Characterization of changes in land cover and carbon storage in Northeastern China: An analysis based on Landsat TM data

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Abstract We use Landsat TM time series data for the years of 1991/1992, 1995/1996 and 1999/2000 to characterize land-cover change in northeast China. With the information on land-cover change and the density of vegetation and soil carbon, we assess the potential effect of land-cover change on vegetation and soil carbon in this region. Our results show a large decrease of 2.76×10^4km^2 in forest area and a rapid increase of 2.32×10^4km^2 in urban area. Land-cover changes in northeast China have resulted in a potential maximum loss of 273.2 Tg C for the period of 1991—2000, with a net loss of 95.7 Tg C in vegetation and 177.5Tg C in soil. . The conversion of forests into other land-cover types could have potentially resulted in a loss of 254.6 Tg C for the study period, accounting for 68.8% of the total potential carbon loss in the northeast China. To quantify the net effect of land-cover change on carbon storage will require accounting for vegetation regrowth and soil processes. Our results also imply that forest protection and reforestation are of critical importance to carbon sequestration in China.

Keywords: carbon storage, China, deforestation, land use.

Quantifying the role of land use/cover change in the global carbon cycle has been critically important to the reduction of the imbalance of the global carbon budget[1—3]. Moreover, land-use management could play an important role in stabilizing the rising atmospheric CO_2 concentration[4]. Therefore, there is an important need to characterize and quantify changes in land-use and land-cover at regional and global levels and their influence on the terrestrial ecosystem processes that control the carbon cycle[3].

Terrestrial ecosystems in the northern extra-tropics play an important role in the global carbon budget, and are especially susceptible to future land-use change and projected climate change[5]. In northeast China (latitude >40°N), the woodland area is about 57.63×10^4 km^2 and forest cover area is about 30% of the whole region[6]. Previous investigation indicated that this region experienced large-scale deforestation in the past several decades[7]. Some recent analyses examined changes in land use associated with land-use structure and intensity along the

IGBP-Northeast China Transect (NECT) and the long-term effect of land-use change on soil carbon storage in grassland ecosystems[8—10]. For the whole region of northeast China, our previous estimate indicated that vegetation and soil organic carbon pools are 2.81 and 26.43 Pg C respectively [11]. Although the land area in northeast China accounts for about 12.94% of the nation, its soil carbon pool is about 28.59% of the national soil carbon pool [11]. Thus the potential changes in carbon storage induced by land-use change in this region could be very large. The magnitude of carbon changes induced by land-use change in the whole region, however, remains uncertain.

In this study, we intend to reduce the uncertainty in estimating land-use change and its potential effect on carbon storage in northeast China. Three major approaches have been used to investigate the impacts of land use/cover change on the terrestrial carbon cycle: (i) book-keeping modeling with information on historic records of land use/land cover change and carbon densities for different land cover types[2,12, 13]; (ii) process-based terrestrial carbon model[14,15]; (iii) a combination of remotely sensed data with the data of field measurement and census records [16]. We use the third approach to assess the potential effect of land use/cover change on carbon storage in the northeast China. In this study, we first estimate land-cover change during 1991—2000 by using Landsat TM data. Second, we refine the data of vegetation and soil carbon density derived from vegetation and soil inventories [11]. Third and finally, we estimate the magnitude of carbon source induced by land-cover change in the region.

1 Materials and method

1.1 Study area

The study area covers about 124×10^4 km^2 in northeast China (115°37′—135°5′E and 38°43′—53°34′N)[6]. It consists of three provinces: Liaoning, Jilin and Heilongjiang, and four Meng Leagues of Inner Mongolia[17]. The size of human population was about 1.07×10^8 in 1999[18—21]. The major types of vegetation on hills and mountains are cold temperate mixed broadleaved deciduous and needleleave forests, cold temperate needleleave forests[6]. The dominant vegetation in the west parts of the region includes semi-arid shrubs, grassland and temperate steppe[6]. Most of northeast China is characterized by temperate monsoon continental climate, except the area north to 50°N, where the cold temperate monsoon climate dominates[6]. Main soil types include dark-brown earths, brown coniferous forest soils, grey meadow soils, black soils and chernozems[6]. The long history of agricultural colonization together with increasing population density and economic development has led to a significant transformation of land-cover types[6, 22].

1.2 Data and methods

Two types of data have been used for our analysis in this study. First, Landsat TM time series data of 1991/1992, 1995/1996 and 1999/2000 are used to calculate the area extent of changes in different land-cover types[23,24]. The spatial resolution of Landsat TM data is 30 m. Satellite data for each period consist of more than 520 TM images obtained from the national resources and environmental remote sensing database in China[23,24]. Second, estimation of carbon content in living vegetation and soils of different ecosystems are estimated from 122 plots of the fourth national forest inventory in the early 1990s, and 388 soil profiles of the second national soil survey in the 1980s[9].

We used a supervised classification to generate land cover maps for the years of 1992, 1996 and 2000. TM image processing includes the following six steps: (i) Geometric correction; (ii) radiometric calibration; (iii) atmospheric correction; (iv) unsupervised classification and supervised classification; (v) error assessment; and (vi) ground truth assessment. Nine land cover types are used in this study, including paddy land, dry land, forest, scrubs woodland, others woodland, grassland, water, city and construction land, and unused land. For the estimation of the vegetation and soil carbon pools for the whole region of northeast China, the site-specific estimates of vegetation and soil organic carbon were extrapolated to the entire area of northeast China by linking with spatial distribution of vegetation and soil types[9]. To estimate carbon release from land-cover change, we also need information on how much carbon in vegetation and soil could be released into the atmosphere. When natural vegetation was converted into cultivated land and pasture, a majority of above-ground biomass was lost during clearing and moving[25]. The largest potential of vegetation carbon change is estimated by changing area and carbon density according to the method as described by Houghton[2]. 25%—50% of the litter and humus may be lost from a forest or other natural vegetation during 20 to 40 years after harvest or other severe disturbance[25—28]. The carbon in soil to a depth of 1 m decomposes following harvest to 50% in temperate forests and studies of the effect clear-cutting in northern temperate forests also indicate that about 50% of the carbon in the forests is lost in 10—15 years following harvest[25]. Here we assume that 50% of carbon in vegetation is lost or gained when vegetated areas decreases or increases, and that soil carbon storage is lost or gained at a rate of 30% of original soil organic carbon when vegetated areas are converted. With the above assumptions, we determine the potential effect of land-use change on vegetation and soil carbon storage.

2 Results

2.1 Land-use/land-cover changes

In the period from 1991 to 2000, five land-cover types showed a decrease in their area while four other land-cover types experienced an increase in their area (table 1). The area of forests shows the largest decrease of 2.76×10^4 km^2 among all types. Cities, residential lands, and other man-made constructions showed a rapid increase in an area up to 2.32×10^4 km^2, which is 3.41 times of the area in 1992. Paddy land also showed a large increase of 1.31×10^4 km^2. In contrast, dry land shows a large decrease of 1.68×10^4 km^2. The farmland for the time period shows a slight decrease of 0.37×10^4 km^2.

Changes in land-cover appear to vary from place to place (Plate I). The eastern part of

Table 1 Land-use/land-cover changes and potential carbon loss from 1992 to 2000 in northeast China

Land use types	Area (×10^4 km^2)			Carbon/MgC/ha		Area Change	Change ratio	Change/Tg	
	1992	1996	2000	vegetation	soil	(×10^4km^2)	(%/a)	Vegetation	Soil
Paddy land	3.26	3.42	4.57	8.2	100.5	1.31	4.02	5.4	39.5
Dryland	33.95	33.28	32.27	9.9	94.5	–1.68	–0.49	–8.3	–47.2
Forest	43.27	41.39	40.51	67.6	194.8	–2.76	–0.64	–93.3	–161.3
Scrubs and dwarf woodland	3.33	4.66	4.75	10.4	104.5	1.42	4.26	7.4	44.5
Others woodland	4.94	4.25	4.75	45.5	171.3	–0.19	–0.38	–4.3	–9.8
Grassland	25.84	25.93	24.29	3.3	92.8	–1.55	–0.60	–2.6	–43.2
Water	1.24	2.25	3.09			1.85	14.92		
City, resident and construction land	0.68	1.66	3.00			2.32	34.12		
Unused land	7.79	7.46	7.07			–0.72	–0.92		
Total	124.30	124.30	124.30					–95.7	–177.5

study period shows much larger change in land-cover than other locations because there are a lot of important heavy industries in Jilin, Liaoning and Heilongjiang provinces and their economic structure experienced a large reformation during 1991—2000[18—21]. Change in the cultivated land occurred mostly in the middle and the east of Northeast China (fig. 1). In the eastern Inner Mogonia region, agriculture and stockbreeding were the main industries[20, 21]. The dominant way of land transformation is the conversion between dry land and grassland[21]. The construction of roads is obvious in the deforested areas. The construction of water conservancy and hydropower station led to a significant increase in water bodies (fig. 1). Rivers in northeast China provided a lot of hydropower resources[6]. Many reservoirs have been built for waterpower exploitation as well as for irrigating farmland[18—21].

2.2 Changes in vegetation and soil carbon

Our results (table 1 and fig. 1) suggest that due to the deforestation and economic development in northeast China, forest vegetation and soil carbon decrease 93.3 and 161.3Tg respectively during 1991—2000. This represents 88.2% and 61.7% of overall loss in vegetation (108.5 Tg) and soil carbon (261.5 Tg) in this region. Vegetation and soil carbon increased about 5.4 and 39.5Tg respectively in paddy land, but decreased about 8.3 and 47.2 Tg C respectively in dry land. Therefore, the net potential loss of vegetation and soil carbon in farmland is 2.9 and 7.7 Tg C respectively. Due to plantation, carbon in scrub and dwarf woodlands increased 7.4 and 44.5 Tg C in vegetation and soil. The total net potential loss of vegetation and soil carbon is about 95.7 and 177.5 Tg in Northeast China from 1991 to 2000, indicating that the loss of soil organic carbon could be 1.9 times that of vegetation carbon.

The conversion of forests and scrubs into agricultural and urban lands is mainly responsible for the loss in vegetation and soil carbon[25—28]. Table 1 and fig. 1 also indicate that forest and woodlands are the main components of carbon storage in terrestrial ecosystems. The destruction of forests and woodlands can result in a big loss of carbon to the atmosphere, thus forest protection and plantation are very important for carbon sequestration in land ecosystems[29].

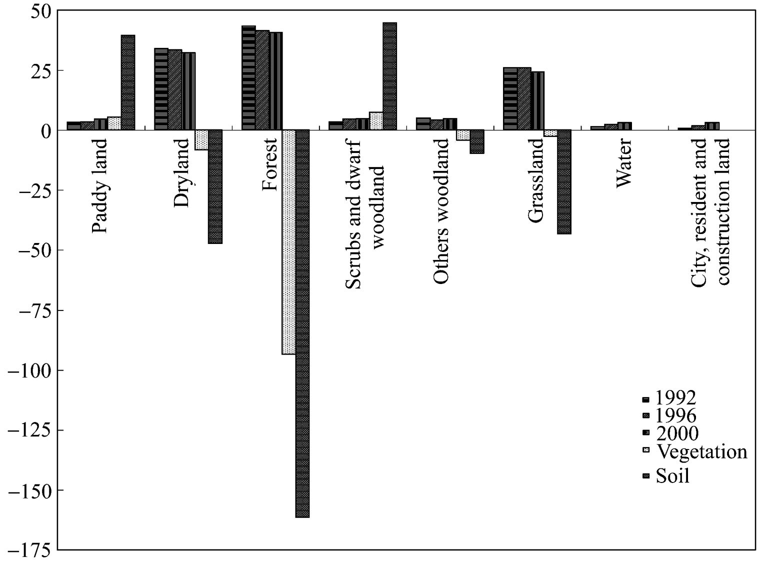

Fig. 1. Area of land cover types and changes of vegetation and soil carbon from 1992 to 2000 (Units: area (×10^4 km^2); carbon (Tg)).

2.3 Discussion

A recent review of the global carbon budget suggested that global land-use change could lead to an average release of 1.7 Pg C (10^{15}) per year to the atmosphere for the 1980s and 1990s[3, 30]. Previous analyses indicated that this amount of carbon release is primarily due to tropical deforestation[2, 31]. Terrestrial ecosystems in mid-latitudes of the Northern Hemisphere have generally acted as a sink of atmospheric CO_2[32—34]. Our analysis here suggests that land-use change in northeast China could have released as much as 273.2Tg C (27.32Tg C a^{-1}) in the period from 1991 to 2000. A recent analysis indicated that China’s forests acted as a small carbon sink of 21Tg C per year mainly due to forest expansion and regrowth from the 1970s to 1998 based on forests inventory materials[35]. China’s forests could act as a small source of carbon to the atmosphere if carbon released from land-use change in northeast China is included and the role of soil carbon sequestration of reforestation is not considered, which might offset the small carbon sink. Due to different data sources, time periods analyzed and estimation methods, there is a large room to improve our research on land uses changes and carbon sink or source in Northeast China. Carbon loss from temperate forests, 254.6Tg C, could be about 68.8% of the total carbon loss (370 Tg C) caused by land-use change (table 1 and fig. 1). Although the forest area decreased only 0.64% or 0.276×$10^4$$km^2$ per year (table 1), deforestation in this region would release more carbon to the atmosphere than the other transformation of land-use because of relatively high carbon densities in soil and vegetation in forest ecosystems.

Some primary forests, older than 200 or 300 years, still exist in the eastern and northern regions of Northeast China[6, 7], as well as meadows, swamps and wetlands, which all store largest quantities of carbon among all vegetation types reported in this study[7, 11]. The loss of any of these vegetation types will lead to large losses of carbon to the atmosphere, and therefore, protection of these ecosystems should be a high priority

The total change in farmland area was small, but the area of paddy land increased quickly at about 4.02% per year (table 1). The conversion of dryland into paddy land could result in an accumulation of soil carbon[36], but it may increase methane production, another greenhouse gas at a rate of 120 Kg $ha^{-1}a^{-1}$ in semi-arid regions to 80—200 Kg ha^{-1} a^{-1} in semi-humid regions[37]. These figures show the large potential of dry land management in northeast China for enhancing soil carbon sequestration.

For lack of data on biomass and soils, we assume that vegetation and soil carbon loses or gains are 50% and 30%, respectively, of their original carbon content when a land use change takes place. However, some studies indicate that the loss or gain of vegetation and soil carbon after land use/cover change is a slow process[26—28, 38, 39], which shows that our analyses would overestimate losses of carbon in the short term due to conversion of naturally vegetated lands into croplands (except in drylands). Moreover, the role of reforestation in fell and wastelands that can lead to carbon sequestration was not considered here. Our analyses have not included either other factors that are known to enhance carbon sequestration such as CO_2 fertilization and nitrogen deposition [3, 40—45].

Uncertainties still exist in our estimates largely due to uncertainties arising from: (i) carbon loss rates for the various types of land-cover changes[46]; (ii) quantifying carbon emissions due to complexity of the spatial patterns of vegetation and soil carbon storage in different ecosystems; (iii) fluxes of terrestrial carbon at different temporal and spatial scales[1, 13, 47]; and (iv) limited capabilities of remote sensing approaches to estimating understory biomass and other processes (e.g. soil respiration[48]). To reduce uncertainty in estimating carbon flux induced by land use, an integrated approach is required, including a combination of field studies, carbon cycle modeling, and spatial analyses with remote sensing and geographical information system.

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