Objective: The objectives of this exercise were as follows:

- To process laser data into commonly used laz format for forest inventory use.
- To visualize ALS data in a 3D viewer.
- To construct a map of forest area using area-based approach, and ABA modelling.
- To detect individual trees at the field plots and estimate their volume.
- To compare the accuracies of ABA and ITD in plot level.

Methods: The following main methods were used for this exercise, but are not described here in detail:

- Data preparation.
- Digital Terrain Models.
- Watershed segmentation (Canopy heigh models).
- Regression analysis, model accuracies, and their comparisons.

Results:

1. 3D visualization of a point cloud from the first plot (user data):

The las file was classified into 1 and 2 values classification: 1 as unclassified, and 2 as ground. For the analysis, the 1 unclassified value was further classified into user data as 0,1,2 and 3.

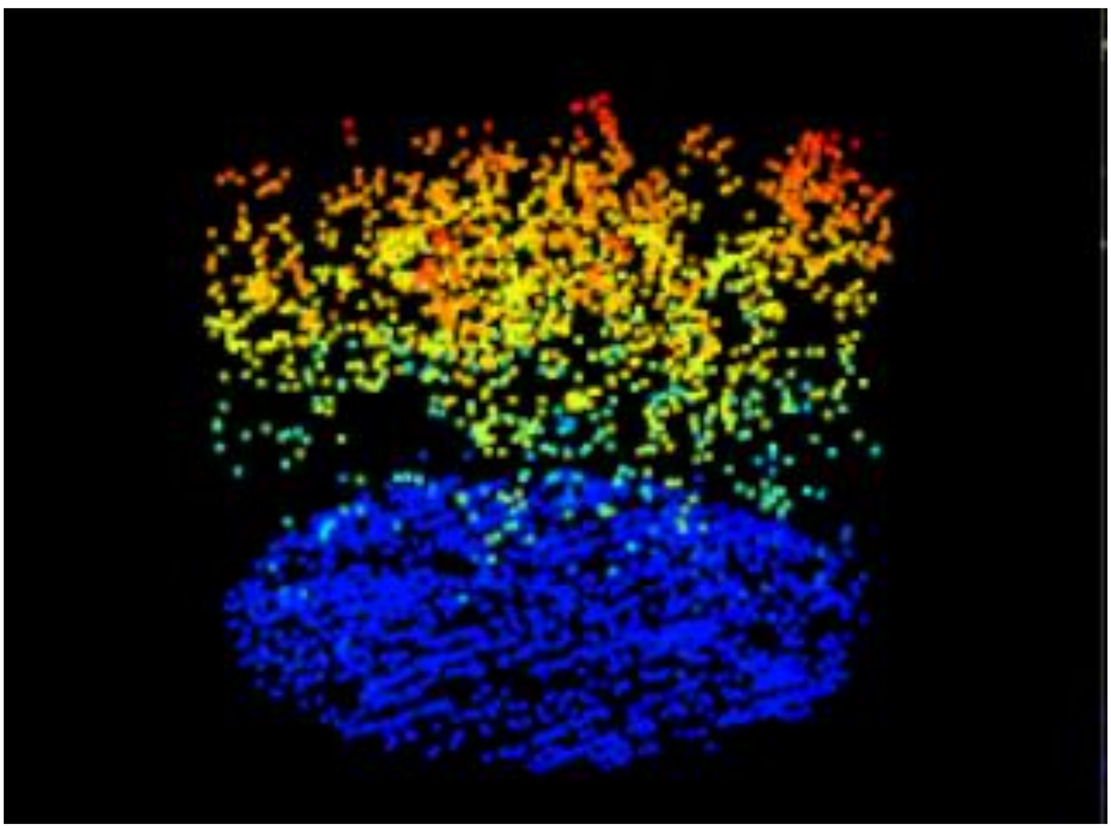

Figure 1:- showing 3D visualization of a point cloud from the first plot.

Here in Figure 1, a 3D visualization of 1st plot was done, where the ground was represented by blue color and the vegetation was represented by green, red, and yellow color.

2. Airborne laser scanning: Area-based approach (ABA):

2.1. Aerial image and predicted image comparison:

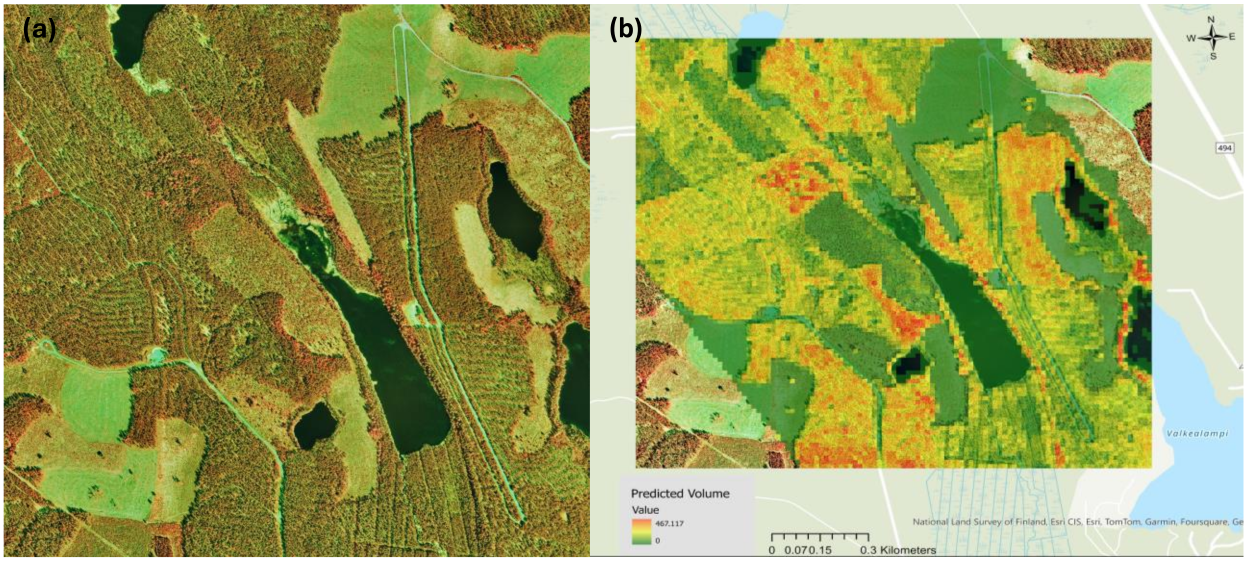

Figure 2:- Figures showing: (a) Orthomosaic aerial image, (b) ABA predicted volumes map overlaid in orthomosaic image.

Comparison between a and b: it is apparent that the predicted volume matches closely with the aerial image, representing the accuracy of the predicted volume to the actual vegetation. The redder color in Figure b represents the higher values of the predicted volume, and hence the predicted volume of the vegetation matches well with the aerial image (Figure a). This implies that the volume is predicted with great accuracy. Additionally, the non-forested land was also predicted accurately including lakes, farmlands, and barren land.

2.2 Linear regression model summary:

Model: Volume = 10557.025 + 27.758 * f_hmean - 15344.057 * l_p80 + 4773.840 * l_p40 (equation 1)

Model coefficients:

Table 1:- Table showing model parameters and significant level.

Coefficients	value	Standard error	t-value	p-value	R^2	r-RMSE	BIAS
Intercept	10557.025	2389.409,	4.418	$p < 0.001$	~0.96	0.076	-1.092235e-17
f_hmean	27.758	1.772	13.871	$p < 0.001$			
l_p80	-15344.057	3366.409	-4.562	$p < 0.001$			
l_p40	4773.840	986.684	4.555	$p < 0.001$			

The above-mentioned equation (1) is the volume prediction model of the area-based approach method. Here it can be said that the model makes sense as the model coefficients are all significant. Additionally, it can be said that predicted volume would be added;

1. by 27.758 with an increase of f_hmean per unit,
2. by 4773.840 with an increase of l_p40 per unit,
3. but decrease by 15344.057 with an increase of predictor l_p80 per unit.

After computation of the above equation (1) with all predictors total volume (wall-to-wall prediction) of the stands comes to 467.12 m^3.

2.3. <u>Scatter-plot between fitted values and residuals:</u>

Scatter-plot (a) shows the fitted values vs residuals of the model around horizontal line 0. Here it can be seen that the residuals are distributed evenly across the horizontal line, representing the homoscedasticity (not a clear homoscedasticity, but neither heteroscedasticity).

Figure (b) shows the fitted volume vs the observed volume of the model. The graph shows the predicted volume matches well with the observed volume for the values of 400, and from 0 to 200 values, but the values around 300 predicted less correspond to the values of fitted values. Additionally, the values do not deviate from the diagonal line depicting the accuracy of the model. Here, the more the values close to the diagonal line the less estimate/overestimate between prediction and observation.

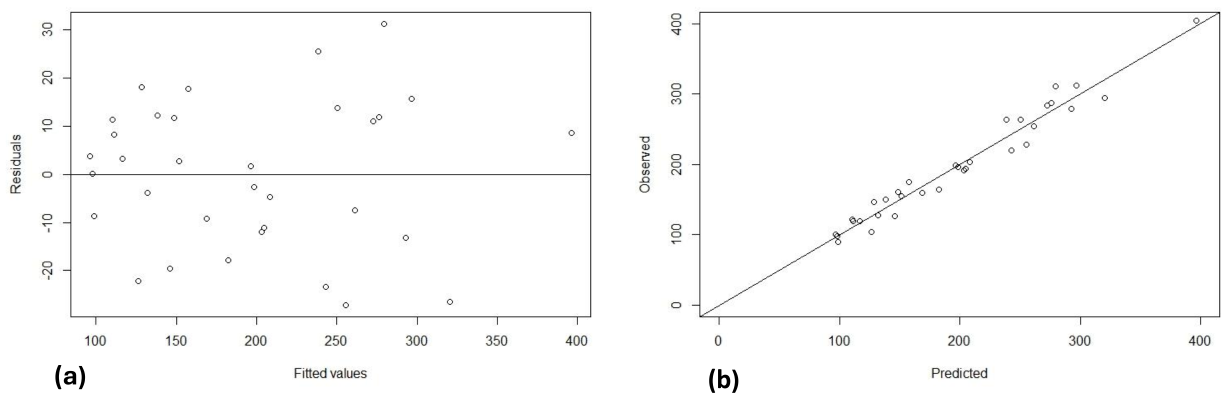

Figure 3:- Figures showing scatter: (a) plot between fitted values and residuals of the model, and (b) predicted vs observed volumes of the model.

3. Airborne laser scanning: Individual Tree Detection (ITD) approach:

3.1. <u>Linear regression model summary:</u>

Tree level model: log (Volume) = -11.57 + 3.53 *log(Height) (equation 2)

Model coefficients:

Table 2:- Model parameters and significant level

Coefficients	value	Standard error	t-value	p-value	R^2	r-RMSE	BIAS
Intercept	-11.57	0.06185	-187.0	$p < 0.001$	~0.937	0.629925	-0.018
Height	3.53	0.02488	141.8	$p < 0.001$			

Here the model (equation 2) describes the relationship between volume and height as logarithmic, in which as height increases exponentially volume also increases exponentially but following a logarithmic pattern. However, the height and volume relationship follow a linear relationship as shown in Figure 4 (a). The relationship is not perfectly linear but somehow follows a linear relationship describing a true phenomenon between height and volume variables. The scatter plot was constructed by converting the model into a linear format by backlog transformation. Figure 4 (b) shows the model residual plot, in which model residuals are scattered around the horizontal line (h=0). This implies that the model's variable follows a homogeneity of variance i.e., homoscedasticity.

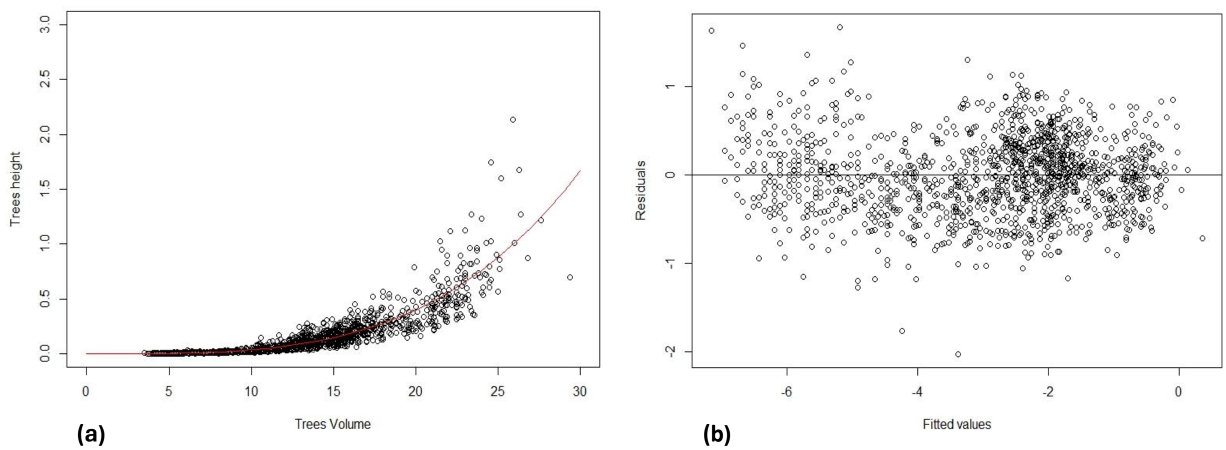

Figure 4:- Figure showing: (a) scatter plot trees height vs trees volume, (b) scatter plot residuals vs fitted values.

3.2. <u>Individual Tree Detection plot level results:</u>

In a comparison between predicted stem numbers and observed stem numbers, it can be observed that the most of values deviate far from the diagonal line (Figure 5, a). This implies that the stem numbers prediction is not predicted with great accuracy.

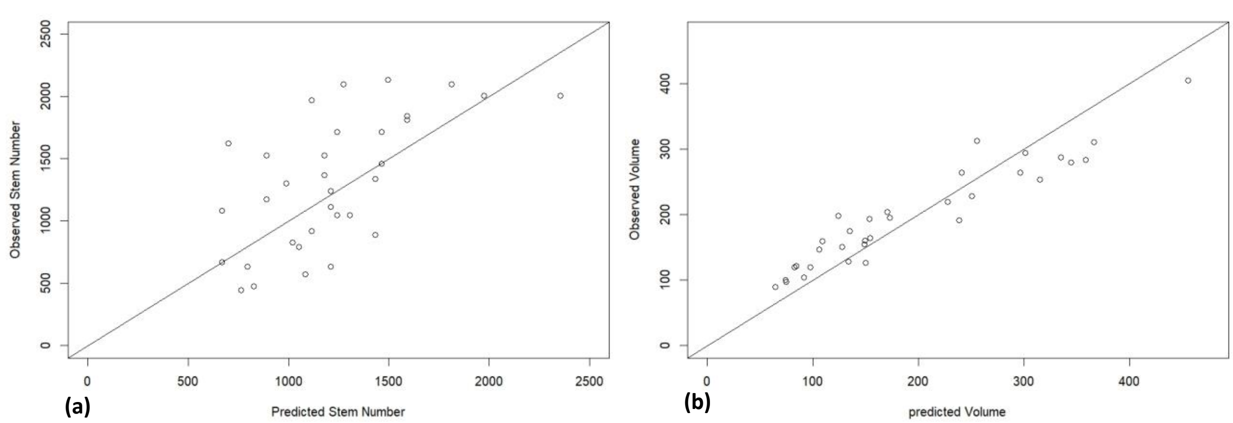

Figure 5:- Figure showing: (a) predicted stem numbers vs observed stem numbers, (b) predicted stem volume vs observed stem volume.

Overall, the individual tree detection method predicted volume more closely than the stem number prediction.

Table 3:- Plot-level volume and number vs ITD volume and stem RMSE.

Volume RMSE-%	Volume BIAS-%	Stem number RMSE-%	Stem number BIAS-%
0.2021075	-0.01887059	0.337903	-0.07278927

Table 3 shows the comparison between plot-level volume and stem number relative mean square error and bias percentages. Here it can be observed that the plot level volume and ITD volume differed by around 20.20% with a bias of -1.88 (-negative sign means underestimate), and stem numbers varied by around 33.73 % with a bias of -7.2 (underestimate). These numbers validate the graph above presented (Figure, 5), where values deviate away from the diagonal lines with underestimation.

Discussion:

A). Comparison between the Individual Tree Detection (ITD) approach and Area-Based Approach (ABA) at plot level:

In my case, the area-based approach was a much better approach than the individual tree detection method. First, the model used in the ITD method was logarithmic, which is a complex method in comparison to the area-based method. In modeling, a simple method is always preferred and the relationship between height and volume is linear. Additionally, model accuracies were also better with area-based methods (RMSE, scatter plots, and bias) as were evident above.

The reason behind the Individual Tree Detection being less accurate is that it is modeled using the canopy height model. CHM method could possess possible errors as it could not detect understorey vegetation, and hence the approach underestimates the prediction. Furthermore, ITD was less accurate as it estimates within small spatial spaces than ABA (discussed in B).

B) Condition when results were evaluated at stand level or estate level:

Normally, predicted errors can be aggregated at different levels including plot, stand, or estate level. This is also related to spatial scales as the plot level has a small spatial scale whereas the stand or estate level has a larger spatial scale. Errors get aggregated on a larger scale leading to a decrease in the variance of error of a small spatial scale. On a large scale, spatial errors of smaller plot levels are omitted (Kotivuori et al. 2021). This may lead to improving the model accuracy of ITD across stand level or estate level.

Reference:

Kotivuori, E., Maltamo, M., Korhonen, L., Strunk, J. L., & Packalén, P. (2021). Prediction error aggregation behaviour for remote sensing augmented forest inventory approaches. *Forestry (London)*, *94*(4), 576–587. https://doi.org/10.1093/forestry/cpab007