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Effects of climate change on biomass carbon sequestration in old-growth forest ecosystems on Changbai Mountain in Northeast China

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ABSTRACT

Old-growth forest ecosystems are large carbon pools, and recent research has found that old-growth forests generally serve as global carbon sinks. However, the impact of climate change on the capacity for carbon sequestration in old-growth forest ecosystems is uncertain. Combining data from 30-year monitoring of permanent plots with that measuring variations in radial growth of dominant trees in an old-growth forest on Changbai Mountain in Northeast China, this study investigated the net biomass carbon sequestration and the effects of climate warming on carbon sequestration for dominant living trees in this forest ecosystem. The results showed that in 2010 biomass carbon density for living trees was 201.22 t ha^{-1} in Korean pine and broad-leaved mixed forest (KBF), 106.46 t ha^{-1} in spruce-fir forest (SFF), and 89.49 t ha^{-1} in Erman's birch forest (EBF). During the past 30 years the net biomass carbon density has increased in KBF and EBF, with annual net increases of 1.79 t ha^{-1} and 1.22 t ha^{-1}, respectively; while net carbon density has decreased in SFF, with an annual net decrease of 0.55 t ha^{-1}. Despite the increase of carbon density in KBF, climate warming has contributed to a decrease of 0.96 t ha^{-1} in biomass carbon sequestration for the period of 1981–2010, an amount equivalent to 1.8% of total stand biomass carbon increase. The increase in net carbon density in KBF was primarily age- or size-related, since that forest is still maturing. The decreased density in SFF may be caused by climate-induced radial growth decline and mortality of dominant trees in these stands. For the period of 1981–2010, climate-induced decrease of carbon sequestration in SFF was 7.30 ha^{-1}. Wind-related tree mortality in SFF may have led to the stand carbon sequestration decrease of 75.09 t ha^{-1}, about 10.3 times that induced by climate warming. In EBF, climate warming has led to a small increase in stand carbon sequestration, and the increase in net carbon density was also primarily age- or size-related, reflecting the fact that this forest is also still maturing. Our study also suggests that the dominance of Korean pine in KBF will decrease and that of Manchurian ash will increase under continuing climate warming, which is in agreement with the results from previous forest models.

1. Introduction

Global warming is caused by increased concentrations of greenhouse gases in the atmosphere, especially that of carbon dioxide. Reduction of carbon emissions and increase of carbon absorption are effective approaches to alleviating the rate of rise in temperature. An old-growth forest ecosystem is a huge carbon pool, and recent research has found that such a forest can continue to accumulate atmospheric carbon dioxide, suggesting that old-growth forests can serve as a global carbon sink (Zhou et al., 2006, 2011; Luyssaert et al., 2008; Tan et al., 2011). However, the impacts of climate change on the capacity of carbon sequestration in old-growth forest ecosystems remains uncertain.

By definition, old-growth forest biomass is that remaining at the point when gains from tree growth and recruitment are balanced by losses due to the deaths of trees and parts of trees. Previous studies on carbon sequestration in old-growth forest ecosystems have found that biomass sequestration has decreased (Taylor and MacLean, 2005; Helama et al., 2011) because mortality is roughly equal to or higher than the production of surviving trees, and thus stand biomass sequestration is close to zero or negative (Xu et al., 2011). In such cases the carbon sink is supplied mainly from soil (Zhou et al., 2006) and woody debris (Zhou et al., 2011). However, some researchers have found that old-growth forests may also display an increase in biomass generated by living tree growth (Luyssaert et al., 2008), especially for very large trees (DBH > 60 cm) (Tan et al., 2011). This may indicate that the carbon sequestration pattern in old-growth forest ecosystems may vary.

In light of the above, increases of biomass carbon in old-growth forests may likely be attributed to the following factors: (a)

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age-related: the forest has not reached a fully mature or over-mature state and thus growth has continued (Wang et al., 2011) and (b) climate-induced: changes in climatic factors have altered the balance of photosynthesis and respiration (Boisvenue and Running, 2006). To date, most results regarding carbon sequestration have been derived from long term site-specific monitoring (e.g., Zhou et al., 2006, 2011). By comparing monitoring data from different observational periods, variations in tree DBH, height, and density can be analyzed to estimate forest ecosystem biomass carbon. However, this approach cannot uncover the underlying dynamic of annual carbon accumulation nor explain the reasons for carbon pool variation.

Changbai Mountain Natural Reserve (CMNR) in Northeast China, most of which is covered by primary forest ecosystems, has not been subject to human disturbance and provides a living laboratory for studying forest carbon sequestration under natural environmental conditions. In order to explore the long term dynamics of stand structure and community composition, three permanent sample plots, representing the three major forest ecosystems types in the reserve, were established on the north slope of the CMNR in 1981. Plot altitudes ranged from 750 m to about 1950 m asl. Studies utilizing data from the permanent sample plots during the past 30 years have reported that all of the three forest ecosystems are carbon sinks (Zhou et al., 2011). However, in two of the three forest types – Korean pine (*Pinus koraiensis* Sieb. et Zucc) and broad-leaved mixed forest and Erman's birch (*Betula ermanii* Cham.) forest – carbon sequestration has occurred primarily in living trees, the carbon density of which increased by 48.5 and 47.0 t C ha^{-1}, respectively. In the third type – spruce-fir forest (*Picea jezoensis* Carr. *var. komarovii* (V.Vassil.) Cheng et L.K. Fu)-(*Abies nephrolepis* (Trautv.) Maxim.) – carbon sequestration has occurred mainly in woody debris and soil. Living tree biomass carbon decreased by 23.8 t C ha^{-1}, while carbon in woody debris and soil increased by 28.4 and 24.0 t C ha^{-1}, respectively. The actual factors affecting the carbon sink capacity and its variation in old- growth forest ecosystems on Changbai Mountain is still unknown.

To date, researchers in Northeast China have designed models to simulate the dynamics of forest composition and structure and the potential distribution of major forest types under different climate change scenarios (e.g., Zhao et al., 1998; Shao, 1996; Shao et al., 2003; He et al., 2005). These studies have suggested that distributions of the dominant conifer tree species in the region under climate warming will be manifest via northward geographic and upward altitudinal shifts. However, few studies have focused on the biomass sequestration or net primary productivity (NPP) under climate warming. Recently, tree ring research has revealed that spruce growth will decrease with increasing temperature in the CMNR (Yu et al., 2011; Li et al., 2011), while the other dominant tree species will benefit from climate warming (Zhang et al., 2007; Yu et al., 2011). While these results may help us better understand how the forest structure will shift under climate warming, the effects of warming climate on biomass sequestration for whole forest ecosystems remain unclear.

Combining tree ring analysis with vegetation monitoring via permanent plots, this study analyzed forest biomass sequestration characteristics and radial growth for every tree species on the north slope of the CMNR in the context of their responses to climate change. The goal of the study was to explore: (1) trends in temperature and precipitation change in the CMNR during the past 30 years; (2) dominant tree radial growth trends in each forest ecosystem and their relationship to climatic factors; and (3) carbon stocks of each forest ecosystem and of all tree species therein during the past 30 years; in order to assess whether carbon sequestration is related to climate change and to identify which climatic factors influenced carbon sequestration in the three old-growth forest ecosystems.

2. Material and methodology

2.1. Climate and vegetation of the study area

The study site is located on the northern slope of the Changbai Mountain Natural Reserve (CMNR) in Northeast China (41°43′–42°26′ N,127°42′–128°17′E) (Fig. 1). The reserve is about 200,000 ha in size, with an elevation ranging from 740 to 2691 m. It was established in 1960 and added to the World Biosphere Reserve Network in 1980 as part of the Man and the Biosphere Program. There has been little human disturbance in the

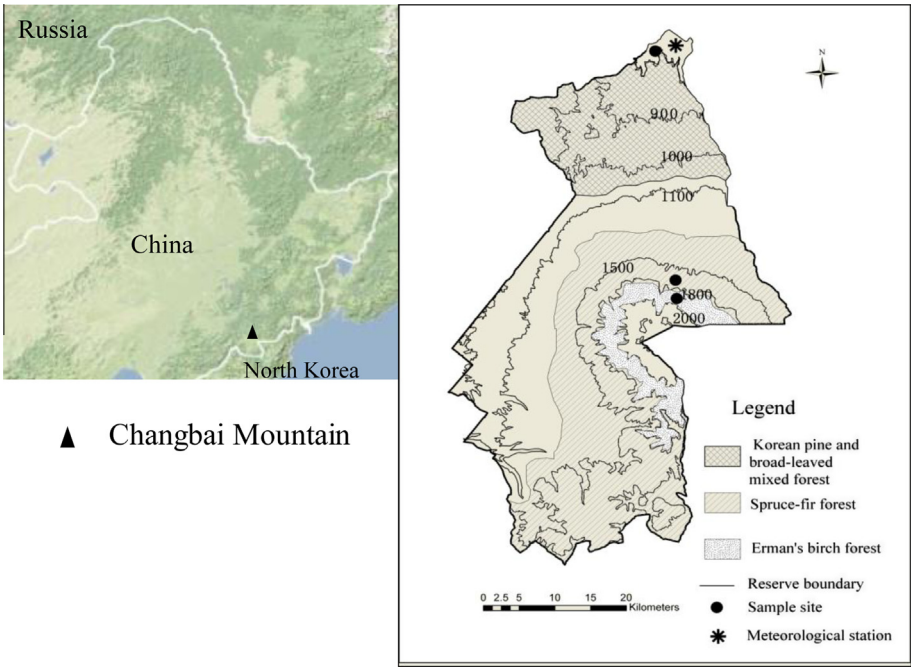

Fig. 1. Location of the Changbai Mountain Natural Reserve in Northeast China.