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Advances in Space Research 58 (2016) 1002–1016

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Estimation of future carbon budget with climate change and reforestation scenario in North Korea

Damin Kim, Chul-Hee Lim, Cholho Song, Woo-Kyun Lee*, Dongfan Piao, Seongbong Heo, Seongwoo Jeon

Department of Environmental Science and Ecological Engineering, Korea University, Seoul 02841, Republic of Korea

Received 14 January 2016; received in revised form 16 April 2016; accepted 27 May 2016
Available online 31 May 2016

Abstract

In terms of climate change, quantifying carbon budget in forest is critical for managing a role of forest as carbon sink. Deforestation in North Korea has been exacerbating at a noticeable pace and caused to worsen the carbon budget. Under the circumstance, this study aimed to assess the impact of climate change and reforestation on the carbon budget in 2020s and 2050s, using the VISIT (Vegetation Integrative SImulator for Trace gases) model. In order to analyze the impact of reforestation, future land cover maps for the 2020s and 2050s were prepared. Among the deforested areas (2.5×10^6 ha) identified by comparing land cover maps for different periods, the potential reforestation areas were selected by a reforestation scenario considering slope, accessibility from residence, and deforestation types. The extracted potential reforestation areas were 1.7×10^6 ha and the increased forest area was spatially distributed to each district. The percentage change in carbon budget caused by climate change from the 2000s to 2020s is 67.60% and that from the 2020s to 2050s is 45.98% on average. Based on the future land cover, NEP (net ecosystem production) with reforestation will increase by 18.18% than that without reforestation in the 2050s, which shows the contribution to carbon balance. In connection with this long term projection, it is revealed that the gross fluxes such as photosynthesis and respiration may be impacted more obviously by the climate change, especially global warming, than the net carbon flux because of the offset between the changes in the gross fluxes. It is analyzed that changes in carbon budget are very sensitive to climate changes, while the impact of reforestation is relatively less sensitive. Although it is impossible to significantly improve carbon sequestration by establishing forest in a short-term, reforestation is imperative in a long-term view as it clearly has a potential mechanism to offset emitted carbon.
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Keywords: Carbon budget; Climate change; Deforestation and reforestation; Land cover change; Ecosystem productivity; Ecosystem respiration

1. Introduction

Since the mid-20th century, anthropogenic carbon dioxide (CO_2) emission from land cover change, fossil fuel combustion, or the burning of biomass is very likely to have led to climate change, which has been disturbing the global biogeochemical carbon cycle (Pachauri et al., 2014). Changes between carbon pools caused by the disturbance would induce uptake or release of CO_2 from the terrestrial biosphere through changes in physiological processes such as photosynthesis, respiration, and decomposition (Ito, 2000; Ito et al., 2007). Among the terrestrial ecosystems, forests are valued for their important role in the global carbon budget by controlling the CO_2 flux to the atmosphere (Dixon et al., 1994; Houghton et al., 1998; Martin, 1991; Walker and Steffen, 1996; Pan et al., 2011). Even though the role of forest based on the United Nations Framework Convention on Climate Change (UNFCCC) has been emphasized as a major carbon sink,

* Corresponding author. Tel.: +82 2 3290 3016.
E-mail address: leewk@korea.ac.kr (W.-K. Lee).

http://dx.doi.org/10.1016/j.asr.2016.05.049
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24% of world's total emission is still composed of AFOLU (Agriculture, Forestry and Other Land-Use) and majority of AFOLU emission is caused by deforestation in developing countries (Pachauri et al., 2014). Land use change, including forestry by human activities, is one of the major causes of disturbances that may have a particularly long-term impact on natural exchange rate of carbon at regional and global scales (Eglin et al., 2010; Watson et al., 2000). In other words, changes in carbon balance between the various carbon pools caused by deforestation, reforestation, or afforestation play an important role in the carbon cycle (Thuille et al., 2000; Watson et al., 2000). Generally, deforestation brings about considerable loss of carbon from vegetation and soils (Davidson and Ackerman, 1993; Mann, 1986). According to House et al. (2002), complete global deforestation, which is the conversion of all the world's forests to grasslands, would increase the atmospheric CO_2 concentrations by approximately 130–290 ppm. In particular, cultivating forest lands results in substantial carbon losses in both biomass and soil. On the other hand, forest regrowth or reforestation contributes to the recovery of significant carbon sink. It has analyzed that an expansion of forest area and forest growth in mid- and high-latitude region sequesters about 0.7 Pg of carbon per year (Dixon et al., 1994) and afforestation activities in Europe possess a major potential for carbon sequestration (Burschel et al., 1993). Reforestation of both naturally and artificially abandoned lands in the tropical forest has been suggested as a means to support the offset of increasing carbon emissions (Silver et al., 2000). Furthermore, establishing forests to reduce carbon levels over long periods has been already proposed (Hall, 2001). However, the current lack of information on areas and spatial patterns of afforestation, deforestation, and forest carbon stock makes it extremely challenging to estimate the accurate extent of carbon sink associated with land use change (Houghton, 2003; Piao et al., 2009).

In East Asia, there has been a rapid land-use change such as fast urbanization or deforestation since the 1990s (Piao et al., 2011). Among the countries in the region, land degradation of North Korea (Democratic People's Republic of Korea) has been exacerbated at a noticeable pace owing to excessive logging and conversion of forest into agricultural land (Kang and Choi, 2014). During the 1980s and the 1990s, forest cover declined sharply with extensive cutting (Lee et al., 1999; Zheng et al., 1997) because of energy and food shortage in the aftermath of the economic contraction in North Korea. It was estimated that the forest cover was about 79% of the total land area in 1945, but it decreased by 12% in 1997 (Piddington, 2003). On the contrary, South Korea (Republic of Korea), located in the Korean Peninsula along with North Korea, has restored its forest cover since the 1970s and acts as a carbon sink till date (Cui et al., 2014). During the same period, the two countries showed completely different patterns in terms of forest distribution, which emphasizes the necessity to manage forest and restore the deforested areas of North Korea in order to respond to climate change in the Korean Peninsula by securing the carbon sink.

Many previous studies have simulated the changes in carbon budget as a response of ecosystem to environmental changes. The response of carbon budget to climate change, especially in forest, was revealed by model simulation (Ju et al., 2007). A process-based model, Vegetation Integrative SImulator for Trace gases (VISIT), has been applied to estimate changes in ecosystem mechanism and carbon budget in East Asia under near-future climate change (Ito, 2010). The model was also applied to assess the impact of changes in climate and land cover on the carbon budget in the Korean Peninsula for the past periods (Cui et al., 2014; Yoo et al., 2013). Although the results need to be explained with care because of the uncertainty within the model as well as a constraint of validation, such studies effectively allow us to understand the impact of various environmental factors.

With regards to the regional perspective of East Asia substantially contributing to the global carbon cycle and climate system (Ito, 2010), the terrestrial ecosystems of the Korean Peninsula play an important role within the region given that it contains plentiful vegetation in South Korea and the recovery potential of the degraded vegetation in North Korea. Although several studies have addressed the contemporary carbon budget in the Korean Peninsula and East Asia, few studies have explored the future response of terrestrial ecosystems particularly in North Korea. Therefore, we assume the restoration of deforested land and apply the process-based model to estimate the carbon budget of North Korean ecosystems using the projected climate scenarios of near-future through 2059. This study aims to assess and compare the impact of changes in forest area and near-future climate on the carbon budget in North Korean terrestrial ecosystems. This projection can contribute to understanding the current and future roles of forest and assessing response of carbon balance to climate change for carbon management, especially in North Korea and even in East Asia.

2. Material and methods

2.1. Study area

The geographic center of North Korea is located at 40° 00′N latitude and 127°00′E longitude (Fig. 1). Around 80% of North Korea's land area is composed of mountains and uplands. The Taebaek Mountains form a backbone down the eastern side of North Korea. From the North Korean Highlands, Gaema-kowon, the ridges mostly trend along north–south, however the valleys extend in all directions (Palka and Galgano, 2003). In particular, the land around Mt. Baekdu near border between China and North Korea has a basalt lava plateau with elevations between 1400 and 2000 m. One of the tallest mountains, Kwanmo Peak, located at the extreme northeastern part of North Korea, is approximately 2540 m in height. As the slopes of moun-

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