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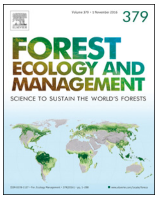

Assessing terrestrial laser scanning for developing non-destructive biomass allometry

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ABSTRACT

Forests provide essential ecosystem services and hold approximately 45% of global terrestrial carbon. Estimates of the quantity and spatial distribution of global forest carbon are built on the assumption that regional- or national-scale allometry accurately captures growth form across the wide spectrum of plant size. Allometry is painstaking and costly to create: trees must be cut, dried, and weighed, over the span of months. This bottleneck has left most equations low in sample size and without large trees (>50 cm), which can contain over 40% of aboveground carbon. Terrestrial laser scanning (TLS) can potentially increase the range and sample size of allometric equations through non-destructive biomass estimation and must be evaluated in this context. We deployed TLS at the Center for Tropical Forest Science - Forest Global Earth Observatory (CTFS-ForestGEO) plot in Front Royal, Virginia and virtually reconstructed 329 trees with diameters up to 123 cm. Three-dimensional tree models were the basis for 22 local allometric relationships for comparison to the Jenkins et al. (2003) and Chojnacky et al. (2014) equations. Overall, TLS allometry had lower RMSE and predicted higher tree-level biomass compared to the equivalent national equations. We evaluated site-wide allometry for errors from insufficient sample size and diameter range. Allometric equations did not stabilize to a consistent set of parameters until 100–200 samples were reached and exclusion of large trees severely limited prediction accuracy. This work implies that current biomass equations may be inadequate and highlights TLS stem modeling as an appropriate method of non-destructive allometric equation development for updating allometry and reducing uncertainty in landscape-level biomass estimates.

1. Introduction

Forests are vital to climate regulation through their influential role in the global carbon cycle. They are estimated to contain at least 350 Pg C in live aboveground biomass (Houghton et al., 2009; Pan et al., 2011), or approximately 45% of terrestrial carbon (Bonan, 2008), and currently act as a sink of carbon, offsetting 32% of anthropogenic fossil fuel emissions from 2007–2016 Quéré et al. (2017). These benefits are threatened by deforestation, which continues as a significant source of CO_2 to the atmosphere, averaging 1.3 ± 0.7 Gt C yr^{-1} — or 12% of total anthropogenic emissions from 2007 to 2016 (Quéré et al., 2017). As society seeks to mitigate climate change (e.g., UNFCCC, 2015), improved estimates of forest biomass and changes therein are key to carbon accounting and future climate projections.

The spatial distribution and absolute magnitude of forest carbon remains uncertain (Mitchard et al., 2014), in part due to direct reliance on unrepresentative tree-level biomass estimates. Currently, most estimates of forest biomass are inferred rather than measured (Saatchi et al., 2011; Baccini et al., 2012). The most commonly measured variable in studies of forest structure is diameter at breast height (DBH), as this is indicative of biomass and several other variables of interest to forest ecologists (Anderson-Teixeira et al., 2015b). DBH is converted to standing aboveground biomass with empirically derived scaling relationships, or allometric equations. Allometric relationships are created with extensive destructive sampling of trees (Picard et al., 2012) and are essential, as they form the backbone of all landscape-level estimates of biomass and carbon storage, as well as carbon sequestration, ecosystem productivity, and woody mortality (Jenkins et al., 2001). Any error or uncertainty within the relationships ultimately propagates to higher-level estimates (Chen et al., 2015), thus it is imperative they be representative of the trees being measured. For this reason, substantial efforts have been made to create species- and regionally-specific allometric equations (TerMikaelian and Korzukhin, 1997) for reducing uncertainty in biomass mapping.

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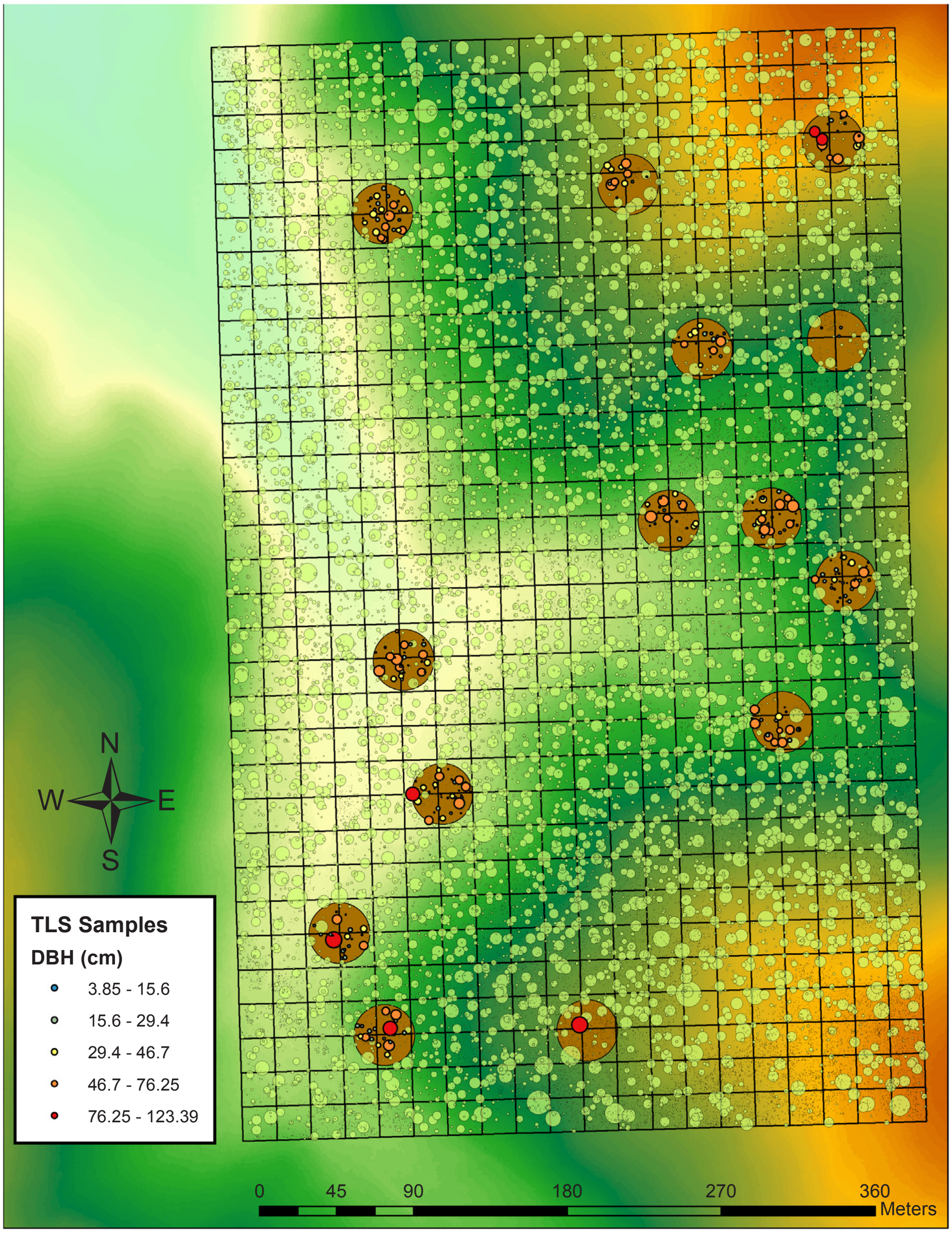

Fig. 1. Smithsonian Conservation biology institute ForestGEO forest with stem map (green points) and terrestrial LiDAR plot locations (brown circles). TLS samples are color coded according to diameter and proportionally sized. Elevation is represented in the background (low: cool, high: warm).

Allometric equations require a high sample size to be dependable (Roxburgh et al., 2015), but logistical limitations often limit the number and spatial extent of samples collected in the field (Chave et al., 2004; Weiskittel et al., 2015). These limitations primarily stem from the significant cost and labor expense involved with destructive sampling. Though destructive sampling is currently the most reliable established method for biomass estimation, inherent challenges in the process limit sample size, potentially introducing bias and error that can propagate to stand-level estimates of biomass (Weiskittel et al., 2015). Biomass estimates are even more uncertain in areas of conservation or cultural significance due to sampling being prohibited. All of these factors are worsened in areas of complex topography, unpredictable climatic conditions, and political restriction, spatially biasing the creation of allometric relationships. The above-mentioned issues are especially true in mature forests, where large trees drive the high biomass density of plot measurements (Brown, 1997). Sampling trees at the fringe of current allometry data will reduce uncertainty in stand-level biomass estimates, but the difficulty and complexity of destructive sampling poses a severe limitation.

Non-destructive sampling overcomes nearly every complicating factor associated with destructive sampling and opens up avenues for more complex long term ecological research. Efficient non-destructive sampling offers a solution to the issue of insufficient sample size in allometric equations (Chave et al., 2004). The time consuming portion of destructive methods is twofold: field work and drying. Non-destructive methods exclude this drying step. Moreover, sampling on private and protected land becomes more feasible when the forest is not disturbed during destructive sampling. A unique benefit also arises since measurements can be made over the entire lifespan of the tree, allowing investigation into fine-scale structural changes over time. Finally, increased sampling efficiency from non-destructive approaches may allow even more specific development of allometric equations that