Exploring the effect of leaves on tree woody surface area estimation with quantitative structural models

David W. MacFarlane[1*], Georgios Arseniou[1], Andrew Burt[2], Vicari, M. B.[2], Mathias Disney[2,3], Kim Calders[4]

[1]Department of Forestry, Michigan State University, East Lansing, Michigan, USA. [2]UCL Geography, North West Wing, Gower Street, London WC1E 6BT. [3]NERC National Centre for Earth Observation, Leicester, UK. [4]Computational & Applied Vegetation Ecology Laboratory, Department of Environment, Faculty of Bioscience Engineering, Ghent, University, Belgium *corresponding author: macfar24@msu.edu

1. Introduction

Advances in terrestrial laser-scanning technology (TLS) and associated data processing algorithms now allow for comprehensive measurements of the structural complexity of trees. Point cloud data generated by TLS can be processed by Quantitative Structural Models (QSMs) to allow for estimation of total surface areas and volumes of trees, by creating a network of connected cylinders approximating the stem and branch network of the trees (Raumonen et al. 2013). One of the challenges for computing the woody surface area of trees is the presence of leaves, because leaves occlude woody parts from being seen by the laser and QSMs may interpret leaves as woody structures (Burt et al. 2021). Another issue is that foliage cannot be represented by cylinders (Stovall et al. 2017). It is not always possible to scan trees during the leaf-off period and evergreen trees are never in a leaf-off condition, unless dead. So, investigators sometimes use QSMs on trees in the leaf-on condition, assuming that, underestimation of woody surface area and volume from occlusion and overestimation from counting leaves as woody parts, cancel out. Here, we tested that assumption for broadleaved, deciduous trees, using needleleaf evergreens as a control. We also used the leaf-removal algorithm of Vicari et al. (2019) to see how artificial leaf removal might pre-process a leaf-on point cloud before estimating wood surface area with a QSM to simulate estimation in a leaf-off condition.

2. Data and Methods

Thirteen trees of two broadleaf, deciduous species (8 *Quercus rubra* and 5 *A. rubrum*) and ten needleleaf evergreens of two species (5 *Tsuga canadensis* and 5 *Pinus strobus*) were scanned during the early spring (April) of 2017, when the deciduous trees were in the leaf-off condition, and then again in the summer (July), in the deciduous leaf-on condition, with a RIEGL® VZ-400, at Harvard Forest (Petersham, MA, USA), to produce point clouds of each tree in both periods. Additionally, leaves of the deciduous species were virtually removed from the summer-scanned point clouds with the *tlseparation* algorithm of Vicari et al. (2019), to examine how similar a leaf-removed condition is to leaf-off. QSMs were produced from the three types of point-clouds, using the TreeQSM algorithm (Raumonen et al 2013), generating cylinders outlining all woody parts of the stem and branches; the sum of all of these was the total surface area of woody parts (woody surface area, WSA, m^2) of each tree. After scanning, trees were felled and measured in detail, including total-tree one-sided leaf area (LA, m^2)- leaves were collected and weighed from throughout the crowns of the felled trees and sub-samples were weighed and had their surface area scanned on a flatbed scanner. Leaf area per unit leaf mass was then extrapolated to the tree's total estimated leaf mass. this enabled estimation of the total LA of each tree. The trees ranged in size from 8 to 50 cm, stem diameter at breast height, and 8 to 25 m in height. Data were error-checked and imported into the R statistical software environment and analysed with custom code to determine the influence of leaves on tree surface area estimation.

3. Results

The results showed a strong, positive correlation between woody surface area with leaves on (WSA_{on}) and off (WSA_{off}) for broad-leaved deciduous trees, but with a positive bias, such that WSA_{on} was significantly higher than WSA_{off} (Fig. 1). There was also a strong, positive correlation between WSA_{spring} and WSA_{summer} for needleleaf evergreens, but the relationship was more variable and showed

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a slightly negative bias (Fig. 1). The leaf removal algorithm removed a significant amount of woody material from the point cloud when trying to separate leaves from the leaf-on point clouds of the deciduous trees (Fig. 2A), resulting in a positive difference between WSA_{off} – $WSA_{removed}$, which increased as the total leaf area of the tree increased (Fig. 2B).

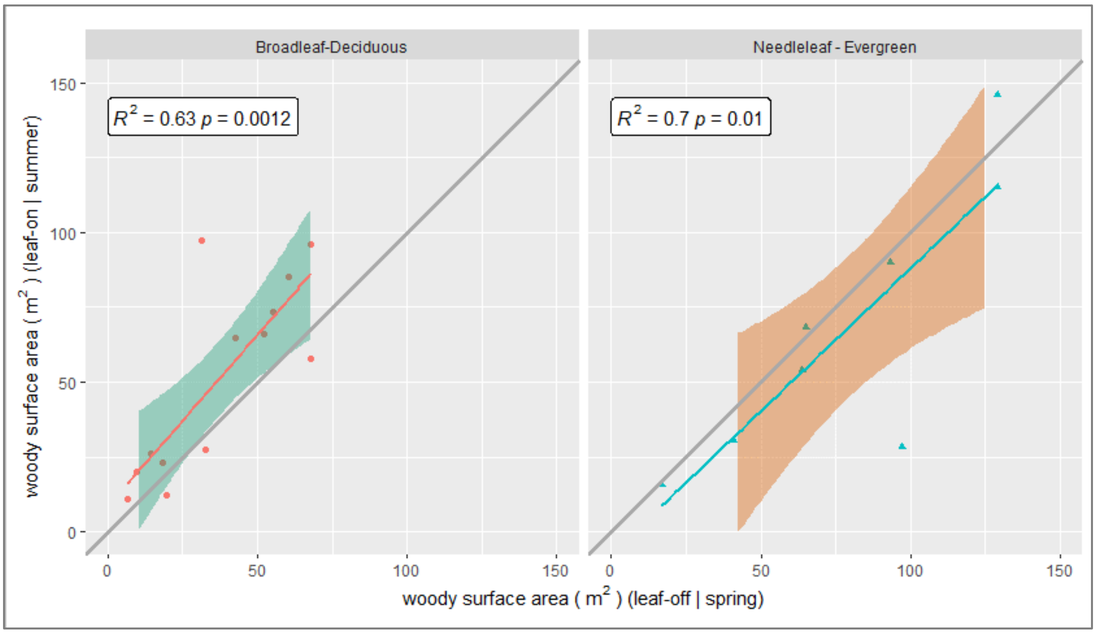

Figure 1. Total woody surface area of trees computed from a QSM with leaves on and leaves off for deciduous trees and summer versus spring scans for the evergreen species.

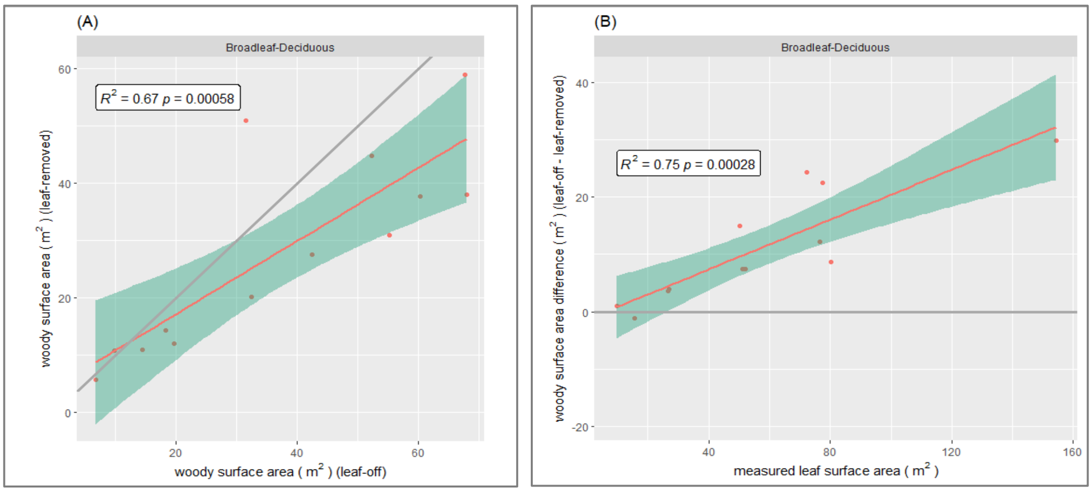

Figure 2: (A) Total woody surface area of deciduous trees with leaves removed from leaf-on scans with an algorithm, prior to processing with a QSM, plotted against the same trees with woody surface area computed from a QSM from leaf-off scans. (B) The difference between woody surface area computed with leaves off versus woody surface area with artificial leaf removal from leaf-on scans, plotted against the measured total tree leaf area from destructive sampling.

4. Discussion

The results of this study show that possible overestimation and underestimation biases in estimates of tree woody surface area, when applying a QSM to a tree in the leaf-on condition, do not strictly cancel each other out, in agreement with the findings of Calders et al. (2018). The net result was an overestimation bias for deciduous trees, that apparently comes from adding leaves to the surface area of smaller branches at the periphery of the crown. When needle-leaved evergreens, scanned in a leaf-on condition at two different times of year (spring and summer) were used as a control, there were differences in the estimated woody surface area, with a slight trend toward lower woody surface area estimated in the summertime. This may be due to greater occlusion of the stem by more full fascicles of needles during the summer. Evergreens regularly shed older needles, though they retain multiple cohorts, thus always maintaining leaves, with their maximum leaf area in summer. The whorled branching architecture and the way that needles directly attach to shoots may also make it more difficult to see woody parts in summer, but follow-up studies are needed, perhaps with deciduous conifers.

When the leaf-separation algorithm was applied to the point clouds of deciduous trees with their leaves-on, the algorithm turned a bias of overestimation of woody surface area into a negative bias, which suggests that smaller branches in the periphery of the crowns were miss-classified as leaves. So, the algorithm overcompensated for the positive bias mentioned above. The fact that the bias increased as the actual surface area of the leaves of the trees increased, indicates that the algorithm would be most effective when trees have relatively low leaf areas. Larger trees with larger leaf areas likely have more complex point clouds, resulting in greater confusion of leaves and branches, which should affect the performance of the leaf-separation algorithm (Vicari et al. 2019, Wang et al. 2019). Significant total tree volume underestimation has been previously found after artificial leaf-removal (Wang et al. 2019), however, Burt et al. (2021) showed that the leaf-removal significantly reduced bias in total tree above-ground biomass from TLS data compared to biomass estimates based on leaf-on point-clouds. In general, leaf-separation algorithms may be necessary for estimating woody surfaces areas of evergreen trees or trees in the leaf-on condition, but the algorithms will need improvement to produce reliable estimates.

5. Conclusion

Applying a QSM to broadleaf, deciduous trees in the leaf-on condition resulted in an overestimation bias for estimates of the woody surface area underneath the leaves. Scanning evergreens both in spring and in summer showed the possibility for seasonal differences, and here, lower woody surface area in summer, possibly due to occlusion of, or confusion with, woody parts and dense fascicles of needle-leaves. Leaf removal algorithms should be applied with caution, as they may simply reverse the direction of bias in estimation of woody surface area.

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