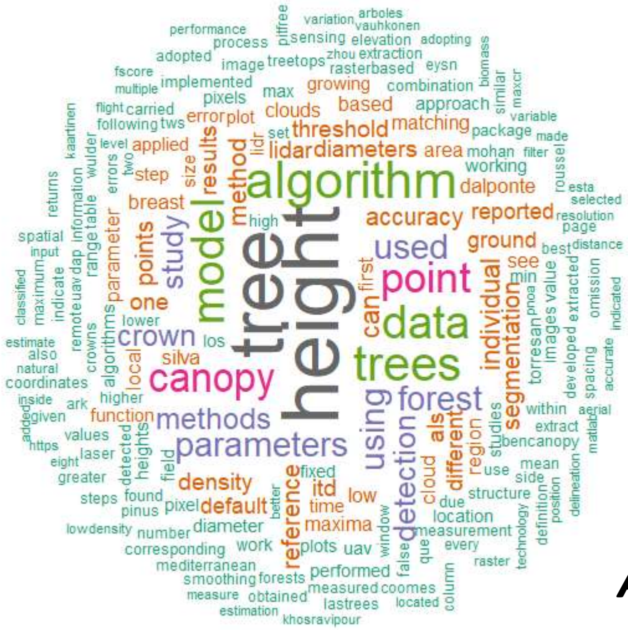

An automatic and effective pipeline for individual tree detection and segmentation using Low-Density Airborne Laser Scanning data in large areas of Mediterranean forest

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1. Introduction

- To mitigate the climate change
- To ensure the maintenance of the forest economical and environmental services
- An effective monitoring of Mediterranean forest is needed
- Above-Ground Biomass (AGB) at tree level is based on knowing the diameter of the trunk at breast height (DBH).

Premise

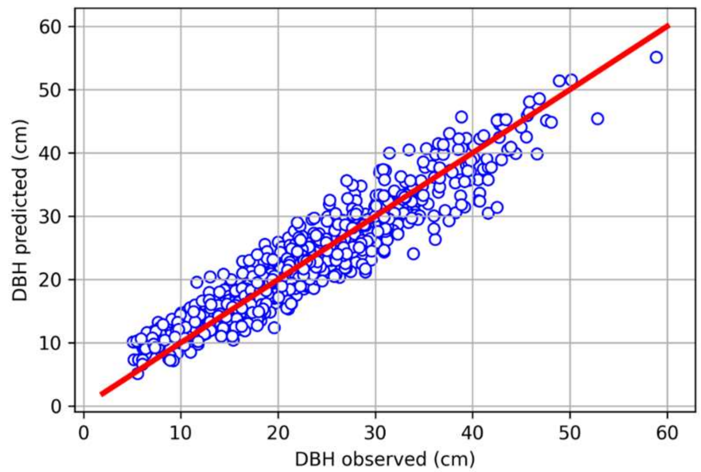
$$(\color{green}{AGB} = 0.128.\ \color{red}{DBH}^{2.29})$$

López-Serrano et al., (2005)[1]

$$\color{red}{DBH} = -4.84 + 1.73149\color{red}{H} + 3.08114\color{orange}{CD}$$

(R^2 = 89.23%)

Aguilar et al., (2022) [2]



[1] López-Serrano, F.R., García-Morote, A., Andrés-Abellán, M., Tendero, A., Del Cerro, A., 2005. Site and weather effects in allometries: A simple approach to climate change effect on pines. For. Ecol. Manage. 215, 251–270. https://doi.org/10.1016/J.FORECO.2005.05.014

[2] Aguilar, F.J., Nemmaoui, A., Aguilar, M.A., Jiménez-Lao, R., 2022. Aleppo Pine Allometric Modeling Through Integrating UAV Image-Based Point Clouds and Ground-Based Data, in: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. pp. 353–360. https://doi.org/10.5194/isprs-annals-V-3-2022-353-2022

Premise

State-of-the-art approaches **use many parameters** that should be tuned to adapt the segmentation algorithm to a specific forest.

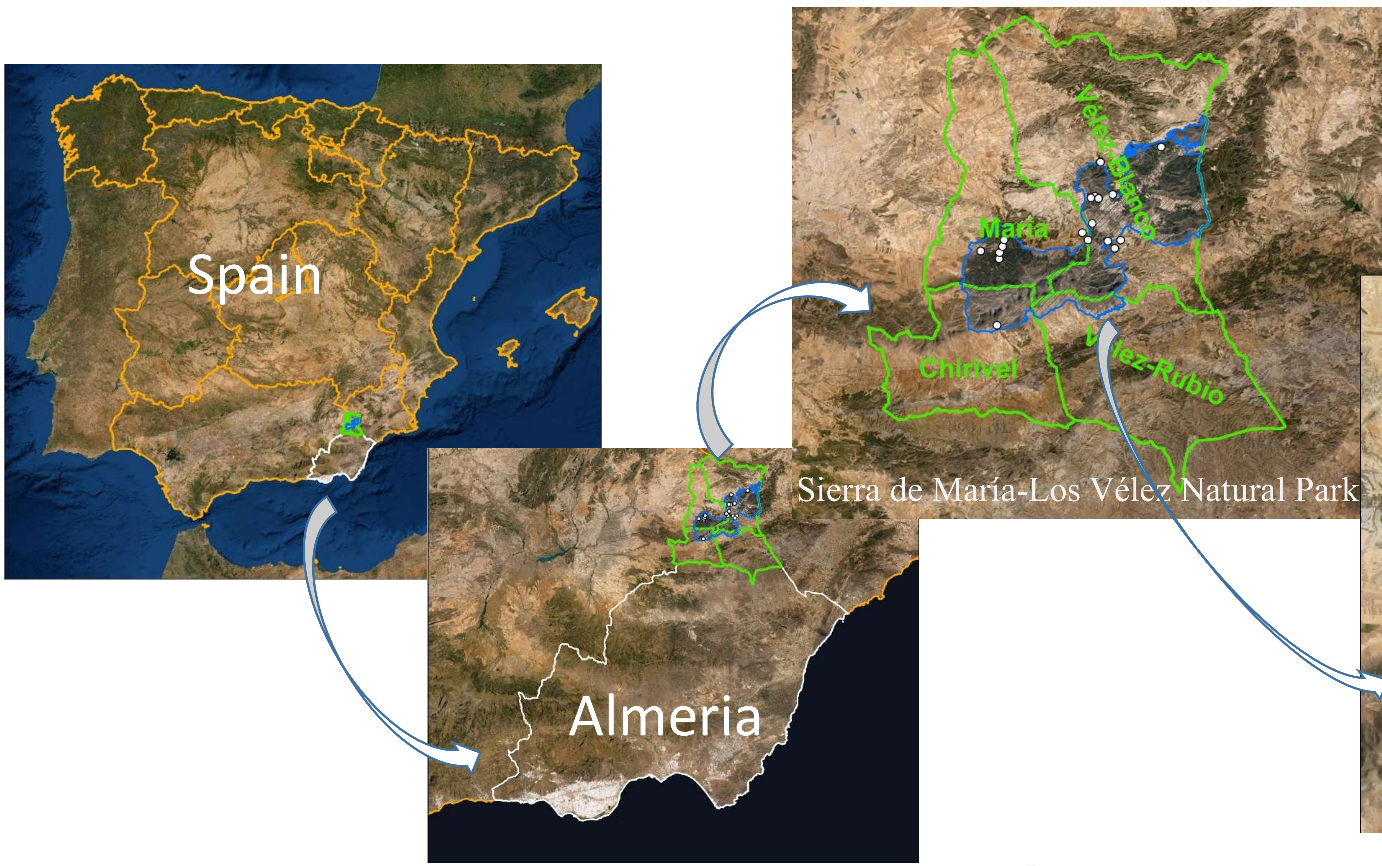
This operation of parameters tuning is **time-consuming** and it requires **to learn and understand** the meaning and the role of each parameters. This intense user interactions is very challenging.

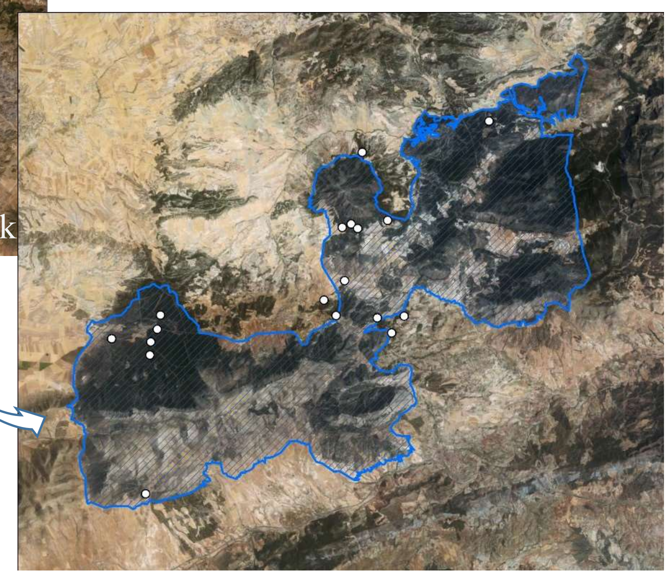
The main goal of this work aims at developing **a pipeline that requires minimal user interaction** when working on **large areas of Mediterranean forests**.

The expected results should facilitate the production of broad-extend individual trees maps and extract the corresponding dendrometric parameters from **low-density** airborne laser scanning (ALS) data without spending time tuning algorithm parameters.

2. Study site

38 square plots
of 25* m side (625 m^2)
[31m (961 m^2): to avoid the edge effect]





2. Study site

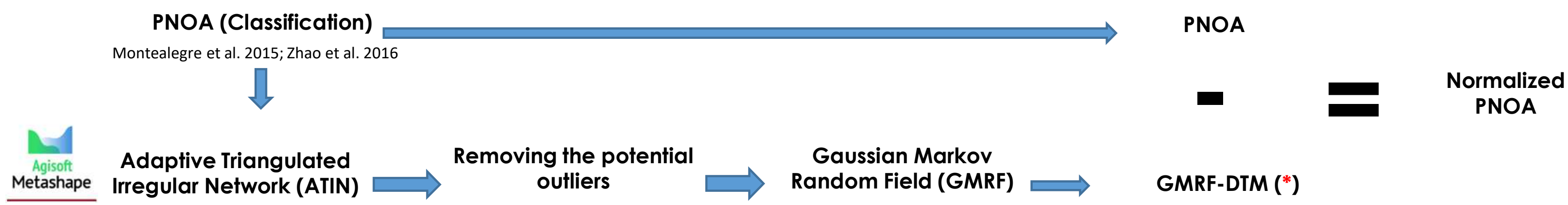
	VC (%) (*)	Density (Trees/ha)	Height (m)	G (m^2/ha)	Lh (m)
Max	86.79	1504	18.66	36.03	16.21
Min	19.99	160	2.03	1.52	3.48
Average	45.29	407.16	8.85	18.36	9.79

Table 1: Characteristics (average, max and min) of the 38 references plots [*Up to 2m Vegetation cover (CV), basal area (G) and Lorey´s height (Lh).

3. Matrials and methods

3.1 Lidar-Data (PNOA (National Plan of Aerial Orthophotography of Spain))

It was taken, between **October 12 and 13, 2020** using **Leica ALS60** discrete return sensor with up to four returns. The average point density was **1.5 points/m²** (all returns) representing a nominal (at nadir) horizontal accuracy (**RMSE$_{xy}$**) and nominal vertical accuracy (**RMSE$_z$**) lower than **0.3 m** and **0.15 m**, respectively.

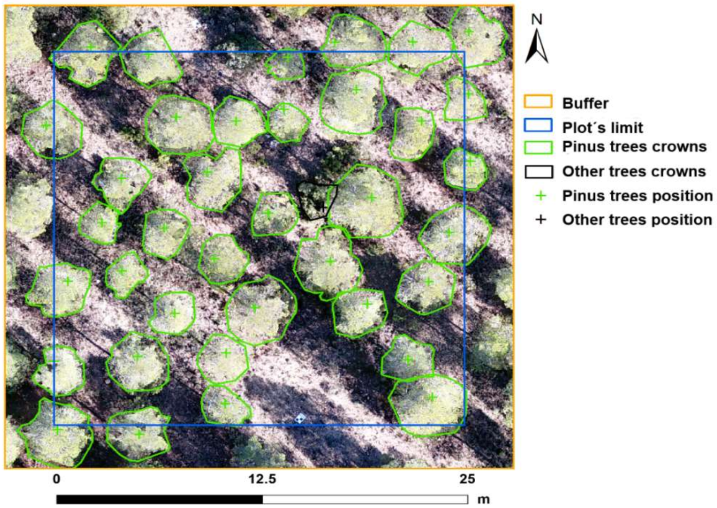


	PNOA (Point/m^2)
Max	10.00
Min	2.12
Average	3.50

Table 2: plot-level point cloud density

(*) Nemmaoui A, Aguilar FJ, Aguilar MA (2023) UAV-Based Digital Terrain Model Generation to Support Accurate Inventories in Mediterranean Forests BT - Advances in Design Engineering III. In: Cavas-Martínez F, Marín Granados MD, Mirálbes Buil R, De-Cózar-Macías OD (eds) Advances in Design Engineering III. INGEGRAF 2022. Lecture Notes in Mechanical Engineering. Springer International Publishing, Cham, pp 565–581

3. *Materials and methods*



RTK - ETRS89 UTM 30N / EGM08 REDNAP

The CD-GT has been extracted from a RPAS-DAP RGB orthoimage 3 cm/pixel (March 2021).

The data can be considered as homogenous due to the application of the same acquisition guidelines and methods applied by the same experienced operators.

3. *Materials and methods*

3.3 Algorithms

- **Raster-Based Algorithms**
  - Silva et al. 2012[1] (LidR)[2]
  - Dalponte & Coomes 2016[3] (LidR)
  - Digital Forest Toolbox (DFT)[4] (*Matlab*)

- **Point-Cloud-Based Algorithms**
  - Li et al. 2012[5] (LidR)

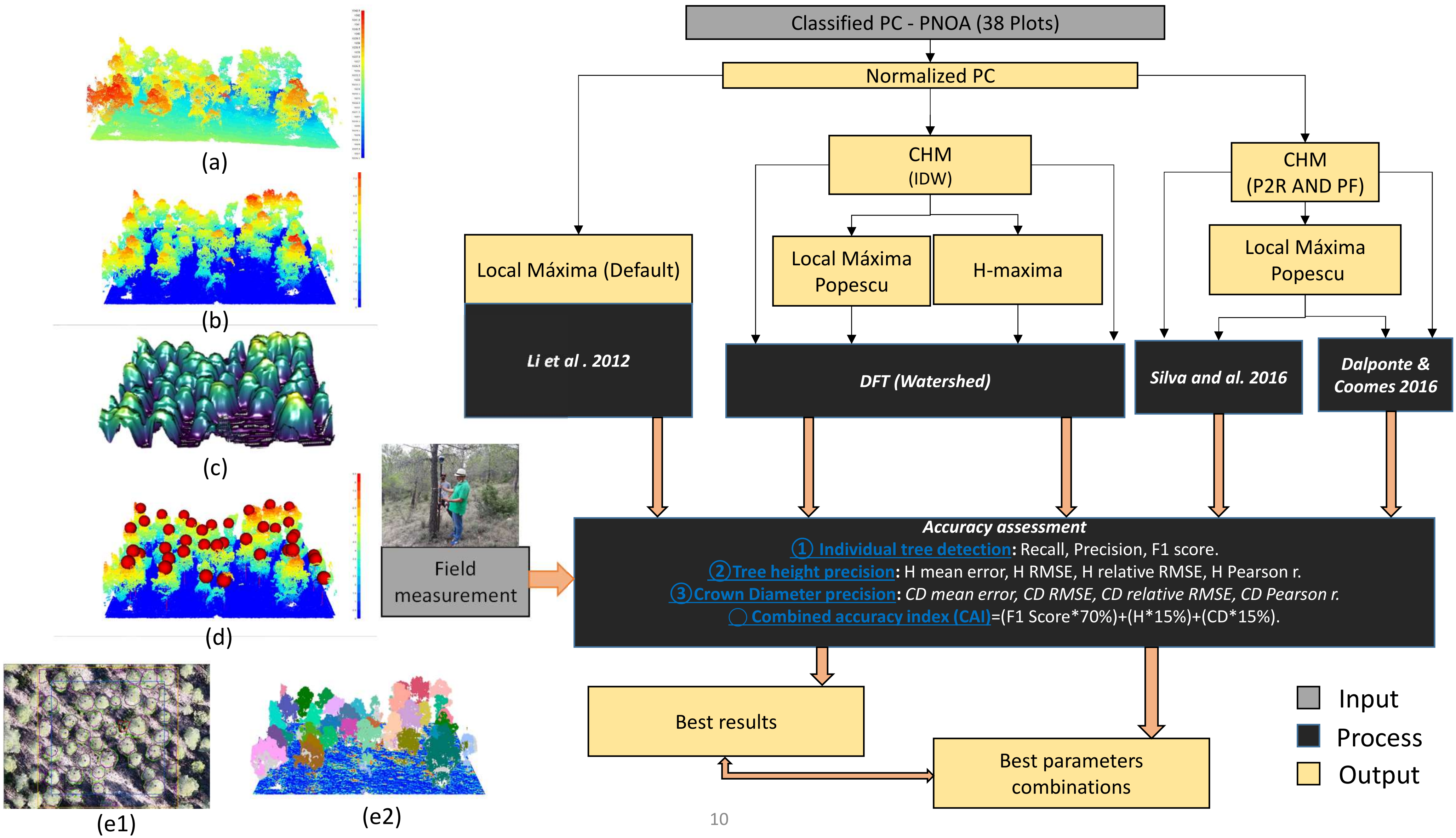
- CHM (R)

  - Point-to-raster (**P2R**): to establish a grid at a defined resolution and attributing the elevation of the highest point to each pixel [Silva et al. 2016[1] and Dalponte & Coomes 2016[3]]
  - Pit-free (**PF**): Combining different CHMs (all first returns + firest returns related with higher –up vegetation) where each cell location has the maximum value across all inputs CHMs [Silva et al. 2016[1] and Dalponte & Coomes 2016[3]].
  - Inverse Distance Weight (**IDW**): The inverse distance or distance-weighting gridding method is a weighted average interpolator. The weight given to a particular data point when calculating a grid node is proportional to the inverse of the distance of the observation from the grid node (DFT)[4].

- TMD

  - Lmf (VWS = f(z), hmin = 2, shape = c("circular")) Popescu, Sorin & Wynne, Randolph. (2004) [(Silva et al. 2016/ Dalponte & Coomes 2016/DFT)
  - H-maxima transformation: [DFT] (Kwak et al. 2007)[6]

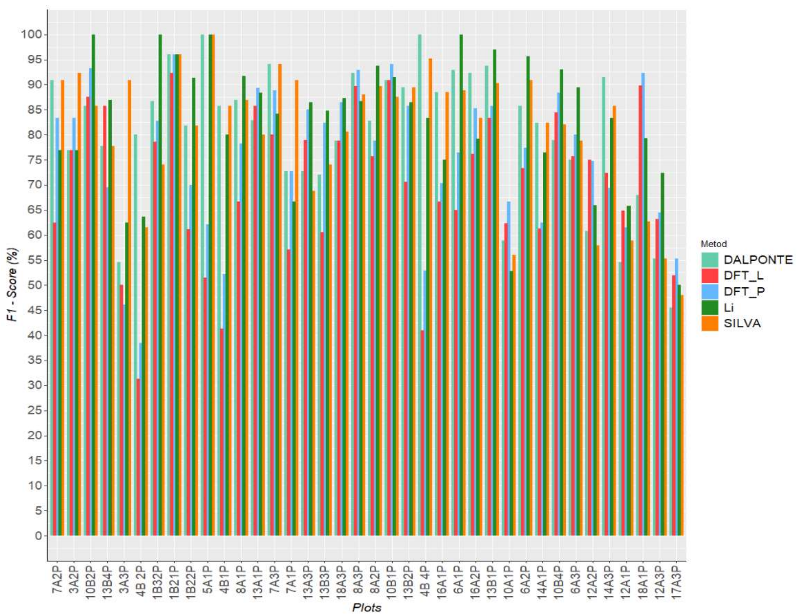
[1] Silva CA, Hudak AT, Vierling LA, et al (2016) Imputation of individual longleaf pine (Pinus palustris Mill.) tree attributes from field and LiDAR data. Can J Remote Sens 42:554–573. https://doi.org/10.1080/07038992.2016.1196582
[2] https://github.com/Jean-Romain/lidRplugins/
[3] Dalponte M, Coomes DA (2016) Tree-centric mapping of forest carbon density from airborne laser scanning and hyperspectral data. Methods Ecol Evol 7:1236–1245. https://doi.org/10.1111/2041-210X.12575
[4] Parkan, M. 2018. http://mparkan.github.io/Digital-Forestry-Toolbox/
[5] Li W, Guo Q, Jakubowski MK, Kelly M (2012) A New Method for Segmenting Individual Trees from the Lidar Point Cloud. Photogramm Eng Remote Sens 78:75–84
[6] Kwak DA, Lee WK, Lee JH, et al (2007) Detection of individual trees and estimation of tree height using LiDAR data. J For Res 12:425–434. https://doi.org/10.1007/S10310-007-0041-9/TABLES/4



(a)
(b)
(c)
(d)
(e1)
(e2)
Field measurement
Classified PC - PNOA (38 Plots)
Normalized PC
CHM (IDW)
CHM (P2R AND PF)
Local Máxima (Default)
Local Máxima Popescu
H-maxima
Local Máxima Popescu
Li et al . 2012
DFT (Watershed)
Silva and al. 2016
Dalponte & Coomes 2016
Accuracy assessment
① Individual tree detection: Recall, Precision, F1 score.
②Tree height precision: H mean error, H RMSE, H relative RMSE, H Pearson r.
③Crown Diameter precision: CD mean error, CD RMSE, CD relative RMSE, CD Pearson r.
Combined accuracy index (CAI)=(F1 Score*70%)+(H*15%)+(CD*15%).
Best results
Best parameters combinations
Input
Process
Output

4. Results

Same combination for all plots

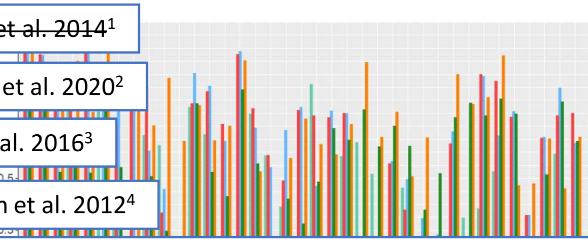


~~Wallace et al. 2014~~[1]

Torresan et al. 2020[2]

Wang et al. 2016[3]

Kaartinen et al. 2012[4]



Torresan et al. 2020 reported that working with very high density Lidar data (i.e. 193 points/m^2), the accuracy of tree segmentation was similar to that obtained when they worked with medium/low density data (i.e. 8 points/m^2).

Wang et al. 2016 reported that if the focus of the ITS is to measure the dominate trees only, ALS data of low point density (2 points/m^2) **provide satisfactory results**.

[1] Wallace L, Lucieer A, Watson CS (2014) Evaluating tree detection and segmentation routines on very high resolution UAV LiDAR ata. IEEE Trans Geosci Remote Sens 52:7619–7628. https://doi.org/10.1109/TGRS.2014.2315649

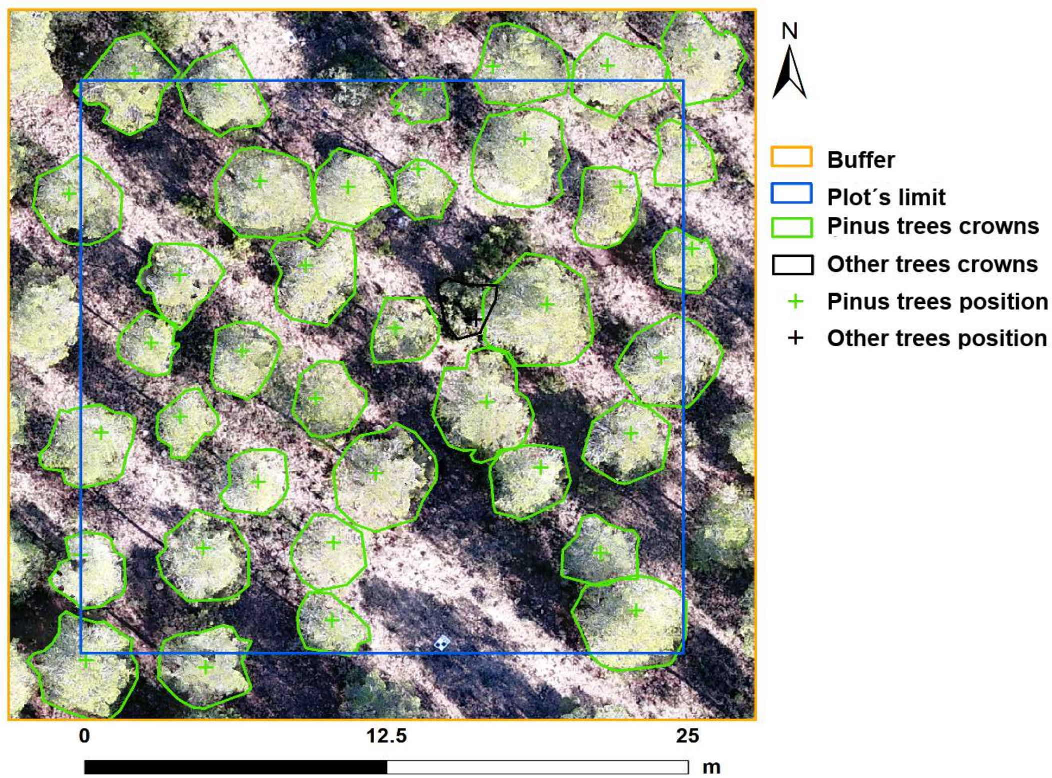
[2] Torresan C, Carotenuto F, Chiavetta U, et al (2020) Individual Tree Crown Segmentation in Two-Layered Dense Mixed Forests from UAV LiDAR Data. Drones 4:10. https://doi.org/10.3390/DRONES4020010Kaartinen H, Hyyppä J, Yu X, et al (2012) An International Comparison of Individual Tree Detection and Extraction Using Airborne Laser Scanning. Remote Sens 4:950–974. https://doi.org/10.3390/RS4040950

[3] Wang Y, Hyyppa J, Liang X, et al (2016) International Benchmarking of the Individual Tree Detection Methods for Modeling 3-D Canopy Structure for Silviculture and Forest Ecology Using Airborne Laser Scanning. IEEE Trans Geosci Remote Sens 54:5011–5027. https://doi.org/10.1109/TGRS.2016.2543225

[4] Kaartinen H, Hyyppä J, Yu X, et al (2012) An International Comparison of Individual Tree Detection and Extraction Using Airborne Laser Scanning. Remote Sens 4:950–974. https://doi.org/10.3390/RS4040950

			ITD			H				CD				CAI
	Parameters	CHM	Recall	Precision	F1 Score	H mean error	H RMSE	H relative RMSE	H Pearson r	CD mean error	CD RMSE	CD relative RMSE	CD Pearson r	Index CAI
SILVA max_cr_factor exclusion	0.3-0.4	P2R	73.70	97.38	82.53	-0.19	0.47	5.34	0.94	-0.28	0.94	22.21	0.68	82.12%
	0.4-0.5	PF	72.08	96.50	81.11	-0.18	0.47	5.41	0.94	0.12	0.91	21.74	0.69	81.23%
DALPONTE th_seed th_cr max_cr	0.2-0.1-4	P2R	71.67	95.36	80.41	-0.19	0.47	5.43	0.94	-1.30	1.67	34.69	0.25	74.18%
	0.1-0.1-4	PF	70.24	95.15	79.30	-0.19	0.48	5.45	0.94	-1.34	1.73	36.10	0.20	72.70%
DFT_L	0.7	IDW	75.36	70.62	70.00	-0.24	0.55	6.28	0.93	-0.39	1.43	32.08	0.61	72.03%
DFT_P	-	IDW	78.67	76.41	75.66	-0.24	0.54	6.09	0.93	-0.28	1.27	28.81	0.61	76.08%
Li Dt1, dt2, R, Speed-up	2-2.2-2-5		80.96	87.78	82.65	-0.25	0.48	5.92	0.94	1.80	2.40	57.06	0.55	66.11%

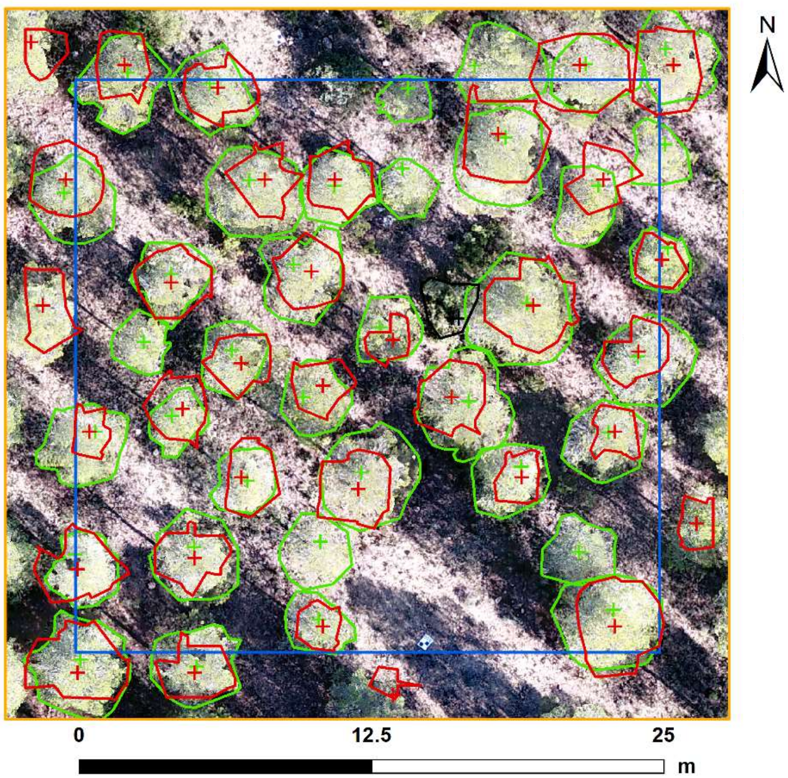
4. Results


N
Buffer
Plot´s limit
Pinus trees crowns
Other trees crowns
Pinus trees position
Other trees position
0
12.5
25
m

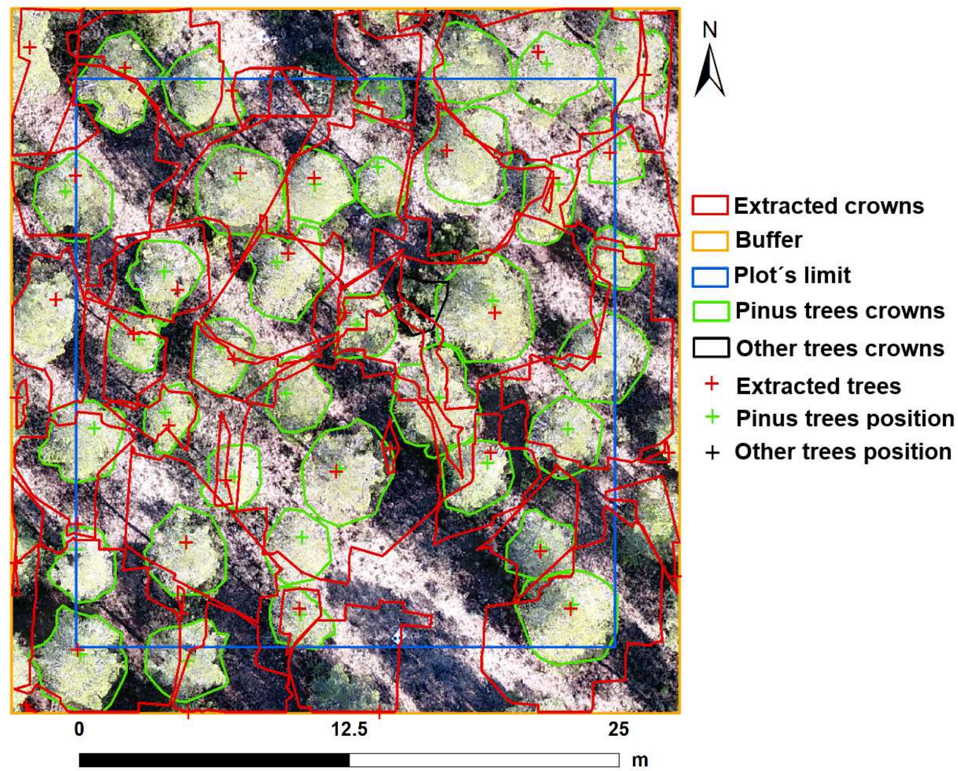
4. Results

Torresan et al. 2020

Torresan C, Carotenuto F, Chiavetta U, et al (2020) Individual Tree Crown Segmentation in Two-Layered Dense Mixed Forests from UAV LiDAR Data. Drones 4:10. https://doi.org/10.3390/DRONES4020010Kaartinen H, Hyyppä J, Yu X, et al (2012) An International Comparison of Individual Tree Detection and Extraction Using Airborne Laser Scanning. Remote Sens 4:950–974. https://doi.org/10.3390/RS4040950

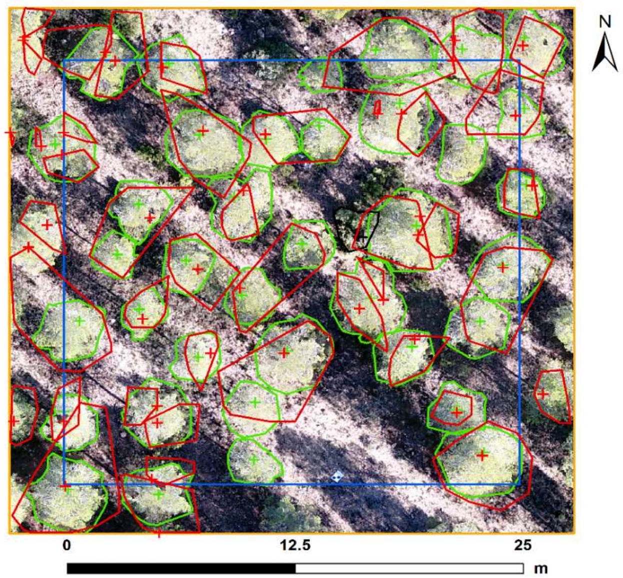


Silva et al.2016 Segmentation

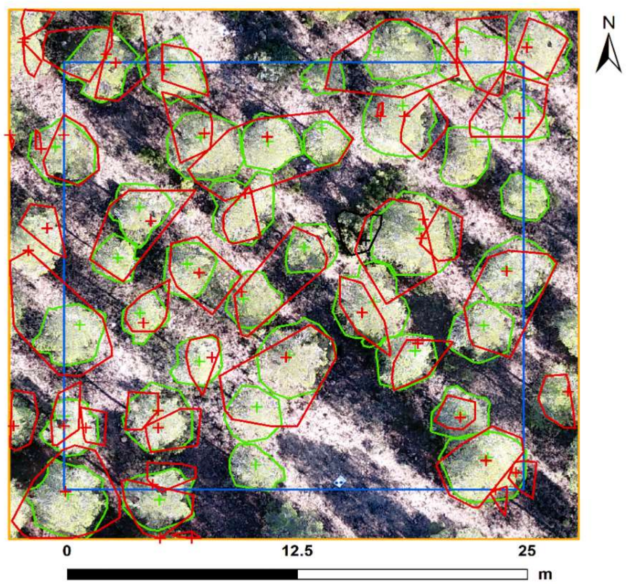


Li et al 2012 et al. Segmentation

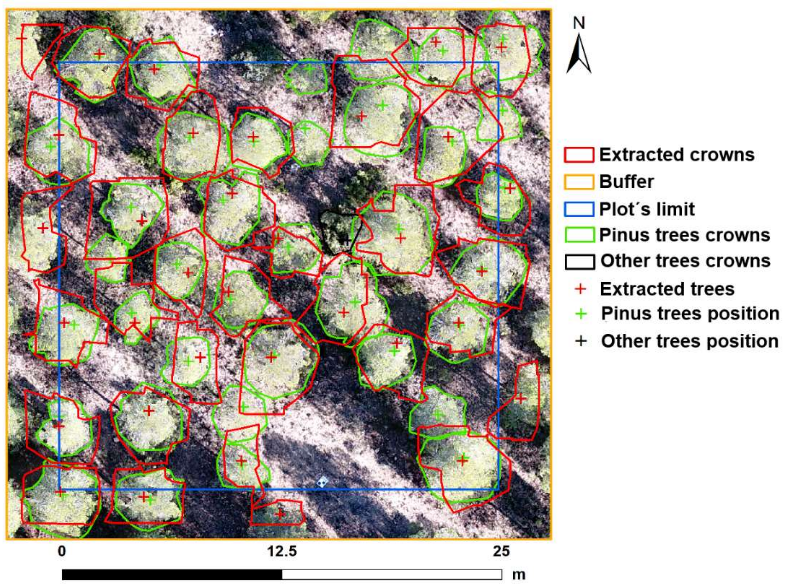
4. Results



DFT_P



DFT_HM

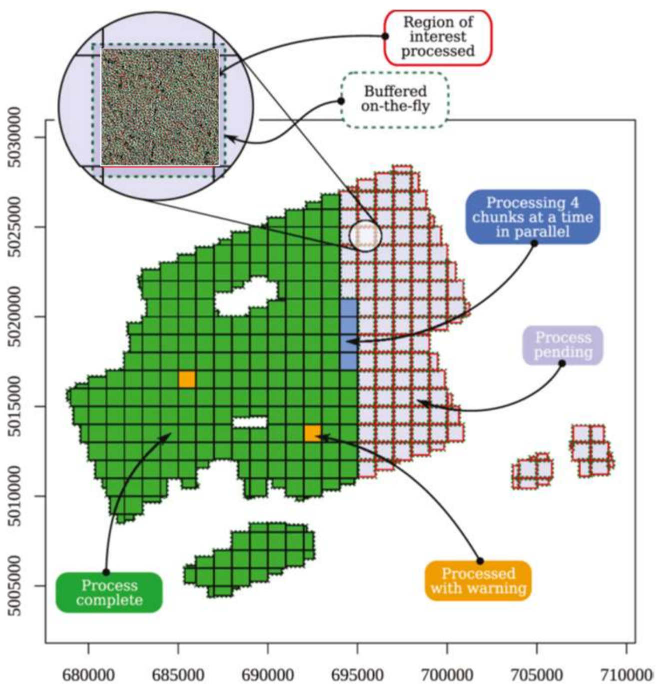


Dalponte & Coomes 2016
Segmentation

5. Conclusions

These results demonstrate that by adopting the pipeline proposed in this work, low density ALS data can be used to accurately estimate Height and CD.

Above-ground biomass prediction using height and crown diameter working on large areas of Mediterranean forests



lidR LAScatalog processing engine

Adopting the proposed workflow (normalization, CHM, etc.)

Silva et al. 2016 Algorithm:
Max crown factor 0.3; Exclusion: 0.4 with P2R CHM

LMF; Variable Window Size (Popescu& Wynne 2004 equation)

6. *Acknowledgments*

- "*Enabling interdisciplinary collaboration to foster Mediterranean forest sustainable management and socio-economic valuation (**ECO2-FOREST**)*". (Proyecto Retos Junta de Andalucía, Spain. Grant number **P18-RT-232**7.

- "*Intervention strategies for an integrated and sustainable management of the Mediterranean forest based on an interdisciplinary analysis and its economic assessment*" (Programa Operativo FEDER Andalucía 2014-2020, Spain. Grant number **UAL2020-SEJ-D1931**).

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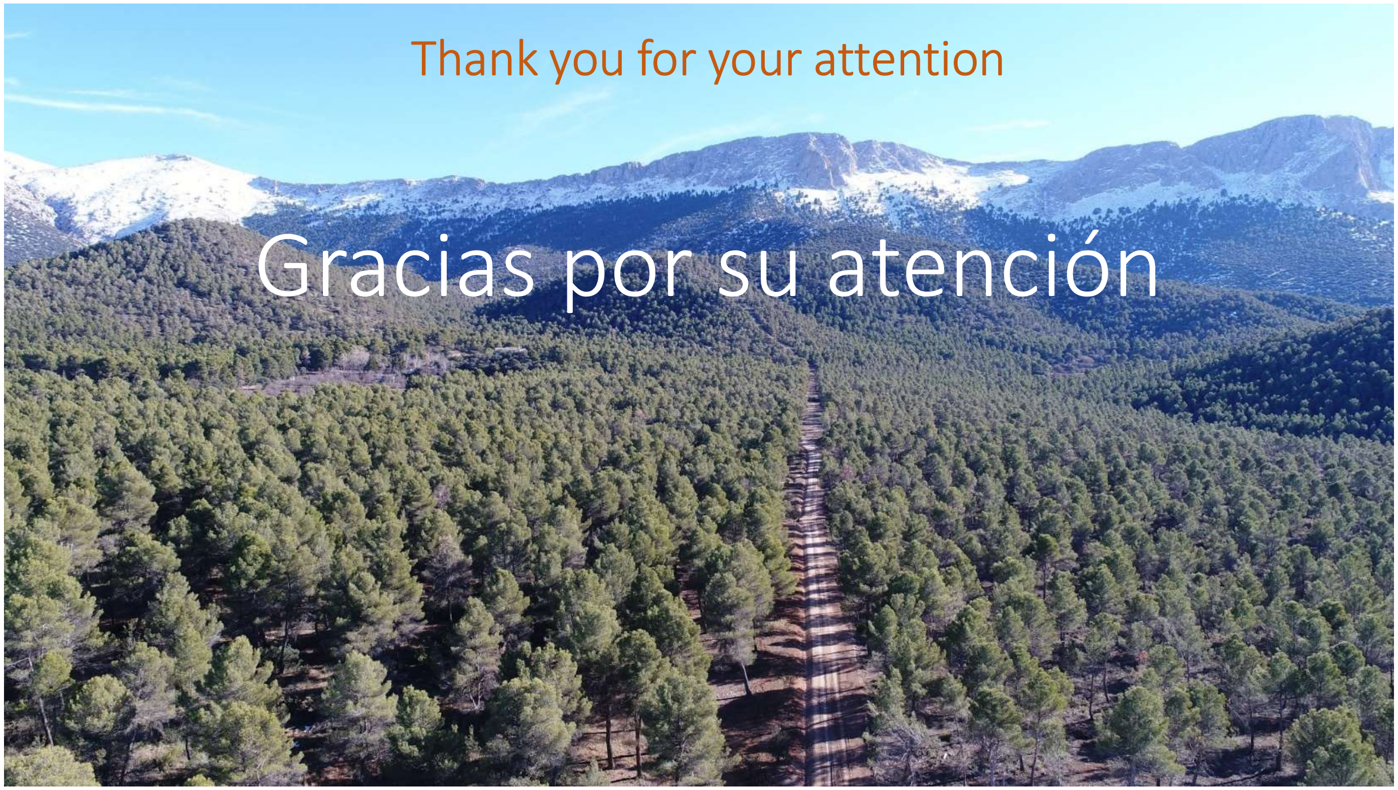
UAL2020-SEJ-D1912



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