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Ecosystem carbon storage distribution between plant and soil in different forest types in Northeastern China

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ABSTRACT

Plant and soil carbon pools are two important elements of forest ecosystems and both are affected by many environmental factors. Although forest types are typically characterized using species composition, the ways in which soil carbon storage (C_S) is distributed between plants and soil in different forest types and the factors influencing this distribution remain unclear. In this study, we calculated C_S in plants and soil by sampling 108 tree plots and 324 soil profiles to determine whether plant and soil C_S varied significantly among different forest types in this region. Boosted regression tree analysis was used to detect factors influencing forest C_S allocation. The results showed that plant C_S varied from 68.09 t ha^{-1} in aspen-white birch forests (AW) to 117.81 t ha^{-1} in mixed Korean pine-broadleaved hardwood forests (KB). Conversely, soil C_S varied from 153.23 t ha^{-1} in KB to 261.58 t ha^{-1} in AW. Forest management was the main factor influencing plant C_S while soil C_S was most influenced by factors relevant to moisture. The influence on the ratio of plant C_S to soil C_S was quite complex because the dynamics of the relationship were affected by managerial, climatic, and topographical factors. In addition to species composition, ecosystem C_S also varied in different forest types and was influenced by complex factors related to climate, topography, and forest management.

1. Introduction

The concentration of atmospheric carbon dioxide (CO_2) continues to increase as a result of human activities (Rawlins et al., 2011). This has led to changes in climatic conditions, such as increased temperatures and changes in precipitation patterns (Barnett et al., 2005). Climate change can meaningfully alter the productivity, species distribution, and natural disturbance regime of forests (IPCC Climate Change, 2013). Forest ecosystems, including the plants and soil, play an important role in mitigating the effects of climate warming (Dale et al., 2001). In addition, forests provide the largest carbon (C) pool in terrestrial ecosystems (Fan et al., 1998; Pan et al., 2011). In tropical and temperate forests, woody biomass commonly sequesters the majority of C in this pool (Scott et al., 2004), and even old-growth natural forests serve as C sinks (Zhou et al., 2006). Soil is also an indispensable component of the global C cycle (Scurlock and Hall, 1998) with the amount of C stored in soils being approximately double the amount in the atmosphere (Davidson et al., 2000). In boreal forests, most C is stored in soil (Liski et al., 1998). Consequently, exploring the distribution patterns of carbon storage (C_S) in forest ecosystems is essential for understanding the C cycle.

Forest C_S and its distribution in different forest ecosystem components are affected by external factors to some extent. In this regard, many studies have explored the spatial distribution of C_S in forest ecosystems at a landscape scale (Chaturvedi and Raghubanshi, 2013; Lettens et al., 2005). Alternatively, the distribution of biomass in the different components of ecosystems has been studied for individual species (Varik et al., 2013). Most published literature reports that the distribution patterns of C_S differ among various spatial landscape patterns, among plant species, and among plant organs. The ability of a forest to sequester C is affected by the species composition of that forest; factors affecting this ability include climatic factors such as temperature and precipitation (Martin et al., 2010; Penuelas et al., 2011); topographical factors such as elevation and aspect, human activities such as afforestation and harvesting, and by natural disturbances such as fire and pest outbreaks (Sivrikaya et al., 2007). In addition, changing land use was another important cause of C emissions in the 1980s and 1990s (Houghton et al., 2000). Some studies have evaluated the changes occurring in forest biomass accumulation after a change in land use (Kerr et al., 2004, 2003).

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Soil organic carbon (SOC) is an important soil property (Schoenholtz et al., 2000) and also provides a significant C pool that reflects the ability of soil to sequester CO_2 in terrestrial ecosystems (Post and Kwon, 2000). However, human disturbance and the very extensive conversion of forestland to agricultural ecosystems in recent decades have caused a considerable proportion of the forest SOC stock to disappear (Murty et al., 2002). The amount of C stored in SOC can be increased by various management strategies, such as reducing the decomposition rate of litter (Post and Kwon, 2000), preventing soil erosion (Lal, 2002), and importing more organic matter into the soil layer (Smith, 2008). Generally, forest soils contain as much as two-thirds of the C in forest ecosystems (Dixon et al., 1994), and many anthropogenic and natural activities such as forest harvesting, fire, fertilization, and afforestation can affect the forest SOC stock (Lal, 2005). Climatic factors, especially those relevant to moisture, also influence C sequestration in soil (Pollard and Thompson, 1995). Because the largest proportion of C is stored as SOC, having a good understanding of the dynamics of forest SOC dynamics is essential to understand the wider distribution of C in forest ecosystems.

Species composition is the important aspect of a forest type, and has great impact on the C sequestration in tropical and boreal forests (Bunker et al., 2005; Ryan et al., 1997). C_S in plants varies largely because of the difference in each species' ability to sequester C. Over a long period of time, varied forest types will represent the development of a forest ecosystem during many periods of forest succession, each of which are always accompanied by various types of disturbance. However, C_S varies in different periods after a disturbance (Nino et al., 2014); this ultimately causes the varied storage rates of C. Similarly, because different species contribute different organic matter to soils through varying pathways (Giardina et al., 2001), soil C_S also varies among forest types. Broadleaved forests commonly have a higher input of organic matter into soil (Gundersen et al., 2009; Le Maire et al., 2008), while coniferous forests have lower decomposition rates (Vancampenhout et al., 2009). Therefore, different amounts of input and output of organic matter in various forest types cause this variation of soil C_S.

Climatic conditions are generally considered to be the most important factor that influences forest C sequestration. In addition, a range of factors such as topographical and managerial factors also affect forest C accumulation in plants and soil (Jandl et al., 2007; Kawasaki et al., 2005; Paul et al., 2002). Although many previous studies have explored how forest C_S changes with different climate conditions, geographical circumstances, and management strategies, few have focused on comparing the relative size of the influences of these factors. Understanding the importance of each factor that affects the distribution of forest C_S is a significant aspect of forest management.

The ratio of soil C_S to plant C_S (R_{SP}) is an important index that reflects the distribution trade-off of C stock between these two main C pools. Understanding the dynamics of this trade-off and relationship will highlight opportunities for increasing the total C sink in these ecosystems. Previous work has shown that at a global scale R_{SP} changes with latitude; the mean values of this ratio at high, mid, and low latitudes were 8.70 ± 7.50, 1.90 ± 0.67, and 1.06 ± 0.15, respectively (Lal, 2005). However, despite their importance for understanding regional C sequestration, the impact of climatic, topographical, and managerial factors on C sequestration and R_{SP} at a regional scale have not previously been quantified and merit further research.

The Lesser Khingan Mountain area in northeastern China is a transitional zone between cold- and moderate-temperate zones with both deciduous and coniferous forests present in this area. Aspen-white birch forests (AW), Mongolian oak-black birch forests (MB), and mixed Korean pine-broadleaved hardwood forests (KB) comprise three typical forest types in this area. The communities typically transition from AW as a common pioneer community to KB as the regional, climatically driven climax community, with MB serving as an intermediate community during long-term vegetation succession.

The objectives of this study were to: (1) compare forest C_S in plants and soil under different forest types and to test the hypothesis that the C_S of forests varies among forest types, which represent different stages of forest succession; (2) explore the important factors influencing forest C_S and its partition in the Lesser Khingan Mountains area; and (3) provide useful suggestions related to forest management with the goal of increasing C sequestration under the future condition of climate change.

2. Materials and methods

2.1. Study sites

The study sites (Fig. 1) were distributed in the Lesser Khingan Mountains area where forests cover 72.6% of the land area and the elevation ranges between 400 and 600 m a.s.l. From the northern to the southern part of this area the topography changes from mountains to hills and low mountains. The temperate continental monsoon climate features long cold winters (mean January temperature, −25 °C) and short warm summers (mean July temperature, 21 °C). The accumulated temperature (greater than 0 °C) ranges from 1800 to 2400 °C. The average annual rainfall ranges between 550 and 670 mm, falling mostly in summer. The typically homogeneously distributed, dark brown soil in this area has an average depth of less than 100 cm.

The main vegetation types in the Lesser Khingan Mountains area are coniferous, broadleaf conifer, and deciduous forest in the northern, central, and the combined southern and marginal sections, respectively. Secondary forests occupy a large proportion of this region while virgin forests can be only found in some protected areas, such as the *Feng Lin and Sheng Shan* nature

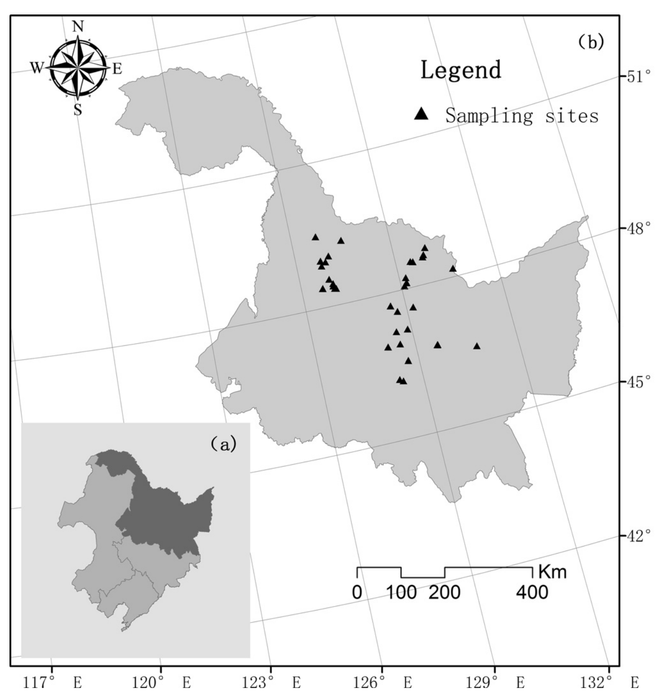

Fig. 1. Location of sampling sites in the Lesser Khingan Mountains area. (a) Northeastern China, (b) Heilongjiang Province in northeastern China.