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Effects of harvest management practices on forest biomass and soil carbon in eucalypt forests in New South Wales, Australia: Simulations with the forest succession model LINKAGES

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Abstract

Understanding long-term changes in forest ecosystem carbon stocks under forest management practices such as timber harvesting is important for assessing the contribution of forests to the global carbon cycle. Harvesting effects are complicated by the amount, type, and condition of residue left on-site, the decomposition rate of this residue, the incorporation of residue into soil organic matter and the rate of new detritus input to the forest floor from regrowing vegetation. In an attempt to address these complexities, the forest succession model LINKAGES was used to assess the production of aboveground biomass, detritus, and soil carbon stocks in native *Eucalyptus* forests as influenced by five harvest management practices in New South Wales, Australia. The original decomposition sub-routines of LINKAGES were modified by adding components of the Rothamsted (RothC) soil organic matter turnover model. Simulation results using the new model were compared to data from long-term forest inventory plots. Good agreement was observed between simulated and measured above-ground biomass, but mixed results were obtained for basal area. Harvesting operations examined included removing trees for quota sawlogs (QSL, DBH >80 cm), integrated sawlogs (ISL, DBH >20 cm) and whole-tree harvesting in integrated sawlogs (WTH). We also examined the impact of different cutting cycles (20, 50 or 80 years) and intensities (removing 20, 50 or 80 m^3). Generally medium and high intensities of shorter cutting cycles in sawlog harvesting systems produced considerably higher soil carbon values compared to no harvesting. On average, soil carbon was 2–9% lower in whole-tree harvest simulations whereas in sawlog harvest simulations soil carbon was 5–17% higher than in no harvesting.
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1. Introduction

Carbon cycles through forests in living vegetation, detritus and soil. Levels of carbon stock and rates of cycling vary considerably with site factors (climate, topography and geology), species composition and natural disturbance and management history. Regional and global inventory analyses and computer simulations indicate that the capacity of forest stands to store carbon is large (Banfield et al., 2002). Dixon et al. (1994) estimated that forest ecosystems contain approximately half of the total terrestrial carbon pool, with two-thirds of this residing in forest soil.

Despite more comprehensive inventory and modeling studies, many aspects of forest carbon cycling remain unresolved. For example, while little doubt exists regarding higher carbon stocks in forest ecosystems compared to other land cover types, the effect of management on carbon stocks and fluxes in forests is less certain. Changing species composition, harvest management practices, rotation length, fire, and other biotic and abiotic disturbances can all have important impacts on carbon stocks and fluxes. Furthermore, long-term effects are complicated by the legacy of residues left on-site at harvest, the type and condition of these residues, the natural decomposition rate of harvest residue and the rate of

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new detritus input to the forest floor from regrowing vegetation (Johnson, 1992; Johnson and Curtis, 2001). There is no simple relationship between the amount of timber harvested from a forest and the amount of carbon stored. Management regimes that maintain a continuous canopy cover and mimic, to some extent, regular natural forest disturbance could achieve the best combination of high wood yield and carbon storage (Thornley and Cannell, 2000).

One approach to estimating carbon dynamics for managed stands is to combine measured forest inventory data with growth models. Individual-based models of forest succession represent an important tool for examining the potential interactions among species composition, harvest operations, and residue management on carbon stored in biomass and soils. In this study, the model LINKAGES (Pastor and Post, 1985) was used to examine carbon sequestration in *Eucalyptus*-dominated forest stands of eastern Australia. The simple representation of soil carbon (SC) dynamics used in the original version of this model was replaced with a more mechanistic description of SC turnover and then used to investigate the influence of several harvest management practices on carbon sequestration. Given existing logging operations commonly used in this area of Australia, our analyses focused on single-tree selection methods of logging where the primary interest is in the production of high-quality sawlogs.

The aim of the study was to analyse impacts of different harvesting cycles and intensities on ecosystem carbon stocks. We based simulations on existing management practices, single tree and small gap harvesting as a starting point and considered more intensive practices that could have greater impacts on carbon stocks.

2. Materials and methods

2.1. Site description and forest inventory data

The effect of harvest regime on aboveground biomass (AGB) and SC stocks were simulated for Kendall State Forest in New South Wales. Kendall State Forest is located near Newcastle in New South Wales (NSW). The site is a native forest of composed various *Eucalyptus* species, dominated largely by blackbutt (*Eucalyptus pilularis* Smith). Other species include tallowood (*E. microcorys*), Sydney bluegum (*E. saligna*), turpentine (*Syncarpia glomulifera*) and bloodwood species (mainly *E. intermedia*). Forest age is not known, but individual trees can live over 400 years. Mean annual precipitation is approximately 1400 mm and mean annual temperature is 18.1 °C. There are number of soil types found at Kendall including Black earth, Chocolate soils, Red earth and Red and yellow podsolics (Isbell, 1996).

Inventory data used in this analysis were gathered from the Kendall Continuous Forest Inventory (Kendall CFI) database. Kendall CFI was established in 1960 and inventory data have since been collected every 5 years. Of the 144 permanent plots in the Kendall CFI, 18 are blackbutt-dominated. Trees within each of four circular sub-plots were counted and measured to determine stems per unit area and size class distribution for each species. Areas covered by four circular sub-plots from the inner plot to the outer plot are 0.04, 0.1, 0.2 and 0.4 ha respectively. Basal area for each tree was calculated from measured stem circumference. Trees in the following DBH classes were recorded: 10–30 cm, 30–50 cm, 50–80 cm, and trees >80 cm. Saplings <10 cm in DBH are not included in the CFI database. More details related to collection of inventory data can be found in Muhairwe (1998).

2.2. Model description

The LINKAGES model is a derivative of the JABOWA/FORET class of forest simulation models (Botkin et al., 1972; Shugart, 1984). It predicts the long-term dynamics and structure of forest ecosystems, as constrained by nitrogen availability, climate, and soil moisture. The model has been described and simulation results compared favorably to independent data on species composition, biomass, net primary productivity, soil organic matter, and nitrogen availability in many different areas (Pastor and Post, 1986; Pastor et al., 1987; Keenan et al., 1993; Post and Pastor, 1996; He et al., 1999; Hall and Hollinger, 2000). LINKAGES differs from other gap models in that it includes explicit decomposition, mineralization, and soil moisture sub-routines, allowing water and nutrient cycles to interact with species composition. It differs from other forest carbon models in that it simulates the growth of individual trees and therefore allows for analysis of inter-species composition and competition and the assessment of the impacts of different disturbance options such as timber harvesting. The stochastic nature of different processes in these types of models means that replicate analysis is required for an adequate description of variation in species composition and forest structure (Yamamoto, 1992). In this study 100 replicate simulations were conducted for each type of treatment.

2.2.1. Modification to soil carbon dynamics in LINKAGES

As originally implemented by Pastor and Post (1986), litter decomposition in LINKAGES was a function of litter input, litter quality (i.e., lignin-to-nitrogen ratio), and evapotranspiration. To improve predictions of SC sequestration for the purpose of this paper, the single soil compartment in LINKAGES was replaced with the RothC (Jenkinson, 1990). This model simulates the behavior of soil organic matter by dividing it into five compartments (Fig. 1). Each compartment decomposes at a characteristic rate as described by a first-order process, with turnover times ranging from several months to over 1000 years.

In this version of LINKAGES, decomposition of aboveground organic matter (i.e., leaf, large and small wood) remains as before – litter cohorts are tracked separately until they reach a critical C/N ratio at which point they are added to a soil pool with dynamics determined by RothC algorithms. In RothC, decomposable plant matter (DPM) and resistant plant material (RPM), represent organic matter (i.e., litter) inputs from both above- and below-ground plant parts. In our modification only fine roots contribute to RPM and DPM. Aboveground litter and

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