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National carbon model not sensitive to species, families and site characteristics in a young tropical reforestation project

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ABSTRACT

Reforestation and restoration offer critical contributions to addressing climate change and biodiversity decline. Enabling carbon credits to be derived from these activities is important for reforestation, particularly since reforestation does not come cheaply. Australia's Carbon Farming Initiative is a world-leading policy that allows carbon credits to be obtained by using published methods-based approaches. Here we apply two different approaches to a young mixed species reforestation project in the wet tropics of Queensland, Australia. One approach assesses carbon sequestration from published allometric equations requiring direct field measurements, and the other applies a national carbon accounting model, *FullCAM*.

Using allometric equations, we found above-ground biomass was influenced significantly by family, species, size class, and the interaction of family and size class. Species in the family Proteaceae outperformed species in other families. Selection of species according to soil nutrient status could enhance growth rates, but if soil nutrients and species responses are not known, then a bet-hedging strategy using mixed species from a variety of families is probably the best option.

For three year old forest plots, *FullCAM* modelled significantly more carbon mass of trees than published allometric models for mixed tropical forests, suggesting that *FullCAM* needs adjustment to more accurately reflect species, families, local conditions and small-scale sites.

Current policy settings are at odds with the needs of carbon farmers, considering the importance of forests and landscape restoration in fighting climate change and biodiversity decline. Legislated national methods allowing the development of species-specific allometrics for small mixed plantations do not account for the costs of developing these allometrics, especially in markets that are marginal.

1. Introduction

It will be difficult to bring the planet within reach of the 1.5 °C pathway aspired to in the Paris Agreement (UNFCCC, 2015) without significant contribution from landuse, including restoration efforts (Delgado et al., 2015). Forest management, including reforestation, is essential to offset much of the carbon released by the use of fossil fuels over the next 35 years while we transition to renewable energy (Houghton et al., 2015). Forest landscape restoration also offers a critical contribution to addressing the global challenge of biodiversity decline.

Established in 2011, Australia's Carbon Farming Initiative allows carbon credits broadly derived from the ecosystem sector, including farming and forestry, using a raft of methods (van Oosterzee, 2012). Currently there are 33 legislated methods (http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods; accessed 12 November 2016) that projects must follow to be awarded carbon credits, paid for by the overarching Emissions Reduction Fund. Project proponents submit their proposals to a competitive tender process which is designed to achieve lowest cost abatement for Government (Comerford et al., 2015), regardless of the variation in the cost of mitigation projects or any co-benefits such as for biodiversity.

Reforestation projects do not come cheaply. Recent research has shown that under plausible costs of establishment and commercial discount rates no areas in Australia were profitable for carbon forestry below about AUD$40 per tonne of carbon dioxide equivalent (CO_2-e) (Polglase et al., 2013), and at this price only limited

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monoculture plantations are profitable. A breakeven price of AUD $109 per tonne of CO_2-e was modelled for environmental planting in the state of Queensland (Evans et al., 2015). The cumulative average price won under the 2015 Emissions Reduction Fund 'reverse auctions' is a fraction of this at AUD$12.25 (http://www.cleanenergyregulator.gov.au/pages/searchcenter.aspx?k=average%20price; accessed 12 November 2016).

Eight methods are currently available for carbon forestry including for managing regrowth, avoiding clearing, monoculture plantations and environmental plantations. Two quite different methods can be applied to environmental plantings. The first is the *Reforestation and Afforestation 2.0* method (Department of the Environment, 2015), which requires direct field measurements and the development of species-specific regression functions (allometric equations) to estimate tree biomass, from which carbon stocks can be derived.

The second methodology is the *Reforestation by Environmental or Mallee Plantings—FullCAM* (Department of the Environment, 2014a). The National Carbon Accounting System (NCAS) (Richards et al., 2005) is an accounting model for reforestation that is based largely on forest data from non-tropical areas. The Full Carbon Accounting Model (*FullCAM*) was developed as a component of the NCAS to model carbon emissions and sequestration across Australia, and is used also for small-scale modelling of carbon stocks. It uses large-scale flux models combined with forest growth, forest productivity, climate and environmental variables, and allometrics to estimate carbon stocks (Department of Climate Change and Energy Efficiency, 2012a; Paul et al., 2013a; Richards and Evans, 2008). *FullCAM* has been modified on a number of occasions, and the most recent iterations have included modified algorithms, based on new (but limited) data for wet tropical forests (Paul et al., 2013a, 2013b, 2016, 2015).

There are two problems in the application of the direct measurement and *FullCAM* model methods. The *Reforestation and Afforestation* method requires that allometrics are developed for each species that are planned to be used for sequestering carbon in trees and the soil. There are no existing allometrics for most species planted in environmental plantings, so project proponents would have to develop their own for each species of interest. The method requires that the allometrics are statistically robust, and that whole trees, including roots, are sampled and measured, and that permanent plots are sampled so that the results are also statistically robust. These requirements impose significant sampling effort and scientific expertise, and therefore costs of development. We test an aspect of the time (and therefore the cost implications) in obtaining sufficient data to meet the requirements of the *Reforestation and Afforestation* method.

The second problem is that, for much of Australia including the wet tropical forests (the focus of our research), the *FullCAM* model is based on few data (Paul et al., 2013a) and the model has not been tested with much empirical data. This applies in particular to young planted forests, which is of vital interest in planning for and measuring the carbon sequestration potential in plantations (Preece et al., 2015).

For the first time in the Australian tropics we field-test two different methods for estimating carbon sequestration in environmental plantings, the *Reforestation and Afforestation* method, and the *FullCAM* method. We sampled young planted forests in the wet tropics in order to estimate the biomass of these forests and to compare the results with several allometric models developed for pan-tropical forests and for Australian tropical forests (Chave et al., 2005, 2014; Paul et al., 2016; Preece et al., 2015). Our aims are to compare the two methods for their efficacy and accuracy, and to identify any problems associated with either method. We also intend to show how the results derived from the methods are affected by different species and families, planting densities and survival rates. We anticipate that this will inform project proponents about the issues associated with using each model.

2. Methods

2.1. Study site

The study was conducted at the Thiaki Rainforest Restoration Site (17.43361°S, 145.51199°E), located in the wet tropical region on the Atherton Tablelands of northeast Queensland (Preece et al., 2013), at an elevation of 1000 m ASL. The Atherton Tablelands region has a cool tropical climate with a warm, humid wet season from December to April and a dry season from August to November. The climate is predominantly humid tropical with mean winter and summer temperatures of 15.6 °C and 25.3 °C, respectively. Median annual rainfall is 1234 mm, with a range of 458–2197 mm, and is distinctly seasonal (Kairi Weather Station #031034, Bureau of Meteorology 2016, http://www.bom.gov.au/climate/; accessed 12 July 2016). Peak rainfall months are from December through April (Bureau of Meteorology data; http://www.bom.gov.au; accessed December 2014).

Rainforest was the predominant original vegetation of the region and site, however apart from protected areas and small restoration sites, the surrounding landscape has been converted to pastoral or agricultural land (Jansen, 2005). Soils are fertile and well drained, typically classified as ferrosols, with some dermosols, derived from basaltic volcanic flows (Whitehead et al., 2007). According to aerial photographs, most of the study site was cleared for pasture in the mid-1940s. Some of the area was cleared in the late 1980s (Department of Agriculture Fisheries & Forestry, http://www.trc.qld.gov.au/sites/default/files/Tablelands%20 Agricultural%20Profile%20final_0.pdf; accessed December 2014). All the planted land was grazed intensively since clearing. Slopes on the site vary from a few degrees to ~40°, and many of the planted plots are over 30°.

The study site comprised 16 ha of a randomised block design of forestry plantings, divided into 64 experimental plots, established in January 2011. Each plot is 50 × 50 m (0.25 ha) on the horizontal plane (i.e. ignoring slope). Plot treatments combine three types of species associations (i.e. monoculture, 6 species, and 24 species; Table 1), and two spacing distances of 1.75 and 3 m (Fig. 1, Table 1). Saplings were around 30 cm tall when planted, and were vigorous and sun-hardened before planting. Neither fertilizers nor water were added to the planted saplings.

2.2. Transect placement and tree measurement plot method

Three 50-m long adjacent transects along planted rows were sampled (Fig. 2) and marked at each end with plastic tree tags. The upper sample plot started at 12.5 m from the top left corner of each plot and sampled three planted rows down, and the second sample plot started at 12.5 m from the bottom right corner and sampled three rows up. Each plot covered an area of 262.5 m^2 (0.026 ha) for 1.75 m density plantings, and 450 m^2 (0.045 ha) for 3 m density plantings (Fig. 2). We measured 1736 living stems in 24 planted plots.

All stems along transect rows were measured. Stem diameter of saplings with stems >1.3 m tall was measured at breast height (1.3 m; dbh) and stems shorter than 1.3 m were measured at their base (d_{base}) to the nearest mm using calipers (Preece et al., 2015). Only the largest stem of multi-stemmed trees was measured. Stems that divided or branched at or near 1.3 m were measured just below 1.3 m. Bumps and distortions were avoided by moving the calipers to above or below the protrusion, by no more than 30 cm (Preece et al., 2012).