# Application Results of Handheld Mobile LiDAR Study in Turkey

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*Growth and Yield Innovations Conference*

# LiDAR Instrument-Handheld

| Technical specifications | |
|---|---|
| Maximum range | 30 m |
| Data acquisition rate | 43,200 points/sec |
| Laser wavelength | 905 nm |
| Scanner line speed | 100 Hz |
| Resolution, horizontal | 0.625° |
| Resolution, vertical | 1.8° |
| Angular FOV | 270°x360° |
| Supply voltage | 12V DC ± 10 |
| Supply current | max 1.5 A, normal 1.0 A |
| Power consumption | less than 20 W |
| Operating temperature | 0 ° to + 50 °C |
| Operating humidity | < 85 RH |
| Mounting operation | hand or vehicle mounted |
| Data storage capacity | 55 GB |
| Relative accuracy | 2–3 cm |
| Absolute position accuracy | 3–30 cm (1 loop) |

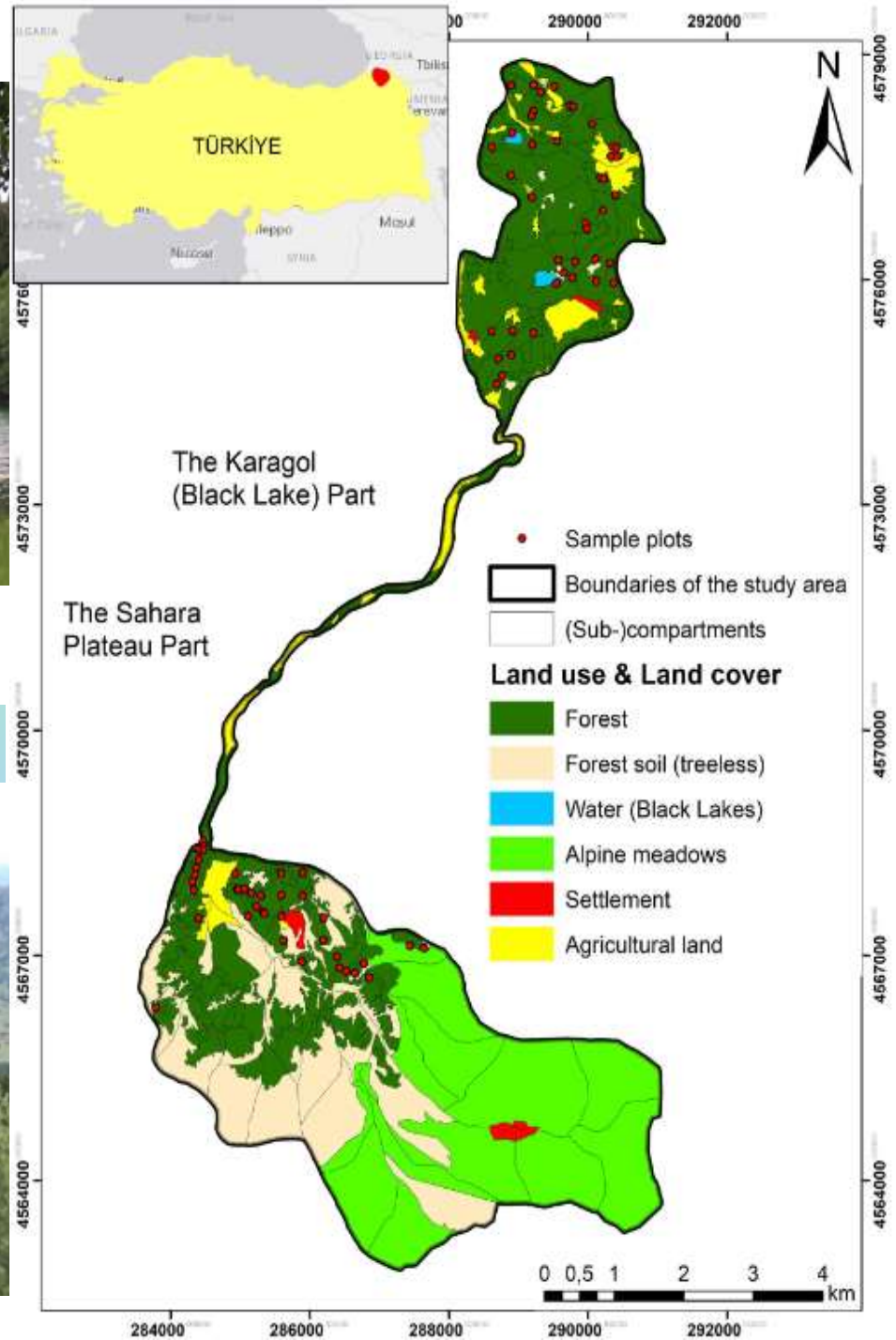
# Study Motivation

- Offering an automated technique,
- Showing how handheld LiDAR can be used in forest inventories,
- Comparing handheld LiDAR vs. traditional forest inventory methods.

# Study Area

- Karagöl-Sahara National Park
- Total 3245 ha
- Natural mixed, uneven and old growth forest
- Slope ~%50
- Elevation ~1300 m.
- A total of 1290 tree measurements were made in 39 sample plots
- Dominant tree species: Spruce, Abies, Poplar, Scotch pine, and Oak





# Data Acquisition

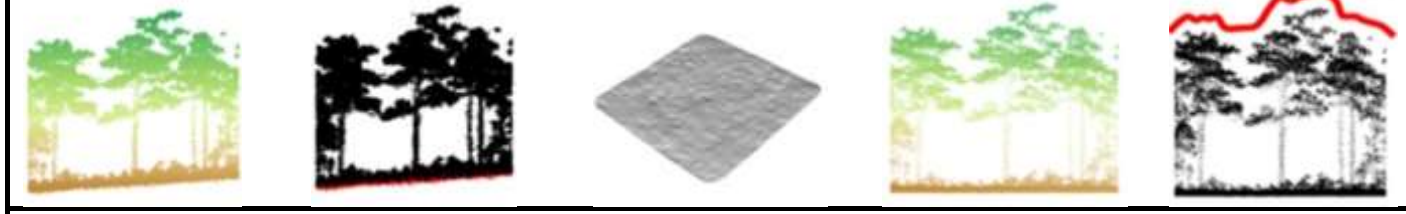
- Making **forest management plan in 2021**
- **Conventional** ground data surveying method
- Circular sample areas of **400-600-800 m²** according to crown closure
- Measurement of **DBH, total height, number of trees, crown closure and volume**

Handheld Mobile LiDAR Survey

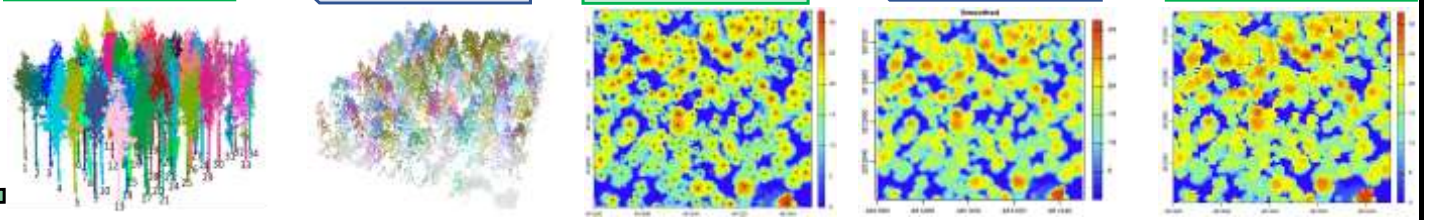
Ground Survey

# Workflow in LiDAR

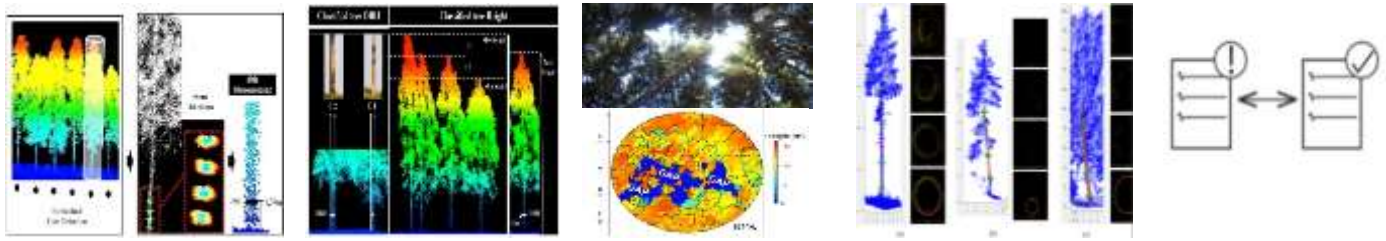
Handheld LiDAR derived 3D Point Cloud → Classify Ground Points → Build DSM and DEM → Normalize Point Cloud Heights → Generate Canopy Height Model (CHM)

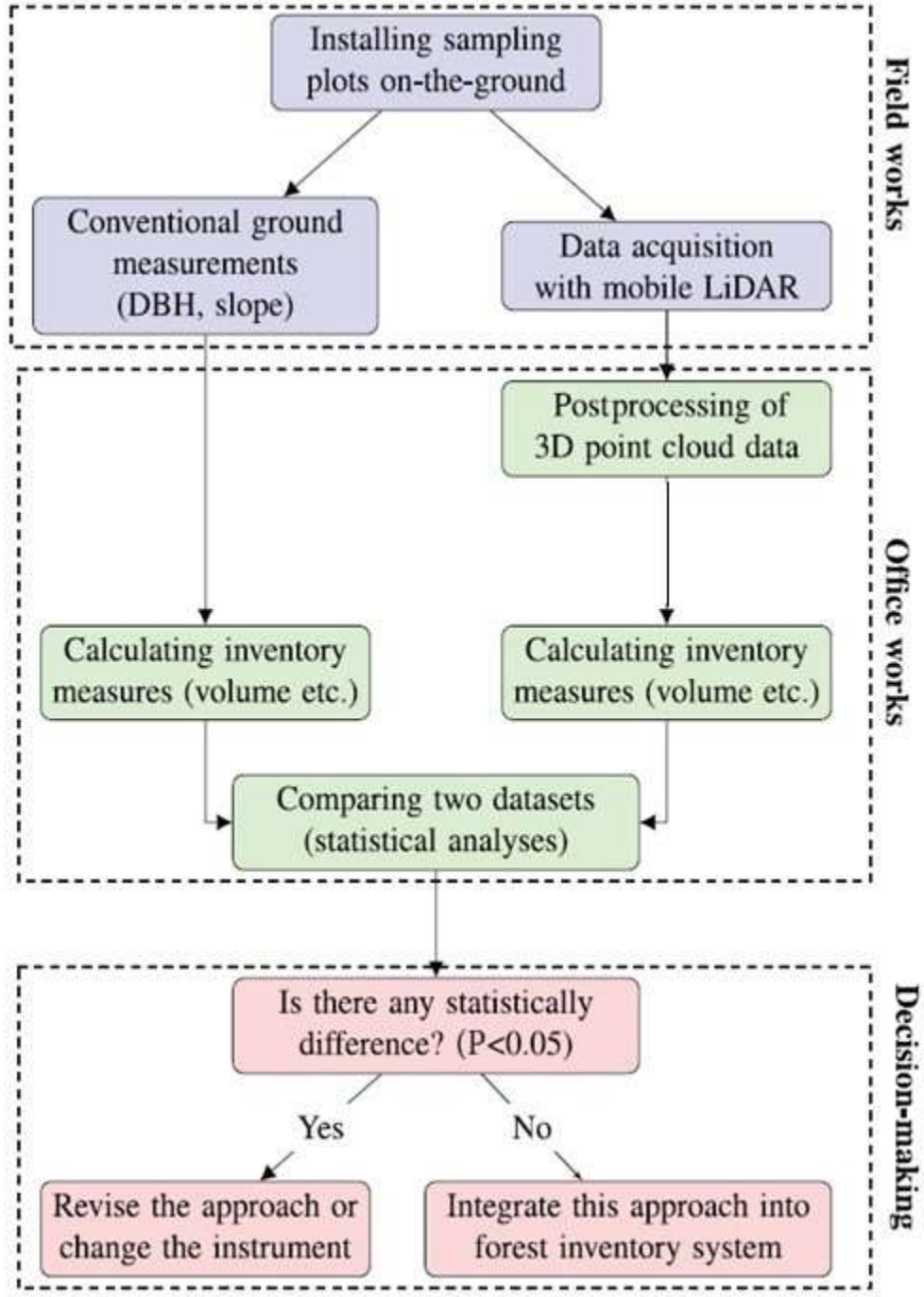


Generate Canopy Grid Model → Apply Smoothing of CHM → Detect Treetops → Individual Tree Segmentation → Number of Trees



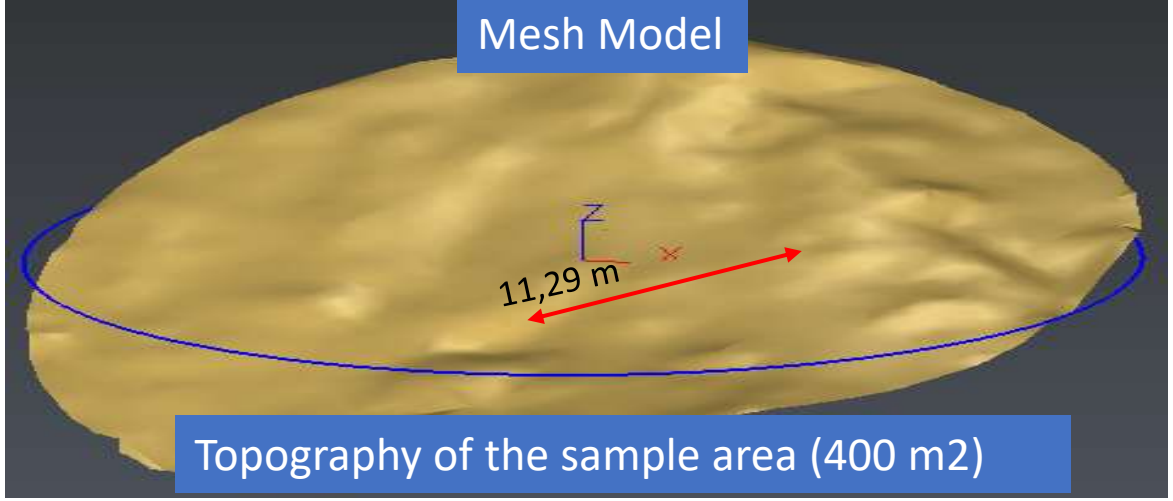
Data cut from $d_{1.30}$ and finding DBH → Tree Heights based on $Z_{values}$ → Tree Crown Closure → Tree Stem Volume → Validation Results

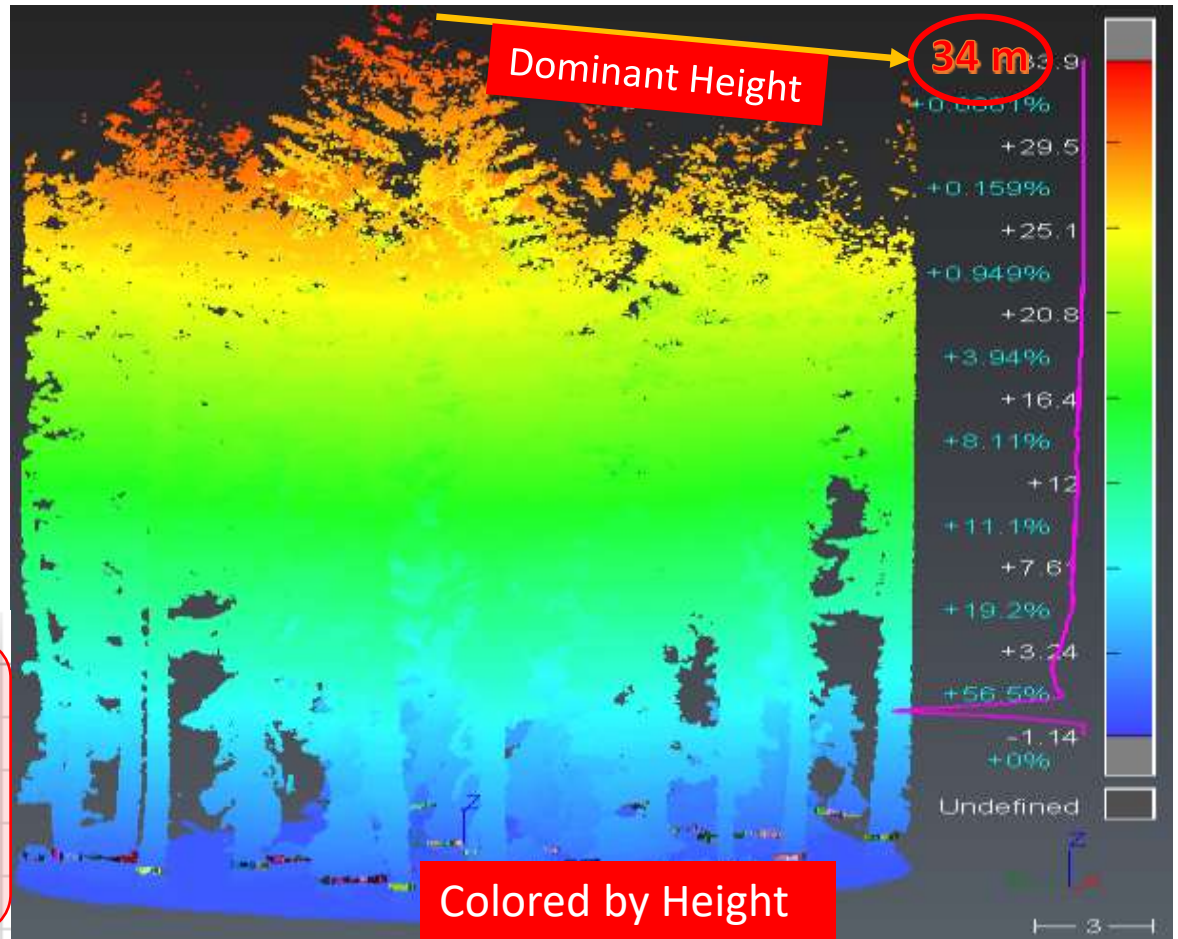




# Height

1. Normalized by *knnidw*(ground points)
2. CHM = DEM – DSM
3. Clipped area for mesh model
4. Tree Heights (m)
5. Dominant Height (m)
6. Reports;



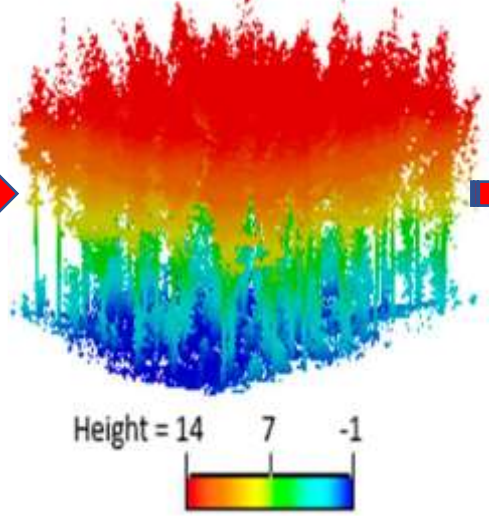




| A | B | C | D | E | F |
|---|---|---|---|---|---|
| Tree ID | X | Y | Radius | Error | H |
| 1 | 1,23484 | 7,852857 | 0,169538 | 0,029649 | 26,36734 |
| 2 | -0,54024 | 8,827336 | 0,135279 | 0,026415 | 25,60224 |
| 3 | 0,179977 | 8,349921 | 0,118251 | 0,031096 | 24,05151 |
| 4 | 0,179977 | 8,349921 | 0,118251 | 0,031096 | 23,9899 |

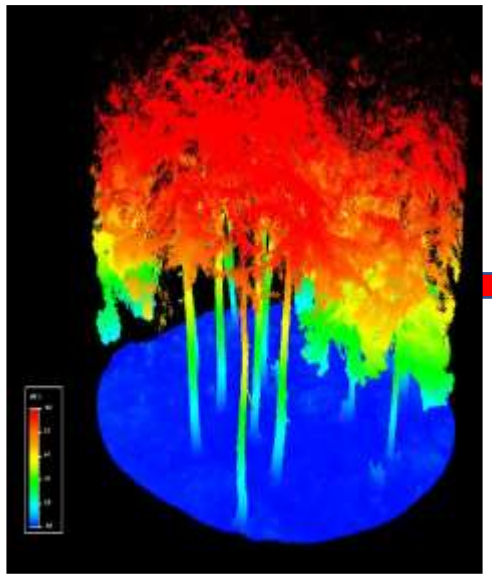
# Diameter at Breast Height

**Raw Data (3D Point Cloud: *.laz*)**

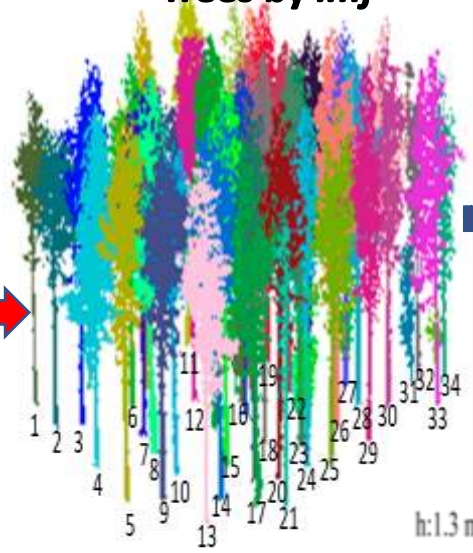
**Classified data (Height)**
**Data truncated by sample field boundaries**



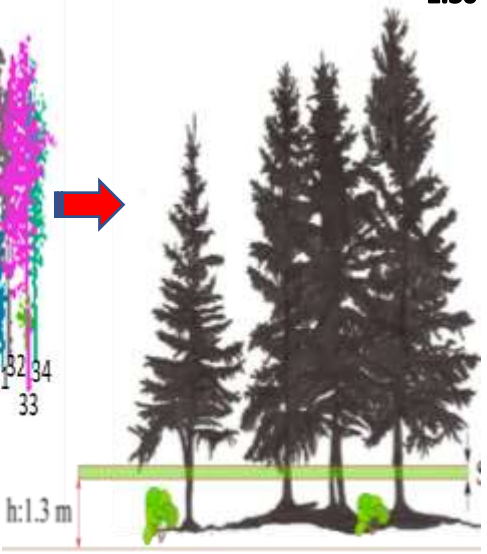

**Normalized by *knnidw***

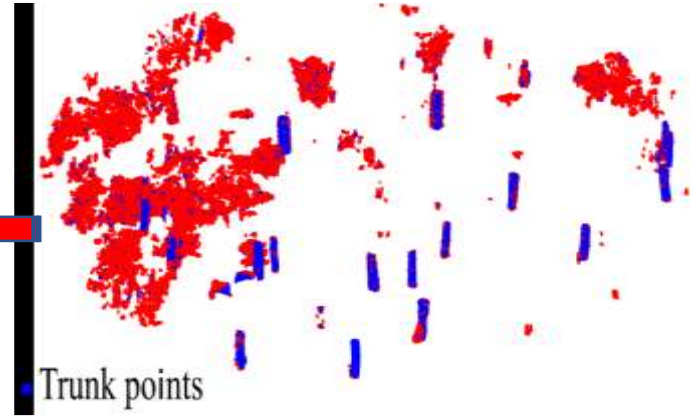


**Located Trees by *Hough Transformation* and Segmented Trees by *lmf***

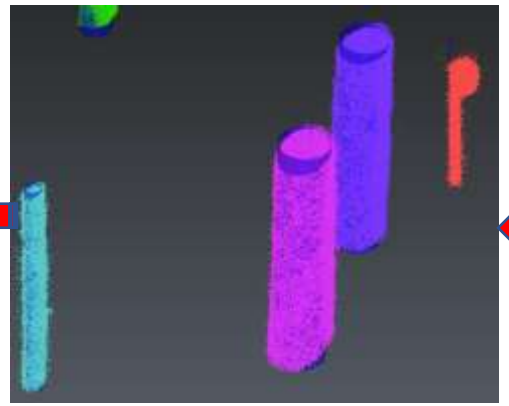


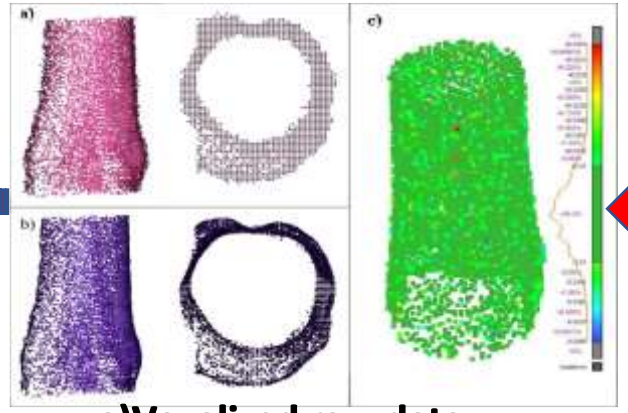

**Data cut from $d_{1.30}$**



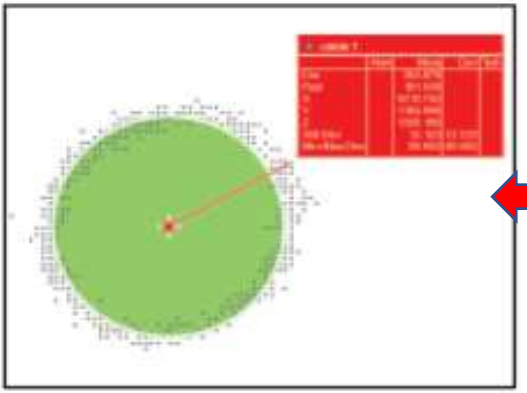




**Cylinder/circle/ellips fitting for $d_{1.30}$ by *RANSAC***





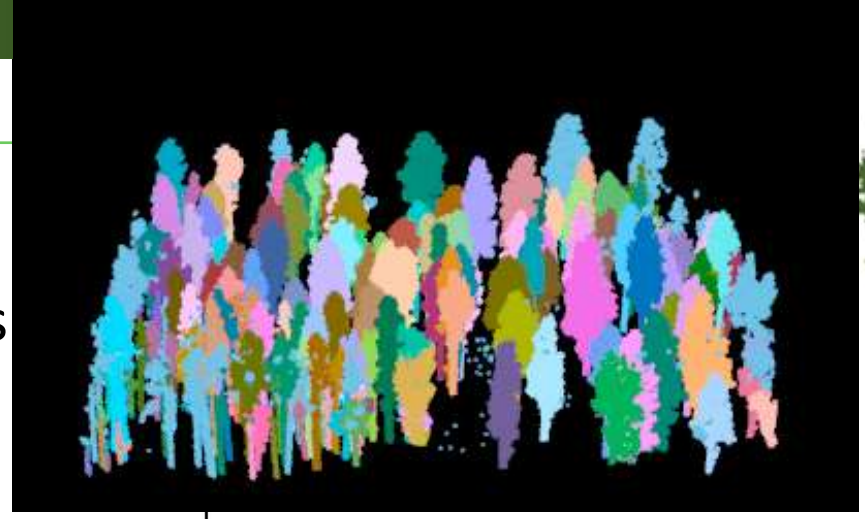

**a)Voxalized raw data**
**b)Data after MLS**
**c)Deviations between raw and treated data**

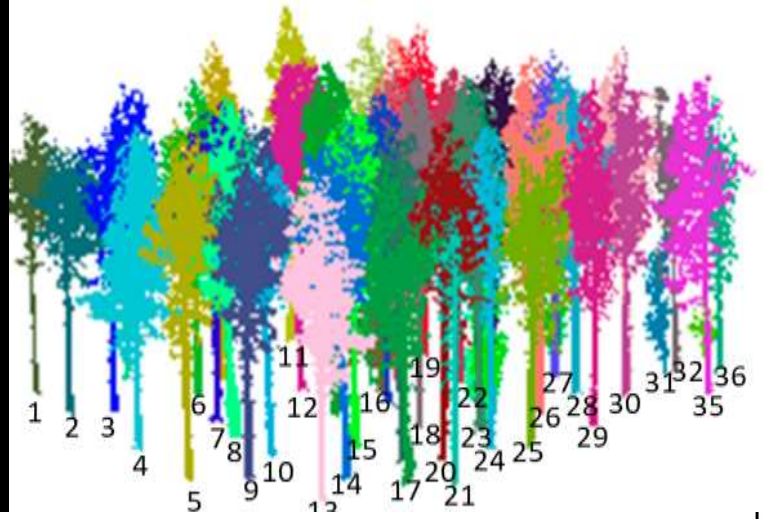


**Report**

# Number of Trees & Location

1. ITD – Local Max. Filter
2. Located Tree stems-Hough Trans
3. Counted Number of Trees
4. Reports;

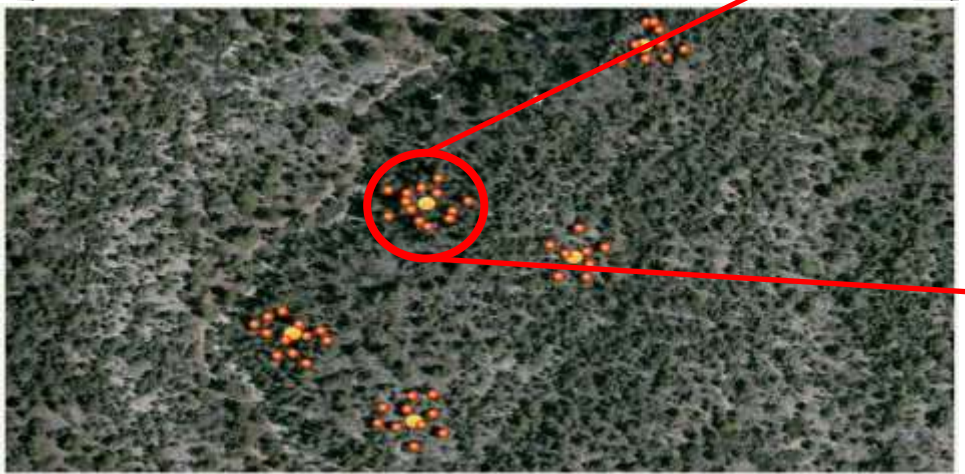


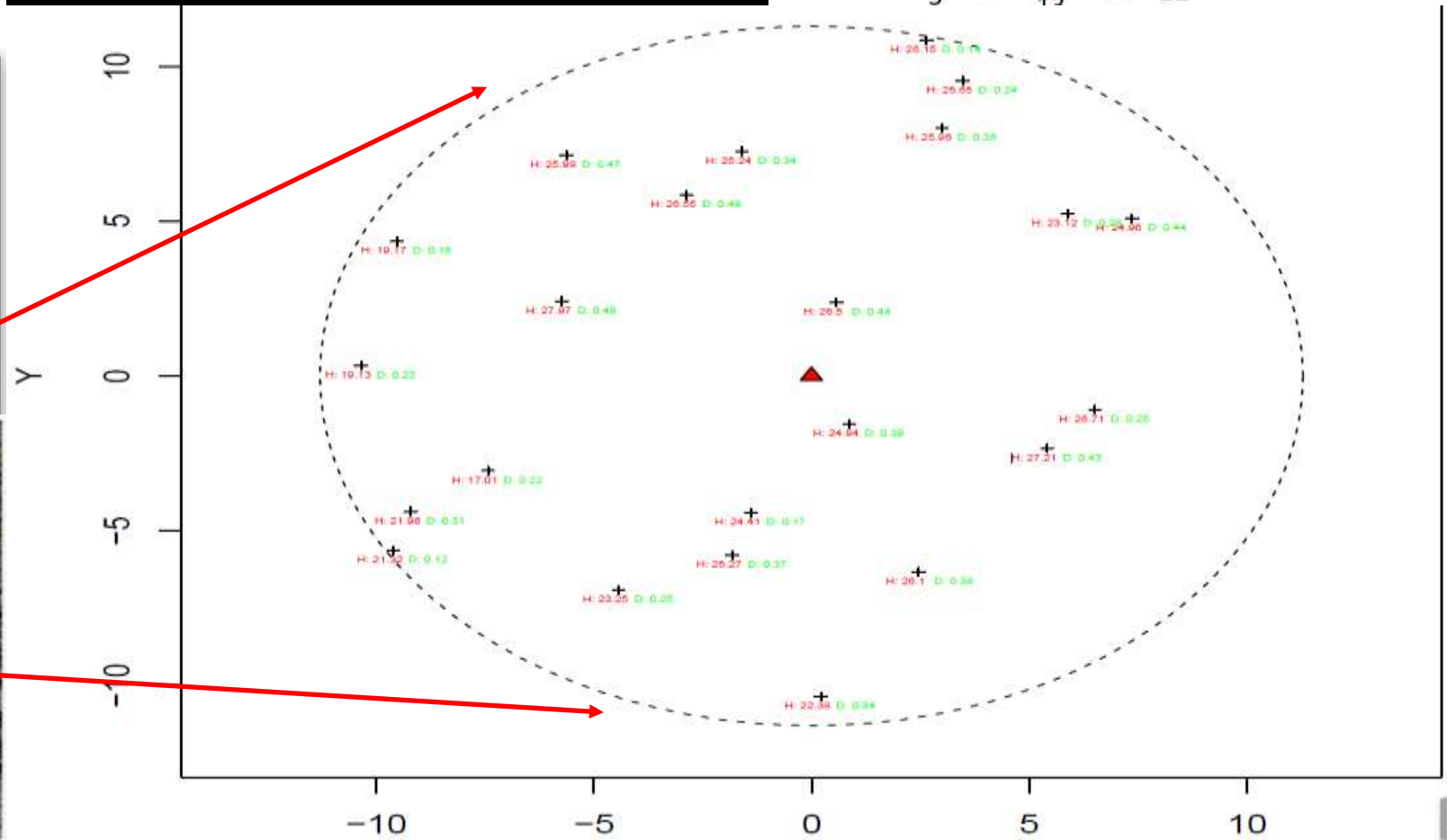



11.txt - Not Defteri

Dosya Düzen Biçim Görünüm Yardım

```
36 selected objects
36 Cylinder(s)
Global bounding box min: -10.150438 -7.5315 -
2.995077
Global bounding box max: 10.679468 8.967381
3.245894
Global Size: DX 20.8299 DY 16.4989 DZ 6.24097
```





# Crown Closure

## 1- Segmentation over point clouds

- Generated raster images by Smoothed CHM (3*3 filter)
- Segmentation (Watershed Algorithm)
- Raster to polygon conversion

## 2- Visual evaluation

- The 4K video of each sample area was watched one by one and the closedness was decided in the office.

| CROWN CLOSURE (%) | CLOSURE CLASS | SIZE OF SAMPLE PLOT ($m^2$) |
|---|---|---|
| 11 – 40 | 1 | 800 |
| 41 – 70 | 2 | 600 |
| 71 – 100 | 3 | 400 |

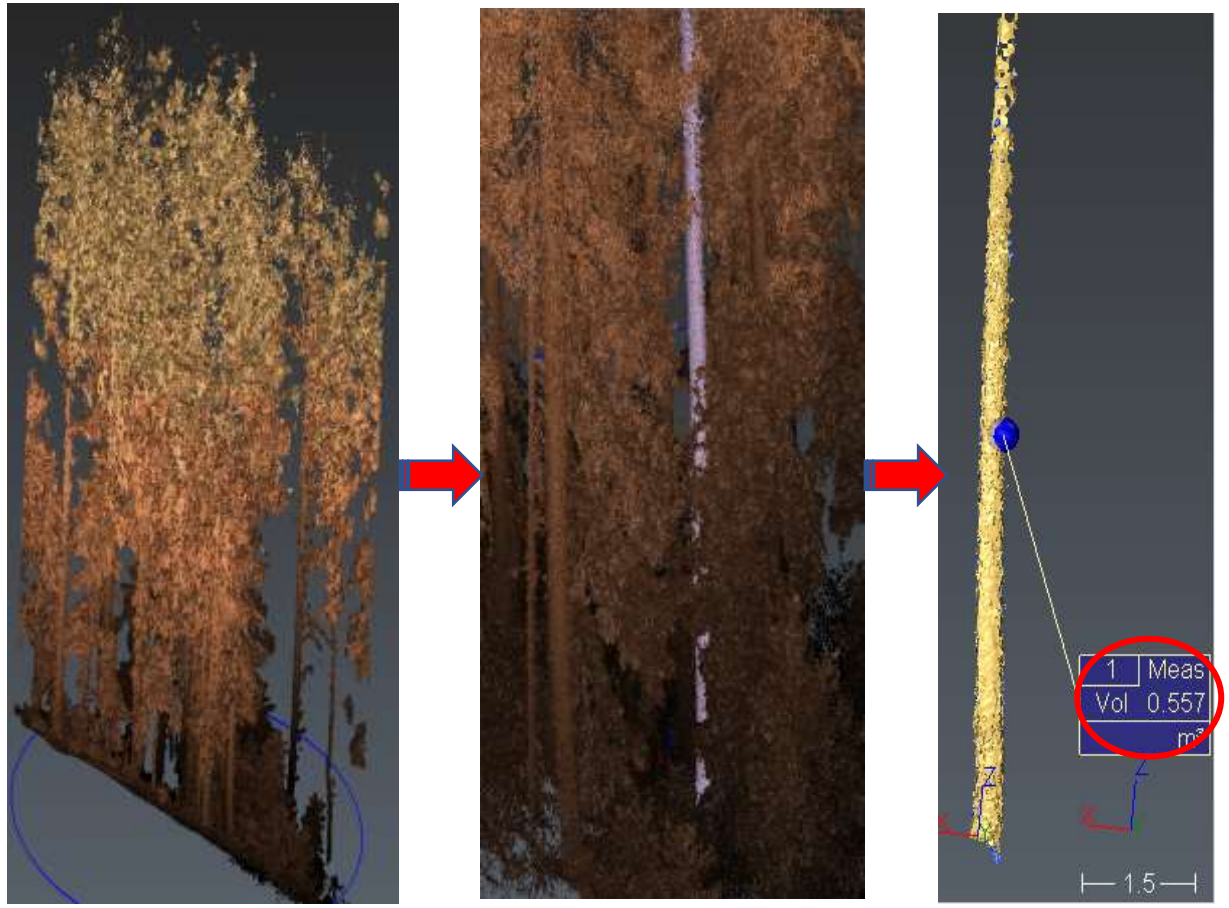

# Volume

## Ground Measurement

$$V_{total} = V_{bottom} + V_{sec.} + V_{top}$$

$$V = \left(\frac{\pi}{4}\right) \times (d_{0.5})^2 \times l$$

## LiDAR Measurement



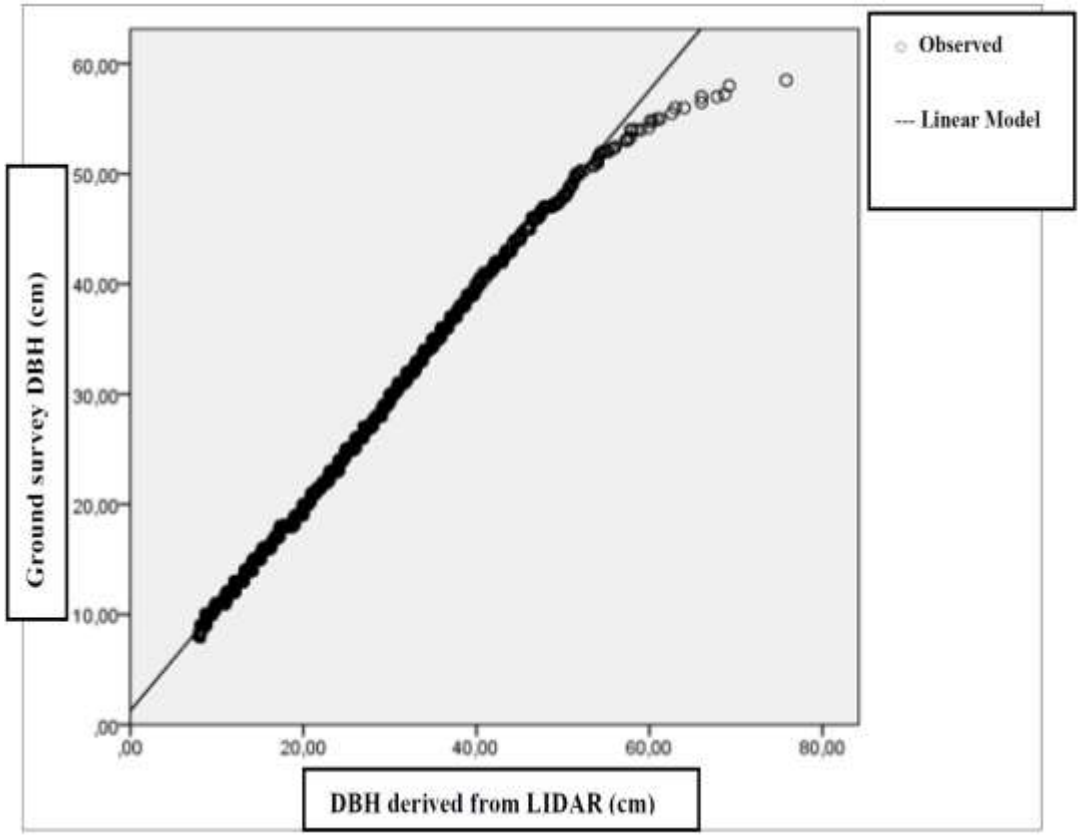

**Sectionized vs. Single Entry Volume Table**

**OVERALL: Bias=0.061 m³, $R^2$=94.9%**

# DBH (cm)

| Plot no. | Stand type | Mean diameter with LiDAR (cm) | Mean diameter measured in the field (cm) | Difference (%) | Plot no. | Stand type | Mean diameter with LiDAR (cm) | Mean diameter measured in the field (cm) | Difference (%) |
|---|---|---|---|---|---|---|---|---|---|
| 6 | L-Çs | 30.9 | 32.3 | -4.5 | 71 | L | 21.8 | 23.1 | -5.5 |
| 7 | Çs-L | 24.7 | 24.0 | +2.9 | 76 | L-Çs | 24.6 | 25.2 | -2.4 |
| 11 | L-Çs | 26.9 | 25.9 | +3.9 | 77 | L-G | 26.9 | 24.5 | +9.9 |
| 12 | L-Çs | 29.6 | 30.2 | -2.0 | 80 | Çs | 31.3 | 30.6 | +2.0 |
| 13 | Çs-L | 12.8 | 14.6 | -11.0 | 81 | Çs-G | 33.8 | 35.2 | -3.8 |
| 21 | L-Çs | 24.0 | 24.1 | -0.4 | 82 | G-Çs | 23.3 | 24.9 | -6.6 |
| 27 | L | 27.5 | 26.3 | +4.4 | 83 | GL | 29.1 | 29.4 | -1.2 |
| 31 | L | 25.9 | 24.9 | +4.2 | 84 | L-Gn | 14.8 | 12.9 | +14.9 |
| 50 | L-Çs | 25.8 | 25.0 | +3.1 | 85 | L-G | 31.1 | 28.9 | +7.8 |
| 51 | L-Çs | 41.9 | 42.2 | -0.8 | 86 | L | 36.7 | 33.5 | +9.5 |
| 52 | L-Çs | 27.0 | 28.7 | -5.8 | 87 | G-L | 31.5 | 31.0 | +1.7 |
| 56 | L-Çs | 33.3 | 33.6 | -1.1 | 90 | G-L | 32.6 | 33.0 | -1.2 |
| 57 | L-Çs | 30.1 | 30.0 | +0.6 | 91 | Çs | 36.0 | 34.1 | +5.5 |
| 58 | L-Çs | 27.0 | 25.4 | +6.0 | 92 | L-G | 31.1 | 35.2 | +5.5 |
| 59 | L-Çs | 26.6 | 26.9 | -1.0 | 93 | G-L | 27.4 | 30.0 | -8.8 |
| 63 | L | 30.0 | 28.7 | +4.7 | 94 | G-L | 36.2 | 38.0 | -4.7 |
| 64 | L | 29.3 | 30.1 | -2.8 | 142 | L-Çs | 28.5 | 28.1 | +1.4 |
| 68 | L-Çs | 26.9 | 24.6 | +9.3 | 200 | Kv-L | 11.9 | 14.6 | -18.2 |
| 69 | L-Çs | 18.3 | 18.9 | -3.5 | 201 | Kv-L | 13.4 | 14.1 | -5.0 |
| 70 | L | 23.0 | 23.9 | -3.8 | | | | | |

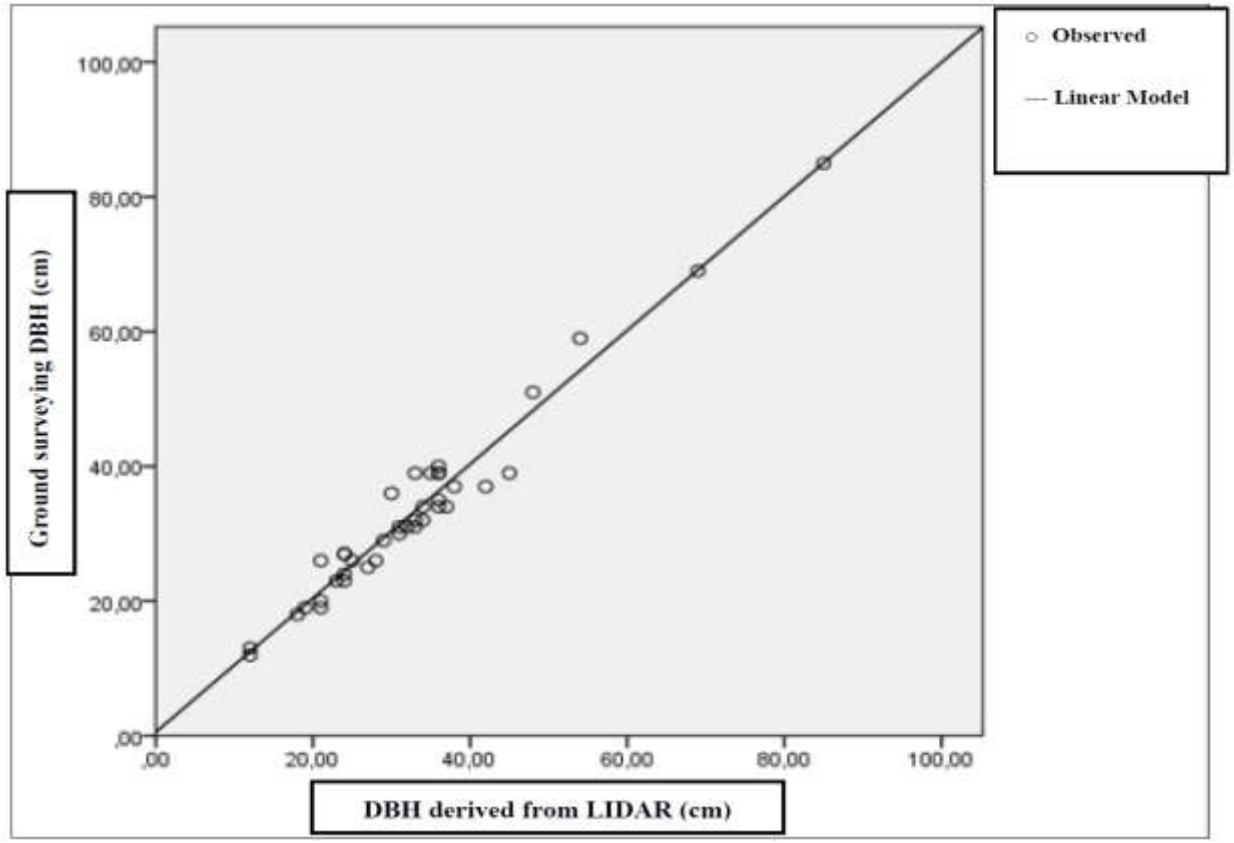
*L: Spruce, Çs: Scotch pine, G: Fir/Abies, Kv: Poplar, Gn: Hornbeam




**OVERALL: r=0.998, $R^2$=99.5%, Bias=0.68 cm**

# Number of Trees (N/ha)

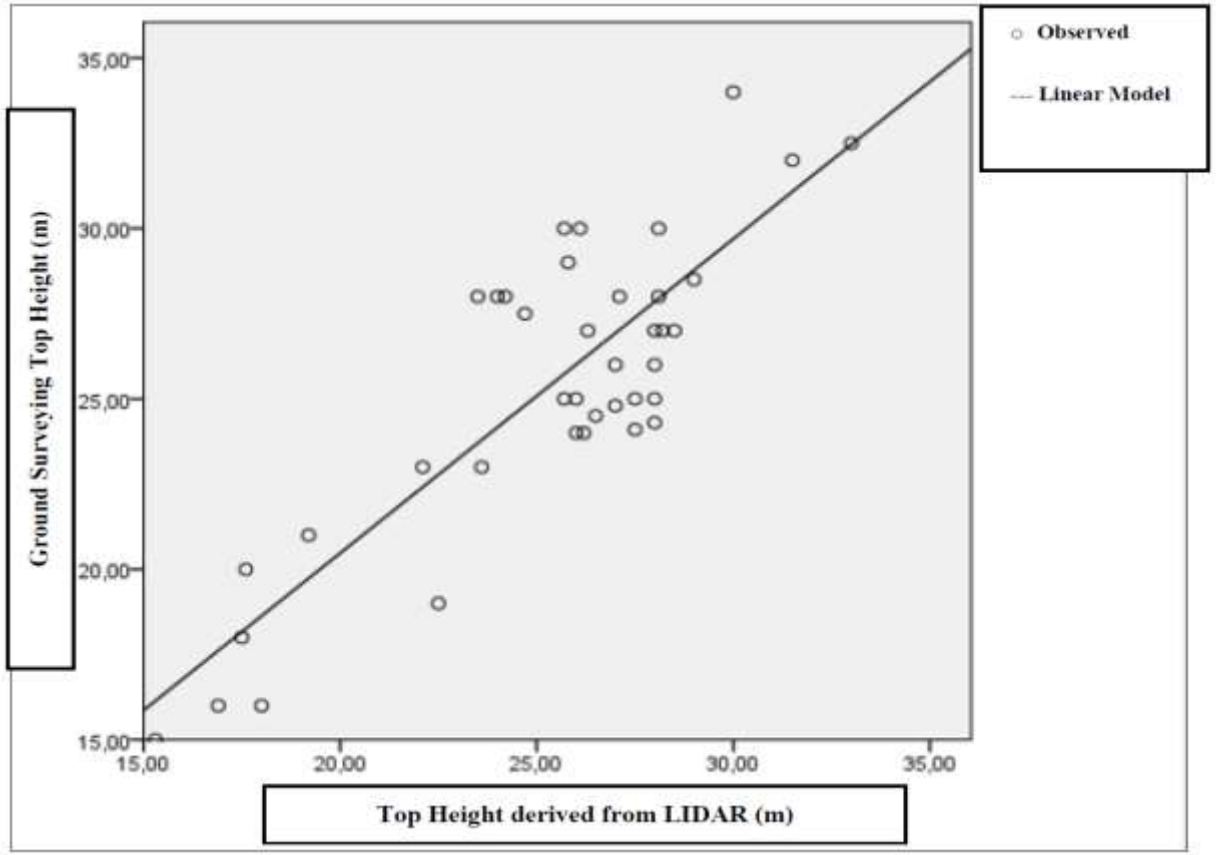
| Plot no. | Number of trees detected by LiDAR (N/ha) | Number of trees measured in the field (N/ha) | Difference (N) | Plot no. | Number of trees detected by LiDAR (N/ha) | Number of trees measured in the field (N/ha) | Difference (N) |
|---|---|---|---|---|---|---|---|
| 6 | 399 | 399 | 0 | 71 | 900 | 875 | +25 |
| 7 | 825 | 775 | +50 | 76 | 825 | 800 | +25 |
| 11 | 900 | 1000 | -100 | 77 | 475 | 475 | 0 |
| 12 | 725 | 725 | 0 | 80 | 675 | 625 | +50 |
| 13 | 1416 | 1416 | 0 | 81 | 625 | 650 | -25 |
| 21 | 1125 | 975 | +150 | 82 | 900 | 975 | -75 |
| 27 | 825 | 975 | -150 | 83 | 850 | 800 | +50 |
| 31 | 875 | 975 | -100 | 84 | 1050 | 925 | +125 |
| 50 | 900 | 850 | +50 | 85 | 525 | 500 | +25 |
| 51 | 450 | 450 | 0 | 86 | 399 | 449 | -50 |
| 52 | 775 | 750 | +25 | 87 | 600 | 675 | -75 |
| 56 | 600 | 575 | +25 | 90 | 950 | 925 | +25 |
| 57 | 575 | 575 | 0 | 91 | 199 | 216 | -17 |
| 58 | 925 | 850 | +75 | 92 | 300 | 300 | 0 |
| 59 | 775 | 775 | 0 | 93 | 700 | 650 | +50 |
| 63 | 525 | 650 | -125 | 94 | 349 | 316 | +33 |
| 64 | 800 | 775 | +25 | 142 | 850 | 850 | 0 |
| 68 | 499 | 599 | -100 | 200 | 900 | 975 | -75 |
| 69 | 899 | 982 | -83 | 201 | 1725 | 1725 | 0 |
| 70 | 1200 | 1275 | -75 | | | | |




**OVERALL: r=0.980, $R^2$=96%, Bias=2.8 trees/ha**

# Dominant Tree Heights (m)

| Plot no. | Top height (m) measured with LiDAR | Top height measured by vertex (m) | Difference (m) | Plot no. | Top height (m) measured with LiDAR | Top height measured by vertex (m) | Difference (m) |
|---|---|---|---|---|---|---|---|
| 6 | 26.3 | 27.0 | -0.7 | 71 | 23.5 | 28.0 | -4.5 |
| 7 | 22.5 | 19.0 | +3.5 | 76 | 26.0 | 25.0 | +1.0 |
| 11 | 28.0 | 27.0 | +1.0 | 77 | 28.2 | 27.0 | +1.2 |
| 12 | 28.5 | 27.0 | +1.5 | 80 | 22.1 | 23.0 | -0.9 |
| 13 | 17.6 | 20.0 | -2.4 | 81 | 25.7 | 25.0 | +0.7 |
| 21 | 24.7 | 27.5 | -2.8 | 82 | 23.6 | 23.0 | +0.6 |
| 27 | 28.0 | 25.0 | +3.0 | 83 | 28.0 | 26.0 | +2.0 |
| 31 | 26.5 | 24.5 | +2.0 | 84 | 16.9 | 16.0 | +0.9 |
| 50 | 27.0 | 24.8 | +2.2 | 85 | 27.5 | 24.1 | +3.4 |
| 51 | 33.0 | 32.5 | +0.5 | 86 | 27.0 | 26.0 | +1.0 |
| 52 | 28.0 | 24.3 | +3.7 | 87 | 28.1 | 28.0 | +0.1 |
| 56 | 31.5 | 32.0 | -0.5 | 90 | 28.1 | 30.0 | -1.9 |
| 57 | 29.0 | 28.5 | +0.5 | 91 | 15.3 | 15.0 | +0.3 |
| 58 | 24.0 | 28.0 | -4.0 | 92 | 24.2 | 28.0 | -3.8 |
| 59 | 26.2 | 24.0 | +2.2 | 93 | 27.1 | 28.0 | -0.9 |
| 63 | 26.1 | 30.0 | -3.9 | 94 | 19.2 | 21.0 | -1.8 |
| 64 | 26.0 | 24.0 | +2.0 | 142 | 27.5 | 25.0 | +2.5 |
| 68 | 25.8 | 29.0 | -3.2 | 200 | 18.0 | 16.0 | +2.0 |
| 69 | 25.7 | 30.0 | -4.3 | 201 | 17.5 | 18.0 | -0.5 |
| 70 | 30.0 | 34.0 | -4.0 | | | | |




**OVERALL: r=0.840, $R^2$=81%, Bias=1.2 m**

# Volume ($m^3$/ha)

| Plot no. | Stand type | Volume-derived LiDAR ($m^3$ /ha) | Volume measured in the field ($m^3$ /ha) | Difference (%) | Plot no. | Stand type | Volume-derived LiDAR ($m^3$ /ha) | Volume measured in the field ($m^3$ /ha) | Difference (%) |
|---|---|---|---|---|---|---|---|---|---|
| 6 | L-Çs | 546 | 456 | +19.8 | 71 | L | 530 | 463 | +14.6 |
| 7 | Çs-L | 488 | 457 | +6.7 | 76 | L-Çs | 630 | 495 | +27.3 |
| 11 | L-Çs | 788 | 658 | +19.7 | 77 | L-G | 403 | 338 | +19.0 |
| 12 | L-Çs | 735 | 603 | +22.0 | 80 | Çs | 574 | 574 | 0.0 |
| 13 | Çs-L | 213 | 272 | -21.5 | 81 | Çs-G | 730 | 761 | -4.0 |
| 21 | L-Çs | 735 | 565 | +30.2 | 82 | G-Çs | 650 | 657 | -1.0 |
| 27 | L | 713 | 722 | -1.4 | 83 | GL | 783 | 718 | +8.9 |
| 31 | L | 648 | 712 | -9.1 | 84 | L-Gn | 173 | 85 | +103.6 |
| 50 | L-Çs | 778 | 562 | +38.4 | 85 | L-G | 618 | 468 | +31.9 |
| 51 | L-Çs | 900 | 789 | +14.0 | 86 | L | 470 | 546 | -14.0 |
| 52 | L-Çs | 780 | 643 | +21.3 | 87 | G-L | 670 | 670 | 0.0 |
| 56 | L-Çs | 848 | 605 | +40.1 | 90 | G-L | 1323 | 999 | +32.4 |
| 57 | L-Çs | 650 | 592 | +9.9 | 91 | Çs | 145 | 221 | -34.5 |
| 58 | L-Çs | 725 | 578 | +25.5 | 92 | L-G | 445 | 413 | +7.8 |
| 59 | L-Çs | 618 | 620 | -0.4 | 93 | G-L | 835 | 702 | +18.9 |
| 63 | L | 713 | 591 | +20.5 | 94 | G-L | 380 | 485 | -21.7 |
| 64 | L | 720 | 690 | +4.3 | 142 | L-Çs | 908 | 749 | +21.1 |
| 68 | L-Çs | 525 | 425 | +23.4 | 200 | Kv-L | 103 | 113 | -9.4 |
| 69 | L-Çs | 521 | 403 | +29.3 | 201 | Kv-L | 275 | 194 | +41.5 |
| 70 | L | 890 | 710 | +25.4 | | | | | |

*L: Spruce, Çs: Scotch pine, G: Fir/Abies, Kv: Poplar, Gn: Hornbeam

Comparison of volumes calculated via LiDAR and single-tree volume table at the plot levels

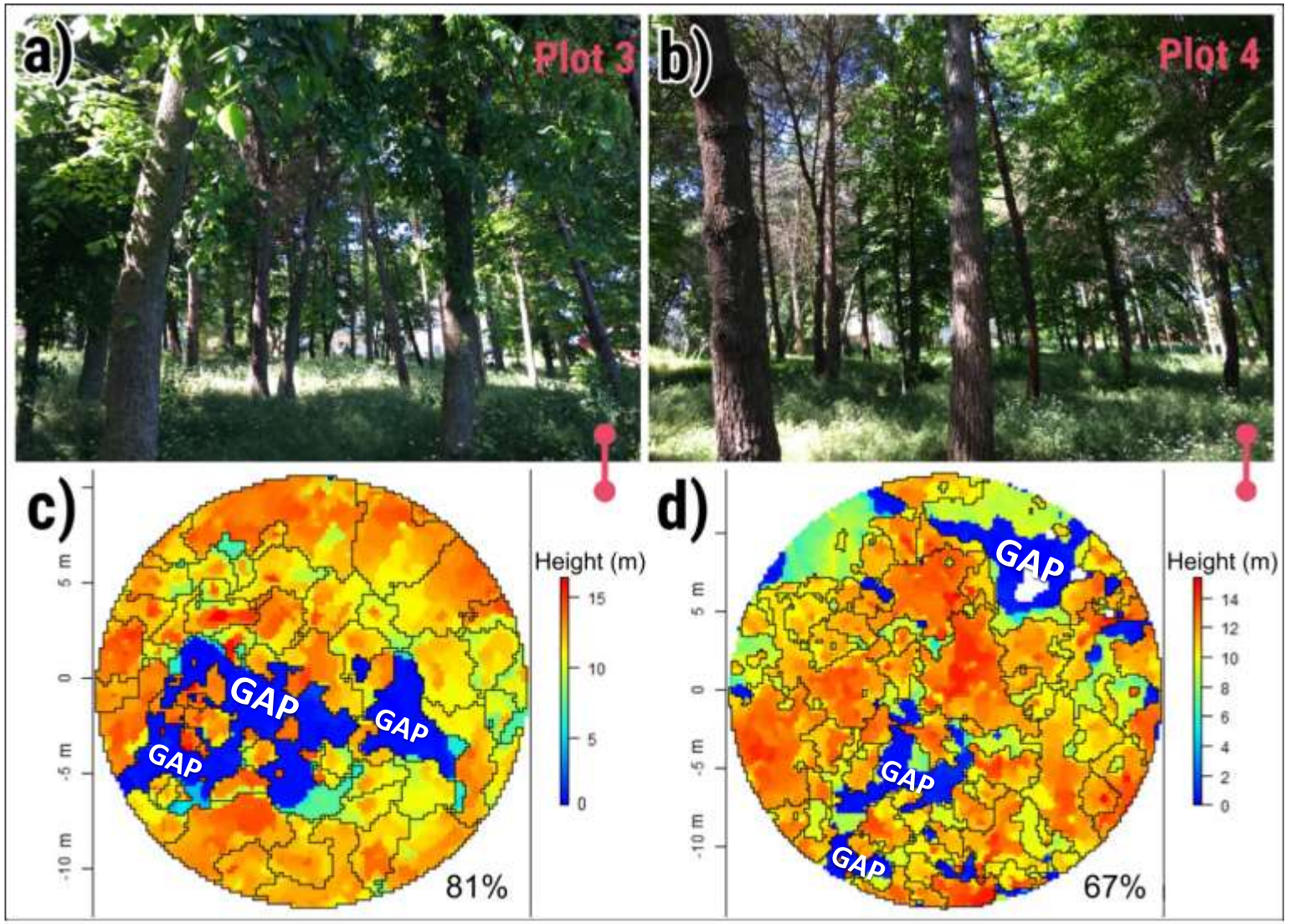
**OVERALL:**

**r=0.850,**

**$R^2$=86%,**

**Bias=14.6 $m^3$/ha**

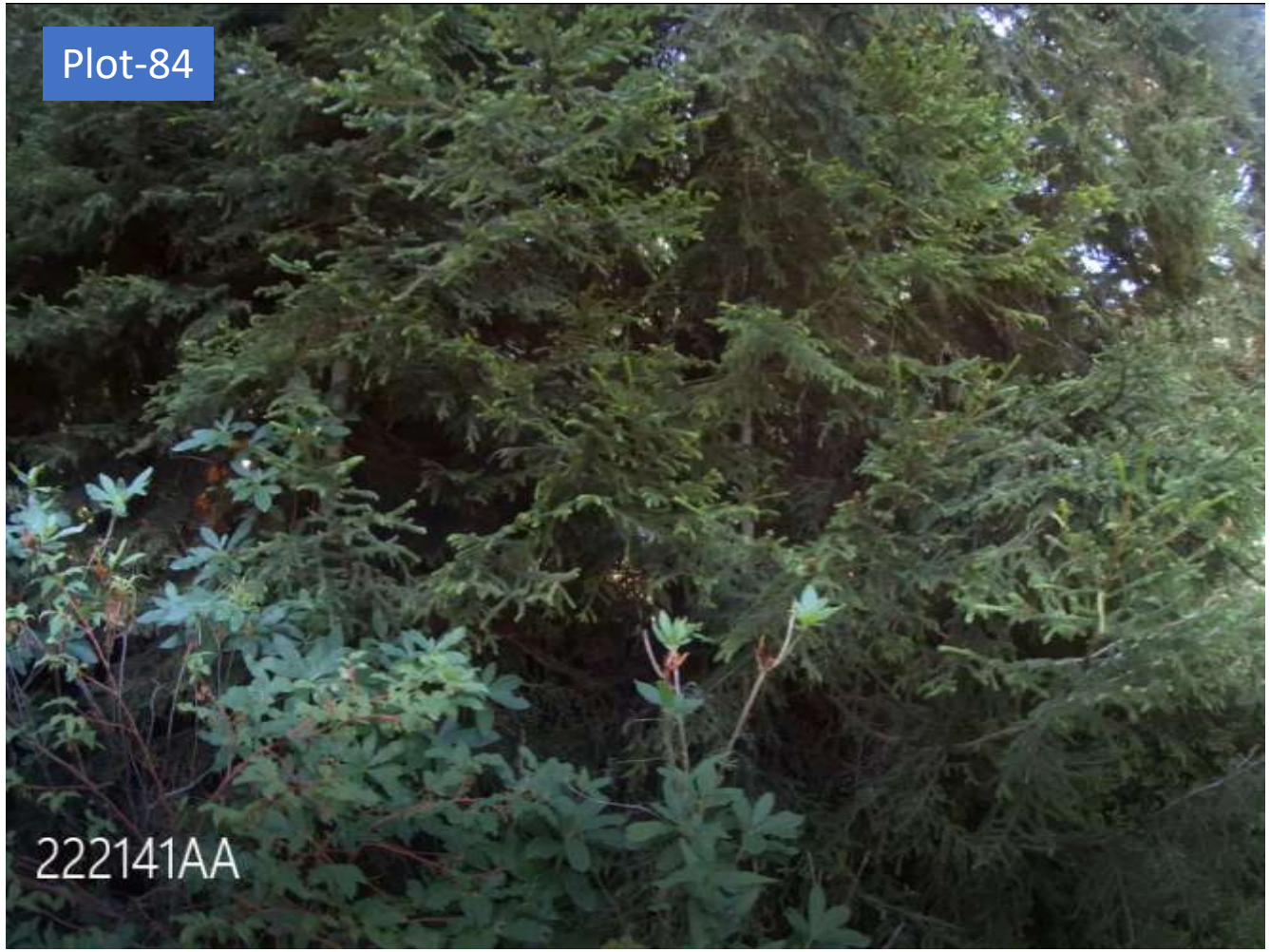
# Crown Closure (%)




Only **three of the 39 plots** differed

LiDAR device correctly estimated the occlusion of **92% of the plots**

# Noisy data




A group of spruces and hornbeam whose number of stems in the interior might not partially be determined due to dense branching to the bottom.

# Calibration and optimization of algorithms


Photos (Plots 84 and 13) from some plots that were difficult to find DBH on LiDAR data

# Handling big data

In "***difficult***" fields are required manual intervention (above), and "***easy***" fields are suitable for automatic information extraction with codes written in the R program (below).

# CONCLUSION

- A comparison of Handheld LiDAR technology and the traditional inventory method in Turkey,
- Increasing efficiency and accuracy,
- Reducing labor work, expenses and time,
- Demanding large storage space and powerful computers.

**Future Steps Here in Alberta:**

- MPB PSP Project will open the way for viability of LiDAR instruments for use,
- ALS, TLS and Hand-held LiDAR surveying and their comparison,
- Monitoring larger areas and different application,
- Model development for individual tree detection,
- identification species and stands from 4K videos using deep learning algorithms ≅ Full Automation

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FOREST GROWTH

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*ERGIN CANKAYA*

*Photo taken from Artvin Şavşat Karagöl in Türkiye*