Effects of land use planning on aboveground vegetation biomass in China

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Abstract Dramatic land use change is expected to take place in China in the coming decades, which will exert great impact on the vegetation biomass. The paper assesses how land use change will influence the size and spatial distribution of the vegetation biomass in China. A spatially explicit land use change model, Dyna-CLUE, is employed together with a biomass density approach to account for the effects of forest age on biomass change. Two scenarios have been developed. The first is a trend scenario where land use trends during the period 1985–1995 are extrapolated, representing the situation before implementing the national ecological restoration program. The second is a planning scenario which takes into consideration a range of land use planning measures. Possible temporal and spatial distribution of land use and vegetation biomass across China was simulated. The results indicate that under the planning scenario, vegetation biomass would be 15.47 Gt in 2030, showing an increase by 0.11 Gt compared to that in 2005. Under the trend scenario, however, the biomass would be 14.62 Gt in 2030, 0.02 Gt higher than that in 2005 due to the forest devastation and forest age effect. Seeming to be relatively trivial, the differences between the scenarios are huge in absolute terms, illustrating the impact of land use planning on biomass variation. Compared with the trend scenario, the area of planted forests under the

planning scenario will be larger and biomass density lower. Thus under the planning scenario, the vegetation biomass will be more likely to increase, acting as a carbon sink in the future.

Keywords Scenarios · Land use change · Spatial model · Landscape · Biomass density · Forest age

Introduction

Land use change is vital for environmental management due to its influence on climate change, biodiversity, livelihoods, and biogeochemical cycling (Houghton 1995; Nagasaka and Nakamura 1999; Feddema et al. 2005; Sitch et al. 2005; Falcucci et al. 2007; Rodriguez et al. 2007; Turner et al. 2007; Rockstrom et al. 2009). In China, since enormous natural resources have been appropriated, sustainable trajectories of land change are becoming increasingly important for environmental services. Thus a series of land use policies have been formulated to improve the ecological environment in China, such as the protection of cultivated land, afforestation and restoration of degraded grassland. Environmental policies and land use planning will exert great influence on land use change processes, which have effects on vegetation biomass (Houghton 1995; Houghton and Hackler 2003; Olofsson et al. 2010). So quantifying the effects of land use change on vegetation biomass is important for understanding how terrestrial ecosystems respond to global change and better estimating carbon sinks and sources (Saatchi et al. 2007; Sales et al. 2007), as well as assessing the influence of land use change on the provision of food, timber and energy (Lioubimtseva and Adams 2004; Hoogwijk et al. 2005; Gehring and Scholz 2009; Perrings et al. 2010). Therefore, biomass

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variation due to land use changes has attracted considerable interest among researchers and policy makers.

Due to the scientific and political significance, numerous studies have been conducted in different regions worldwide (Schroeder 1996; Houghton 1995, 2010; Fearnside 2000; Wang et al. 2001; Kerr et al. 2003; Houghton and Goodale 2004; Bondeau et al. 2007; Zaehle et al. 2007; Schulp et al. 2008; Zhao et al. 2009; Geoghegan et al. 2010; Cantarello et al. 2011). Land use change models applied in these studies range from simple system representations to simulation systems. The simple models include a few driving forces while the simulation systems are based on the understanding of interactions among numerous factors as well as policies. Reviews of land use models and effects of land use change on biomass have been provided by Matthews et al. (2007), Geoghegan et al. (2010), and Cantarello et al. (2011).

Although there are many studies in China on land use change (Verburg et al. 1999, 2000; Liu et al. 2003, 2010; Yue et al. 2007), vegetation biomass by carbon density methods (Fang et al. 2001; Ni 2001; Wang et al. 2001; Piao et al. 2009) and applications of biogeochemical models (Peng and Apps 1997; Cao et al. 2003; Mu et al. 2008; Tao and Zhang 2010), few spatially explicit assessments have been undertaken to assess the influence of land use change on biomass. Few studies have been published internationally to assess the effects of land use change and planning on terrestrial biomass at the scale of territorial China. One exception is the recently published study by Xu et al. (2010). However, this study estimated the overall forest carbon storage rather than the spatial distribution of biomass in China during 2000–2050 based on predicted forest area from the national forestry development planning.

This paper is to estimate the impact of national level land use planning on the spatial configuration of vegetation biomass for the period 2005–2030 in China. Two scenarios in 2030 were developed, the trend scenario and the planning scenario. The trend scenario was based on a continuation of land use change of the past several years (1995–2005), under which no spatial policies were implemented. The planning scenario was derived from a long-term land use policy, and was projected based on the national level development targets of forests, grasslands, wetlands, and other land use types. Under this scenario, land use change was excluded in restricted areas such as national parks and wildlife sanctuaries. Specific objectives were (1) to forecast on land use change in China at a high spatial resolution (2×2 km) based on two scenarios, and (2) to analyze the impact of land use change on biomass.

Then this paper presents, respectively, the method, results and discussion with respect to policy implications and other studies.

Methods

To analyze the impacts of land use change and planning on vegetation biomass, we used the Dyna-CLUE model (Verburg and Overmars 2009) to downscale land use changes from macro-level to landscape. A carbon density method was applied to assess the future spatial pattern of carbon biomass based on predicted land use change. To evaluate the costs of inaction, the results of a scenario that accounts for land use planning and policy were compared to a trend scenario that projects the recent trends of changes in land cover.

Land use types

Land use maps of China for 1985, 1995, 2000, 2005 are produced by the Chinese Academy of Sciences through human–machine interactive interpretation based on the Landsat TM (Thematic Mapper) data (Liu et al. 2003). The original land use classes derived from these land use maps are classified into 25 land use categories. Considering the methods and available information, it is necessary to aggregate the original land cover type into seven main classes. The seven classes include: (1) built-up land, (2) cultivated land, (3) grassland, (4) shrub, (5) forest, (6) water area, and (7) other land use types including bare land, rocky areas, glaciers and wasted land. The principles of classification are described in Table 1.

Scenarios to 2030

Two scenarios of land use change at the national level for the period 2005–2030 have been developed: a trend scenario is developed based on the extrapolation of land use trends for the period 1985–1995, just before implementing the national ecological restoration program. A planning scenario is projected using a set of land use policies. Due to population pressure, the area of cultivated land is critical to ensure food security in China. According to the Development Plan Outline for Medium and Long-Term Food Security of China, the area of cultivated land in 2020 should be no less than 1.2 million square kilometers. Since forests play an important role in carbon pools of the terrestrial ecosystem as well as environmental protection, the Sustainable Development Strategy of Chinese forestry sets a goal to increase the forest coverage from 16.3 % of the total territory in 2005 to 17.5 % by 2010, 20.1 % by 2020 and 21.3 % by 2030. As for grassland, the National Program of Grassland Conservation and Development aims to widely restore the desertified grassland, alkali-saline grassland and degraded grassland. It is predicted that in 2030 the grassland area would be equal that area in the 1980s. In 2010, urbanization area in China accounted for

Table 1 Land use classes and variables used to explain the spatial distribution of land use

Variable	Description
Land use types	
Built- up land	Land for cities and town, industrial, transportation and residential quarters in rural areas
Cultivated land	Include irrigated and non-irrigated land
Grassland	Grassland with a ground-coverage higher than 5 %
Shrub	Shrubs and forest with crown density between 10 and 30 %
Forest	Natural forest and plantations with crown density higher than 30 %
Water area	Natural water area and water resources facilities
Others	Desert, Gobi, bare ground, bare rock and the rest of unused lands
Driving factors	
Population	Population density (persons km ⁻²)
GDP	Gross regional domestic product (ten thousand yuan)
Accessibility	Distance to nearest main road (km)
Sunshine	Average percentage of sunshine (%)
Precipitation	Total precipitation (mm year ⁻¹)
Temperature	Average temperature (°C month ⁻¹)
DEM	Height (m)
Slope	Slope (derived from DEM, in degrees)
Aspect _i _{index}	The influence factor of aspect on precipitation
Soil PH	Topsoil pH (0–20 cm)
Soil texture	Soil texture class (coarse, medium, fine)
Soil depth	Soil depth class (shallow soil: ≥30 cm; deep soil: <30 cm)
Soil drainage	Soil drainage class (well, poor)
SOC	Soil organic carbon

47 %, much lower than that in developed countries. Therefore, the urbanization process will continue in China. It is assumed that the built-up area will continue to grow at the same rate as before to meet the national economic and social development targets. Under the planning scenario, the national level land use areas for each type in the coming 30 years are defined based on the above-mentioned information. The characteristics of the two scenarios are summarized in Table 2.

Spatial land use change modeling

The national land use changes mentioned above are spatially allocated using the Dyna-CLUE model based on dynamic simulation of competition between land uses (Verburg and Overmars 2009). The spatial allocation rules are determined by integrating into account empirical analysis, user-specified decision rules, and neighborhood

Table 2 Characteristics of land demand scenarios in 2030

	Scenario 1: trend	Scenario 2: planning
Cultivated land target	Based on trends: 20.3 %	19.0 %
Forest target	17.6 % (annual loss follows trend of 0.005 % annual loss)	21.3 %
Grassland target	Based on trends: 29.2 %	31.7 %
Other land use claims	Based on trends: shrub land (0.07 %), water area (0.03 %)	Shrub land (0.06 %). Water area was assumed to remain unchanged
Spatial policies	No spatial policies implemented	Restriction (no land use change) within natural reserves

characteristics. A detailed description of the Dyna-CLUE model is given by Verburg and Overmars (2009). The actual allocation accounts for constraints defined by the model user based on the processes and constraints relevant to the scenarios and land use types (Verburg et al. 2006a). The parameterization is central to the simulation since simulation results will depend on different input and variable settings interpreted from the scenario storylines. The settings and data inputs can be grouped into four categories: location suitability, land requirements, land use type-specific conversion rules and designated areas (Fig. 1).

The location suitability exerts huge impact on the competitive advantage of the different land use types at a specific location. It is based on the relations between land use distribution, climatic and geophysical features (including soil properties) and socioeconomic characteristics. In addition, neighborhood effect also influences the location suitability. In this study, the location driving factors include demographic, soil-related, geomorphologic and climate variables, which are potential determinants of the spatial pattern of land use as listed in Table 2. All data sets were converted into the equal area projection. The grid size is 2 × 2 km (4 km²). Logistic regression was used to correlate land use patterns with the driving factors.

The requirements for land use types determine the total area of corresponding type at the national level specified in the scenario. These requirements determine the overall competitive power of land use types since all the types are simulated synchronously. The demands for land by different land use types are based on an extrapolation of trend in the trend scenario, while in the planning scenario, the land requirements are based on the land use policies as described above.

Since land use types have distinctive features that can influence conversion behavior, each land use type is characterized by a set of conversion rules and conversion

elasticity. In this study, parameterization of the conversion rules and conversion elasticity for each land use type is calibrated based upon experts' judgment and the information of specific conversion processes. For example, conversion of cultivated land into shrub land is scheduled after 3 years of fallow given the time for re-growth of shrubby vegetation. Unrealistic conversions are excluded (Table 3). The conversion elasticity implies the reversibility of land use change, which ensures the influence of current land use pattern on the future pattern (McConnell et al. 2004). The values of the conversion elasticity range from 0 (easy conversion) to 1 (irreversible change). In this study, conversion elasticity values for built-up land, cultivated land, grassland, shrub, forest, water area, etc., are set to be 1, 0.7, 0.6, 0.5, 0.9, 1 and 0.3, respectively.

Spatial policies restrict certain land use changes in designated areas. In this study, the conversion from

grassland, shrub, and forest to built-up and cultivated land is prohibited in the nature reserve areas, meaning that people cannot disturb the ecosystem in preservation zones by land use conversions.

After the specification of the parameters in the Dyna-CLUE model according to scenario situations, the required areas of different land use types are allocated synchronously in an iterative procedure.

Validation method

Validation of the Dyna-CLUE model is possible for historical land use changes when the land use pattern is known for two time points with several years in between. For China, distribution data for land uses are available for 1985 and 2005. Simulated land use distribution in 2005 was compared with the observed data in 2005. Kappa statistics were used to validate allocation algorithm and evaluate the relationships between land use types and the driving factors using the methods by Pontius (2000). Since the land requirements are derived from interpolated aggregate area changes between 1985 and 2005 using the observed data, only the correctness of spatial allocation has been validated.

Biomass calculation

Distribution of aboveground biomass in China was projected with a common density method based on future land use spatial pattern and province-specific biomass densities. In China, province-specific biomass densities are available for grassland, shrub and forest (Fang et al. 1996, 1998; Piao et al. 2007). The biomass for cultivated land is calculated based on yield data from the China Rural Statistical Yearbook and the relationship between yield and biomass for each staple crop. In large scale studies, it is difficult to find sufficiently detailed input information and avoid aggregation (Verburg et al. 2006b), so it is assumed that the biomass densities of grassland and cultivated land are constant during the 25-year simulation period. Forest biomass density varies with forest age (Nabuurs 2001;

Fig. 1 Schematic representation of the calculation approach

Table 3 Land cover conversion matrix indicating the possible conversions outside of the natural reserves

A value of 1 indicates that the conversion is allowed, a value of 0 indicates that the conversion is not allowed. 100 + n indicates autonomous conversion will occur after n years

	Land cover ($t + 1$)					
	Built-up land	Cultivated land	Grassland	Shrub	Forest	Water area
Land cover (t)						
Built-up land	1	0	0	0	0	0
Cultivated land	1	1	1	103	0	1
Grassland	1	1	1	102	0	1
Shrub	1	1	1	1	1	1
Forest	1	1	1	0	0	0
Water area	0	0	0	0	0	1

Table 4 The regression models and the ROC values

Land use type	Regression model	ROC
Built-up land	$p = \frac{\exp(0.96 - 0.121 \times \text{slope} - 0.071 \times \text{altitude} + 0.15 \times \text{drainage}_{\text{low}} + 0.006 \times \text{temp} + 0.16 \times \text{GDP} - 0.8 \times \text{dist} + 0.156 \times \text{pop})}{1 - \exp(0.96 - 0.121 \times \text{slope} - 0.071 \times \text{altitude} + 0.15 \times \text{drainage}_{\text{low}} + 0.006 \times \text{temp} + 0.16 \times \text{GDP} - 0.8 \times \text{dist} + 0.156 \times \text{pop})}$	0.98
Cultivated land	$p = \frac{\exp(3.73 - 0.062 \times \text{altitude} - 0.49 \times \text{soil}_c - 0.75 \times \text{soil}_{\text{sm}} + 0.02 \times \text{PH} - 0.58 \times \text{drainage}_{\text{low}} - 0.32 \times \text{GDP} - 2.1 \times \text{dist} + 1.72 \times \text{pop})}{1 - \exp(3.73 - 0.062 \times \text{altitude} - 0.49 \times \text{soil}_c - 0.75 \times \text{soil}_{\text{sm}} + 0.02 \times \text{PH} - 0.58 \times \text{drainage}_{\text{low}} - 0.32 \times \text{GDP} - 2.1 \times \text{dist} + 1.72 \times \text{pop})}$	0.92
Grassland	$p = \frac{\exp(-2.81 + 0.055 \times \text{altitude} + 1.06 \times \text{soil}_t - 0.19 \times \text{soil}_{\text{sm}} + 0.097 \times \text{SOC} - 0.003 \times \text{temp} - 0.5 \times \text{prec} - 0.29 \times \text{pop})}{1 - \exp(-2.81 + 0.055 \times \text{altitude} + 1.06 \times \text{soil}_t - 0.19 \times \text{soil}_{\text{sm}} + 0.097 \times \text{SOC} - 0.003 \times \text{temp} - 0.5 \times \text{prec} - 0.29 \times \text{pop})}$	0.81
Shrub land	$p = \frac{\exp(0.41 + 0.04 \times \text{slope} - 0.56 \times \text{soil}_{\text{sm}} + 0.004 \times \text{temp} + 1.16 \times \text{prec} - 0.39 \times \text{radiation} - 0.038 \times \text{GDP} - 0.27 \times \text{dist} - 0.19 \times \text{pop})}{1 - \exp(0.41 + 0.04 \times \text{slope} - 0.56 \times \text{soil}_{\text{sm}} + 0.004 \times \text{temp} + 1.16 \times \text{prec} - 0.39 \times \text{radiation} - 0.038 \times \text{GDP} - 0.27 \times \text{dist} - 0.19 \times \text{pop})}$	0.82
Forest	$p = \frac{\exp(-0.95 + 0.14 \times \text{slope} - 0.088 \times \text{altitude} - 1.05 \times \text{soil}_{\text{sm}} + 0.21 \times \text{SOC} + 3.20 \times \text{prec} + 0.17 \times \text{dist} - 0.45 \times \text{pop})}{1 - \exp(-0.95 + 0.14 \times \text{slope} - 0.088 \times \text{altitude} - 1.05 \times \text{soil}_{\text{sm}} + 0.21 \times \text{SOC} + 3.20 \times \text{prec} + 0.17 \times \text{dist} - 0.45 \times \text{pop})}$	0.91
Water area	$p = \frac{\exp(1.51 - 0.016 \times \text{altitude} + 1.21 \times \text{drainage}_{\text{high}} + 1.45 \times \text{prec} - 0.07 \times \text{dist} - 0.11 \times \text{pop})}{1 - \exp(1.51 - 0.016 \times \text{altitude} + 1.21 \times \text{drainage}_{\text{high}} + 1.45 \times \text{prec} - 0.07 \times \text{dist} - 0.11 \times \text{pop})}$	0.86

In the models, $\text{drainage}_{\text{low}}$ soil drainage is low, $\text{drainage}_{\text{high}}$ soil drainage is high, temp temperature, prec precipitation, dist the distance to the main road, pop population, soil_c soil texture is coarse, soil_{sm} shallow and medium soil (≤ 30 cm), SOC soil organic carbon

Pussinen 2001). Therefore, carbon densities are modified by age based on the empirical relations between forest age and biomass carbon stock. The default forest biomass stock density is calculated through province-specific biomass density and corresponding forest age. The forest age in 2005 was derived from China's national forest inventory data during 2004–2008. Forest ages in the future are based on the results of the land use model that tracks the year of forest establishment or deforestation. In forest areas, plots are frequently clear-cut, die-off or replanted, so it is assumed that the average forest age increases by 2 years per 10 years and the age of a new forest by 1 year per 2 years (Nabuurs et al. 2007).

Results

Land use change results

The simulated and observed land use patterns of 2005 are compared using Kappa statistics to validate the performance of the model. The Kappa coefficient for location is 0.85, indicating that the model can specify the location very well.

In general, regression models of land use types and geomorphologic, soil, climatic and socioeconomic variables could well explain the current land use distribution, with the receiver operating characteristic (ROC) values ranging between 0.81 and 0.98. The results of regression models and ROC values are shown in Table 4. The results indicate that spatial determinants selected area that could explain a large part of the current distribution of land use types. The probability maps derived from the logistic regression results are presented in Fig. 2, coinciding with natural environment and socioeconomic conditions in China.

Simulation results of land use change under trend scenario and planning scenario are presented in Fig. 3. For the

major land use types, the aggregated areas are calculated (Table 1). In the trend scenario, the area of grassland continued to decrease. Grasslands are mainly transformed into cultivated land in eastern China, into shrub land in the south of China and degraded into desert in northwestern China. In the planning scenario, the deterioration of grasslands is prevented and the government will take measures to contain the degradation, aridity and salinization of the grasslands. As a result, grassland deteriorated in the past two decades will be restored in western and northern China (Fig. 4). Under both scenarios, built-up land area would increase with the development of the economy and the society. The expansion of built-up land mainly occurred in the eastern and central China. Cultivated area is expected to shrink under both scenarios, but the converting rate is lower under the planning scenario due to government policies to ensure food security. In late 20th century, the loss of cultivated land accelerated along with agriculture adjustment, ecological returning to forest, construction projects and natural disasters. In recent years, food supply and demand imbalances were aggregated by global population growth, scarce cultivated land and water resources and global climate change. Therefore, the state starts to protect the cultivated land to safeguard food security. In the trend scenario, the forest would decrease at many locations, especially in southwestern and northeastern China. In the planning scenario, however, forest coverage would increase from 16.3 to 21.3 %. The simulated hotspots of forest increase are presented in Fig. 4.

Future biomass distribution

In China, the built-up land, with a low biomass density, accounts for only 0.7 percent of the total land area. Thus the biomass of built-up land is not considered due to its small amount. It is assumed that the biomass of cultivated land, grassland, shrub and forest consists the total biomass

Fig. 2 Probability maps for cultivated land (a), grassland (b), shrub (c) and forest (d) in China

of China. The biomass of other land use types, including desert, Gobi, bare ground, bare rock and so on, is also neglected due to the low biomass density. Under the trend scenario, the total biomass would decrease from 14.37 Pg in 2005 to 14.29 Pg in 2015 due to continuous forest exploration, grassland deterioration and the conversion from cultivated land to built-up land. The overall biomass in 2020 and 2030, however, is larger than that in 2005 because the effects of the shrinking forest area would in part be offset by the effects of the increasing average forest age (Table 5). In 2030, the planning scenario witnesses 7.66 % increase in biomass (1,100 Tg) than in 2005, thanks to the afforestation and restoration of grassland. The biomass in the planning scenario is higher than that in the trend scenario by 0.35, 0.37 and 0.85 Pg in 2015, 2020 and 2030, respectively. In addition, in the planning scenario, the area of planted forests is larger and biomass density is lower than that in trend scenario (Table 5). Thus in the planning scenario, the vegetation is more likely to become a carbon sink due to high potential of biomass increase.

Figure 5 shows the size and distribution of aboveground biomass in 2005 and 2030 in two scenarios. Biomass results are aggregated to six regions in China. The spatial variability in biomass is considerable because of the topographic complexity and climatic variability. In 2005, the biomass in the southwestern region (e.g., Tibet, Yunnan, Guangxi, Guizhou, Sichuan and Chongqing provinces) was highest, followed by the northeastern region (including Heilongjiang, Jilin and Liaoning provinces). Over half total biomass was stocked in these two regions. The south central region (including Guangdong, Guangxi, Hainan, Henan, Hubei and Hunan provinces), eastern region (including Anhui, Fujian, Jiangsu, Jiangxi, Shandong, Shanghai and Zhejiang provinces), northern region (including Beijing, Hebei, Inner Mongolia, Shanxi and Tianjin provinces), and northwestern region (including Gansu, Ningxia, Qinghai, Shannxi and Xinjiang) together account for about 40 % of the total biomass. This coincides with the natural and social environment in China, with large forest area in northeastern and southwestern regions, high population density in eastern and south

Fig. 3 Land use map in **a** 2005, **b** 2030 of planning scenario and **c** 2030 of trend scenario

Fig. 4 Identification of hotspots of expansion of grassland and forest and contraction of cultivated land in the planning scenario

central regions and low rainfall in northern and northwestern regions. The regional distribution does not change in 2030 in either of the scenarios. Biomass variation, however, takes place in all regions. For example, under the planning scenario, biomass in all regions increases as a result of afforestation and grassland restoration. Under the trend scenario, biomass of northwestern region and southwestern region decreases due to deterioration of natural ecosystems. In eastern and south central regions, forest is characterized by young age; therefore, the biomass in these two regions increases with the growth of forest age.

Discussion

In this paper, national-scale scenarios of land use change are downscaled to land use patterns with spatial resolution of 2×2 km, and the impacts of land use changes on the biomass are estimated. National scale policies and land use planning are linked with the impact at regional, local and landscape levels, which helps identify priority areas and test the consequences of land use policies and planning. The method can also be used to explore the distribution of land use change and biomass for alternative development pathways. Furthermore, similar assessments are possible for other ecological and social indicators. For example, biodiversity assessment is feasible based on the landscape structure. Such studies have been carried out in Europe (Schroter et al. 2005; Schulp et al. 2008; Hellmann and Verburg 2010) based on consolidated land use modeling results. This study provides such an analysis in China.

The validation of land use simulations indicates that the Dyna-CLUE model can well capture the land use dynamics. Although the validation is possible only for historical

Table 5 Total area and aboveground biomass of each land use type for four periods from 2005 to 2030 in the two scenarios

Year	Cultivated land		Grassland		Shrub		Forest			Total
	Area (km ²)	Biomass (Tg)	Area (km ²)	Biomass (Tg)	Area (km ²)	Biomass (Tg)	Area (km ²)	Density (kg/m ²)	Biomass (Tg)	Biomass (Tg)
Trend scenario										
2005	1,836,008	1,650.26	2,897,348	231.88	812,160	1,472.10	1,539,436	7.15	11,014.36	14,368.60
2015	1,799,080	1,621.87	2,855,612	224.54	858,768	1,418.11	1,513,552	7.29	11,030.43	14,294.94
2020	1,780,760	1,607.43	2,834,896	221.64	881,544	1,624.02	1,500,024	7.36	11,046.93	14,500.02
2030	1,737,584	1,576.99	2,791,400	216.07	921,748	1,708.96	1,453,164	7.65	11,117.76	14,619.79
Planning scenario										
2015	1,792,256	1,618.95	2,937,312	233.54	735,796	1,366.23	1,727,108	6.61	11,423.6	14,642.31
2020	1,792,344	1,618.88	2,957,680	234.87	699,176	1,297.74	1,852,364	6.33	11,717.89	14,869.38
2030	1,791,592	1,617.69	2,998,456	238.12	625,684	1,165.79	2,022,992	6.15	12,447.04	15,468.64

land use changes, it still indicates the validity of down-scaling procedure and allocation algorithm in the model.

However, there are some limitations in our study. First, the changes of climatic and socioeconomic factors are not considered due to their trivial effects over the timeframe and data availability. In reality, some changes are expected under both scenarios. This assumption might introduce some deviation in the results. Nevertheless, we assume that this deviation would be trivial when extrapolating a climatic and socioeconomic condition for 2030. Second, in line with many previous studies (Milne and Brown 1997; Eaton et al. 2008; Cantarello et al. 2011), the built-up land, water area and other land use types (including the desert, Gobi, bare ground, bare rock and nival area), were assumed to have zero biomass. The biomass density for these land use types is unavailable. As the biomass density of these land use types are negligibly small, they should have little influence on the overall biomass. On the other hand, urban growth that took place at the expense of forest land could affect the biomass significantly, and the effect can be seen from the results of this study. Third, biomass densities for forests are modified by forest age. As for grassland, shrub and cultivated land, however, their biomass densities are assumed constant in the next 25 years, which is not entirely accurate. In addition, we use province-specific biomass density for each land use type from authoritative published sources (Fang et al. 1996, 1998; Piao et al. 2007). However, biomass densities are not only province specific and land use type specific, but also influenced by other features, such as sunshine, soil texture, soil fertility. The detailed information, however, is lacking for each pixel. Due to such uncertainties, the results should be treated as explorations of the possible patterns of land use change and biomass rather than the forecasts for future events.

Several studies have been carried out to estimate historical and future biomass at the national scale in China. Fang et al. (2001) estimated forest biomass from 1949 to

1998 for China, using the biomass expansion factor of forest and a 50-year national forest resource inventory in China. Then Piao et al. (2009) calculated forest biomass from 1999 to 2003 using the same method. The canopy coverage to define forest, however, was changed to >20 % in the estimation of forest biomass between 1999 and 2003. In this study and the one by Fang et al. (2001), the forest means natural and planted forest with >30 % canopy cover. In their studies, biomass was converted to carbon content using a factor of 0.5 in line with the IPCC approach; so the results to biomass were recalculated by multiplying 2. The trend of forest biomass of China is presented in Fig. 6, listing the results of Fang et al. (2001), Piao et al. (2009) and this study. In view of this, our results are reasonable under the investigative background.

Xu et al. (2010) predicted the biomass carbon stocks in forest in China from 2000 to 2050. The relationship between forest biomass density and forest age for major forest types has been investigated based on China's national forest resource inventory data and direct field measurements. Future forests area changes were derived from the national forestry development plan. Xu et al. (2010) modeled total forest biomass of 21.67 Gt using the statistical approaches for 2030. The result in Xu et al. (2010) is larger than that in our study (12.45 Gt under planning scenario and 11.12 Gt under trend scenario in 2030). The difference might be attributed to two reasons. First, forest is defined with >20 % canopy coverage in Xu et al. (2010) while in our study it is >30 % canopy coverage (Zheng et al. 2012). Second, Xu et al. (2010) assumed that neither clear-cuts nor dies-offs would occur. However, the cuts and die-offs were considered by assuming that the forest age increases by 2 years per 10 years and the age of a new forest by 1 year per 2 years (Nabuurs et al. 2007). Spatial pattern of biomass could not be compared because Xu et al. (2010) only estimated the total biomass carbon stocks in the forests in China.

Fig. 5 Spatial pattern of aboveground biomass in China in **a** 2005, **b** 2030 in trend scenario and **c** 2030 in planning scenario

Fig. 6 Biomass for forest from 1949 to 2030 in China. (the data from 1949 to 1998 are derived from Fang et al. 2001; the data for 1999 to 2003 are derived from Piao et al. 2009; the data from 2005 to 2030 are from this study)

Tao and Zhang (2010) simulated the vegetation carbon storage across China based on calibrated Lund–Potsdam–Jena dynamic global vegetation model under four IPCC SRES emission scenarios. The overall vegetation carbon storage in 2030 by Tao and Zhang (2010) is estimated to be around 58 Gt, much larger than that in our study. It would be difficult to interpret the difference, since the studies differed in many respects, such as classification principle of land use, scenarios, assumption, time span as well as resolution. However, the spatial pattern of vegetation carbon storage in Tao and Zhang (2010) corresponds to the results in our study.

To sum up, comparison of different studies on future biomass in China can only be done in general terms due to differences in scenarios, research object, assumptions, methods and research field. Studies using the same scenarios and land use type classification in different simulation methods should be performed to better compare the results.

Conclusion

This study explores the spatial pattern of land use and vegetation biomass in the future under different land use pathways. It is the nationwide estimation of biomass changes in China, fully accounting for land use changes. The method can contribute to multi-scale assessment of future biomass under a wide range of land use types. Vegetation biomass can be expected to increase due to afforestation and restoration of grassland under the planning scenario. Under the trend scenario, the decrease in biomass due to shrinking forest and grassland could be partially offset by the increase in average forest age.

In southern China, the forests are, on average, relatively young. Compared with the trend scenario, large areas of planted forest in the planning scenario in 2030 are featured with younger age and lower biomass density. Since young forest has a high potential to increase the biomass, it can become a carbon sink. Carbon sequestration in biomass change would regulate the atmospheric carbon dioxide and exert an impact on climate change. The simulated spatiotemporal dynamic of biomass distribution is useful for understanding the climate change caused by CO₂ emissions. Under the planning scenario, the increase in vegetation biomass could help contain the global warming. To assess the global warming containment effects, however, other aspects should also be considered, such as species composition and distribution, phenology and so on. In summary, despite some uncertainties, the spatially explicit analytical methods in this study can facilitate policy makers and scientists to evaluate impacts of national-scale land use policies on landscape, identify critical regions and places for biomass change and develop sound regional-scale policies and planning.

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