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# Conversion of sub-tropical native vegetation to introduced conifer forest: Impacts on below-ground and above-ground carbon pools

Tom Lewis[a,b,*], Timothy E. Smith[a,b], Bruce Hogg[a], Scott Swift[a], Luke Verstraten[b], Philippa Bryant[b], Bernhard J. Wehr[c], Neil Tindale[b], Neal W. Menzies[c], Ram C. Dalal[c,d]

[a] Dept of Agriculture and Fisheries, Queensland Government, University of the Sunshine Coast, Sippy Downs, 4556, Australia
[b] Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Sippy Downs, 4556, Australia
[c] School of Agriculture and Food Sciences, The University of Queensland, St Lucia 4072, Australia
[d] Dept of Science, Information Technology and Innovation (DSITI), Queensland Government, Ecosciences Precinct, 41 Boggo Rd, Dutton Park, 4102, Australia

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ABSTRACT

Land-use change can have a major influence on soil organic carbon (SOC) and above-ground C pools. We assessed a change from native vegetation to introduced *Pinus* species plantations on C pools using eight paired sites. At each site we determined the impacts on 0–50 cm below-ground (SOC, charcoal C, organic matter C, particulate organic C, humic organic C, resistant organic C) and above-ground (litter, coarse woody debris, standing trees and woody understorey plants) C pools. In an analysis across the different study sites there was no significant difference ($P > 0.05$) in SOC or above-ground tree C stocks between paired native vegetation and pine plantations, although significant differences did exist at specific sites. SOC (calculated based on an equivalent soil mass basis) was higher in the pine plantations at two sites, higher in the native vegetation at two sites and did not differ for the other four sites. The site to site variation in SOC across the landscape was far greater than the variation observed with a change from native vegetation to introduced *Pinus* plantation. Differences between sites were not explained by soil type, although tree basal area was positively correlated with 0–50 cm SOC. In fact, in the native vegetation there was a significant linear relationship between above-ground biomass and SOC that explained 88.8% of the variation in the data. Fine litter C (0–25 mm diameter) tended to be higher in the pine forest than in the adjacent native vegetation and was significantly higher in the pine forest at five of the eight paired sites. Total litter C (0–100 mm diameter) increased significantly with plantation age ($R^2 = 0.64$). Carbon stored in understorey woody plants (2.5–10 cm DBH) was higher in the native vegetation than in the adjacent pine forest. Total site C varied greatly across the study area from 58.8 Mg ha$^{-1}$ at a native heathland site to 497.8 Mg ha$^{-1}$ at a native eucalypt forest site. Our findings suggest that the effects of change from native vegetation to introduced *Pinus* sp. forest are highly site-specific and may be positive, negative, or have no influence on various C pools, depending on local site characteristics (e.g. plantation age and type of native vegetation).



## 1. Introduction

There is global concern that land-use change results in a depletion of soil organic carbon (SOC), terrestrial biomass and consequent increases in atmospheric $CO_2$ (e.g. Houghton, 2003; Strassmann et al., 2008). Conversion of forest to agricultural land-uses usually results in loss of above-ground biomass C and SOC, particularly when conversion is to cultivated land (Brown and Lugo, 1990; Ellert and Gregorich, 1996; Murty et al., 2002; Guo and Gifford, 2002). However, the impacts of change from one forest type to another are less clear and there is a high degree of uncertainty regarding the degree and direction of change (Bashkin and Binkley, 1998; Rhoades et al., 2000) due to factors such as plantation age, type of plantation (native or exotic species), soil type and environmental factors (e.g. climate) and management factors (Kasel and Bennett, 2007).

The role of different forest compositions on forest C stocks and dynamics is poorly understood (Jandl et al., 2007) and there is a paucity of detailed information on soil C stocks in sub-tropical forests. An international review by Guo and Gifford (2002) reported

* Corresponding author at: Dept of Agriculture and Fisheries, Queensland Government, University of the Sunshine Coast, Sippy Downs, 4556, Australia.
*E-mail address:* tom.lewis@daf.qld.gov.au (T. Lewis).

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that, on average, SOC stocks declined by 15% following conversion from native forest to conifer plantation, but there was variability in this change depending on plantation species, rainfall and plantation age. Studies in southern Australia (e.g. Turner and Lambert, 2000; Turner et al., 2005) also reported reductions in SOC stocks following land-use conversion to conifer plantations. Further, in the sub-tropics, Chen et al. (2004) and Richards et al. (2007) reported significant reductions in total SOC following conversion of native vegetation to hoop pine (*Araucaria cunninghamii*, a native species to the region) plantations. The losses in SOC are likely due, at least in part, to site preparation for tree planting, which involves cultivation (e.g. ripping and mounding) that disturbs soil structure and breaks down soil aggregates (Jandl et al., 2007). However, few published studies have reported the impacts of conversion to introduced conifer plantations in the sub-tropics, and few studies have considered the form of soil organic C (i.e. humic, particulate or resistant) which is important when considering the resilience of these C stocks and our ability to model SOC changes.

Following clearing of native forest there is an initial reduction in above-ground plant biomass. In the case where native forest is replaced with plantation forest, above-ground biomass may be lower (Chen et al., 2005), similar, or reach higher levels than in the previous vegetation (e.g. Lugo, 1992), usually through modification of the site productivity (e.g. addition of fertilizer, Oren et al., 2001). Reports of the amount of above-ground biomass for *Pinus* plantations in the sub-tropics suggest approximately 316 Mg ha$^{-1}$ ($\sim$155 Mg C ha$^{-1}$) can be sequestered by age 30 (Simpson et al., 2000). Tree C stocks in native vegetation in sub-tropical Australia may vary greatly from site-to-site but range from approximately 40 to 220 Mg C ha$^{-1}$ depending on the soil type and site productivity (Westman and Rogers, 1977; Hero et al., 2013; Ngugi et al., 2014; Moroni and Lewis, 2015). We are unaware of any studies that consider the impact of conversion of native vegetation to *Pinus* sp. plantation on tree C and litter C stocks in the sub-tropics of Australia.

In both native vegetation and plantation forest, a significant C stock can be found in the litter layer, which potentially plays an important role in building soil C (Liski et al., 2002). This C pool may be dynamic (Bubb et al., 1998; Birk and Simpson, 1980), but often a steady state between litterfall and decomposition is reached over time (Olson, 1963) and incorporating litter C into total site C stocks can be important when assessing land-use changes (Richter et al., 1999; Paul et al., 2002). *Pinus* sp. forests are known to contain particularly high litter biomass stocks, partly due to slower rates of decomposition relative to native forests (e.g. Paul and Polglase, 2004; Prescott, 2010), however, there are few published comparisons between *Pinus* sp. forests and native vegetation in tropical and sub-tropical regions.

The commercial plantation forestry estate covers approximately two million hectares in Australia, of which 51% is planted with softwood species (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2013) with approximately 18% of this softwood estate occurring in Queensland. This study focusses on the impacts of change from native vegetation to plantation forest, which occurred 28–60 years ago, using paired comparison sites in Queensland. We aimed to determine, across a range of sites with varying soil types and plantation ages, whether C pools differed between introduced *Pinus* plantations and adjacent native vegetation. Based on the above-mentioned studies in southern Australia we hypothesised that SOC would be lower in the conifer plantations, but litter C would be higher in these plantations relative to the native vegetation. We also hypothesised that above-ground woody plant C would be lower in the *Pinus* plantations, particularly in young plantations, given the likely relationship between above-ground biomass and plantation age.

## 2. Methods

### 2.1. Site details

Eight paired sites were selected from within the *Pinus* sp. plantation resource in south-eastern Queensland, Australia (Fig. 1). *Pinus* sp. plantations in the paired comparisons varied from six to 34 years since planting (mean age of 21 years, Table 1). Plantation plots were either in their first or second rotation (Table 1). Soil types varied between the eight sites (classified using Australian Soil Classification, Isbell, 1996): two sites were on yellow Kandosols, two sites were on brown Kandosols, one site was on a grey Chromosol and three sites were on Podosols (Table 1). Pine plantations were dominated by *Pinus elliottii* var. *elliottii*, *Pinus caribaea* var. *hondurensis* and *P. elliottii* × *P. caribaea* hybrids (Table 1). Adjacent native vegetation varied between sites; in most cases (six sites) it was naturally occurring forest dominated by tree species including *Eucalyptus racemosa*, *Corymbia intermedia*, *Eucalyptus acmenoides*, *Lophostemon suaveolens*, *Syncarpia glomulifera* and *Melaleuca quinquenervia*, or open woodland (one site) and heathland (one site) with dominant species such as *Eucalyptus umbra*, *Banksia aemula* and *Melaleuca viridiflora* (Table 1). In all cases the native vegetation was multi-aged remnant vegetation and hence could not be accurately aged. Mean annual rainfall across the study region varied from 1193 to 1611 mm (average = 1408 mm, Table 1), with rainfall being higher in the summer months. Mean minimum temperature ranged from 14.7 °C to 15.8 °C while mean maximum temperature ranged from 25.1 °C to 26.6 °C. Climatic data for the study area were based on spatially interpolated Bureau of Meteorology observational data from 1889 to 2013 (Jeffrey et al., 2001).

### 2.2. Plot layout

Paired-comparison sites were chosen on the basis of sufficient area of the target vegetation being on the same soil type, with the same slope position. Plots were 0.5 ha (in most cases 100 × 50 m) in both the pine and native vegetation, and were separated by <200 m at each site. Six of the eight paired sites were selected as part of an earlier (unpublished) study in 1998 and the authors are currently investigating temporal trends in soil nutrients over this time. Each plot was divided into 50 sub-plots of 10 × 10 m and six sub-plots were randomly selected for sampling (stratified simple random sampling, Fig. 1b). Plots and sub-plots were established using tape measures, optical squares and sighting posts to ensure right-angles. Each sub-plot contained 100 1 × 1 m squares, of which ten were randomly selected for sampling (e.g. Fig. 1c). Each selected sub-plot and square was marked with line-marking paint to delineate the sampling positions. The positions of sub-plots and sampling squares were referenced from the plot corner positions to determine their UTM reference points and to allow future sampling within the same locations. Sampling took place between May and November 2013.

### 2.3. Litter sampling and above-ground carbon estimates

A steel quadrat (0.5 × 0.5 m square) was placed in the centre of each 1 × 1 m sample square, and all dead and detached vegetation (litter) was collected down to the soil surface, being careful to exclude mineral soil. All litter material ⩽25 mm diameter was defined as fine litter and litter material >25 mm and <100 mm diameter was defined as coarse litter. All material collected within each sub-plot was bulked by litter type (i.e. fine and coarse) and fine litter was weighed in the field. A representative sub-sample (>25% of the total biomass) of the fine litter from each sub-plot was placed in a paper bag, weighed in the field