Supplementary Information for

Tree to Regional Scaling of Stem Volume Estimates: Leveraging airborne lidar, Landsat and LANDFIRE data

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1. Individual tree detection

- Tree tops were detected by applying a Local Maximum Filter (LMF) with variable window size in the lidR R package to a 0.5 m canopy height model generated from aboveground airborne lidar data. In the variable window approach, the window size used to detect local maxima is adjusted based on a specified crown diameter- tree height relationship. To apply a variable window, regression models were established between measured crown diameter and tree height for pines and mixed forests groups. The window size, *ws*, was variably adjusted according to Equations (1) and (2) for pines and mixed forests, respectively:

$$ws = \begin{cases} 3, h \leq 10 \\ 0.2082h + 0.8125, \quad 3 < h \leq 20 \\ 7, h > 20 \end{cases} \quad [1]$$

$$ws = 0.1024h + 3.0718 \quad [2]$$

where *h* is the height of the local maximum.

2. Crown segmentation

- Detected tree crowns were segmented using the method proposed by Silva et (2016). In the lidR package the function took as input the 0.5 canopy height model used in the individual tree detection and detected tree locations. The function also has hyper-parameters: 1) *max_cr_factor*, which represents the maximum value of a crown diameter given as a proportion of the tree height, 2) *exclusion*, used to exclude pixels with an elevation lower than exclusion multiplied by the tree height. *max_cr_factor* was adjusted from its default value of 0.6 to 0.25 for both pines and mixed forests. Other parameters were left at their default values.

3. Assessment of Individual tree detection and crown segmentation

- After (Malambo et al. 2019), ten (10) 30 m diameter plots were randomly selected in pine and mixed forest areas and corresponding airborne data was clipped. For each plot, the lidar data was visually analyzed and all visible tree locations digitized by marking a central point within each crown to provide tree counts and planimetric (x-y) location data. The marking of trees was carried out using CloudCompare (version 2.10.2) (Girardeau-Montaut 2020), a free software that is used for point cloud processing and analysis.
- Tree detection accuracies expressed by the overall accuracy (OA), omission error (OE), and commission error (CE) and were assessed as follows:

$$OA = \frac{N_t}{N_R} \times 100 \quad [3]$$

$$OE = \frac{N_o}{N_R} \times 100 \quad [4]$$

$$CE = \frac{N_m}{N_D} \times 100 \quad [5]$$

where N_t is the total number of correct tree detections – trees within 1 m distance of digitized locations, N_R is total number of digitized trees, N_o is the number trees omitted – trees without a digitized location within 1 m buffer, N_D is the total number of detected trees, Nm, calculated as ($N_d - N_t$), is the number of wrongly detected trees.

Table S1: Summary of tree detections and associated accuracies.

	N_r	N_D	N_t	N_o	N_m	OA	OE	CE
Pines	276	269	250	26	7	90.6	9.4	2.6
Mixed	163	180	133	30	17	81.6	18.4	9.4

- From all the digitized x-y data, we selected a random sample of 30 trees each for pines and mixed forests - 3 trees per plot. The FUSION/LDV (version 3.60) (McGaughey 2009) was then used to manually measure the tree height and crown diameter for selected trees. FUSION/LDV is a free software for LiDAR-based measurement, analysis, and visualization mainly for forest environments. FUSION/LDV provided 3D visualization of point clouds and tools, which enhanced the measurement of individual tree attributes. Table 2 list the measured and estimated tree height and crown diameters for a random sample of 30, each for pines and mixed forest.

Table S2: Measured (Meas.) and estimated (Est.) tree heights and crown diameters (CD)for randomly selected trees for pines and mixed forests. Unmatched trees not detected or segmented were removed reducing the sample from 30 in each cased

	Mixed				**Pines**			
ID	Meas. height	Meas. CD	Est. height	Est. CD	Meas. height	Meas. CD	Est.height	Est. CD
1	22.8	5.3	22.4	6.4	13.5	5.2	13.1	4.8
2	24.4	6.3	24.0	6.0	14.0	4.7	13.8	4.3
3	23.0	5.6	22.5	4.4	16.3	5.1	15.3	4.9
4	12.0	4.9	11.8	4.2	14.1	3.5	14.0	3.6
5	26.3	6.4	26.0	7.7	15.4	4.4	15.0	5.7
6	17.0	5.7	16.9	6.6	16.5	4.5	16.3	5.2
7	23.5	9.7	23.3	8.6	13.2	4.3	14.5	5.2
8	23.0	5.2	22.6	5.9	15.5	3.8	15.3	5.5
9	27.2	7.5	26.0	7.3	15.5	3.8	15.3	5.5
10	22.2	5.3	22.1	6.6	14.1	3.7	14.0	4.3
11	11.4	5.2	11.1	6.4	19.1	3.6	19.1	4.8
12	21.9	7.1	21.7	7.4	11.0	3.8	10.9	4.2
13	23.7	6.7	23.3	6.9	19.8	5.5	19.5	5.6
14	38.5	6.9	38.2	6.9	22.1	5.8	22.0	5.3
15	36.0	6.6	35.7	7.5	21.3	4.8	21.1	6.3
16	21.5	4.1	21.3	4.5	20.7	4.2	20.5	5.5
17	12.4	3.9	9.2	3.8	16.1	4.5	16.1	5.0
18	28.8	6.0	28.7	7.0	24.4	10.1	24.0	9.7
19	23.8	3.8	23.3	3.6	23.7	4.4	25.3	5.0
20	24.2	3.7	25.4	4.9	16.1	3.7	16.0	4.8
21					16.2	3.5	16.0	4.7
22					15.4	3.2	15.9	4.7
23					9.8	3.0	9.7	3.3
24					10.8	3.5	9.6	2.6
25					21.4	6.2	21.3	6.9
26					19.3	2.9	19.4	3.8
27					15.8	2.7	15.7	3.5
28					21.7	5.3	21.6	6.6
29					22.7	5.3	22.6	6.1

- Regression analysis was used to assess the agreement between tree automatic and manually measured tree height and crown estimates.

Table S3: Assessment of estimated tree height and crown diameter for pines (N = 29) and mixed (N = 20) forests

	Tree height (m)				Crown diameter (m)			
Type	Estimated	Measured	R^2	MAE (m)	Estimated	Measured	R^2	MAE (m)
Mixed	22.8	23.2	0.98	0.52	6.1	5.8	0.71	0.72
Pines	17.0	17.1	0.98	0.34	5.3	4.4	0.75	0.82

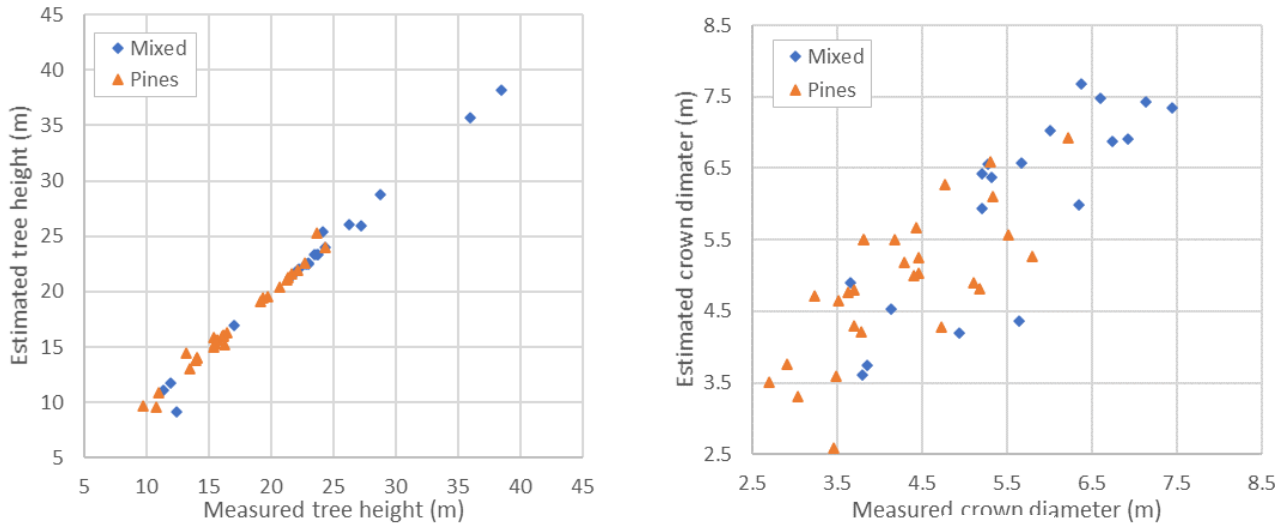

Figure S1: a) Estimated versus measured tree height for pines (N = 29) and mixed forests (N = 20), b) Estimated versus measured crown diameter for pines (N = 29) and mixed forests (N = 20)

Girardeau-Montaut, D. (2020). CloudCompare (Version 2.10. 02)[GPL Software]. In http://www.cloudcompare.org

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