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Carbon budget from forest land use and management in Central Asia during 1961–2010

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ABSTRACT

The carbon budget that was derived from forest land use has been extensively explored in most regions/countries of the Northern Hemisphere but is poorly documented in Central Asia. In this study, we proposed a localized bookkeeping model and estimated the sources and sinks of carbon from forest land use and managements between 1961 and 2010 in two arid regions of Central Asia, e.g., Kazakhstan and Xinjiang, China. The results indicate that the forest land use in these two regions acted as a carbon sink, with a total carbon sequestration of 43.27 Tg and 20.74 Tg respectively. Accelerated afforestation led to strong carbon sequestration (47.43 Tg in Xinjiang and 34.29 Tg in Kazakhstan) and forest fire were the main carbon sources (2.99 Tg in Xinjiang and 12.51 in Kazakhstan) in both regions. Although there were large amounts of wood production from logging, the carbon flux from this activity was small due to the joint action of wood oxidization and trees recovery. Compared with logging, deforestation area for cultivation was much smaller, but its carbon emission was considerable. The differences on the forestry regimes such as afforestation incentives, logging and fire prohibitions in these two regions were significant, resulting in different effects on their carbon fluxes. This study elucidates the carbon function of forest land use in Central Asia and further deepens our understanding of the influence of forest land use on the global carbon balance.

1. Introduction

As the carbon cycle has become increasingly important to global change, an accurate account of the carbon budget has become one of the most important concerns in global change research during the past half century (Naughton-Treves and Wendland, 2014). Understanding the effect of human activities (e.g., fossil fuel and cement, land use change and goods and services) on global carbon changes is an urgent challenge faced by earth sciences. This challenge is complicated by considerable difficulty in accurately estimating the carbon budget (Canadell et al., 2009; Houghton, 2010). Land use and land cover change (LULC) is the largest source of uncertainty in the estimation of the global carbon budget (Levy et al., 2004; Houghton et al., 2012; Pongratz et al., 2014), especially regarding the magnitude, geographic distribution and driving forces of carbon sink at the middle latitudes of the Northern Hemisphere (Goodale et al., 2002; Houghton, 2003a). According to the Global Carbon Budget 2014 (Le Quéré et al., 2014), the carbon emissions from land use and land cover changes in 2013 were approximately 0.89 Gt C, whereas the uncertainty is about ±0.5 Gt C. Most research regarding the carbon budget from LULC focuses on Europe, North America and East Asia (Brown, 1993; Houghton, 1999; Houghton, 2003b; Wong and Alavalapati, 2003; Kasel and Bennett, 2007; Krankina et al., 2012; Conti et al., 2014; Tadesse et al., 2014; Birdsey and Pan, 2015). Central Asia, however, has not been investigated to the same extent

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(Chuluun and Ojima, 2002). Additionally, previous research on the carbon budget in Central Asia exhibits large uncertainties (Lal et al., 2007).

LULC affects the carbon cycle by changing the structure and function of terrestrial ecosystem (Levine et al., 1995; Guo and Gifford, 2002; Peichl and Arain, 2006; Qiu et al., 2012; Conti et al., 2014). The process of LULC always produces carbon sequestrations or emissions (Houghton, 2010). Different types of LULC can result in completely different carbon budgets (Watson et al., 2000). For example, the degradation of grassland is normally a carbon source because the grass carbon density decreases (Chuluun and Ojima, 2002), while afforestation often increases the carbon pool of terrestrial ecosystems (Fang et al., 2001). Even two similar land cover changes may create opposite carbon budgets. For example, the change from highly covered grassland (e.g., meadow) to farmland normally results in carbon loss (Guo and Gifford, 2002; Qiu et al., 2012) while sparsely covered grassland (e.g., desert steppe) to farmland always absorbs carbon from the atmosphere (Chuluun and Ojima, 2002).

Forest ecosystems play a dominant role in the global carbon budget (Dixon et al., 1994; Fang et al., 2001; Goodale et al., 2002). Many studies have shown that the forest ecosystems in the middle and high latitudes of the Northern Hemisphere have been acting as an important carbon sink (Goodale et al., 2002; Pan et al., 2011). Forest land use changes produce significant effects on the terrestrial carbon pool because approximately 30% carbon of fossil fuel CO_2 emissions was absorbed by established forests (Pan et al., 2011; Birdsey and Pan, 2015). Numerous studies have estimated the carbon budget from forest land use changes at global or regional scales (Dixon et al., 1994; Winjum and Schroeder, 1997; Watson et al., 2000; Wong and Alavalapati, 2003; Ciais et al., 2008; Rotenberg and Yakir, 2010; Krankina et al., 2012). However, most of these studies did not sufficiently consider the carbon density variations among different stages and tree species and the speed of changes in the carbon density because these studies lacked specific local data (Kasel and Bennett, 2007). In addition, the carbon budget from arid forest land use change was often estimated as a single and rough value (Goodale et al., 2002; Lal, 2004). Actually, arid forest ecosystems are indispensable for maintaining the energy balance of entire arid ecosystems because they can conserve water in oasis regions and absorb carbon dioxide (Grünzweig et al., 2003). Additionally, arid forest ecosystems are very vulnerable because the growth and survival of trees are subject to the availability of water (Grünzweig et al., 2003). Thus, carbon storage in arid forests also changes easily under anthropogenic disturbances and requires longer recovery time than tropical forest.

The arid region in Central Asia normally consists of six regions, namely, five Central Asian Republics (CARs) and Xinjiang Province in China (Xinjiang) (Li et al., 2015). Over the past 50 years, the main types of forest land use in this region have generally included afforestation, logging, deforestation for cultivation and forest burning. Considering the limited amount of detailed data concerning forest land use in these six regions, we chose two typical regions, namely, the nation of Kazakhstan and Xinjiang Autonomous Region in China (the total area of these two regions accounts for more than 77% of Central Asia), as our study areas. Xinjiang is apparently different from the other five regions regarding the magnitude of forest land use because of the different regimes between the Soviet Union and China. Kazakhstan is a typical representative of the five CARs because of their similar forestry policies and economic development. Our objective is to (1) quantify and compare the carbon budget from forest land use in Kazakhstan and Xinjiang and (2) provide a basic understanding of the carbon sinks and sources that were derived from forest land use in semiarid and arid regions.

2. Study area and materials

2.1. Study area

Xinjiang, the largest province in China, is located in the northwestern part of the country. Kazakhstan is a contiguous transcontinental country in Central Asia and the world's largest landlocked country by land area. Both are far from the Pacific Ocean (more than 2500 km) and belong to arid or semi-arid climates with precipitation from below 50 mm in desert areas to 900 mm upwind of mountains (Bothe et al., 2012). The main land cover types in both regions generally consist of temperate evergreen forest (i.e., spruce, *Pines sylvestris*, *Abies sibirica*, etc.), temperate deciduous forest (i.e., *Populus*, *Betula*, *Ulmus*, etc.), temperate shrub land (i.e., *Haloxylon*, etc.), grassland (i.e., alpine meadow, desert steppe), cultivated land, built-up lands and bare soil.

2.2. Data

2.2.1. Afforestation area

Annual afforestation area data for Xinjiang from 1961 to 2010 was obtained from the Xinjiang Statistical Yearbook (http://www.xjtj.gov.cn/sjcx/xjwsn_3749/; accessed 10 July 2014; see Table S1). Limited plantation area data for certain years (5 or 7 years) from 1961 to 2001 and the annual documented plantation areas from 2002 to 2010 in Kazakhstan were obtained from the Almaty Branch of the Kazakh Scientific Research Institute of Forestry and UNEP (UNEP, 2007) (see Table S2 for the integrated data after reconstruction). Plantations in the two regions consisted of three types: protective plantations, timber plantations and economic plantations. Details about data reconstruction for annual afforested area of these tree types in the two regions are provided in S1 of the Supplementary Material section.

2.2.2. Wood harvest data

Four types of forest harvest products (fuel wood, paper and paperboard, timber wood and man-made boards) were documented. The annual wood harvest production from 1961 to 2010 in Xinjiang was obtained from a series of Chinese Forestry Statistical Yearbook (see Table S3). Forest production in Kazakhstan after its independence was obtained from the Forestry Database of Food and Agriculture Organization (FAO) (http://www.fao.org/forestry/statistics/80570/en/; accessed 10 July 2014;) and World Forest Report 2009 (FAO, 2009) (see Table S4). Unfortunately, forest production during the existence of the Soviet Union was not recorded. During this time (before 1992), commercial logging was completely banned in Kazakhstan because of its very low forest cover and significant attention by the government towards environmental conversation (FAO, 2009). All commercial wood was imported from the Russian Federation. Therefore, we assumed that the yields of paper and paperboard, timber wood and man-made boards in that time were naught. Fuel wood has been used for heating and cooking for thousands of years in Kazakhstan. We estimated the yield data of fuel wood from 1961 to 1990 (Kazakhstan gained independence in 1991) according to a change ratio of fuel wood in Central Asia from 1980 to 2009 (FAO, 2009).

2.2.3. Deforestation for cultivation

The annual deforestation area for cultivation in the two regions was obtained from the Xinjiang and Central Asia Scientific Data Sharing Platform (http://midasia.geodata.cn/Portal/index.jsp; accessed 27 October 2015) (see Table S5).

2.2.4. Forest burned area

Annual burned area in Xinjiang was acquired from a series of Xinjiang Forestry Yearbook and limited burning area data for