32 CONGRESO INTERNACIONAL INGEGRAF 2023

CONGRESO INTERNACIONAL | CÁDIZ | ESPAÑA | 21 - 23 JUNIO

New Efficient and Automatic Approach to Extract Dendrometric Features from Terrestrial LiDAR Point Clouds in Forest Inventories

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1. Introduction

Some important facts (and one question that needs to be answered):

- ✓ **Forests play a key role in the promotion of ecosystem services and social benefits**. Costanza et al. (1997) estimated the annual value of forest ecosystem services at $4.7 trillion/year, representing approximately 15% of the World GNP (gross national product).

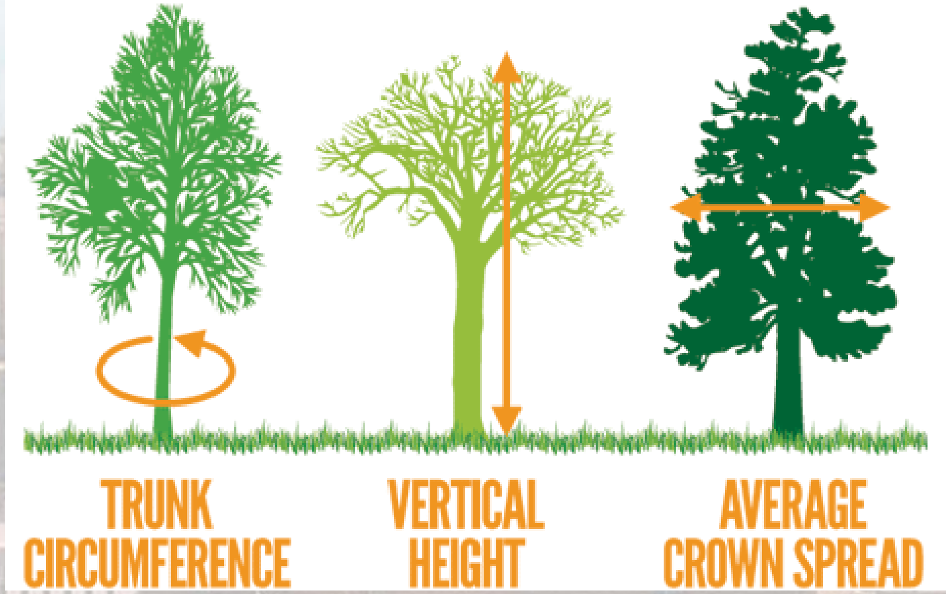
- ✓ Forest area in Mediterranean countries has been increasing since 1990. Unfortunately, **an increasing forest area tell us nothing about forest degradation and potential capacity to adapt to climate change**. It is needed to take a closer look.

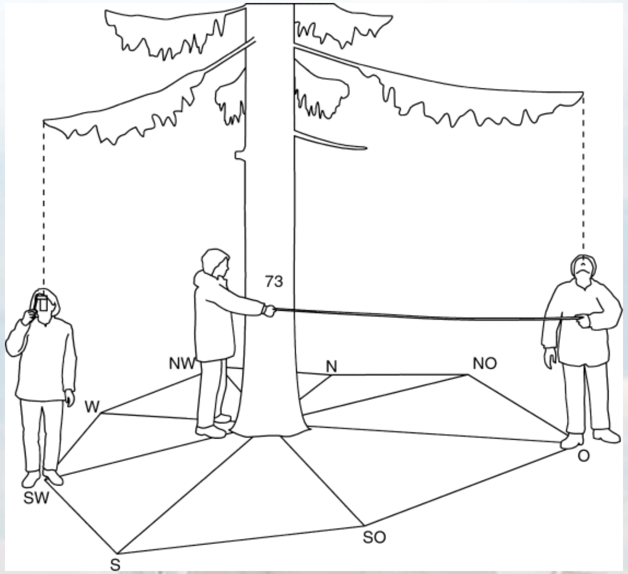
In this sense, **effective monitoring of forest structure turns out to be a key role for adapting to climate change**.

But, how to deal with it?

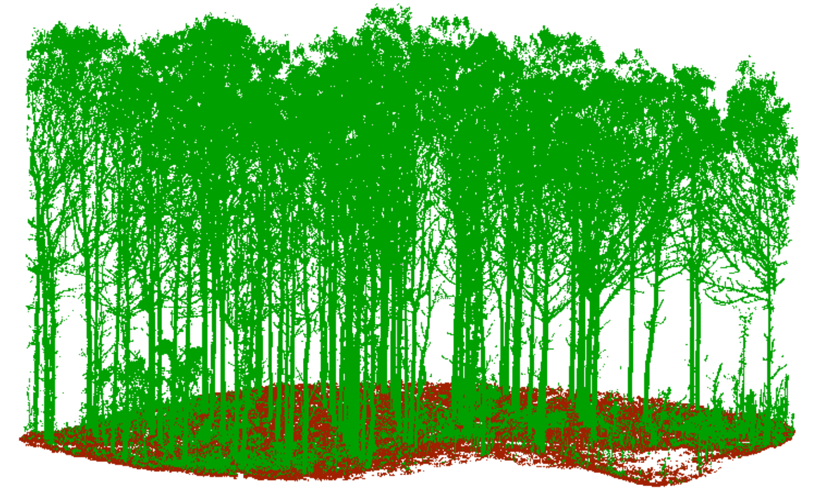
1. Introduction

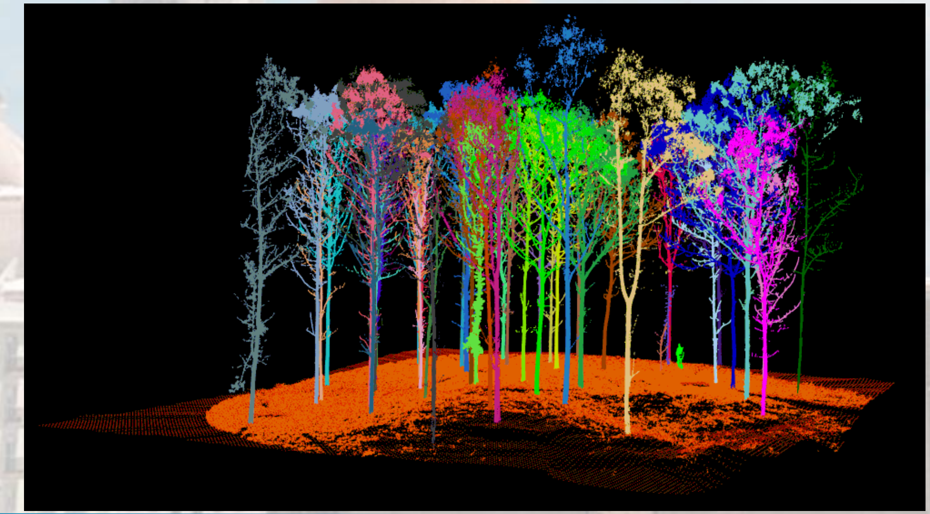
2/3 of the program costs within the context of the US Forest Service Forest Inventory were for field work on the reference plots (Gulding, 2000).





1. Introduction

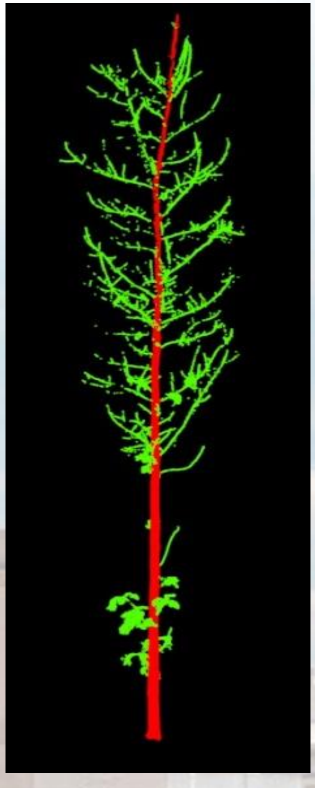




Individual Tree Detection (ITD)

Individual Tree Segmentation (ITS)

Individual Tree Crown Delineation (ITCD)



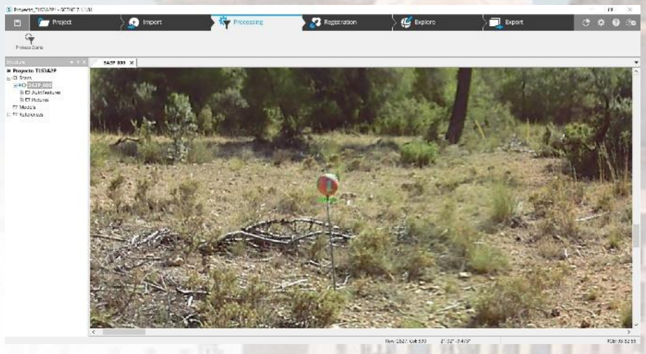
2. Materials and Methods

Study Site 1

Sierra de Maria-Los Vélez Natural Park

2. Materials and Methods

Study Site 1



2. Materials and Methods

Study Site 2

Province of León:

1. Toral de los Vados
2. Villasabariego
3. Villamañan

2. Materials and Methods

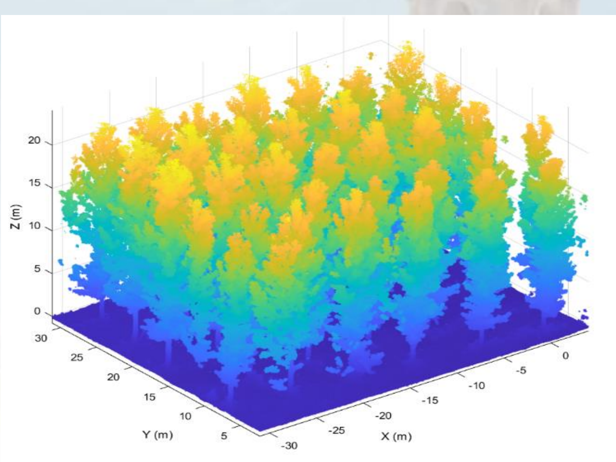
Study Site 2

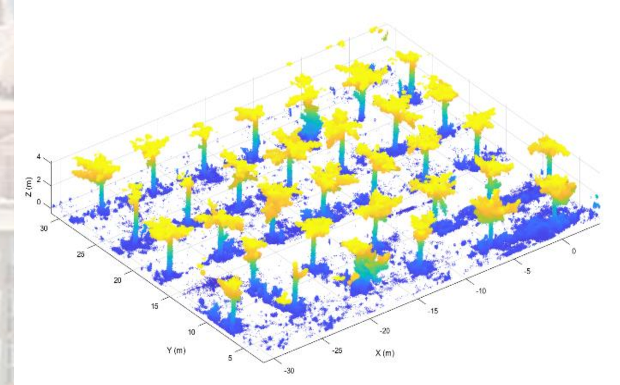
2. Materials and Methods

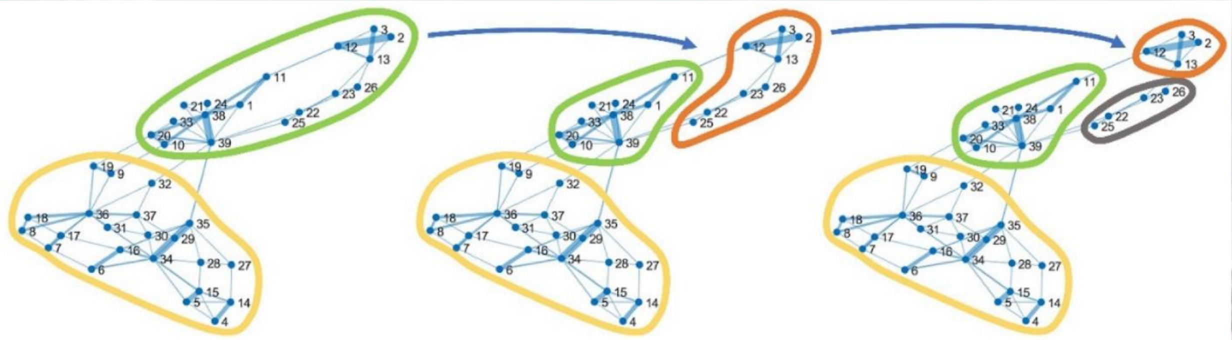
Field Data and Processing Methods

UALtree

UALtree → External Processing → Normalization, ground points removal, height cutoff threshold → Initial tree segmentation (Cut-pursuit 3D graph) → Refinement (removal of non-true trees). Vertical tree continuity M-estimator SAmple Consensus (MSAC) (cylindrical shapes) → Estimate of DBH and tree position → Refinement of low branches. Density points heat maps and Hough transform → Tree height estimation





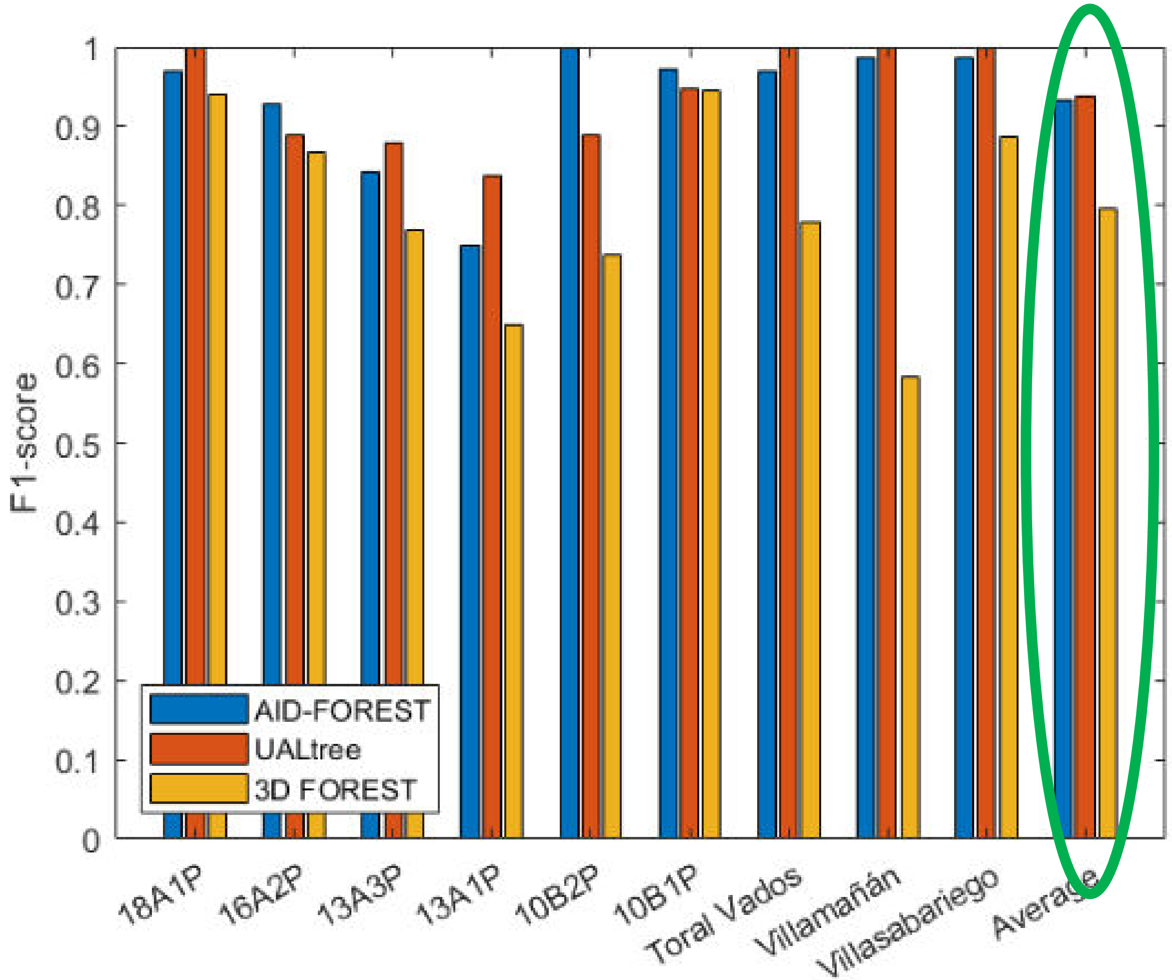


3. Results

Tree detection accuracy

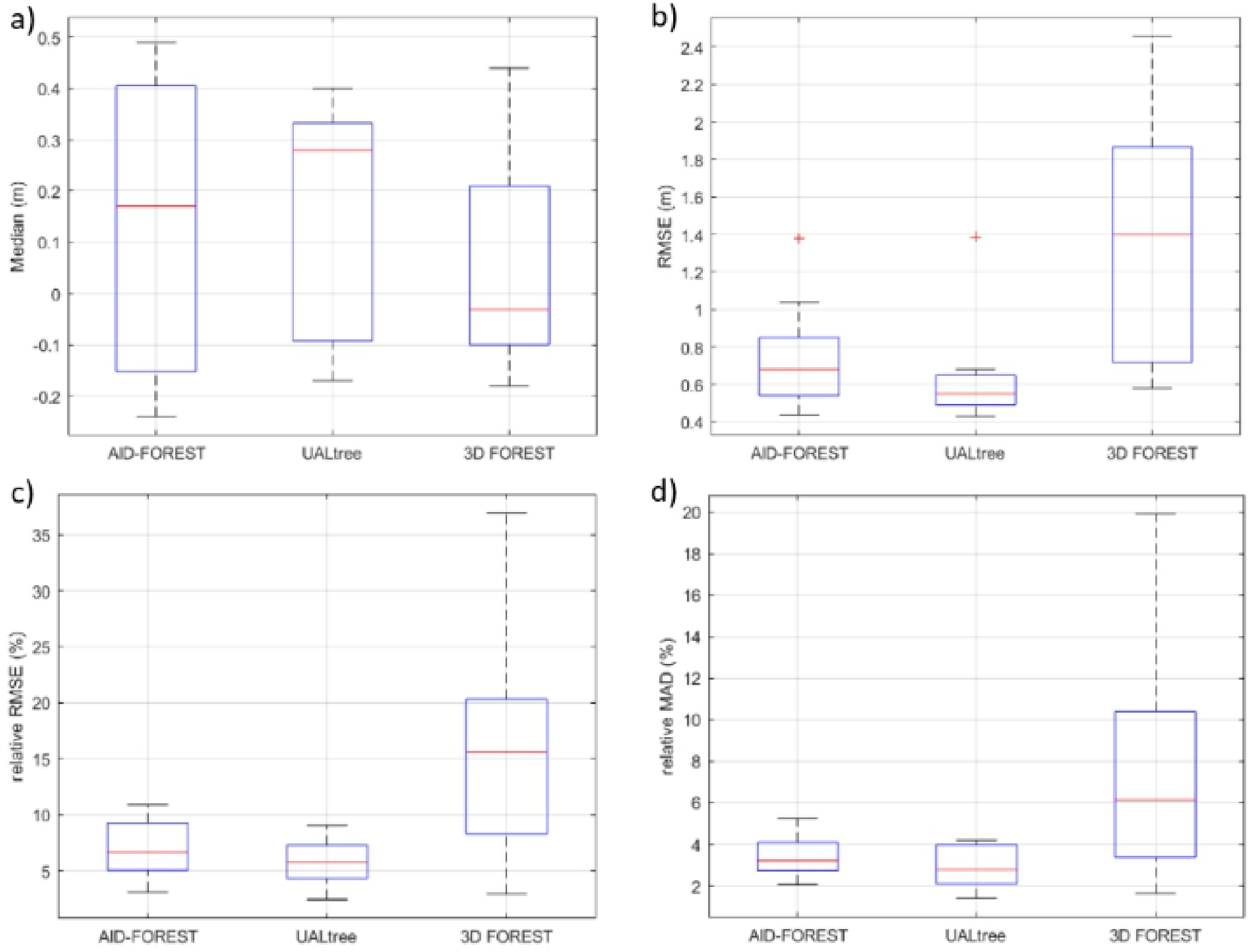
Tree detection assessment in terms of F1-score:

- **AID-FOREST**
- **UALtree**
- **3D FOREST**



3. Results

Accuracy of tree height estimation



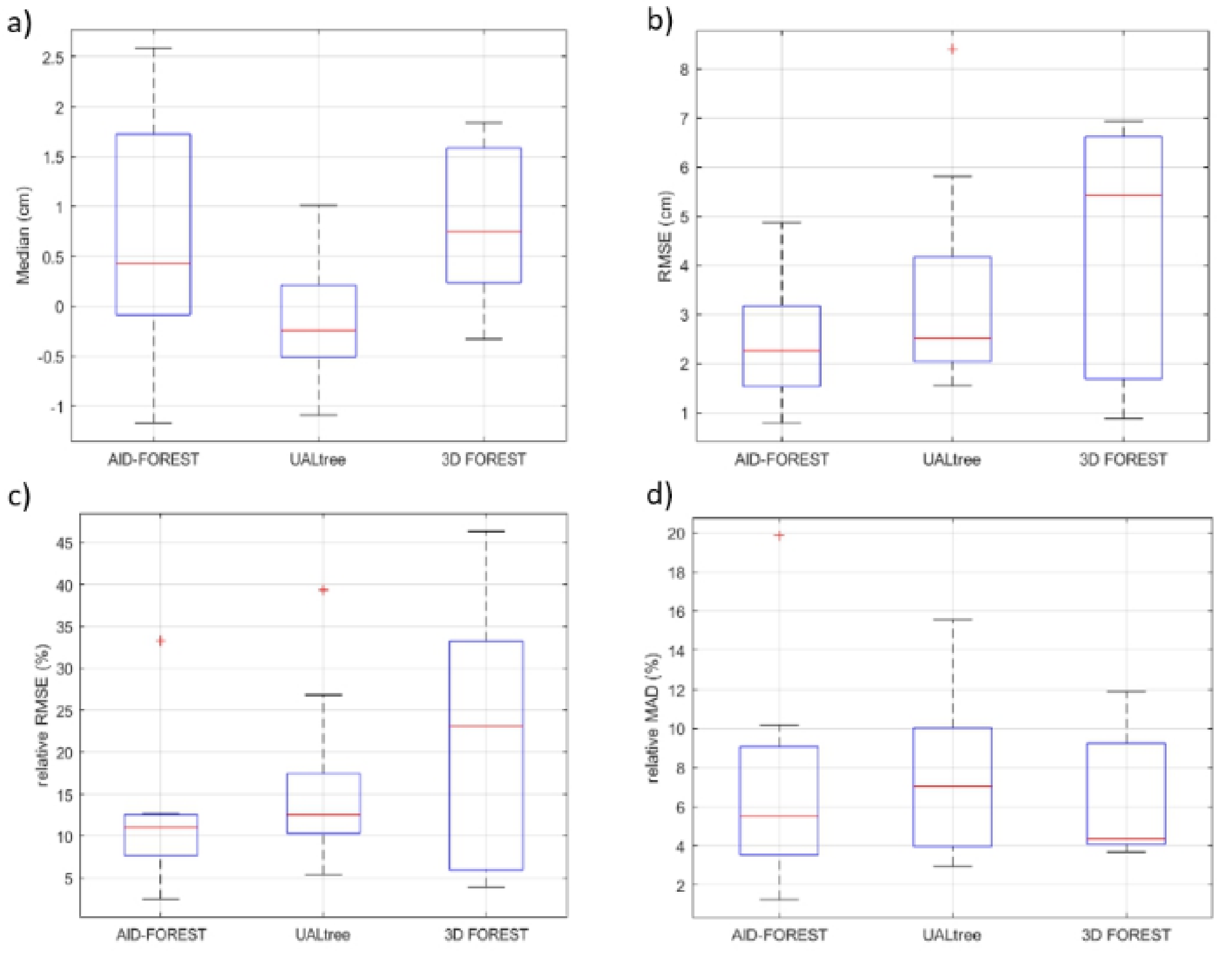
3. Results

Tree detection accuracy

Table 2. Wilcoxon (W-test) applied to tree height (H) extracted using AID-FOREST and UALtree. N = sample size (matched trees in each plot). The average results ± standard deviation are reported. (*) Significant differences ($p<0.05$) between estimated and observed measurements at tree level.

Plot	*AID-FOREST*				*UALtree*			
	N	$H_{estimated}$ (m) *Average*	$H_{observed}$ (m) *Average*	*W-test p-value*	*N*	$H_{estimated}$ (m) *Average*	$H_{observed}$ (m) *Average*	*W-test p-value*
18A1P	32	7.09 ± 1.03	7.09 ± 1.03	0.083	34	**7.04 ± 1.15**	**6.95 ± 1.17**	**0.010***
16A2P	26	**6.84 ±1.10**	**6.41 ± 1.13**	**0.0001***	24	**6.82 ± 1.00**	**6.45 ± 1.08**	**0.0003***
13A3P	16	6.55 ± 1.07	6.34 ± 1.04	0.255	18	**6.51 ± 1.23**	**6.19 ± 1.15**	**0.003***
13A1P	15	**5.52 ± 1.04**	**5.09 ± 1.09**	**0.003***	18	**5.58 ± 1.17**	**5.21 ± 1.14**	**0.0001***
10B2P	8	11.60 ± 1.23	11.83 ± 1.18	0.779	8	11.90 ± 1.14	11.83 ± 1.18	0.575
10B1P	18	10.51 ± 1.06	10.40 ± 1.03	0.371	18	10.62 ± 0.90	10.40 ± 1.03	0.077
Toral Vados	33	22.35 ± 1.25	22.54 ± 1.42	0.075	33	**22.39 ± 1.10**	**22.54 ± 1.42**	**0.028***
Villamañán	34	**23.85 ± 1.15**	**24.43 ± 1.73**	**0.037***	34	23.90 ± 1.12	24.43 ± 1.73	0.092
Villasabariego	34	19.16 ± 3.20	19.53 ± 2.80	0.069	34	19.36 ± 2.72	19.53 ± 2.80	0.205

3. Results Accuracy of DBH estimation



3. Results Accuracy of DBH estimation

Table 3. Wilcoxon (W-test) applied to Diameter at Breast Height (DBH) extracted using AID-FOREST and UALtree. N = sample size (matched trees in each plot). The average results ± standard deviation are reported. (*) Significant differences ($p<0.05$) between estimated and observed measurements at tree level.

Plot	*AID-FOREST*				*UALtree*			
	N	*$DBH_{estimated}$ (cm) Average*	*$DBH_{observed}$ (cm) Average*	*W-test p-value*	*N*	*$DBH_{estimated}$ (cm) Average*	*$DBH_{observed}$ (cm) Average*	*W-test p-value*
18A1P	32	20.00 ± 3.75	19.77 ± 4.21	0.389	34	19.36 ± 4.68	19.41 ± 4.46	0.063
16A2P	26	17.12 ± 2.03	16.73 ± 2.74	0.533	24	17.04 ± 3.60	16.81 ± 2.82	0.977
13A3P	16	19.00 ± 3.62	18.07 ± 4.46	0.062	18	**18.32 ± 5.35**	**17.48 ± 4.89**	**0.047***
13A1P	15	**17.63 ± 3.34**	**14.63 ± 4.43**	**0.010***	18	16.47 ± 6.82	14.76 ± 4.56	0.285
10B2P	8	**30.81 ± 5.09**	**31.35 ± 5.22**	**0.049***	8	28.48 ± 9.25	31.35 ± 5.22	0.779
10B1P	18	**26.67 ± 5.97**	**28.69 ± 6.18**	**0.0005***	18	28.55 ± 6.24	28.69 ± 6.18	0.285
Toral Vados	33	**26.23 ± 2.52**	**23.77 ± 2.41**	**0.0000***	33	23.31 ± 3.71	23.77 ± 2.41	0.126
Villamañán	34	**30.46 ± 2.75**	**29.10 ± 2.39**	**0.002***	34	**28.22 ± 3.24**	**29.10 ± 2.39**	**0.041***
Villasabariego	34	**21.28 ± 4.12**	**20.69 ± 4.12**	**0.001***	34	**19.36 ± 4.47**	**20.69 ± 4.12**	**0.0000***

3. Results Processing time

Table 4. Processing time expressed in seconds per million points processed. All calculations were executed with Intel® CoreTM i7-8565U 4 X 1.99 GHz, 16 GB RAM, and NVIDIA Quadro P520.

Method	*18A1P*	*16A2P*	*13A3P*	*13A1P*	*10B2P*	*10B1P*	*Toral Vados*	*Villamañán*	*Villasabariego*	***Average***
AID-FOREST	32.69	85.08	93.50	119.73	94.58	46.80	24.93	52.81	75.68	**69.53**
UALtree	12.07	18.96	29.09	39.68	28.82	23.96	17.67	12.11	19.75	**22.46**
3D FOREST	156.29	135.50	134.30	132.38	119.34	179.82	370.32	301.10	397.54	**214.07**

4. Conclusions

- UALtree proved to perform similarly to AID-FOREST in terms of F1-score (tree detection). Both algorithms yielded much better accuracy rates than 3D FOREST.

- AID-FOREST and UALtree provided similar figures regarding tree height and DBH estimation. Both better than 3D FOREST.

- Wilcoxon non-parametric test evidenced that UALtree was able to estimate the observed DBH distribution slightly better than AID-FOREST.

- UALtree worked faster.

Thank you very much for your kind attention