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Effects of understory management on trade-offs and synergies between biomass carbon stock, plant diversity and timber production in eucalyptus plantations

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A R T I C L E I N F O

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A B S T R A C T

Understory vegetation management is prevalent in successive short rotation eucalyptus plantations to control interspecies competition and improve tree growth and timber yields. Managing for multiple ecosystem services is critical for sustainable forests. Yet trade-offs and synergies between plant diversity, biomass carbon stock, and timber yields under different management approaches is poorly understood. Using eucalyptus plantations under different understory vegetation management approaches, in subtropical China, we examined the effects of understory vegetation management on tree growth, biomass carbon stocks, timber production, the composition and diversity of understory plant communities. We then assessed trade-offs and synergies among biomass carbon stocks, plant diversity attributes and timber production. Manual band tending (manual removal of the above-ground portion of understory vegetation in a 1 m band around the eucalyptus trees) did not affect the diversity of understory plant communities and favored biomass carbon stock and timber production. Thus, this treatment resulted in positive synergies between biomass carbon stock, plant diversity and timber production. Repeated broadcast herbicide application led to declines in understory plant diversity and increased exotic plant invasion, but also improved biomass carbon stock and stand volume. Trade-offs favoring carbon stock and timber production existed in broadcast herbicide application plots. Intensive disturbance of the understory and 0–5 cm topsoil removal led to declines in biomass carbon stock, plant diversity and timber production, and a negative synergy existed among these services. Our results confirm that manual band tending of understory vegetation in eucalyptus plantations, which results in positive synergies among plant diversity, biomass carbon stock, and timber production, should be a favorable management strategy for multiple ecosystem services. Although broadcast herbicide application can effectively improve carbon stock and timber production, attention should be paid to controlling invasive species after application.

1. Introduction

Globally, eucalyptus species (*Eucalyptus* spp.) are among the most important plantation trees (Forrester, 2013), covering more than 19 million hectares (Iglesias-Trabado and Wilstermann, 2008). China has more than 4.5 million hectares of eucalyptus plantations (Chinese Society of Forestry, 2016), which are typically managed as successive short rotation forestry for timber, pulpwood, charcoal, and fire-wood production. In order to reduce vegetative competition, increase eucalypt timber production, and enhance economic profit, intensive understory vegetation management, such as broadcast herbicide application, is conducted twice a year during the growing seasons, for the first three years in a typical 5–7 year rotation (Wen, 2008). In some eucalyptus plantations, understory and topsoil is removed at the early development of the stands due to topsoil containing plant propagules and seeds, and seedling recruitment from seeds, as well as resprouting from root fragments, bulbs, xylopodia, rhizomes, corms, and tubers in the topsoil is considered as a main pathway for vegetation regeneration (Woodward, 1996; Ferreira and Vieira, 2017). These intensive understory vegetation managements have exerted serious disturbance on

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soil and understory plants and resulted in serious declines in biodiversity (Wen, 2008).

Understory vegetation is an important component of forest ecosystems and plays a very important role in maintaining biodiversity, soil nutrient cycling, and carbon stocks (Wu et al., 2011a,b; Zhou et al., 2017). High plant diversity may enhance the resilience of forest ecosystems, generating greater biomass for carbon stocks and forest products (Pedro et al., 2014; Rana et al., 2017). Moreover, recent concerns about climate change have extended management objectives further to include carbon sequestration in order to decrease atmospheric CO_2 concentration (Pacala and Socolow, 2004; McKinley et al., 2011). Consequently, managing for multiple ecosystem services (i.e., plant biodiversity, carbon stock, and forest products) is critical for sustainable forest management (Hartley, 2002; Stephens and Wagner, 2007; Carpentier et al., 2017). Although several earlier studies have demonstrated that trade-offs or synergies exist between these management goals in forests (Bradford and D'Amato 2012; Burton et al., 2013; Carpentier et al., 2017; Rana et al., 2017), it remains unclear whether trade-offs or synergies also exist between timber yields, carbon stock, and biodiversity in eucalyptus plantations under different understory vegetation management strategies.

In this study, we examines the influence of different intensive and frequency of understory vegetation managements on stand volume, plant diversity, and biomass carbon stock, and the trade-offs and synergies between these ecosystem services in a full seven-year rotation of eucalyptus plantations, in subtropical China. The objectives of our study were to: (1) examine the effects of understory vegetation management on tree growth, biomass carbon stock, and stand volume; (2) estimate the effects of understory vegetation management on the composition and diversity of understory plant communities; (3) assess the trade-offs and synergies between biomass carbon stock, plant diversity attributes (i.e., plant richness, Shannon-Wiener index, and phylogenetic diversity), and stand volume in eucalyptus plantations under different understory vegetation management approaches.

2. Materials and methods

2.1. Study site

This study site was located in the Dongmen Forest Farm (22°17′ ~ 22°30′ N, 107°14′ ~ 108°00′ E) in Chongzuo City, Guangxi province, China. The study area is in the subtropical region, with an annual mean rainfall of approximately 1300 mm (from 1980 to 2010), occurring primarily from April to September. Annual mean temperature is 22.8 °C with a mean monthly minimum temperature of 12.8 °C, and a mean monthly maximum temperature of 28.6 °C. Soils in the region are mainly lateritic red earth with a typical soil depth of 80 cm or more and are derived from arenaceous shale with a heavy texture, poor nutrients, and a pH ranging from 4 to 5 (Wen, 2008).

The eucalyptus plantations in this study were converted from native *Pinus massoniana* forests, and managed intensively for wood production. The establishment and development of the plantations typically include a clear-cut harvest of the preceding forests, followed by prescribed burn, site preparation, weeding, and fertilization. The understory vegetation is dominated by *Euodia lepta*, *Rhus chinensis*, *Rubus cochinchinensis*, *Mallotus barbatus*, *Mallotus apelta*, *Maesa japonica*, *Mussaenda pubescens*, *Miscanthus floxidulus*, *Woodwardia japonica*, *Dicranopteris linearis*, *Pteris semipinnata*, and *Blechnum orientale* (Wen et al., 2004).

2.2. Experimental design

The stands selected were harvested and the sites burned during the summer of 2002. The sites were prepared in the autumn of 2002, which included mechanized tillage and digging of planting holes (50 cm × 50 cm × 50 cm). In early spring 2003, before eucalyptus seedlings planting, a base fertilizer (0.5 kg per seedling; N:P:K = 10:15:5) was added into each hole under each seedling and covered with soil. Seedlings of *E. urophylla* × *E. grandis* were planted at a spacing of 4 m × 2 m.

In May 2003, an experiment consisting of three treatments and a control arranged in a randomized block with four plots (10 m × 10 m) design with 30 replicates was established. In order to eliminate the edge effect, a 10 m buffer zone was established between each plot in each block. The three treatments were manual band tending (MBT), broadcast herbicide application (BHA), and understory and topsoil removal (UTR). A specialized eucalypt fertilizer with a mix of 200 g nitrogen, 150 g phosphorus, and 100 g potassium was applied per tree in all the plots to promote eucalypt tree growth for the first three years.

In MBT plots, the above-ground part of understory vegetation was manually removed at ground level with help of machete knife in a 1 m band around the trees. In BHA plots, herbicide was manually sprayed overall with 22.5 kg ha^{-1} of glyphosate-isopropylammonium. In UTR plots, understory and topsoil (0–5 cm) was manually removed with help of shovel. Since May and September are the understory growing seasons, the MBT and BHA treatments were implemented during these months for the first three years after planting. Understory and topsoil removal were conducted only once in May 2003.

The three understory management approaches in our study were different from the frequency, intensity and duration of the disturbance in these treatments. The MBT and BHA treatments had the same frequency, but differed from intensity and duration. The MBT treatments were considered as intermediate disturbance in our study due to the relatively low levels of destruction of understory plant biomass (Catford et al., 2012). High frequency of BHA exerted more serious disturbance because of the negative influence of herbicide on soil and plants (Miller and Chamberlain, 2008), thus was considered as a high level disturbance. In addition to plant propagules and seeds, topsoil also contains substrate, organic matter, soil microorganisms, soil mesofauna, and plays a critical role in nutrient cycling and plant recruitment (de Dios et al., 2005; Bai et al., 2015). Therefore, UTR was considered as the most severe disturbance in this study although it just conducted once.

2.3. Floristic surveys

In order to facilitate the floristic surveys in understory and guarantee all the species in the plot are recorded, each plot was further evenly subdivided into four 5 m × 5 m subplots. In August 2010, we examined species richness, abundance, and coverage of the understory plant species in each subplot. Species richness was estimated by tallying the number of plant species in each plot. Abundance was the individuals of a species in the entire 10 m × 10 m plot. Coverage was the ratio of the area of vertical projection of the aboveground part of a species to the area of the plot. Plant species diversity was examined by using the Shannon-Wiener index (Magurran, 1988), Pielou's evenness index (Pielou, 1966), and phylogenetic diversity (Faith and Baker, 2006). To examine the changes in understory functional group, we grouped the plant species into woody plants, vines, herbaceous plants, and invasive plants.

The Shannon-Wiener index (H') was estimated for each stand using the following equation (Magurran, 1988):

$$H' = -\sum_{i=1}^{s} P_i \ln P_i \tag{1}$$

where P_i = the ratio of the numbers of each species to the total numbers of all the species in each plot and s = the number of species in each plot.

Pielou's evenness index (E) was estimated for each stand using the following equation (Pielou, 1966):

$$E = H'/\ln S \tag{2}$$