To better understand local water flow characteristics, information about soil properties (granulometry, density, filtration etc.) is needed.

#### Comparison of modelled and empirically detected depressions

Depressions which are at least 500 m<sup>2</sup> were modelled using Fill sinks algorithm. Minimal depth of depressions were selected as 0.05 and 0.02 m. Results shows that modelled depressions with minimal depth of 0.05 m overlaps empirically surveyed depressions on average by 47 % (a) (Figure 5). Depressions with minimal depth of 0.02 m overlaps empirically surveyed depressions on average by 62 % (b). Soil texture and infiltration properties should be implemented in future studies in order to correctly determine borders of wet areas.

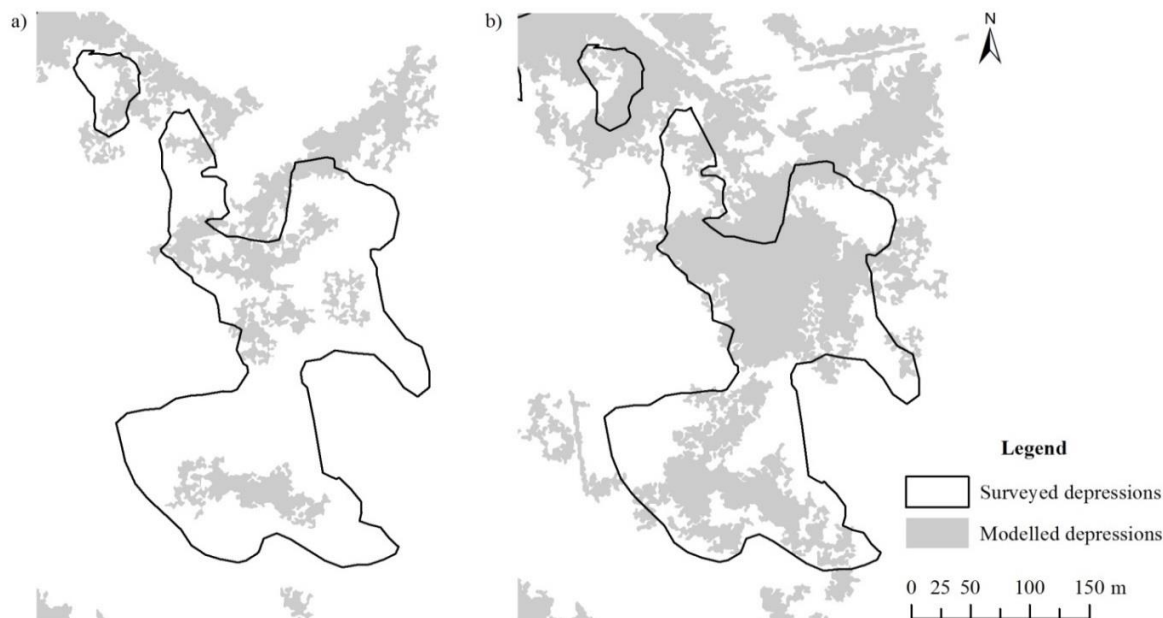


Figure 5. Comparison of depressions with different modelling parameters

Further studies are needed to evaluate different depression detection algorithms as well as capabilities of different remote sensing data. TWI index could not correctly detect depressions and potentially wet areas because of relatively flat area.

#### CONCLUSIONS

Detection of depressions using LiDAR data and already available algorithms is perspective and useful for management and planning of forestry activities. Results shows that there is significant differences in tree species and tree height in depressions and control plots. To take full advantage of options provided by LiDAR data, methods of data processing and analysis have to be improved. Different remote sensing data should be applied to characterize changes in tree species composition and soil moisture.

Field studies showed that there was large variability in modelling precision in configuration of wet areas. Information about soil characteristics should be implemented in future studies in order to understand rate of potential infiltration and water regime in depressions. It is important, because in different soil settings and climate conditions, depressions and riparian buffer zones may be in different shapes and some parts of depressions may be dry and trafficable.

To improve used methods, water flow and accumulation should be modelled, to better evaluate locations of water concentration. Information about water flow characteristics would be useful in drainage system planning.

#### ACKNOWLEDGEMENTS

The study is implemented within the scope of the Forest Sector Competence Center project No. 1.2.1.1/16/A/009.

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