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Development and testing of allometric equations for estimating above-ground biomass of mixed-species environmental plantings

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ABSTRACT

To quantify the impact that planting indigenous trees and shrubs in mixed communities (environmental plantings) have on net sequestration of carbon and other environmental or commercial benefits, precise and non-biased estimates of biomass are required. Because these plantings consist of several species, estimation of their biomass through allometric relationships is a challenging task. We explored methods to accurately estimate biomass through harvesting 3139 trees and shrubs from 22 plantings, and collating similar datasets from earlier studies, in non-arid (>300 mm rainfall year^{-1}) regions of southern and eastern Australia. Site-and-species specific allometric equations were developed, as were three types of generalised, multi-site, allometric equations based on categories of species and growth-habits: (i) species-specific, (ii) genus and growth-habit, and (iii) universal growth-habit irrespective of genus. Biomass was measured at plot level at eight contrasting sites to test the accuracy of prediction of tonnes dry matter of above-ground biomass per hectare using different classes of allometric equations. A finer-scale analysis tested performance of these at an individual-tree level across a wider range of sites. Although the percentage error in prediction could be high at a given site (up to 45%), it was relatively low (<11%) when generalised allometry-predictions of biomass was used to make regional- or estate-level estimates across a range of sites. Precision, and thus accuracy, increased slightly with the level of specificity of allometry. Inclusion of site-specific factors in generic equations increased efficiency of prediction of above-ground biomass by as much as 8%. Site-and-species-specific equations are the most accurate for site-based predictions. Generic allometric equations developed here, particularly the generic species-specific equations, can be confidently applied to provide regional- or estate-level estimates of above-ground biomass and carbon.

1. Introduction

Afforestation of low productive agricultural land is an opportunity to sequester atmospheric carbon and potentially make a contribution to climate change mitigation (IPCC, 2007). We need to understand rates of carbon sequestration by different types of planted forests (single- or mixed-species, native or exotic species). While there is information on single-species plantations, less is

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known about the potential for native mixed-species plantings, which can provide additional environmental benefits such as enhancing biodiversity (e.g. Bennett and Ford, 1997; Felton et al., 2010) and reclamation from dry-land salinity (e.g. Stirzaker et al., 2002). Accurate and efficient estimation of biomass in such plantings is central to understand and monitor their net contribution for sequestering atmospheric carbon.

In Australia, environmental plantings accounted for up to 20% of the 1.14 Mha of afforestation which has occurred between 1990 and 2012 (DCCEE, 2012). Recent Government policy incentives (e.g. DSEWPaC, 2012) encourage land owners to establish plantings for both natural resource management and sequestration of carbon outcomes (e.g. Harper et al., 2007; Mitchell et al., 2012). Accordingly, an increased rate of establishment of environmental plantings is expected. In order to assess the likely returns for carbon and environmental benefits, and thereby facilitate investment, reliable and accurate estimates of biomass production are required. However, because these plantings are largely established on marginal land, costs associated with current measurement of biomass carbon could be a significant proportion of the carbon credits likely to be obtained (Polglase et al., 2013; Paul et al., 2013a). It is therefore essential that biomass estimates are obtained as efficiently as possible to reduce costs while maintaining accuracy. One way is to develop and apply improved allometric equations (e.g. relationships between stem diameter and live biomass) to convert field inventory data to stand-based estimates of biomass.

Because there may be over 100 species in mixed-species plantings (e.g. Preece et al., 2012), it is impractical to develop species-specific allometric equations for each species at all sites. Efficiency may be improved through the use of generalized equations which are applicable to measurements across sites and species. These should be tested given they may result in some loss of precision (e.g. Williams et al., 2005).

Several studies have developed generic equations for mixed-species plantings in southern Australia (Forrester et al., 2005; Hamilton et al., 2005; England et al., 2006; Barton and Parekh, 2006; Paul et al., 2008, 2010; Hawkins et al., 2010; Hobbs et al., 2010; Jonson and Freudenberger, 2011). These studies have shown that the precision of the generic equations is appropriate for the species and locations in which they were developed, but there reliability for a wider set of species, or locations, remain unknown. There is a need to determine whether generalised equations are applicable broadly, and whether they are best applied constrained within species, genus and growth-habit (i.e. tree or shrub form), or even wider groupings of trees or shrubs.

The objective of this study was to determine the loss in accuracy with increased generality of allometric equations for mixed-species plantings by testing predictions of above-ground biomass against that directly measured by whole-plot harvesting. The impact of including categories of site (namely climate) and species factors on the efficiency of these equations was also assessed.

2. Methods

2.1. Study sites

Several sources of data on individual tree or shrub above-ground biomass were utilised in this study (Table 1). These datasets were collated from sites in southern and eastern Australia (where rainfall was >300 mm year^{-1}, Fig. 1), and were grouped into six categories based on genus and/or growth-habit. Three of these were categories of trees: *Eucalyptus*, *Acacia* and Casuarinaceae (*Allocasuarina* and *Casuarina)* species. There were also three categories of shrubs: *Acacia* and *Melaleuca* species, and other shrubs such as shrub-form species of *Atriplex*, *Bedfordia*, *Dodonaea*, *Cassia*, *Calothamnus*, *Eremophila*, *Gynatrix*, *Hedycarya*, *Leptospermum*, *Olearia*, *Pomaderris*, *Prostanthera*, *Rhagodia*, and *Senna*. These were largely from environmental plantings, some from remnant native woodlands and others from farm forestry plantings.

In addition to collecting data from previous work, we measured above-ground biomass of 3139 individual trees and shrubs from 22 sites, representing contrasting climatic regions and planting types (Table 2). At eight of these sites, whole-plots were harvested and above-ground biomass determined. This was used for assessing the bias, precision and accuracy of different classes of allometric equations in order to validate them. Table 3 provides a summary of characteristics of these eight sites. The key mix of species at each of these sites varied as listed: Strathearn (*E. blakelyi*, *E. camaldulensis*, *E. cinerea*, *E. crenulata*, *E. macarthurii*, *E. mannifera*, *E. melliodora*, *E. polyanthemos*, *E. stellulata*, *E. viminalis*, *A. baileyana*, *A. decurrens*, *A. cardiophylla*, *A. rubida*), Moir (*E. leucoxylon*, *E. loxophleba*, *E. occidentalis*, *E. phaenophylla*, *E. platypus*, *E. pluricaulis*, *E. spathulata*, *E. sporadic*, *E. utilis*, *A. acuminata*, *A. micobotrya*, *A. cyclops*), Jenharwill (*E. leucoxylon*, *A. decurrens*, *A. brachybotrya*, *A. calamifolia*, *A. hakeoides*, *A. pycnantha*), Gumbinnen (*E. fasiculosa*, *E. largiflorens*, *A. pycnantha*, *A. trineura*), Moorland (*E. calycogona*, *E. incrassata*, *E. leptophylla*, *E. phenax*, *E. porosa*, *E. socialis*, *A. calamifolia*, *Melaleuca* sp., *Casuarina* sp.), and Leos (*E. globulus*, *E. kitsoniana*, *E. melliodora*, *E. talyuberlup*, *E. tereticornis*, *A. baileyana*, A. *penninervis*, *Melaleuca*

Table 1
Number of individual trees and shrubs included in the collected dataset to represent different species and/or growth-habits, where – indicates no data available.

Trees			Shrubs			Source
Eucalyptus	*Acacia*	Casuarinaceae	*Acacia*	*Melaleuca*	Other	
1965	365	62	462	115	170	This study
41	23	14	30	16	–	Paul et al. (2010)
35	35	–	28	–	–	England et al. (2006)
–	28	9	17	23	–	Hawkins et al. (2010)
316	130	5	69	14	69	G. McArthur *pers. com.*
–	11	–	–	–	–	R. Sudmeyer *pers. com.*
–	12	–	–	–	–	Forrester et al. (2005)
3	1	–	–	3	–	B. Rose *pers. com.*
65	7	10	–	–	–	Jonson and Freudenberger (2011)
145	–	–	–	–	–	Barton and Parekh (2006)
18	–	–	–	–	–	Hamilton et al. (2005)
24	–	–	–	–	–	Paul et al. (2008)
19	–	–	–	–	–	S. Theiveyanathan *pers. com.*
9	–	–	5	1	–	Hobbs et al. (2010)
2640	*612*	*100*	*611*	*172*	*239*	*4374 Totals*