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Climate change mitigation potential of trees in shelter belts of drainage ditches in cropland and grassland

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Latvian State Forest Research Institute SILAVA

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REPORT

Spatial tool for monitoring of tree growth and carbon stock changes in "biomass factories" using LiDAR and radar data (how to use package of vector data) [1]:

Salaspils, 2023

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1 V01 – after acceptance or improvements suggested by by ERDF experts will be published online with ISSN number, first published online 2023-11-29 on https://www.silava.lv/en/research/active-projects/climate-change-mitigation-potential-of-trees-in-shelter-belts-of-drainage-ditches-in-cropland-and-grassland

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Introduction

Availability of high resolution terrain data (LiDAR) and satellite data, as well as quick development of UAV technologies provides new possibilities for innovations in management planning of the shelter belts, particularly identification of areas with exceeding moisture, structure of run-off water streams, planning of harvesting and deliveries of biomass and monitoring of the growth and identification of potential risks (Glendell 2012; Ivanovs et al., 2017; Ivanovs & Lazdins, 2018). The assessment of biomass quantity within a forest stand is imperative for landowners to make informed decisions regarding the valuation and utilization of their forested land. Numerous methodologies for quantifying biomass, particularly utilizing remotely sensed data such as LiDAR data, have been rapidly disseminated, exhibiting escalating intricacy and a diverse array of techniques. LiDAR data prove to be well-suited for biomass estimation, given that point clouds generated from forest canopies can accurately represent the physical attributes of the canopy surface. These physical attributes exhibit correlations with biomass and can be statistically modeled against variables such as diameter at breast height or biomass, thereby facilitating the development of comprehensive LiDAR-biomass models.

Accurately estimating biomass on an individual tree basis represents a significant step forward in precise forest biomass analysis. Moreover, the fundamental comprehension of specific ecological processes, such as the influence of environmental factors on tree growth and competition among individual trees, relies on the evaluation of forest biomass and dynamics at the individual tree scale. The challenge lies in extending the replication of forest biomass estimation from the individual tree scale to broader scales, encompassing populations, communities, ecoregions, and even global assessments.

Materials and methods

Empirical data acquisition

For LiDAR data acquisition we used the DJI Zenmuse L1 laser scanner mounted on the DJI Matrice 300 drone. The estimated vertical accuracy for the scanner is +-5 cm and horizontal accuracy is 10 cm. Obtained point cloud density is 160 p m^{-2} and flights were conducted during on-leaf season in the year 2022.

UAV flights and LiDAR data as well as field measurements of woody crops for reference data were obtained in 45 objects throughout Latvia (Figure 1 Placement of research sites in Latvia.Figure 1).

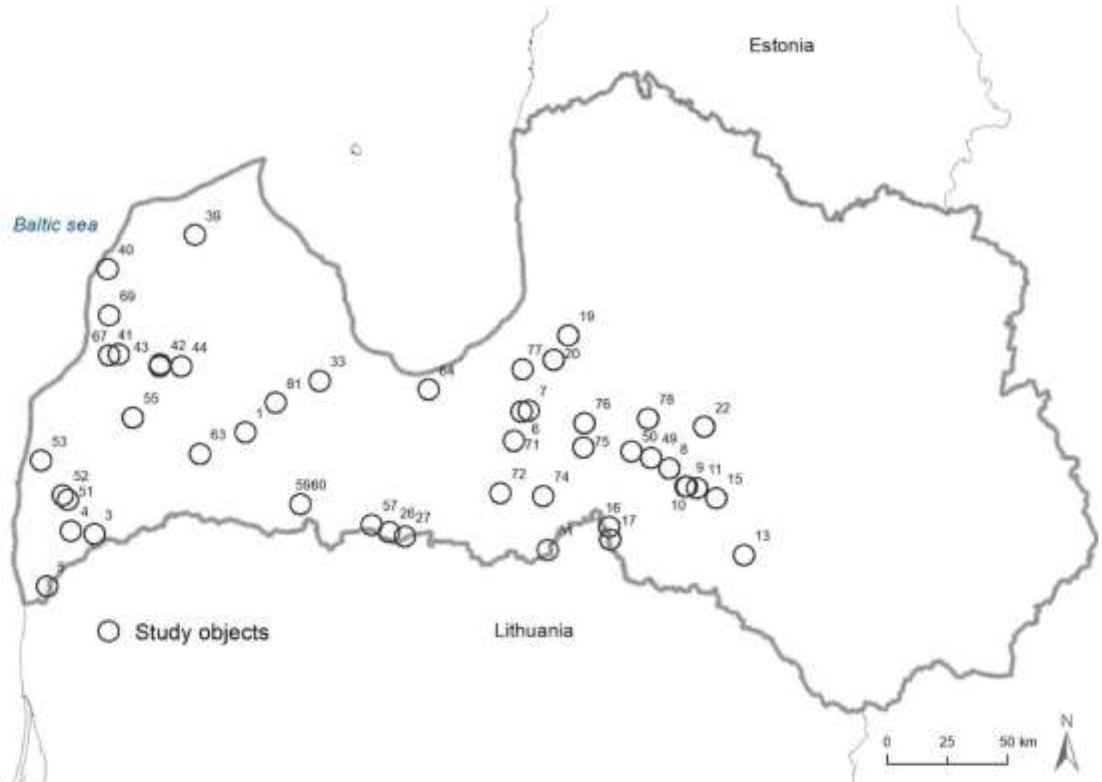

Figure 1 Placement of research sites in Latvia.

Manual woody crop measurements were done placing 3 plots located 250 m apart in one object. In the SW corner of the first sample plot, according to the Latvian coordinate system, the coordinates are determined, which were used for creation of the sample plot. Each plot is assigned a number depending on its location near the object. Each sample plot is formed in a 20 m long strip, and the width is determined - the width depends on the total width of the two slopes of the ditch in the respective object, forming a rectangular shape: from the arable row on one side to the arable row on the other side of the ditch and from the mowed part of the meadow on one side to the mowed part of the meadow on the other side.
Within the sample plot, all standing trees and bushes (living, dry root or stump) are measured, the diameter of which at a height of 1.3 m above the neck of the roots is at least 2.1 cm. Several parameters are recorded in the protocol:

- tree, shrub species;
- diameter at a height of 1.3m using a caliper (accuracy of 0.1 cm);
- height using a height measuring device, as Vertex (0.1 m accuracy):
- The height of the tree is measured from the point where the top of the tree can be seen exactly.

All trees and shrubs that are thinner than 2.1 cm at a height of 1.3 m are listed in the sample area, including the number by species, as well as the diameter and height of the visually selected average specimen. During the census, all the shoots that have grown from the ground or the stump and are at least 10 cm tall are counted.

Biomass calculations

In this study, we focus on the monitoring and calculation of above ground biomass, and for its calculation we use biomass equations previously developed and validated in Latvia (Liepins et al. 2021; Liepins et al.

2022). This equation is used to calculate biomass for individual trees and in this study we are using it as a reference data to elaborate LiDAR based ditch shelter belt biomass equation. Authors of this equation revealed that it is the most flexible with respect to the fit to the study data, in comparison to the linearized power functions, and ensured more accurate biomass estimations for most of the components. Breast height diameter is an essential predictor for the biomass estimations, whereas height alone tends to be less informative (Equation 1).

$$\text{Biomass, kg} = k \times \exp\left(a + b \times \left(\frac{D}{D+m}\right) + c \times H + d \times \ln(H) + e \times \ln(D)\right)$$

Where a, b, c, d, e, k are regression coefficients,
D is breast height diameter;
H is the height of the tree.

Remote sensing data processing

For the creation of a tool for assessing the height and number of trees in ditch shelter belts, using data obtained from an unmanned aerial vehicle and LiDAR, tools from a previously developed tool for processing LiDAR data were used (Ivanovs, Lazdins 2018; Melniks et al. 2019). In order to elaborate methodology to calculate height, number and biomass of the woody crops, a canopy height model (CHM) was created using a digital surface model (DSM) and a digital elevation model (DEM).
The canopy height model was created with a horizontal resolution of 0.1 m and further processed by adapting the methodology used to determine the height of trees from CHM (Ivanovs, Lazdins 2018; Melniks et al. 2019). The determination of local maxima in the digital surface model was performed to obtain a raster image from the CHM in which treetops are represented as local maxima. Using the sliding window principle, each cell in the newly created raster image is assigned a value corresponding to the maximum value in the CHM raster, at a distance specified by the user. Since the CHM raster cell size is 0.1 m, the local elevation (tree top) would have to be approximately 1 - 1.5 m away from another to be identified in the new raster image. In the developed model, these parameters can be adjusted depending on the condition of the shelter belt and the dominant woody crop height and density (Formula 1).

if((X[-1,-1] == X[0,0]&&(X[-1,0] == X[0,0])&&(X[-1,-1] == X[0,0])&&(X[0,-1]) == X[0,0])&&(X[0,1] == X[0,0]&&(X[1,-1] == X[0,0])&& (1)(X[1,0] == X[0,0])&&(X[1,1] == X[0,0]),X,null())

where X – raster of local maxima, numbers in square brackets are coordinates for neighboring pixels;
operator == means “logical equal”;
operator && means “logical and”.

In the next step the model processes the resulting raster image of local maxima and determines the locations of the highest points of all elevations in the area. Since trees are represented as clusters of raster cells in the local maxima raster image, the model finds the middle cell that indicates the location of the tree (Figure 2).

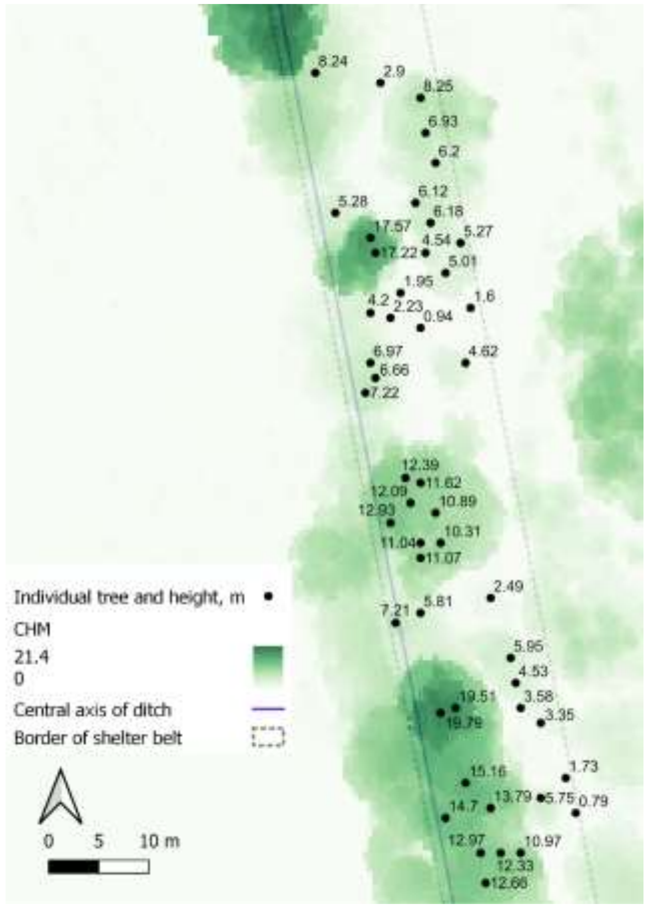

Figure 2 Sample area where individual trees and their height are extracted from LiDAR data.

Next step after identification of individual trees in the ditch shelter belts is to estimate the density and count of shrubs in the second floor. It is essential to do so also if the height of the crops in the sample plot is lower than 5 m. It is done by using *K Means Clustering* in QGIS software. This tool does segmentation of the specific height of the woody crops which is then used to estimate the number of shrubs using reference data.

After extraction of most essential parameters (height and number of woody crops) for biomass calculation are extracted from LiDAR derived models, regression analysis to estimate diameter, sample plot basal area, volume and biomass are performed using ground truth data.

Results and discussion

Analyzing relationship between measured individual tree height and diameter, the R^2 value of 0.8058 suggests that approximately 80% of the variability in tree height is explained by the variability in tree diameter according to this regression model (Figure 3). These results are representing all of the trees in the ditch shelter belts measured in our study.

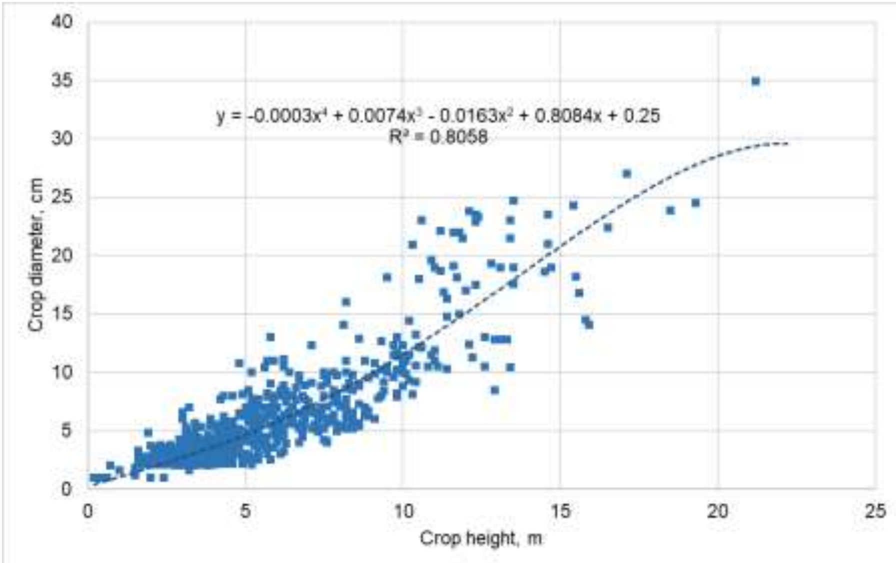

Figure 3 Polynomial regression between individual measured woody crop height and diameter in ditch shelter belts.

We found quadratic regression which implies that the relationship between tree volume and above-ground biomass is not strictly linear but involves a quadratic component (Figure 4). The positive coefficient for the quadratic term indicates that the relationship is curvilinear, with an increment in above ground biomass as sample plot volume increases.

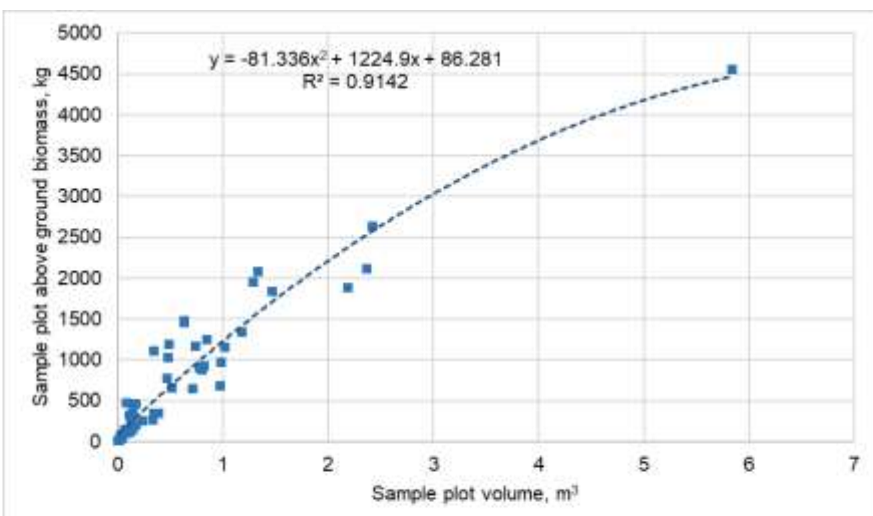

Figure 4 Polynomial regression between plot volume and above ground biomass.

Using correlation analysis, we identified the most important factors in both groups of woody crops, which have the highest importance in biomass calculations considering individual parameters. In plots where the diameter of woody plants is over 2.1 cm, the most important factor for biomass calculation is the basal area, which in turn requires the diameter and number of trees in the plot. In plots where the diameter of woody plants is below 2.1 cm, the most important factor for biomass calculation is only the number of trees, the assessment of which is based on cluster analysis using the canopy height model and the regression equation with field measurements (Figure 6).

In sample plots, where mean tree diameter is higher than 2.1 cm, equation with plot basal area explains more than 92 % of the above ground biomass, but in sample plots where crop diameter is less than 2.1 cm, number of crops explains 92% of the basal area which is then used for biomass estimation.

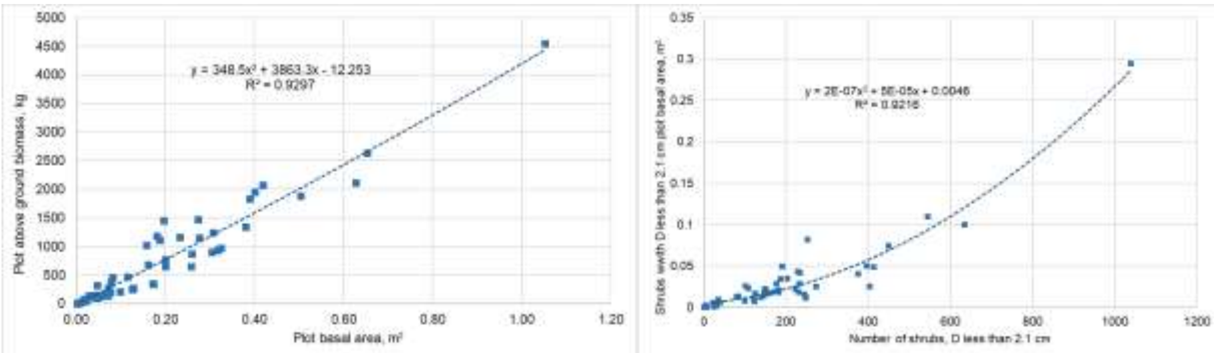

Figure 5 Left - Polynomial regression between basal area and above ground biomass. Right - polynomial regression between basal area and above ground biomass in crops with diameter less than 2.1 cm.

To estimate crop parameters from LiDAR derived variables, analysis is done in the plot level. In order to obtain an equation to calculate plot average crop diameter (in crops with diameter higher than 2.1 cm), we used a regression equation created from field measurements (Figure 6). Results show, that analyzing sample plot mean height and diameter, height explains almost 91% of diameter values which is approximately 10% more than using individual tree heights.

Modelling plot mean breast height diameter, model explains 83 % of the cases, but tends to underestimate.

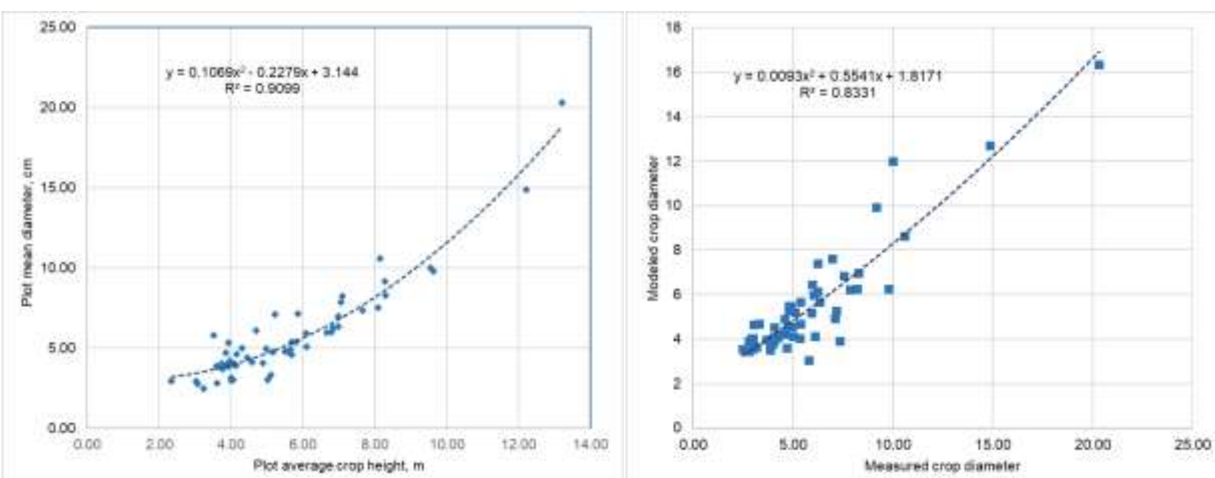

Figure 6 Regression equation (left) for plot mean diameter calculation using mean height. Right - regression between measured and modeled crop diameter.

Referring to the previous analysis, another important factor for calculating basal area and biomass is the number of trees. In both cases, both for trees whose average diameter is below 2.1 cm and for those above, the regression model explains more than 90% of cases, respectively, 94% and 97%, but in both cases it significantly underestimates the number of trees in most of the cases. High R^2 value but underestimation means that it is constant in most on the plots due to high density and variability on the species and composition (Figure 7).

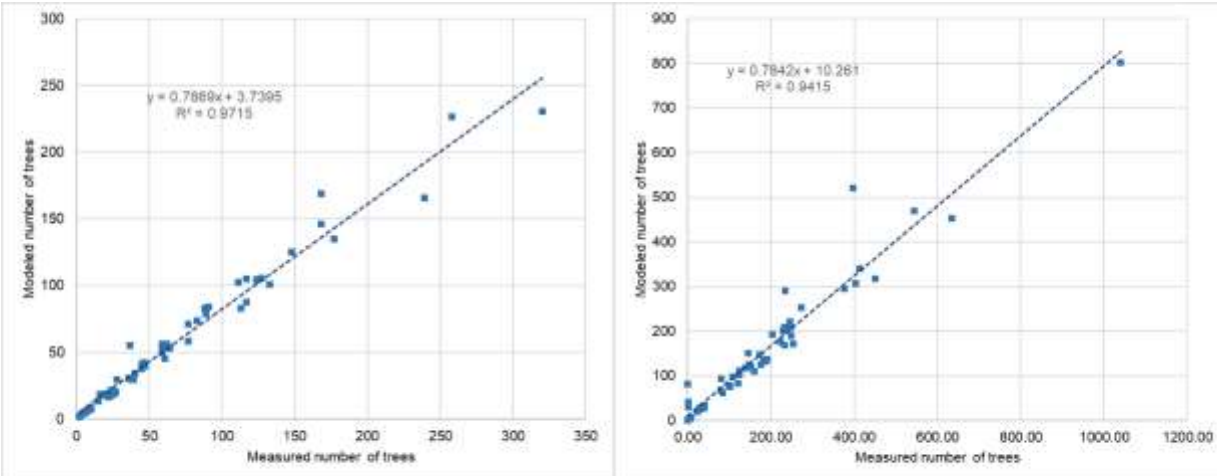

Figure 7 Left - regression of measured and modeled count of the trees with diameter higher than 2.1 cm, right - with diameter less than 2.1 cm.

Using previously calculated parameters from LiDAR data, we performed biomass estimates and also compared them with direct field measurements. Relatively high accuracy was obtained when the calculation was made at the plot level, and the model explained biomass in 76% of the cases of woody crops with a diameter above 2.1 cm and 78% of the cases for crops with diameter less than 2.1 cm (Figure 8).

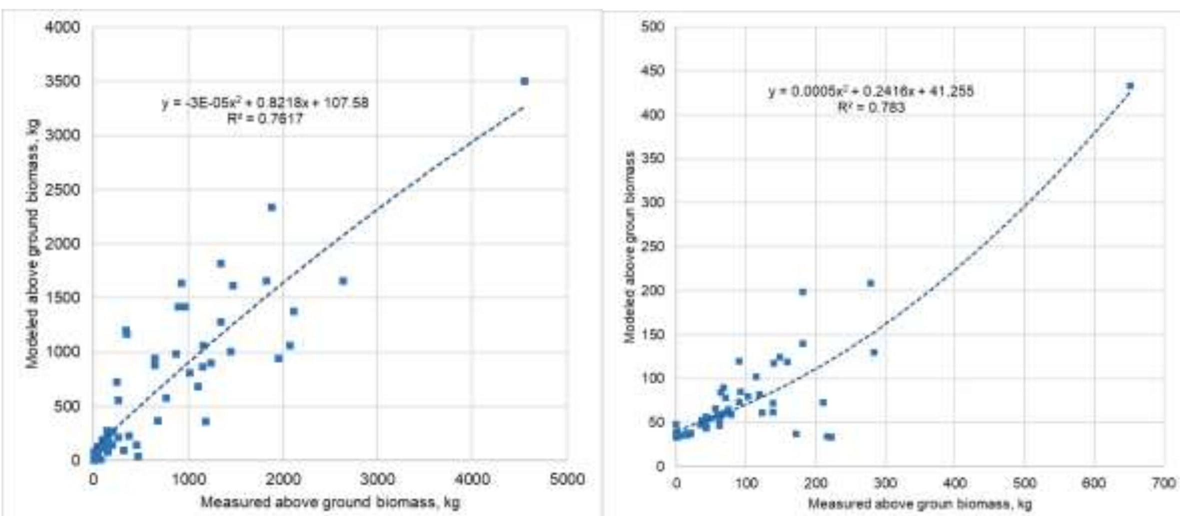

Figure 8 Left - regression between modeled and measured above ground biomass in crops with diameter higher than 2.1 cm, right - crops with diameter less than 2.1 cm.

Analyzing total above ground biomass in the sample plots, total uncertainty combines and accuracy reduces to 70% of total explained cases. In most of the sample plots (where mean crop height and diameter is low, and number of crops is higher), model underestimate total biomass.
Considering this, the most important factor that limits the accuracy and introduces underestimation in the accurate estimation of the number of trees using LiDAR data (Figure 9).

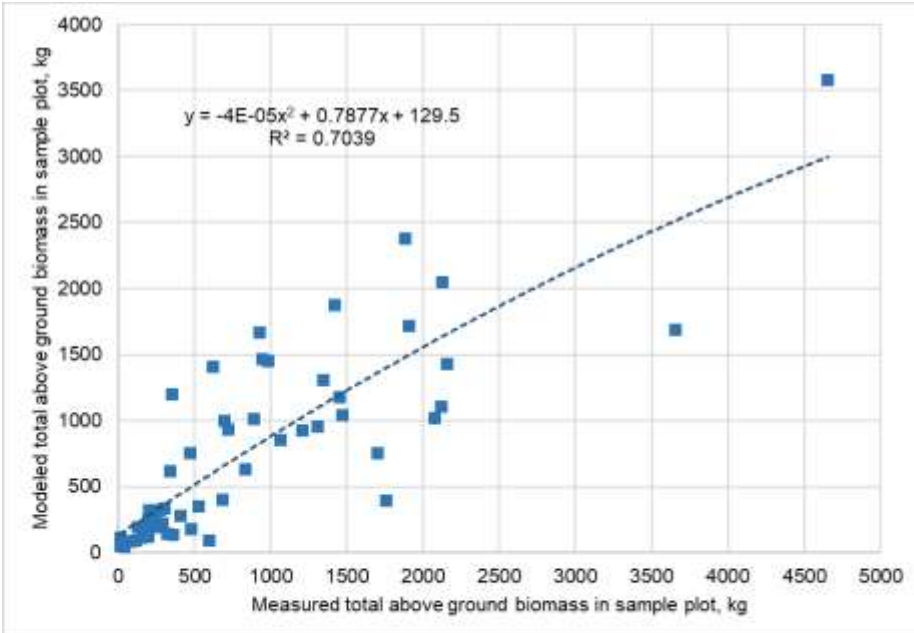

Figure 9 Regression between measured and modeled total ABG biomass in sample plots.

Discussion

Using a similar methodology, researchers (Melniks et al. 2019; 2018; Ivanovs 2023) have come to the conclusion that the accuracy of the model in determining the height of trees, especially in the leaf on season, is 90 - 97% and in most cases the model underestimates the height of trees. Ivanovs et al. 2023 reveals that The results show that for a universal forest stand height model, the RMSE value is 1.91 m and the MAE is 1.41 m. For the forest stand height models, which are stratified by scanner, individual tree species and seasons, the RMSE value is within the limits of 1.4 m for forest stands dominated by Scots pine in leaf-on canopy condition to 3.8 m for birch in leaf-off canopy condition. It should be noted that this type of methodology has been tested using LiDAR point clouds with significantly lower point density. In this study, using LiDAR data with a significantly higher point density (160 p m^{-2}), we achieved similar accuracy in determining tree height. It should be noted that in the mentioned studies, as well as in other equivalent ones, the height of trees was determined in mature and well managed forest stands, not in poorly managed ditch sides, which significantly affects the obtained results.

Other studies (Salum et al 2020; where forest biomass is estimated using LiDAR data, shows 15 – 35 % errors. For example, (Gleason et al. 2012) reveals that the accuracy of the crown delineation used to generate predictor variables affects biomass estimation differently depending on the scheme that is employed and further work is needed to assess the relationship between crown delineation accuracy and biomass estimation for both individual tree and plot level estimates of biomass. Which are comparable conclusions to ours.

Research did by Knapp et al. 2020 reveals relatively higher accuracy for biomass estimation R^2 0.74 – 0.78. In this study Data from temperate and tropical forest plots was combined to develop a general equation for biomass (and basal area) estimation based on a set of forest structure metrics from LiDAR. The different structural predictors were defined for biomass calculations but Not all of those forest attributes can be derived from LiDAR data. For maximal stand density and mean wood density field-based information is required at the site level. All of the studies points that extraction of all parameters needed for more accurate biomass mapping are challenging to obtain and further studies in this field are needed.

Conclusions

Using high-precision LiDAR data, it is possible to determine the height of trees in ditch shelter belts with an accuracy of more than 90%, which is very important for directly repeated monitoring of these areas in order to evaluate the dynamics of the development of woody crops.

The number of trees can be calculated with 70-80% accuracy, taking into account the high heterogeneity of ditch shelter belts and the various composition of trees.

Using parameters derived from LiDAR, it is possible to calculate such important parameters of tree plantations as basal area and stand volume.

The biomass of the first and second floor of trees can be calculated with an average of 77% accuracy, while the total surface biomass is calculated with 70% accuracy, which is mainly affected by the underestimation in the diameter and number of trees.

Further research in this field to elaborate more accurate second floor of ditch shelter belt monitoring techniques are crucial.

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