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Research Article

Net Primary Production of Chinese Arborvitae Plantations under Different Densities

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Abstract: In this study, we measure the distribution of carbon pools and component fluxes of Net Primary Production (NPP) in an Chinese arborvitae (*Platycladus orientalis* (*L.*) Franco) plantation in Beijing from 2009 to 2010. At 22 years old, the plots were reduced from 5900 to 4100 and 3000 trees/ha in three replicates. Results shown that aboveground biomass was highest in the N4100 treatment plots, lowest in the N3000 treatment and intermediate in the unthinned control plots. Annual net biomass increment followed the same pattern across treatments. NPP measures suggested that the control forests and forests from the N4100 treatment have functioned as carbon sinks (4.06 and 4.59 t C/ha/year, respectively), while forests from N3000 treatment appeared to be also a carbon sink (2.95 t C/ha/year).

Keywords: Carbon pools, production, temperate forest, thinning

INTRODUCTION

Forest ecosystem in the temperate ecosystem plays a leading role in global terrestrial carbon cycle (Battle *et al*., 2000; Myneni *et al*., 2001; Fang *et al*., 2001; Goodale *et al*., 2002). Studies at the global scale have indicated that temperate forests function as significant carbon sinks in the Northern Hemisphere (Dixon *et al*., 1994; Fang *et al*., 2005, 2007). However, many temperate forests suffered significant loss over the past century but are gradually recovering as second-growth and plantations in many world regions (Chen and Huang, 1997). Therefore, it is crucial to understand current carbon stocks and sequestration potential in temperate ecosystems for more accurate estimation of the global carbon budget (Valentini *et al*., 2000; Hudiburg *et al*., 2009).

For temperate forests, several management practices have been evaluated for the carbon sink/cycle in a significant manner, e.g., Fertilization (Chen *et al*., 2000; Adams *et al*., 2005; Samuelson *et al*., 2009), increased rotation length (Liski *et al*., 2001), thinning method (Finkral and Evans, 2008; Cambell *et al*., 2009), irrigation (Samuelson *et al*., 2009), prescribed burning (Ryu *et al*., 2009; Ma *et al*., 2004), fuels treatments (Kobziar and Stephens, 2006). Among all the practical silvicultural strategies, thinning has been widely used to reduce competition in favor of species/individuals of interest, increase their resistance to pests, reduce fire risk and thereby achieve improved forest health within a shorter time period in comparison to natural succession (Nilsen and Strand, 2008; Campbell *et al*., 2009; Vargas *et al*., 2009). Past studies on carbon cycle have often focused on understanding the related ecological processes and driving forces in China (Fang *et al*., 1995, 2007; Liu *et al*., 1998; Wang *et al*., 2006, 2008, 2009). Also, detailed analysis of how thinning affect forest carbon dynamics in forest plantations in China has been lacking to date.

In this study, we investigated Chinese arborvitae forest plantations, a major/special forest cover type in warm temperate area (Chen and Huang, 1997). Following a foregoing study emphasizing thinning effects on stand growth, undergrowth and soil in the same forest (Duan *et al*., 2010), we further assessed the effects of silviculture thinning on carbon pools and fluxes in this arborvitae plantation using long-term monitoring data. This study will potentially contribute to the knowledge base in support of better urban forest management towards enhanced carbon sequestration.

The specific objective of this research was to quantify the influence of silviculture thinning on the distribution of carbon among functionally distinct pools as well as Net Primary Production (NPP). We intend to address the following research questions:

- What's the transition of carbon pools over 5 years after thinning?
- How has the thinning treatment affected the distribution of ecosystem carbon as stored in different component pools and respiration rates?
- How does the thinning treatment affect NPP, 5 years after thinning?

METHODOLOGY

Study area: The monitoring was conducted in a national forest in Hanbao Mountain, Changping

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Table 1: Stand characteristics across thinning treatments

Treatment	Average height (m)	Basal area (m^2/ha)	Canopy height (m)	Site index
Control	6.07±0.67	19.83±1.31	4.28±0.69	5.5
N3000	5.68±0.78	12.44±1.82	4.32±0.50	5.5
N4100	6.50±0.40	19.02±2.01	4.75±0.33	5.5

(40°44′N, 116°35′E), a municipal district of Beijing. The study site is located at a mostly southeast facing hillside with an average slope of 20% and elevation from 120-150 m. The site features a temperate continental monsoon climate with hot, wet summers and cold, dry winters. Annual mean air temperature is 0-3°C; average annual precipitation ranges 450-500 mm; and average mean relatively humidity is around 68%. The soils in the study area are 60-70 cm deep, with dark-brown colored topsoil and high organic matter content.

Experimental design: The experimental stand was divided into a grid of nine plots under three treatments with three plots in each treatment. The thinning activities were applied based largely on different management objectives and resource availability in April of 2004. An early thinning was done with a tree density reduction to 4100 (N4100 treatment), 3000 (N3000 treatment) trees/ha. The N5900 (control) represents conditions with no treatment applied. Large slash piles were removed from forest the floor away after thinning prescribed. Table 1 gives information on forest characteristics in 2009, 5 years of thinning.

Aboveground biomass: Height and Diameter at Breast Height (DBH) were recorded respectively for all trees (dead and live) with DBH>2 cm in each plot at the end of the growing seasons of 2009 and 2010. Trees biomass for each plot was estimated using species-specific allometric equation based on tree height and DBH (Chen *et al*., 1986). Simultaneously, carbon stocks were estimated from biomass using component conversion factors of 0.5. Since the same allometric equations were used to estimate tree biomass across all treatments. Therefore, reported differences in trees biomass across treatments reflect only differences in tree stems.

To determine plot-level understory (shrubs and grass) biomass, five subplots (2×2 m) were chosen in each plot in summer of 2009. We then took all samples to a laboratory to measure biomass by oven-drying at 75°C and used a conversion factor of 0.5 to estimate the carbon fraction in biomass.

Belowground sampling: The mass of tree root was estimated for each plot using an allometric equation in Xi mountain of Beijing relating DBH to root mass of Chinese arborvitae (Chen *et al*., 1986). Since the same equation was applied to all treatments, differences in coarse root biomass across all treatments reflected only differences in tree size.

Production: Net tree biomass (stem, branches, foliage and root) increment was estimated for each plot. We assumed that understory shrub biomass remained constant during the period given that they were relatively stable communities with potentially small interannual changes in total biomass.

In early March 2010, five litter collectors were placed arbitrarily within each plot in a regular pattern (1×1 m). Growing season litter fall was collected every month, while winter litter fall was collected every two months. The litter fall was dried at 75°C and weighted and divided into components of foliage, branched and fruit. Oven-dried litter biomass was converted to carbon mass using a factor of 0.5.

Production: The component ecosystem carbon fluxes described above can be combined to estimate aggregate ecosystem fluxes such as the net biomass increment (△B), Litterfall production (L), Net Primary Production (NPP) Eq. (1) (Schulze *et al*., 2000; Chapin *et al*., 2002):

$$NPP = L + \triangle B \quad (1)$$

Statistical analyses: The treatment effects on various carbon pools and carbon fluxes were examined by performing one-way analysis of variance in a ANOVA procedure (SAS, 1999) with three replications as random effects. If the effects of treatments were significant on a various, means were further compared by Duncan's multiple range tests with a confidence level of $p<0.05$.

RESULTS

Carbon pools: There was a clear that the N4100 treatment plots had higher biomass than the control plots in total aboveground carbon pools, but this difference was not significantly (Fig. 1). For tree stem, branches, foliage and roots, a significant difference was only observed in the N3000 treatment and N4100 treatment.

The patterns in over story shrub biomass is different from that of the trees biomass. All shrub components across thinning treatments were significantly different except for shrub wood where the

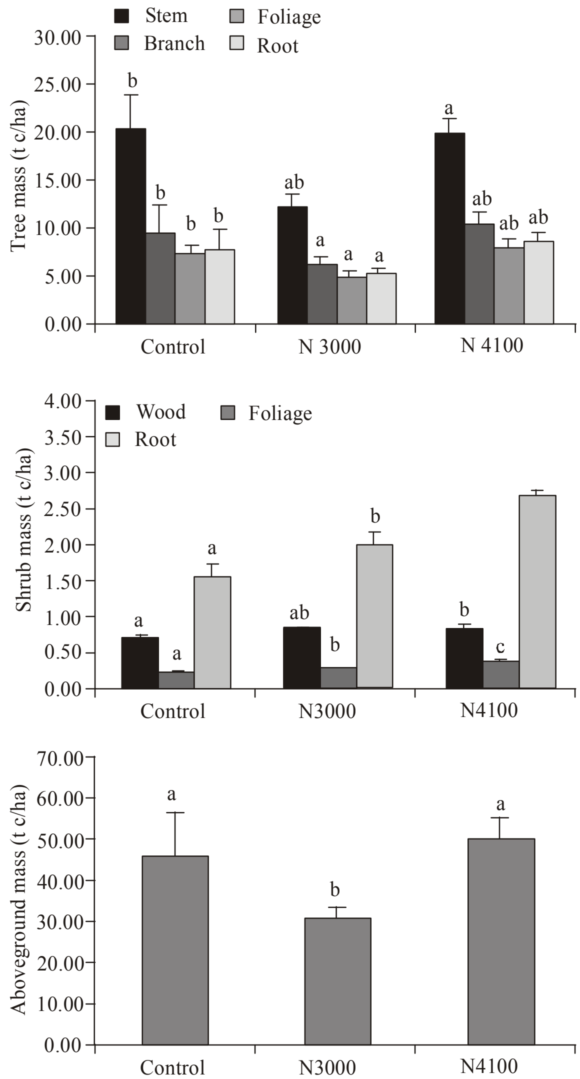

Fig. 1: Distribution of biomass among ecosystem pools and across thinning treatments
Error bars are standard error for the mean; Bars with the same lower case letter above the bar are not significantly different (p<0.05, LSD test)

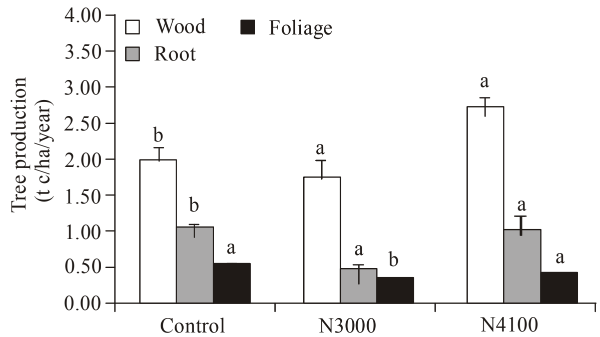

Fig. 2: Distribution of production in among tree pools and across thinning treatments
Stocks bars show the mean value of three plots within each treatments; Bars with the same lower case letter above the bar are not significantly different (p<0.05, LSD test)

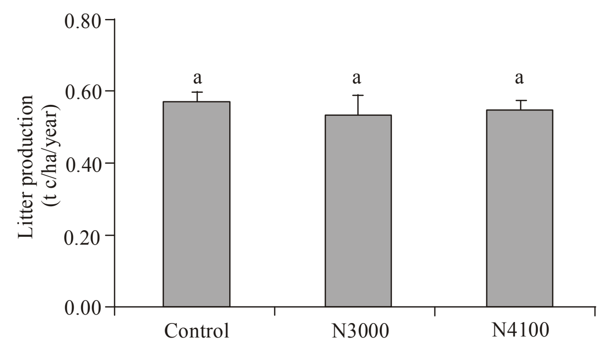

Fig. 3: Production of litterfall in the different treatment during 1 year
Stocks bars show the mean value of three plots within each treatment; Bars with the same lower case letter above the bar are not significantly different (p<0.05, LSD test)

difference was obviously observed between the N3000 and the control plots. However, the response of total aboveground biomass in N3000 treatment to thinning is similar to that of the over story stem biomass since the shrub in ecosystem-level biomass ration are remarkably conserved at 5%.

Production: Productions in different tree components (wood, foliage and root) appear to be affected by the treatments (Fig. 2). In N3000 treatment stands, the tree wood biomass is, on average, 0.85 of that measured in control stands. Simultaneously, estimations of tree foliage and root are about 50% and two third of that respectively of that measured in control stands. While measurement of total tree biomass in N4100 treatment is 1.16 times higher than in control stands which suggest a more than doubling of wood biomass and a stabilization of foliage.

In Fig. 3, no significant effect of thinning treatment could be traced on the amount of carbon stocks for a 1-year period (2009-2010). We also found that the increased carbon in litterfall is associated with trees number. Compared with unthinned stands, the amount of annual litterfall in N3000 and N4100 treatment was respectively about 92 and 95%.

Ecosystem productions: Table 2 shows the average estimates of ecosystem productions for each of the thinning treatments. The results show that estimations

Table 2: Aggregate ecosystem carbon fluxes estimated in different treatments (t C/ha/year)

	Treatment		
Carbon fluxes	Control	N3000	N4100
NPP	4.06	2.95	4.59

of NPP in N3000 treatment plots were about one third of that measured in control plots, while measurements of NPP in N4100 treatment plots suggest a relative stabilization of that measured in control plots. Additionally, it seems that plots from the N3000 treatment, thinning treatment had the effect of reducing NEP from 0.85 to -1.32 t C/ha/year and that the NEP had reduced to 0.19 t C/ha/year in plots from N4100 treatment. All these suggest that arborvitae plantation was functioning as a small carbon sink in plots from the control and the N4100 treatment during 2009-2010, whereas plots from the N3000 treatment was a small carbon source.

DISCUSSION

Carbon pools: The research is one of the few studies to apply silvicultural thinning in Chinese arborvitae, temperate forest (Duan *et al*., 2010). Mass of semimature arborvitae plantations in Beijing ranged from 49.3-61.6 t C/ha which was significantly higher than the mean mass for that in Xi Mountain in Beijing (19.9 t C/ha) (Chen *et al*., 1986). Our goals was to reduce the concentration of carbon dioxide in the atmosphere by means of finding the optimal residual stand density and assess the carbon consequences and dynamics of thinning-induced changes over 5 years.

Historically, thinning has been one of the long-standing forest management practices to increase stem-level productivity and countless empirical studies demonstrate that the thinning initially leads to a periodic decrease in overall stand production while increasing the productivity of remaining trees (Hoover and Stout, 2007; Campbell *et al*., 2009). Therefore, it is anticipated that the N4100 treatment showed the highest aboveground carbon (50.2 t C/ha) and annual increment in carbon accumulation (4.05 t C/ha/year). The magnitude of the effect of thinning on aboveground carbon stocks depends very much on the number of thinning and their intensity. The mass and its accumulation rates in N4100 treatment are comparable to the study in the thinned forests in Pennsylvania Alleghen (Hoover and Stout, 2007). The plots in N4100 treatment are comparable to the plots thinned from below which had larger carbon accumulation 25 years after thinning.

The thinning prescriptions considered in this study appear to have resulted in a substantial increase in the mass of understory shrubs. The magnitude of this response is directly to dependent on the residual stand density (Duan *et al*., 2010). It is expected that a high density standing is likely to have restricted light penetration and water availability so as to confine the growth and accumulation of undergrowth (Lieffers *et al*., 1999; Simonin *et al*., 2006). Actually, the shrub mass in response to thinning prescription amounts to just 5-11% of mass in trees, but the compensatory responses of understory shrub may have a large impact on carbon dynamics because shrubs often allocate a larger biomass to root than trees (Law and Warning, 1994; Campbell *et al*., 2009).

Carbon dynamics: In the different treatment, NPP was significantly larger than that of these pine forests (0.77-4.9 t C/ha/year) (Valentini *et al*., 2000; Dixon *et al*., 1994; Fang *et al*., 2007). Measurement of NPP in this study has suggested that light thinning treatments had the effect of increasing NPP from 4.06 to 4.59 t C/ha/year (Table 2). This is evident that small changes in CO_2 efflux from stand could have a large impact on net production because the annual amounts of plantation respiration are between 30 and 70% of assimilation (Ryan *et al*., 1994, 1996).

CONCLUSION

Based on one-year (2009-2010) measurement of all major components and processes of carbon dynamic, we conclude that the arborvitae plantations from 4100 trees/ha in China was highest in aboveground carbon stocks and net biomass increment, while the forests from 3000 trees/ha is lowest 5 years after thinning. Study time period longer than five years is probably needed to detect significant effects of thinning, although preliminary results indicate that thinned forests in 4100 trees/ha form a carbon sink (4.59 t C/ha/year).

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