

# Forest carbon research in Inner Mongolia: current knowledge, opportunity and challenge

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**Abstract.** Carbon storage in forests in Inner Mongolia Autonomous Region plays a significant role in the terrestrial carbon budget due to its largest forest coverage and forest growing stock among all the provinces in China. Nevertheless, scientific research on forest carbon is comparatively less as compared with the research on the main ecosystem, steppe in this area. We are still short of knowledge of forest carbon sequestration's rate, mechanism and potential in the area. Now we are conducting a research program aiming at making clear the above scientific issues. So knowing well previous research work and key findings is essential and helpful for our underway study. In this paper we reviewed the current knowledge, opportunity and challenges of forest carbon research in Inner Mongolia. The total carbon storage in forest of this region increased significantly from 0.417Pg carbon in 1949 to 0.719Pg carbon in 2008 with an annual increase of 2.842Tg~5.226Tg carbon and a dramatically increment of carbon storage in shrub. Carbon storage varied with dominant tree species, forest age and forest growth situation with an average forest carbon density of 42.68 t-C·hm<sup>-2</sup>, displaying a downtrend before 1980 and later a slow smooth uptrend. It is suggested that increase in vegetation carbon sequestration potential be achieved through selection of plant species and forest management.

## 1. Introduction

Carbon dioxide (CO<sub>2</sub>) is one of major greenhouse gases which are considered to contribute to human-induced global warming, and its concentration in the atmosphere has been increasing steadily since its initial observation at Mauna Loa, Hawaii in 1958 [1-3]. Forests play a significant role in global carbon cycle through photosynthesis fixing and storing CO<sub>2</sub> and respiration emitting CO<sub>2</sub> [4], as well meeting social needs of wood products, fiber, energy and other ecosystem services, such as tourism, biodiversity and water conservation et al [5]. Research on forest as carbon sinks has attracted more and more attention since the signature of United Nations Framework Convention of Climate Change (UNFCCC) and the Kyoto Protocol aiming at reducing the emission and mitigating climate change [4,6]. It is believed that afforestation, reforestation and forest management activities can enhance carbon sequestration from the atmosphere and thus contribute to the balance of carbon budget and the mitigation of climate change [4].



China's forest area and forest growing stock rank respectively fourth and fifth in the world, and can contribute significantly to global terrestrial carbon sinks [7]. In the last decades, China has been persevering in conducting large-scale afforestation and reforestation [8,9] as well forest conservation [10,11], and has scored tremendous achievements in forestry construction, with its forest area reaching  $1.95 \times 10^8$  ha (20.36% of total land area of China) and forest growing stock expanding to  $149.13 \times 10^8$  m<sup>3</sup> by 2008.

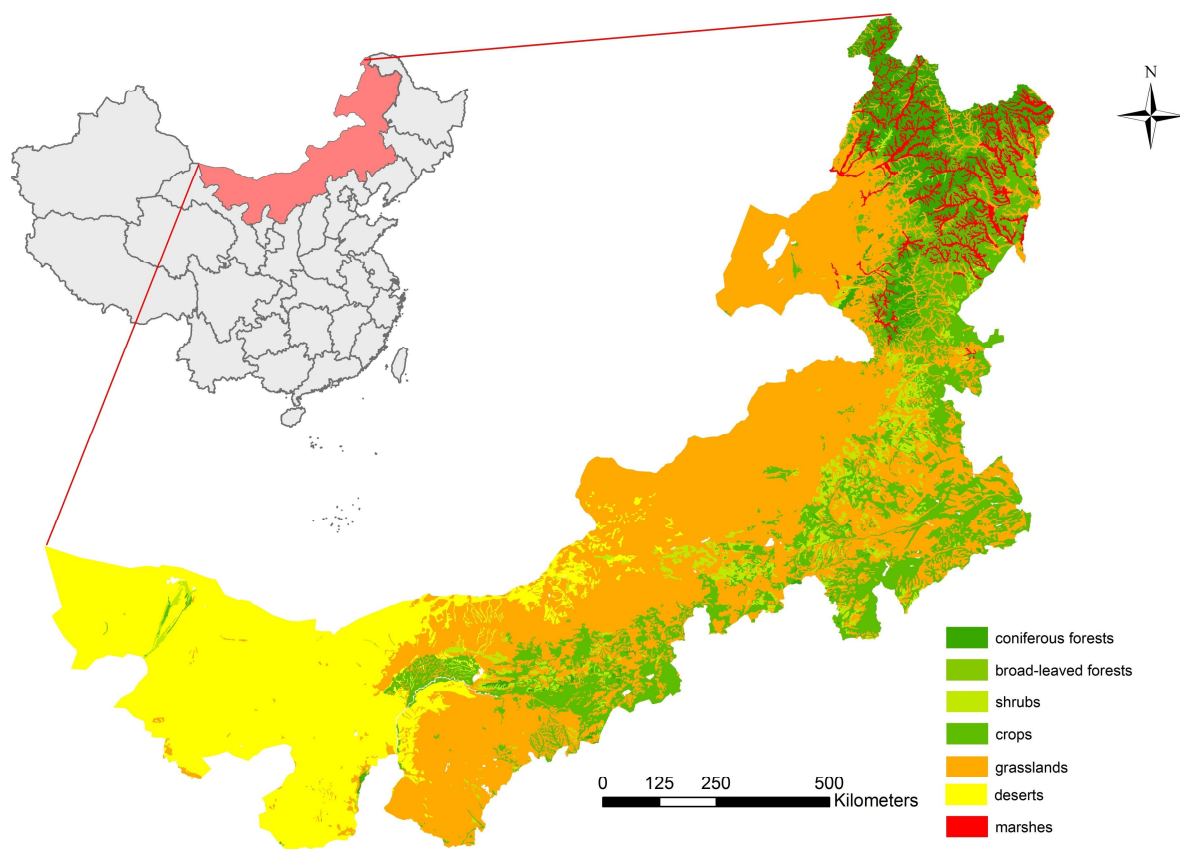
Inner Mongolia Autonomous Region (short form: Inner Mongolia), located in the north of China and extending from 37°24'N to 53°23'N in the latitude and from 97°12'E to 126°04' E in the longitude, is the third largest province in area in China with its land area over  $1.18 \times 10^8$  ha [12] (Figure 1). It belongs to temperate continental monsoon climate (transitional climate from monsoon to continental climate having both monsoon and continental climate character) with a sharp rainfall gradient from 50 mm in the west to 450 mm in the northeast, while evaporation capacity in most area of this region is more than 1200 mm. Most of the rainfall occurs from May to September, coinciding with high temperature in summer season. As a transition zone, Inner Mongolia is characterized by diverse ecosystems, including vast forests and agricultural lands, the world's largest temperate grasslands and extensive sandy lands and deserts [13].

Inner Mongolia preserves rich forest resources with its total forest area and living forest stock volume amounting to over  $23.66 \times 10^6$  ha and  $13.6 \times 10^8$  m<sup>3</sup>, respectively, ranking first among all the provinces in China. Forest vegetation in the region is predominated by larch, Mongolian Scotch pine, Chinese pine, spruce, Chinese arborvitae, birch, oak, linden, elm, poplar, willow, et al. and is mainly distributed in the mountain regions of Greater Khingan Mountains, north of Yan mountains, Yinshan mountains and Helan Mountains (Figure 1).

Forests in Inner Mongolia also have tremendous carbon storage mainly due to their vast forest area and living wood stock volume, though their coverage and carbon density lag behind many other provinces in China. Thus, as a whole, they play a significant role in Chinese terrestrial ecosystem carbon cycle and in turn play an important role in the global carbon cycle.

As a climate transition zone with a sandy physiognomy, this region is highly sensitive to natural variations and anthropogenic changes. Thus, massive man-made forests are established in this region in order to prevent desertification, fix sands and improve fragile and vulnerable ecosystems. The very famous six key national forestry programs (i.e., the Three Norths Shelter Forest System Project, the Grain for Green Project, the Natural Forest Conservation Program, the Wildlife Protection and Nature Reserve Development Program, the Beijing Neighboring Area Sand-Control Project, the Fast-growing and High-yield Plantation Construction Program) all cover this region and it is the only region among all the provinces which benefits from all of the above programs. As a consequence, large-scale afforestation and reforestation and natural forest conservation since 1978 have resulted in massive forest reserves and huge carbon storage with great contribution to carbon sequestration.

Though forests in Inner Mongolia have great contribution to balancing the carbon cycle acting as carbon sinks, so far we are not quite clear the carbon sequestration's rate, mechanism and potential of these forests. We are now conducting a research program to figure out the above unsolved issues. Understanding current situation of forest carbon research in this region is essential and important and will lay a necessary foundation and be a good beginning for our subsequent research to make clear the rate, mechanism, potential of the forest carbon sequestration and then present scientific, efficient and feasible forest management strategies to enhance the carbon sequestration. In this paper we reviewed the current knowledge of forest carbon research in this region, including research approaches, forest carbon storage, forest carbon storage change in terms of different dominant species and different forest age. Finally, we discussed existing problems at present and which issues we should pay close attention to in our future research [14].



**Figure 1.** Location of Inner Mongolia and its vegetation

## 2. Current knowledge of forest carbon research

Forest carbon storage is related to forest area, species and forest resource quality. As a major province with vast forest reserves, carbon storage of forest in Inner Mongolia and its change will exert a great influence on China's forest carbon storage and carbon sequestration capacity [15]. Fang et al. presented an improved method with BEF (biomass expansion factor) and estimated the forest biomass carbon storage and its change of whole China's forest, based on National Forest Resource Inventory databases [6]. By use of this method and on Inner Mongolia's forest inventory data, Yan et al. [15, 16] estimated Inner Mongolia's forest biomass carbon storage. The sixth Inner Mongolian forest inventory (1999~2003) reported that the total area and the living wood stock volume of the forest in Inner Mongolia are  $23.66 \times 10^6$  and  $13.6 \times 10^8 \text{ m}^3$ , respectively. Yan et al.'s research showed the carbon storage of dominant tree species in Inner Mongolia was  $6.4281 \times 10^8$  tons and living biomass carbon amounted to  $7.4305 \times 10^8$  tons, with the conversion coefficient (volume to biomass) being 0.87.

### 2.1. Forest carbon storage in dominant species

Mean forest biomass carbon density of the different dominant species in Inner Mongolia is  $28.72 \text{ t-C ha}^{-1}$  with large variation. Among them, the broad-leaved mixed forest has the largest capacity of carbon sequestration with its biomass carbon density of  $80.98 \text{ t-C ha}^{-1}$ , the second is Mongolia Scotch pine with the biomass carbon density of  $67.44 \text{ t-C ha}^{-1}$ , and the third is white birch with biomass carbon density of  $49.13 \text{ t-C ha}^{-1}$ . The dominant species with its biomass carbon density exceeding  $40 \text{ t-C ha}^{-1}$  are as follows: broad-leaved mixed forest ( $80.98 \text{ t-C ha}^{-1}$ ), Mongolia Scotch pine ( $67.44 \text{ t-C ha}^{-1}$ ), white birch ( $49.13 \text{ t-C ha}^{-1}$ ), spruce ( $45.16 \text{ t-C ha}^{-1}$ ), larch ( $44.69 \text{ t-C ha}^{-1}$ ), coniferous and broad-leaved mixed forest ( $44.15 \text{ t-C ha}^{-1}$ ), oak ( $40.37 \text{ t-C ha}^{-1}$ ) (Table 1).

The comparison of the dominant species biomass carbon density displays that planting broad-leaved mixed forest, Mongolia Scotch pine, larch and coniferous and broad-leaved mixed forest in appropriate sites and reinforcing forest management is profitable for boosting the carbon sequestration [15, 16].

**Table 1.** Main dominant species in Inner Mongolia and their occupied area, forest biomass carbon density and forest carbon storage.

Dominant species	Area (ha)	Carbon density (t-C ha <sup>-1</sup> )	Carbon stock (t-C)
Spruce	26400	45.16	1192200
Larch	4977300	44.69	222452100
Mongolian Scotch pine	283600	67.44	19124800
Chinese pine	237400	12.19	2893100
Chinese arborvitae	19800	24.11	477400
Quercus robur	216800	40.37	8752100
Oak	1866100	19.40	36193100
Birch	89100	22.74	2026400
White birch	4688400	49.13	230329600
Mongolian birch	758500	35.22	26714000
Elm	309900	7.33	2270100
Locust tree	6600	7.78	51300
Malus baccata	13200	5.70	75300
Poplar	2047400	21.40	43813200
Willow	151800	21.74	3299800
Other kinds of soft broad-leaved trees	12900	11.07	142900
Aspen	929300	38.98	36225400
Diversiform-leaved popular	6600	12.92	85300
Alder	52700	14.95	788000
Linden	6600	4.36	28700
Broad-leaved mixed forest	33000	80.98	2672200
Coniferous and broad-leaved mixed forest	72600	44.15	3205200
Summary	16806000		642812100

## 2.2. Carbon storage in different forest age groups

Forest age is a key indicator to show forest structure and growth potential. A sound forest ecosystem with rational age structure can function well and further for itself sustainable development.

In Inner Mongolia forest inventory data, forests were clustered into five forest age groups, young-aged forest, mid-aged forest, premature forest, mature forest and over-mature forest. Forest area, per unit volume, carbon density and storage of each forest age groups are showed in Table 2. Wood stock volume and carbon density increased with the forest age (Table 2). The middle-aged forest group preserved the largest carbon storage among all the age groups because of its largest area. Wood stock volume and carbon density were 18.59m<sup>3</sup> ha<sup>-1</sup> and 14.94t-C ha<sup>-1</sup> for young-aged forests and 121.92 m<sup>3</sup> ha<sup>-1</sup> and 59.98 t-C ha<sup>-1</sup> for over-mature forests, respectively (table 2). Both wood stock volume and carbon density showed large gaps between young-aged forests and over-mature forests, suggesting great potential of carbon sequestration for the young forests. A large proportion and absolute area of young-aged and middle-aged forests demonstrated huge carbon sequestration capacity of Inner Mongolia forests in the future [15,16].

**Table 2.** Forest area, per unit forest stock volume, forest carbon density and total carbon storage in different forest age groups in Inner Mongolia.

Age group	Area (unit: ha)	Per unit forest stock volume (m <sup>3</sup> ha <sup>-1</sup> )	Mean carbon density (t-C ha <sup>-1</sup> )	Carbon storage (10 <sup>8</sup> t-C)
Young-aged forest	4043300	18.59	14.94	0.668
Middle-aged forest	6247900	61.96	35.26	2.418
Premature forest	2653200	86.99	45.17	1.329
Mature forest	2630600	88.48	44.18	1.311
Over-mature forest	1231000	121.92	59.89	0.698
Total	16806000	48.40	28.73	6.424

### 2.3. Carbon storage dynamics in different dominant tree species and age groups

The total forest area in Inner Mongolia presents a gradually increase trend. The area of each age-group of forests and its portion in whole forests changed with time. The larch and birch forests hold overwhelming superiority, in spite of somewhat descent, throughout all previous forest investigations, accounting for 75.7%, 67.52%, 54.94% of total in the periods of 1977-1981, 1988-1993, 1999-2003, respectively. Accordingly, the carbon storage in forests also increases with the forest area expansion (Table 3) [15,16].

**Table 3.** Area, carbon storage and carbon density in different investigation period in terms of tree species. (“-” indicates data that were not collected) .

Tree species	Area (Unit: thousand ha)			Carbon storage (Unit: Tg C)			Carbon density (Unit: t-C ha)		
	1977- 1981	1988- 1993	1999- 2003	1977- 1981	1988- 1993	1999- 2003	1977- 1981	1988- 1993	1999- 2003
spruce	2.4	1.7	2.6	0.5	0.4	0.5	20.2	25.6	19.3
larch	524.5	438.8	488.0	259.5	199.6	204.3	49.5	45.5	41.9
Mongolian Scotch pine	21.2	24.4	25.1	11.0	13.5	17.8	51.7	55.3	71.2
Chinese pine	7.0	13.1	18.5	0.4	0.8	1.7	5.9	5.9	9.4
Quercus	—	213.2	214.8	—	46.8	54.4	—	21.9	25.3
Birch	308.4	452.4	556.3	86.0	151.8	203.9	27.9	33.6	36.7
Hard broad-leaved	96.3	9.5	20.5	6.4	0.3	0.6	6.7	3.3	2.8
Poplar	90.3	155.8	261.4	4.5	15.5	30.1	4.9	9.9	11.5
Soft broad-leaved	50.1	11.0	19.8	10.9	1.8	2.7	21.8	16.3	13.5
Total(Mean)	1100.2	1320.0	1608.2	378.9	430.4	516.0	34.4	32.6	32.1

### 3. Opportunity and challenge

Inner Mongolia is a unique area characterized by a vast territory with a sparse population in China. Meanwhile it also is a climate and ecosystem transition zone and is sensitive and fragile to climate change and human intervention. So forests, as carbon sink and other ecosystem service provider, are faced with many opportunities as well challenges in the area.

First, Inner Mongolia has the largest land area suitable for afforestation and forestation, accounting for 36.21% of the total area which is suitable for afforestation and forestation in China, so it has a great potential to enlarge the forest area for much more CO<sub>2</sub> sequestration from the atmosphere [17].

Second, the forest wood stock volume level of 48.4m<sup>3</sup> ha<sup>-1</sup> is very low, compared to the international average of 110 m<sup>3</sup> ha<sup>-1</sup>, which also means that there is much space of promotion in per unit forest wood stock volume in this area.

Third, about two thirds of forests in Inner Mongolia are categorized as young or mid-aged stands which tend to have higher growth rates though their stocking levels are disappointingly low and the

growth rate are very low at present. Implementing effective forest management to tend the younger forests certainly will result in a gain in carbon stock level.

Meanwhile there are many challenges as well opportunities. For a long time forests in the area are lack of management with the extensive degradation of existent stands and poor stand quality and low productivity. The aggravation of desertification accompanying warming and drying trend under climate change is a huge threat to the forests. In addition, along with the increase of the population and development of social economy in the area the demands of wood and other derivative products from forests will expand rapidly and the forests will be under threat of disturbances and deforestation. Therefore, we should emphasize the efficiency and productivity of the forests in Inner Mongolia through improving silvicultural practices in terms of site and tree species. So far, our efforts on forest management are not yet enough, only tending and thinning, and so on.

In conclusion, Inner Mongolia's forests can serve as a very significant carbon sink and provider of other ecosystem services. In order to realize their carbon sequestration potential, we must focus on improving forest quality and productivity by bring good sivilcultural practices and forest management.

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