Forest Ecology and Management 432 (2019) 102–114

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Testing the generality of below-ground biomass allometry across plant functional types

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ARTICLE INFO

Keywords:
Acacia
Carbon
Stem diameter
Eucalyptus
Multi-stemmed
Roots
Shrubs
Plant functional types

ABSTRACT

Accurate quantification of below-ground biomass (BGB) of woody vegetation is critical to understanding ecosystem function and potential for climate change mitigation from sequestration of biomass carbon. We compiled 2054 measurements of planted and natural individual tree and shrub biomass from across different regions of Australia (arid shrublands to tropical rainforests) to develop allometric models for prediction of BGB. We found that the relationship between BGB and stem diameter was generic, with a simple power-law model having a BGB prediction efficiency of 72–93% for four broad plant functional types: (i) shrubs and *Acacia* trees, (ii) multi-stemmed mallee eucalypts, (iii) other trees of relatively high wood density, and; (iv) a species of relatively low wood density, *Pinus radiata* D. Don. There was little improvement in accuracy of model prediction by including variables (e.g. climatic characteristics, stand age or management) in addition to stem diameter alone. We further assessed the generality of the plant functional type models across 11 contrasting stands where data from whole-plot excavation of BGB were available. The efficiency of model prediction of stand-based BGB was 93%, with a mean absolute prediction error of only 6.5%, and with no improvements in validation results when species-specific models were applied. Given the high prediction performance of the generalised models, we suggest that additional costs associated with the development of new species-specific models for estimating BGB are only warranted when gains in accuracy of stand-based predictions are justifiable, such as for a high-biomass stand comprising only one or two dominant species. However, generic models based on plant functional type should not be applied where stands are dominated by species that are unusual in their morphology and unlikely to conform to the generalised plant functional group models.

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https://doi.org/10.1016/j.foreco.2018.08.043
Received 28 June 2018; Received in revised form 19 August 2018; Accepted 23 August 2018
0378-1127/

1. Introduction

Both above-ground biomass (AGB) and below-ground biomass (BGB) contribute to the woody vegetation sink within the global carbon budget (Le Quéré et al., 2015). Climate change may result in shifts in the ratio of tree BGB to AGB (e.g. via changes in water deficit that affect partitioning or the size distribution of trees), with far-reaching consequences for the global carbon budget (Ledo et al., 2018). However, BGB cannot be quantified using remote sensing metrics as has been done for the AGB component (Haverd et al., 2013; Mitchard et al., 2013; Chen et al., 2015). Therefore, the development of models to explain BGB is critical to informing predictions of biomass yields or biomass carbon stocks (Richards and Evans 2004).

BGB can be estimated from AGB at either an individual- or stand-level through the use of root-to-shoot ratios (BGB:AGB, Ledo et al., 2018), and this approach has merit when broad-scale AGB estimates are obtained via remote sensing products rather than via field-based assessments. However, this approach has limitations. Estimating BGB based on predictions of AGB are subject to relatively high uncertainties; for example, mean absolute prediction error of AGB was 15–39% and 13% at the individual- and stand-level, respectively, for plant functional types across the Australian continent (Paul et al., 2016). In contrast, if BGB of an individual is predicted by applying verified allometric models to field measurement of stem diameter (*D*) measured at a specified height above the ground, the uncertainty is likely to be much lower because errors in *D* estimation are relatively small (e.g. 2–7%, Paul et al., 2017). Moreover, BGB:AGB defaults obtained from the average of multiple stands of a given ecosystem (Mokany et al., 2006) do not explicitly account for variations in stand density and the mix of species; both of which influence BGB (Westman and Rogers, 1977; Bernardo et al., 1998; Ritson and Sochacki, 2003; Xue et al., 2011; Gonzalez-Benecke et al., 2014). Stand-based estimates of BGB, resulting from application of allometric models with *D* as a predictor variable to each individual within a stand, may inherently account for stand density and species-mix.

When developing allometric models for prediction of BGB of woody plants, it is unclear to what extent data should be pooled or separated according to their morphological, phylogenetic and/or phenological characteristics; variation often encapsulated by classification of species into plant functional types. It is also unclear whether the inclusion of stand characteristics or bioclimatic variables improves the performance of BGB allometric models compared with using *D* alone. A true test of the accuracy of such models is direct validation at the stand-level by comparing allometry-predicted BGB against that measured through whole-plot excavation. Although such stand-level validation has been undertaken previously by Paul et al. (2014) for young plantings in southern Australia, no such validation has been undertaken for more broadly-applicable BGB allometric models derived from root data sampled from both planted and natural systems, and across a range of stand ages and ecosystem types.

Australia provides a good case study for testing generalised allometric models given its long history of research contributions to BGB data sets (e.g. Forrest, 1969; Baldwin and Stewart, 1987; Applegate, 1982) spanning a broad range of ecoregions (i.e. arid shrublands to tropical rainforests) with plant functional types ranging from shrubs and short multi-stemmed trees to some of the largest trees in the world (Sillett et al., 2015; Specht and Specht, 2002, 2013). Improving the assessment of Australia's vegetation carbon sink is of global importance as the high inter-annual variability that is characteristic of the global vegetation sink is in large part due to variability in the carbon capture of the semi-arid ecosystems of Australia (Houghton et al., 2012; Poulter et al., 2014; Ballantyne et al., 2015).

Here we collated destructively-measured BGB datasets from individual trees and shrubs sampled from a broad range of stands from differing climatic regions of Australia, including those in natural ecosystems or otherwise established through human intervention (i.e. planted). We then analysed this data set to assess whether *D*-based allometric models of BGB were improved: (i) when based on species rather than plant functional groups; and (ii) by the inclusion of stand characteristics (age and management) or climatic variables. Our objectives were to recommend the most appropriate allometric model(s) for estimating BGB in ecosystems across the Australian continent, and to quantify the accuracy of the recommended model(s) when tested against direct measurements of stand-level BGB obtained using whole-plot excavation across a range of contrasting sites. The recommended models for predicting BGB were applied together with those previously recommended for prediction of AGB (Paul et al., 2016) to provide estimates of BGB:AGB ratios for plant functional types of differing allometry.

2. Methods

2.1. Data set

2.1.1. Data compilation

Data sets of BGB from destructive harvesting of 2054 individual

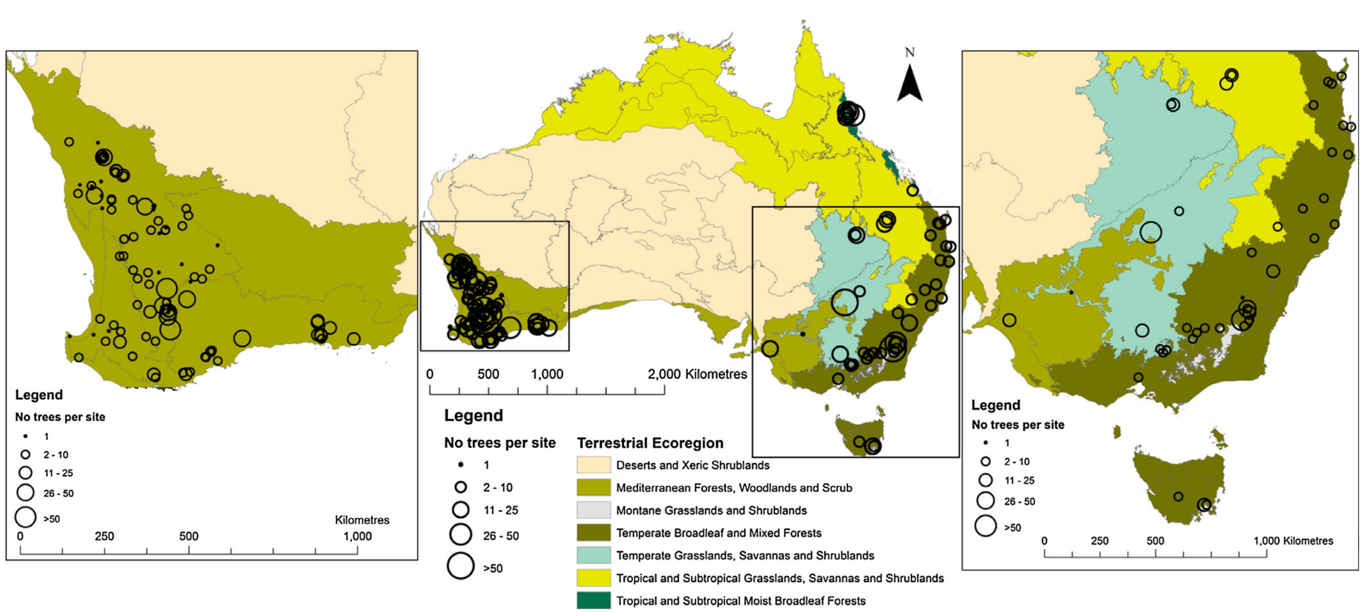

Fig. 1. Location of trees or shrubs sampled for biomass by terrestrial ecoregion across Australia (DSWPC, 2015).