Deriving Forest Structural Biodiversity Traits with Terrestrial Laser Scanning

Atticus E.L. Stovall[1,2], Lola Fatoyinbo[1], John Armston[2], Lisa Patrick Bentley[3], Kim Calders[4], Mat Disney[5]

[1]NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD, United States
Email: atticus.stovall@nasa.gov; lola.fatoyinbo@nasa.gov

[2]Department of Geographical Sciences, University of Maryland, College Park, MD 20742, USA
Email: atticus@umd.edu; armston@umd.edu

[3]Department of Biology, Sonoma State University, 1801 E. Cotati Ave., Rohnert Park, CA 94928, USA
Email: lisa.bentley@sonoma.edu

[4]CAVElab - Computational & Applied Vegetation Ecology, Department of Environment, Ghent University, Belgium
Email: Kim.Calders@UGent.be

[5]UCL Department of Geography, Gower Street, London WC1E 6BT, UK
Email: mathias.disney@ucl.ac.uk

1. Introduction

Spatially representative maps of forest biodiversity are directly limited by a lack of suitable in-situ representations and drivers of ecosystem structure. Biota interact with ecosystems in three dimensions, yet structural indicators of biodiversity are typically only captured with one- (e.g. tree height) or two-dimensional (e.g. canopy cover) measures. More complex and objective measures of habitat structure or, what we call structural biodiversity traits (SBTs; e.g. volume, crown dimensions, tree-level leaf area, branching architecture) that are more compatible with remotely sensed measurements would refine floral and faunal biodiversity mapping efforts, but we currently lack a consistent, spatially representative global dataset of SBTs for testing scaling predictions.
Terrestrial Laser Scanning (TLS) is a ground-based LiDAR technology that directly addresses a lack of SBTs by enabling collection of unprecedented 3D measurements of tree- and plot-level structure, revolutionizing how we characterize forests (Calders et al., 2020; Disney, 2019). Now, we are able to capture detailed 3D tree measurements with TLS - from branching angle and crown architecture to tree volume and biomass - directly capturing the fundamental elements of structural biodiversity and habitat structure (Verbeeck et al., 2019). The measurements capable with TLS make it the single most promising technology for moving from traditional plot-based measures to next-generation 3D characterization of forests (Disney et al., 2019; Stovall & Shugart, 2018).

Here, we provide an overview of a recently funded project that will bring together thousands of TLS plot locations from the laser scanning community to develop a first of its kind global database of SBTs (Figure 1). With this database this project will enable hypothesis testing of unprecedented ecological questions.

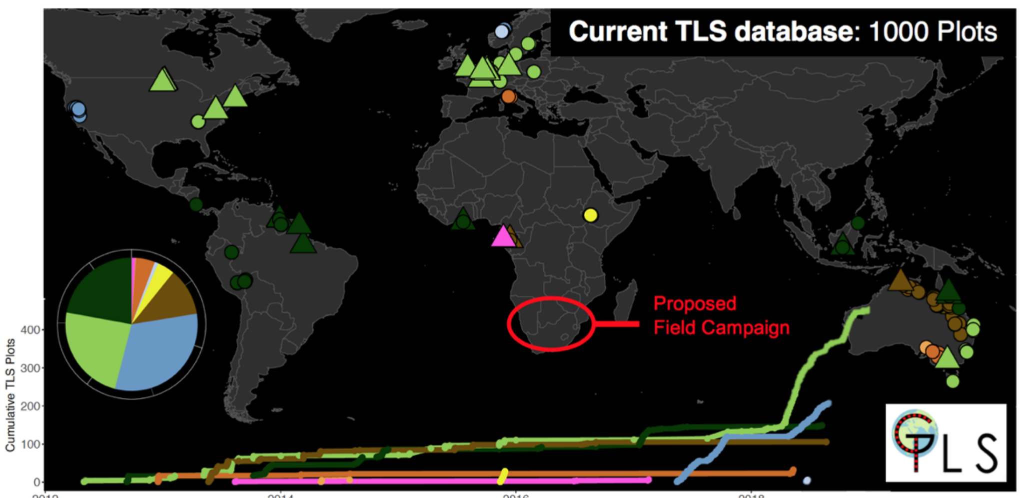

Figure 1: Current global TLS database of >1000 forest plots covering 10 biomes.

Published in: Markus Hollaus, Norbert Pfeifer (Eds.): Proceedings of the SilviLaser Conference 2021, Vienna, Austria, 28–30 September 2021.
Technische Universität Wien, 2021. DOI: 10.34726/wim.1861
This paper was peer-reviewed. DOI of this paper: 10.34726/wim.1990

2. Methods

TLS is already collected at forest sites around the globe (Figure 1). Sites with processed tree-level data (triangles) span a large proportion of our database. Our preliminary assessment also highlights data gaps for future contributions and field campaigns planned in South Africa.

We will derive a standardized set of tree-level metrics from TLS data (See Table 1; Calders et al., 2015a; Krishna Moorthy et al., 2019; Raumonen et al., 2013; Verbeeck et al., 2019; Walter et al., 2021). In addition, we will derive plot-level estimates of cover, plant area index, plant area vegetation density, and leaf angle distribution (Calders et al., 2014; Stovall et al., 2021).

Table 1: 3D architecture structural biodiversity traits we will derive.

SBTs	Description
Top-heaviness	Ratio of total woody volume in the crown to the stem woody volume
Aspect ratio	Ratio of maximum crown width to crown height
Relative Crown Width	Ratio of maximum crown width to tree height
Crown Area	Maximum ground area covered by the crown viewed from above
Leaf Area	Total tree leaf area
Crown Density	Ratio of crown area to woody volume in the crown
Mass Taper Exponent	Exponent of a power law fit to the vertical profile of volume
Path Fraction	Ratio of mean to maximum base-to-twig path length
Crown Asymmetry	The ratio of maximum to mean of 8 angular crown segments
Branching Angle	The average angle between two cylinders at each branching point

3. Outlook and Impact

The key deliverable from this work will be a global database of 3D structural biodiversity traits (SBTs) that will refine our understanding of scaling relationships and can be leveraged for improved biodiversity mapping. Our work will provide a first-of-its-kind global analysis of the drivers of SBTs, directly improving predictions of aboveground structure in forests. Indeed, the results gleaned from this global-scale analysis of the controls on scaling relationships will inform functional ecosystem modeling efforts and remote sensing of biodiversity. A database of SBTs is a critical step towards informing a global remote sensing-based approach to mapping and monitoring the habitat structure and biodiversity, directly supporting conservation efforts.

Acknowledgments

We would like to thank all persons involved with the field work and TLS data collection used in this project. The project would not be possible without the contributions of TLS data from the following institutions/projects: University College London, NASA CMS 3D Change, University of Virginia, NASA Goddard Space Flight Center, University of Maryland, Sonoma State University, Wageningen University and Research, Ghent University, University of Yaoundé, Colorado State University, and TERN AusCover.

References

Calders, K., Adams, J., Armston, J., Bartholomeus, H., Bauwens, S., Bentley, L. P., Chave, J., Danson, F. M., Demol, M., Disney, M., Gaulton, R., Krishna Moorthy, S. M., Levick, S. R., Saarinen, N., Schaaf, C., Stovall, A., Terryn, L., Wilkes, P., & Verbeeck, H. (2020). Terrestrial laser scanning in forest ecology: Expanding the horizon. *Remote Sensing of Environment*, *251*, 112102. https://doi.org/10.1016/j.rse.2020.112102

Calders, K., Armston, J., Newnham, G., Herold, M., & Goodwin, N. (2014). Implications of sensor configuration and topography on vertical plant profiles derived from terrestrial LiDAR. *Agricultural and Forest Meteorology*, *194*, 104–117. https://doi.org/10.1016/j.agrformet.2014.03.022

Calders, K., Newnham, G., Burt, A., Murphy, S., Raumonen, P., Herold, M., Culvenor, D., Avitabile, V., Disney, M., Armston, J., & Kaasalainen, M. (2015). Nondestructive estimates of above-ground biomass using terrestrial laser scanning. *Methods in Ecology and Evolution*, *6*(2), 198–208. https://doi.org/10.1111/2041-210X.12301

Disney, M. (2019). Terrestrial LiDAR: a three-dimensional revolution in how we look at trees. *New Phytologist*, *222*(4), 1736–1741. https://doi.org/10.1111/nph.15517

Disney, M., Burt, A., Calders, K., Schaaf, C., & Stovall, A. (2019). Innovations in Ground and Airborne Technologies as Reference and for Training and Validation: Terrestrial Laser Scanning (TLS). *Surveys in Geophysics*. https://doi.org/10.1007/s10712-019-09527-x

Krishna Moorthy, S. M., Calders, K., Vicari, M. B., & Verbeeck, H. (2019). Improved Supervised Learning-Based Approach for Leaf and Wood Classification From LiDAR Point Clouds of Forests. *IEEE Transactions on Geoscience and Remote Sensing*, 1–14. https://doi.org/10.1109/TGRS.2019.2947198

Raumonen, P., Kaasalainen, M., Åkerblom, M., Kaasalainen, S., Kaartinen, H., Vastaranta, M., Holopainen, M., Disney, M., & Lewis, P. (2013). Fast Automatic Precision Tree Models from Terrestrial Laser Scanner Data. *Remote Sensing*, *5*(2), 491–520. https://doi.org/10.3390/rs5020491

Stovall, A. E. L., Masters, B., Fatoyinbo, L., & Yang, X. (2021). TLSLeAF: automatic leaf angle estimates from single-scan terrestrial laser scanning. *New Phytologist*, *n/a*(n/a). https://doi.org/10.1111/nph.17548

Stovall, A. E. L., & Shugart, H. H. (2018). Improved Biomass Calibration and Validation With Terrestrial LiDAR: Implications for Future LiDAR and SAR Missions. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *Preprint*(99), 1–11. https://doi.org/10.1109/JSTARS.2018.2803110

Verbeeck, H., Bauters, M., Jackson, T., Shenkin, A., Disney, M., & Calders, K. (2019). Time for a Plant Structural Economics Spectrum. *Frontiers in Forests and Global Change*, *2*. https://doi.org/10.3389/ffgc.2019.00043

Walter, J. A., Stovall, A. E. L., & Atkins, J. W. (2021). Vegetation structural complexity and biodiversity in the Great Smoky Mountains. *Ecosphere*, *12*(3). https://doi.org/10.1002/ecs2.3390