Effect of airborne laser scanning pulse density on accuracy in quantifying forest structure using an unmanned aerial vehicle.

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1. Introduction

Accurate quantification of forest structure is required for a number of practical applications including management, environmental protection, fire behavior analysis, and carbon accounting. Stand structure is typically estimated through manual field measurement. This approach is often constrained by site accessibility, the availability of effective measurement techniques, management requirements and the cost of labor. The development and application of remote sensing technologies have opened new frontiers in terms of the scale of data acquisitions and the features that can be measured. In particular, airborne laser scanning (ALS) remote sensing for forestry operations has broadened forest mensuration capabilities. These tools are being integrated into the mensuration practices of forest industry but questions remain regarding the deployment and accuracy of ALS.

Recent improvements in technology have permitted the use of unmanned aerial vehicles (UAVs) as a viable remote sensing platform offering a combination of multi-temporal high-resolution data captured at a significantly lower survey cost (Rothmund et al., 2017), but often only at small scales. There is uncertainty that high pulse densities will yield better accuracy in the estimation of forest features. Jakubowski et al. (2013) state that metrics related to coverage (e.g. canopy cover) were more sensitive to low pulse densities (<20 pulses m^{-2}) as opposed to metrics such as tree height, diameter at breast height, shrub height and total basal area which were relatively unaffected until pulse density reduced to below 1 pulse m^{-2}. Features of interest which are smaller than the plot-level, in particular individual trees, are subject to more uncertainty regarding a minimum required pulse density for the specific detection of that feature (e.g. Kamoske et al. 2019).

Various light penetration indices have been developed in order to estimate leaf area index (LAI) at the field plot level, generally defined as total one-sided leaf surface area per ground surface area (Chen and Black, 1992). By their nature, these approaches are highly dependent on the density and structure of vegetation in situ and a pulse density high enough to return data from the lower vertical strata of a forest plot is required to ensure accuracy. Additional uncertainty comes from transferring these approaches to different sites and ALS acquisitions.

There is a growing volume of research literature concerning the development of increasingly complex methods for the delineation of individual tree crowns (ITC). More recently, methods have been developed to delineate ITCs directly from ALS point cloud returns that could potentially improve delineations, as stated in Kaartinen et al. (2012) and Ferraz et al. (2016). Improving the accuracy of ITC delineations may be

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possible with new methodologies that include higher pulse densities. Depending on which structural feature is being estimated, there are varying degrees of accuracy in their measurement.

The overall goal of this study was to evaluate the effects of a range of ALS pulse densities, from high (>300 pulses m^{-2}) to low (0.25 pulses m^{-2}), have on our ability to delineate individual trees and on the accuracy of individual tree estimates of top height and crown width, and plot-level LAI.

2. Data and Methods

Our study location was an 8-year-old experimental site with varying of individual tree and stand structures of loblolly pine (*Pinus taeda* L.) plantation forest in the North Carolina, USA (34°49′49.63″N, 78°35′18.52″W). The site contains different three planting densities (low, medium and high densities - 618, 1236 and 1854 trees per hectare, respectively), six genetics and two levels of silviculture. A total of 108 field experimental units were established with 63 trees in each (7 rows of 9 trees) (more details can be found in Yáñez et al. 2017). Field measurements for individual trees consisted of: (i) GPS locations; (ii) tree top height (measured via hypsometer); (iii) crown horizontal extent; and (iv) survival (in year 9). LAI measurements using a LI-COR LAI 2200 plant canopy analyzer (LI-COR, 2012).

Discrete return UAV ALS data was acquired in August 2017 to coincide with peak-leaf area conditions. A laser pulse density of >300 pulses m^{-2} was acquired with up to two returns per laser pulse. Eight pulse densities were randomly subsampled for testing purposes, these were: 300, 100, 50, 10, 5, 1, 0.5 and 0.25 pulses m^{-2}.

Initial ITCs were delineated by implementing the method outlined in Li et al. (2012). This approach functions directly to the point-cloud. A number of modifications to this approach are proposed, which exploit 3D clustering and distance between clusters to refine the ITC classification. ITCs were then paired with the closest field tree via GPS coordinates, unless the distance was over 1 m. LAI was estimated using the above/below ratio index (ABRI) as described in Sumnall et al. (2021). In addition to a comparison of estimated versus field values, a (generalized) linear mixed-effects model approach was implemented in order to state if the difference between the estimates created is significant.

3. Results and Discussion

The success of the ITC method used in the current research is mainly dependent on stem density, in addition to ALS pulse density. Delineation accuracy, when stratifying for the three stem densities tested, was relatively consistent in terms of RMSE (±6%) for pulse densities above 5 pulses m^{-2}. The largest proportion of delineated ITCs that corresponded to field GPS coordinates were observed within plots that had the lowest stem density. Correct ITC delineations accounted for a mean of 85% for low-density, 70% for medium-density and 55% for high-density plots, as illustrated in Figure 1. No commission error was observed within the current research. From this, we conclude that some ITC objects represent a cluster of tree crowns.

For estimates of tree top height higher pulse densities (≥50 pulses m^{-2}) are more accurate. Stratification of results by planting stem density showed differences in terms of root mean square error (RMSE), where high-density plots were the poorest. RMSE values ranged from of 0.48 to 1.25 m (300 pulses m^{-2}) to 1.74 to 1.85 m (0.25 pulses m^{-2}).

The accuracy of crown diameter estimates decreases relative to decreases in ALS pulse density. RMSE values ranged from of 0.98 to 1.78 m (300 pulses m^{-2}) to 2.11 to 3.29 m (0.25 pulses m^{-2}). For pulse density greater than or equal to 50 pulses m^{-2}, RMSE for all stem densities tested was relatively consistent (±0.2 m) when stratifying by the three stem densities.

The correspondence between ALS estimates and field measured LAI was relatively similar across all pulse densities above 1 pulses m^{-2}. RMSE varied from 0.78 to 1.11. These RMSE values were higher to those reported in Sumnall et al. (2021). We must assume this increase in uncertainty was related to the method of acquisition. The indirect nature of the field measurement represents an additional source of uncertainty.

When considering the comparison of pulse density results, only comparisons between higher pulse densities (between 300 and 50 pulses m^{-2}) resulted in statistical difference ($p > 0.05$) for all metrics estimated. The implication of which is that features may or may not be present at different pulse densities.

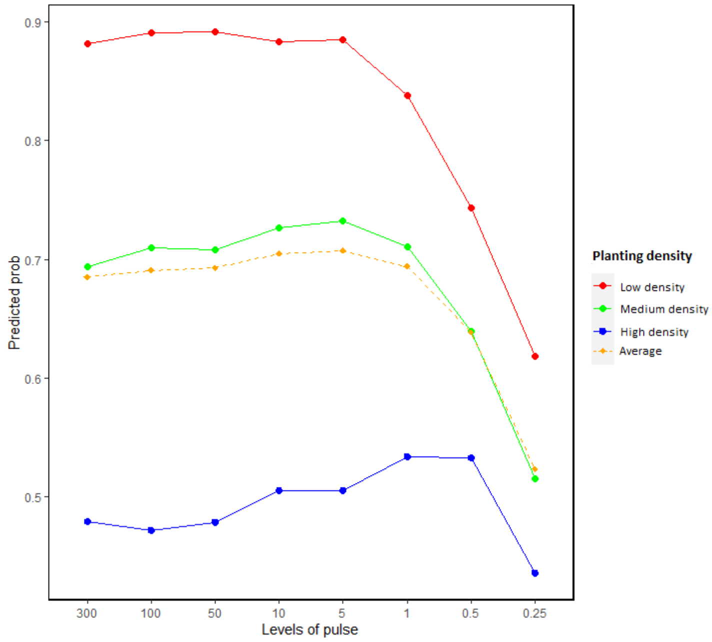

Figure 1: The detection probability of individual tree crowns relative to pulse density, stratified by stem density (low = 618 trees per hectare (TPH), medium = 1236 TPH, high =1854 TPH).

4. Conclusions

The tradeoff of data quality and coverage against cost when planning new ALS acquisitions is a critical one for forest managers. For the plot scale estimates of LAI, estimate accuracy was relatively consistent, and only decreased at low pulse densities (≤5 pulses m^{-2}) as observed in other research (e.g. Kamoske et al., 2019 and Shao et al., 2019). When considering the ITC-scale, however, estimates appeared to be more sensitive to pulse density. Where higher pulse densities produced the highest accuracy (i.e. lowest RMSE). This implies that the size of the object being studied is an important consideration when designing an ALS acquisition with regards to pulse density. One of the main limitations of the method outlined in the current research is the success of the ITC delineation. In all cases, 100% of the stems in a plot were not located correctly in the current study, implying that some of the ITC delineations were clusters of crowns.

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References

Ferraz, A., Saatchi, S., Mallet, C. and Meyer, V., 2016. Lidar detection of individual tree size in tropical forests. *Remote Sensing of Environment*, Vol. 183, p.318-333.

Jakubowski, M.K., Guo, Q. and Kelly, M., 2013a. Tradeoffs between lidar pulse density and forest measurement accuracy. *Remote Sensing of Environment*, Vol. 130, p.245-253.

Kaartinen, H., Hyyppa, J., Yu, X. W., Vastaranta, M., Hyyppa, H., Kukko, A., Holopainen, M., Heipke, C., Hirschmugl, M., Morsdorf, F., Naesset, E., Pitkanen, J., Popescu, S., Solberg, S., Wolf, B. M., and Wu, J. C., 2012. An international comparison of individual tree detection and extraction using airborne laser scanning. *Remote Sensing, Vol.* 4 (4), p. 950-974.

Kamoske, A.G., Dahlin, K.M., Stark, S.C. and Serbin, S.P., 2019. Leaf area density from airborne lidar: Comparing sensors and resolutions in a temperate broadleaf forest ecosystem. *Forest Ecology and Management,* Vol. 433, p. 364–375.

Shao, G., Stark, S.C., de Almeida, D.R. and Smith, M.N., 2019. Towards high throughput assessment of canopy dynamics: The estimation of leaf area structure in Amazonian forests with multitemporal multi-sensor airborne lidar. *Remote Sensing of Environment,* Vol. 221, p. 1–13.

Sumnall, M.J., Trlica, A., Carter, D.R., Cook, R.L., Schulte, M.L., Campoe, O.C., Rubilar, R.A., Wynne, R.H. and Thomas, V.A., 2021. Estimating the overstory and understory vertical extents and their leaf area index in intensively managed loblolly pine (Pinus taeda L.) plantations using airborne laser scanning. *Remote Sensing of Environment*, Vol. 254, p.112250.