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## Article

# Spatial Patterns and Temporal Variations of Carbon Storage in Forest and Grassland Ecosystem of China's Nature Reserves

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**Abstract:** carbon (C) storage is a key factor in ensuring the provision of ecosystem services such as biodiversity conservation, especially in nature reserves. C storage and its changes in China's Nature Reserves (NRs) are important to act on its role in ecosystem conservation. We based on NDVI values to assess the spatial and temporal variations of vegetation C storage in NRs from 2000 to 2015 in China. Results showed that the C storage in NRs increased by 63.06% within 15 years, of which the C storage of forest vegetation and grassland vegetation increased by 60.05% and 86.33% respectively. 90% of the NRs generally showed positive growth rate, and the growth rate of the northeast and west part NRs of China was higher than other regions. The carbon density of forest vegetation in nature reserves was higher than the region outside nature reserves, however, the grassland showed an opposite result. In general, the vegetation C storage in NRs showed an increasing trend in 15 years, and nature reserves played an important role in protecting forest carbon function, but the effect on protecting grassland vegetation carbon function was not obvious.

**Keywords:** forest; nature reserves; vegetation carbon storage; grassland

## 1. Introduction

Nature reserves (NRs) are widely considered as main approach for protecting biodiversity, which is threatened by human activities and environment pollution (Strassburg *et al.* 2020; Jenkins *et al.* 2009). Since the establishment of first NR in 1956 in mainland China, the number and area of NRs increased rapidly (Chen *et al.* 2009). By the end of 2015, China established 2,763 NRs, accounting for 15.68% of China's land area. Of all NRs, 428 are national level (covering 10.04% of China's land surface) and the remaining are local reserves. Evidence showed that NRs not only secured biodiversity (Weiskopf, *et al.* 2024; Bruner *et al.* 2001), but also provided ecosystem services such as mitigating climate change (Soares-Filho *et al.* 2010), and enhance ecosystem resilience (Game *et al.* 2009). Among these ESs, sequestration and storage of C are incredibly important, given the long-term threat that climate change poses for global biodiversity and ecosystems (Thomas *et al.* 2013, Anderson-Teixeira 2018, Hisano *et al.* 2018), particularly when acting jointly with other ecosystem pressure such as habitat fragmentation (Isbell *et al.* 2015). Furthermore, C sequestration and storage are strongly linked with other ecosystem traits and processes (Thompson *et al.* 2014, Adhikari *et al.* 2016). Plant diversity and ecosystem productivity (Tang *et al.* 2016) for example are strongly linked to C storage. An analysis of C storage alone therefore already represents an effective basis for ecosystem function assessments (Mo *et al.* 2023; Juan *et al.* 2015). In China, the rapid increase in C emissions since the early 21<sup>st</sup> century is posing very serious problems both locally and globally. Between the years 2000 and 2012, China's C emissions more than doubled from 3350.3 m t to 8250.8 m t (Li *et al.* 2017), and per capita emission rate of 7.2 t surpassed that of Europe by 2013. A great enhancement of C storage is seen as one potential mitigation measure for C emissions. Therefore, analysing the change trend of C stocks in nature reserves is conducive to judging whether nature

reserves have played an important role in improving ecosystem services and alleviating C release in recent years.

Studies have reported that the spatial distribution of carbon sequestration was mismatch with nature reserve locations in China. In comparison with the nature reserve network's 15.1% coverage of China's total land surface, it contributes only 11.0% of carbon sequestration (Xu *et al.* 2017). Other relevant research was mainly implemented in a separate nature reserve. There are few studies on the temporal and spatial variation of vegetation carbon storage in nature reserves on a national scale in recent decades.

In order to expolat spatial and temporal variations of C stocks of NRs, we try to addresses the following issues, how C stocks were changing in NRs from 2000 to 2015? in which areas, the C storage of NRs have improved or degraded?

## 2.Methods

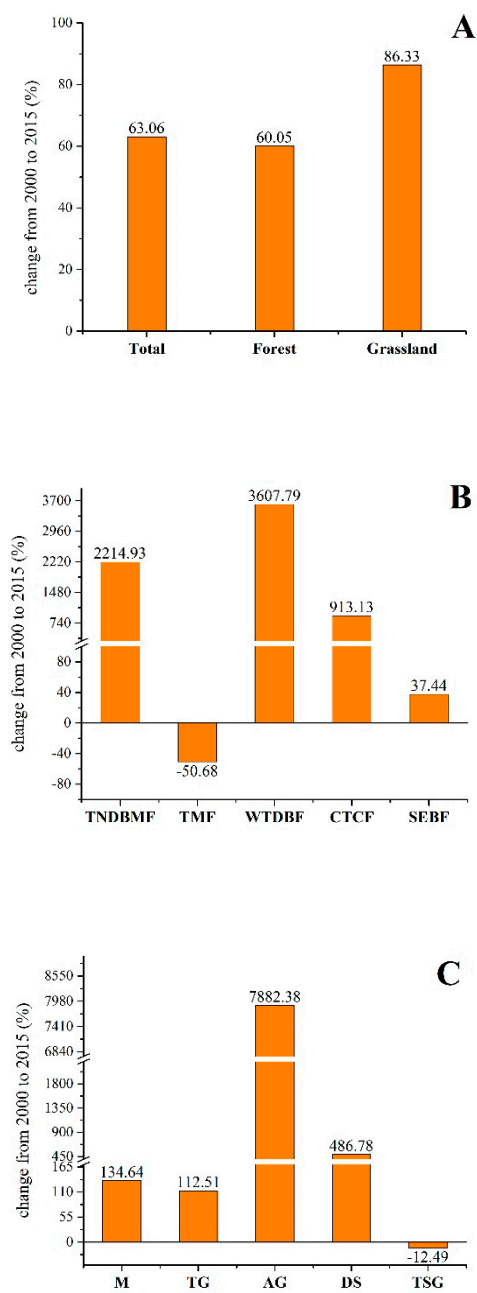
The data sets from Luo *et al.* (2013) and Song *et al.* (2018) were used to obtain national forest and grassland vegetation biomass and 1:1 000000 Chinese vegetation atlas vector data was used to extract forest and grassland vegetation types. These data were combined with monthly MODIS-NDVI imagery (250m resolution) between 2000 and 2015 in multivariate linear regression models that allowed us to estimate the overall vegetation biomass across China in both ecosystems in this 15 years. The final C stock was calculated using a conversion factor of 0.5 between biomass and C stock (Fang *et al.* 2001). And each vegetation type was calculated separately, so we obtained different regression models for different vegetation types. We then used the NR spatial layer to specifically extract the C storage and its temporal dynamics for the NR network, alone. The resulting specific linear regression equations used in each year to estimate the C storage across China for both forests and grassland ecosystems (Appendix A).

## 3.Results

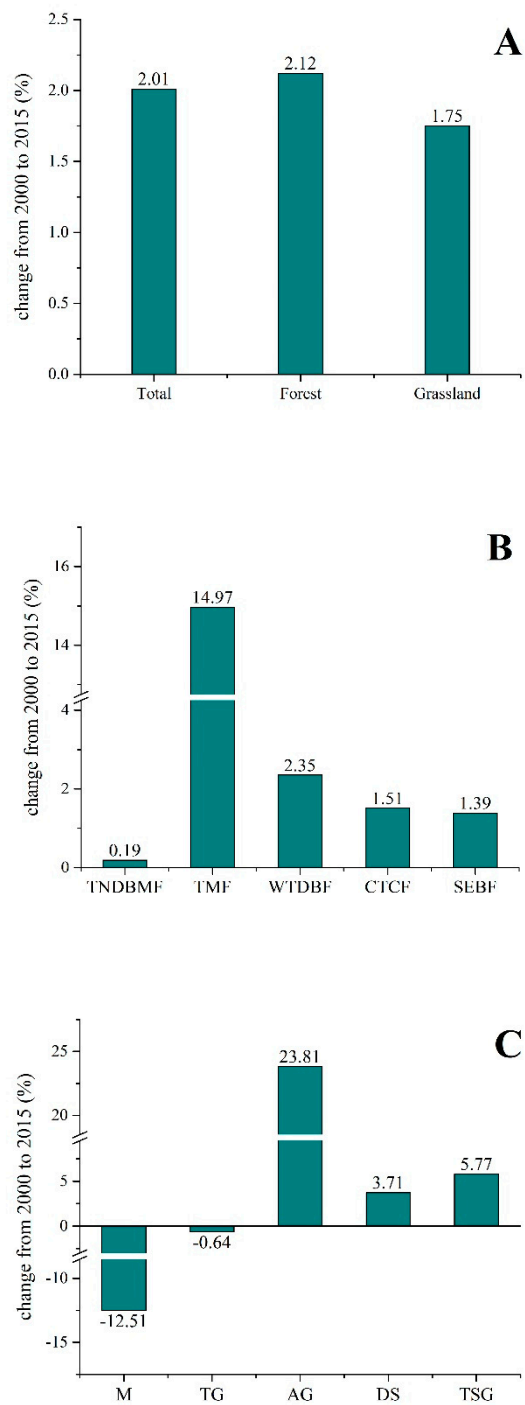
### 3.1. Change of Vegetation C Storage in NRs from 2000 to 2015

The C storage of all vegetation in NRs increased by 63.06% in 15 years, of which the C storage of forest vegetation and grassland vegetation increased by 60.05% and 86.33% respectively (Figure 1A). The C storage in forest vegetation of NRs increased between 2000 and 2015. Warm temperate deciduous broad-leaved forest had the largest increase (3607.79%), followed by temperate needles, deciduous broad-leaved mixed forest (2214.93%), cold temperate coniferous forest (913.13%) and subtropical evergreen broad-leaved forests (37.44%), whereas tropical monsoon forest decreased (-50.68%) (Figure 1B). C storage in grassland vegetation of NRs showed an increasing trend in addition to the tropical shrub-grassland. Alpine grassland had the largest improve (7882.38%), followed by desert steppe (486.78%), meadow (134.64%) and typical grassland (112.51%), whereas tropical shrub-grassland decreased slightly (-12.49%) (Figure 1C).

The increase proportion of total vegetation C storage in NRs to the national overall C storage is 2.01%, with forest and grassland increased 2.12% and 1.75% respectively (Figure 2A). The proportion of all types of forest vegetation C storage to the whole country was increased from 2000 to 2015, with tropical monsoon forest had the largest increase (14.97%), followed by warm temperate deciduous broad-leaved forest (2.35%), cold temperate coniferous forest (1.51%), subtropical evergreen broad-leaved forests (1.39%) and temperate needles, deciduous broad-leaved mixed forest (0.19%) (Figure 2B). The proportion of two types of grassland vegetation C storage to the whole country was decreased, while the other three types were improved. Among them, alpine grassland had the largest increase (23.81%), followed by tropical shrub-grassland (5.77%) and desert steppe (3.71%), whereas the meadow had larger decreased (-12.51%) than the typical grassland (-0.64%).



**Figure 1.** C storage in tropical monsoon forest and tropical shrub-grassland in NRs from 2000 to 2015. (A) The growth rate of all vegetation C storage in the NRs, including the forest and the grass. (B) Aggregate change in C storage of different forest vegetation types, for the five types: TNDBMF, temperate needles, deciduous broad-leaved mixed forest; TMF, tropical monsoon forest; WTDBF, warm temperate deciduous broad-leaved forest; CTCF, cold temperate coniferous forest; and SEBF, subtropical evergreen broad-leaved forests. (C) Aggregate change in C storage of different grassland vegetation types, for the five types: M, meadow; TG, typical grassland; AG, alpine grassland; DS, desert steppe; and TSG, tropical shrub-grassland.



**Figure 2.** Changes in the proportion of C storage in NRs to the whole country and decline in some of the grassland types from 2000 to 2015. (A) The growth proportion of all vegetation C storage in the NRs, including the forest and the grass. (B) Aggregate change in the proportion of different forest vegetation types, for the five types: TNDBMF, temperate needles, deciduous broad-leaved mixed forest; TMF, tropical monsoon forest; WTDBF, warm temperate deciduous broad-leaved forest; CTCF, cold temperate coniferous forest; and SEBF, subtropical evergreen broad-leaved forests. (C) Aggregate change in the proportion of different grassland vegetation types, for the five types: M, meadow; TG, typical grassland; AG, alpine grassland; DS, desert steppe; and TSG, tropical shrub-grassland.



3.2. Spatial Distribution of C growth Rates in Various NRs

Not all NRs had a positive trend. 90% of the NRs generally showed positive growth, and the growth rate of the northeast and west part of China was higher than other regions (Figure 3A). The other NRs C storage showed a decline trend in 15 years, mainly in the northern part of Heilongjiang Province and the southern part of China, among which the NRs in the tropical monsoon rainforest area have declined more (Figure 3B). As far as forest C stocks in NRs were concerned, the growth rate in warm temperate deciduous broad-leaved forest region was higher than other vegetation regions (Figure 3C), while there were some NRs showed decreased C storage in subtropical evergreen broad-leaved forests regions in 15 years (Figure 3D). Only about 50% of NRs had a positive growth rate of grassland C storage. The NRs with relatively higher grassland C growth rate were distributed in the western and central regions (Figure 3E), while most of the NRs in the southeastern region showed negative growth status. In Heilongjiang provinces, the protected areas also showed a negative growth state (Figure 3F).

**Figure 3.** Spatial distribution of total (A, B)/ forest (C, D)/ grassland (E, F) C storage growth rate in each nature reserve within 15 years.

3.3. Differences in Carbon Density Between Inside and Outside of Nature Reserves

The total of NRs in China was 138.76 million ha, with a total vegetation carbon storage of 1395.08Tg in 2015 (1212.85Tg for forest vegetation and 182.23Tg for grassland). The carbon density of forest vegetation in nature reserves was higher than the region outside nature reserves, and similar results were found for different forest types. However, the grassland showed an opposite result to forest that the carbon density outside nature reserves was higher than the protected areas, and different grassland types also showed the same (except tropical shrub-grassland) (Table 1). Therefore, nature reserves played an important role in protecting forest carbon function, but the effect on protecting grassland vegetation carbon function was not obvious.

**Table 1.** Comparison of vegetation carbon density between inside and outside of nature reserves.

Forest C density (Mg/ha)			Grassland C density (Mg/ha)		
	Inside NRs	Outside NRs		Inside NRs	Outside NRs
Total	0.80*10 <sup>-2</sup>	0.68*10 <sup>-2</sup>	Total	0.03*10 <sup>-2</sup>	0.08*10 <sup>-2</sup>
Temperate needles, deciduous broad-leaved mixed forest	0.57*10 <sup>-2</sup>	0.49*10 <sup>-2</sup>	meadows	0.03*10 <sup>-2</sup>	0.05*10 <sup>-2</sup>
Tropical monsoon forest	5.41*10 <sup>-2</sup>	2.31*10 <sup>-2</sup>	Desert steppe	0.06*10 <sup>-2</sup>	0.07*10 <sup>-2</sup>
Warm temperate deciduous broad-leaved forest	0.50*10 <sup>-2</sup>	0.47*10 <sup>-2</sup>	alpine grasslands	0.006*10 <sup>-2</sup>	0.02*10 <sup>-2</sup>
Cold temperate coniferous forest	1.29*10 <sup>-2</sup>	1.12*10 <sup>-2</sup>	tropical shrub-grassland	0.34*10 <sup>-2</sup>	0.33*10 <sup>-2</sup>
Subtropical evergreen broad-leaved forests	0.63*10 <sup>-2</sup>	0.60*10 <sup>-2</sup>	typical grasslands	0.05*10 <sup>-2</sup>	0.08*10 <sup>-2</sup>

4.Discussion

4.1. There Are Some Differences in the Changes of Carbon Storage in Different Vegetation Types

Overall, the vegetation C storage in NRs showed an increasing trend in 15 years. Grassland growth rate was higher than that of forest. However, different vegetation types had different change

trends. The forest vegetation C stocks of NRs in cold temperate zone, temperate zone and warm temperate zone had an increasing trend. One of the causes of this result was the increase in the area and number of the forestland NRs. In addition, before 2010, the Six Key Forestry Programs (SKFPs) were established to promote a more sustainable forest policy (Wang *et al.* 2007) and all had a positive effect on the development of NRs, such as Natural Forest Protection Program (NEPP) (Wang *et al.* 2007). These programs on forestry have contributed more or less to the protection and development of forest ecosystems in NRs, increasing the area of forest land, reducing the amount of wood felling, using economic compensation to return farmers to forests, and soil erosion, desertification has been treated to a certain extent. However, it is worth noting that the tropical monsoon forests carbon stocks in NRs was particularly striking which had a 190.92Tg reduction from 2000 to 2015. We all know that the increase in tree species diversity will increase the carbon stocks and ecosystem services of forest ecosystems (Ruiz-Jaen *et al.* 2011), but the lack of differentiation in forest quality has led to a large number of deforestation and plantation expansion, including the occupation of protected areas in Hainan (Zhai *et al.* 2013). In the study period, Rubber and pulp plantations were extensively expanded, and the higher economic benefits made the plantation status higher than the natural tropical rainforest, which made the biodiversity become single and greatly reduced the carbon storage capacity of the ecosystem (Zhai *et al.* 2012). And many studies have proved that the regeneration of tropical secondary forests and plantations cannot offset the carbon emissions caused by tropical deforestation, thus determining the net carbon loss of tropical lands, so plantations cannot replace natural forests as large carbon sinks (Song *et al.* 2014). At the same time, invasive species in tropical regions of China also strongly influence the stability of ecosystem function. They present a major conservation concern, strongly affecting native communities via competition, predation and disease (Axmacher *et al.* 2013). For example, Ganshiling Nature Reserve has 46 species of invasive alien species, accounting for 3.5% of the number of seed plants, and there are 38 invasive species in Hainan Bawangling Nature Reserve which belonging to 17 families (Rongjing Zhang *et al.* 2011, Xuehua Hu *et al.* 2011). These NRs were critical to the protection of tropical rainforests, but there were still serious problems. Although there were many problems in the protection of tropical rain forests, the coverage of carbon storage in China's nature reserves was much higher than other types of forests. This truth indicated that in the case of the destruction of tropical monsoon forests throughout the country, NRs reduced the extent of damage to tropical monsoon forests within their scope.

The alpine grassland had the largest growth rate of all types of grassland. The NRs vegetation C in the alpine grassland in 2000 was very small (0.28Tg), so it has a very large growth rate after increasing to 22.36 Tg in 2015. Besides, the fractional vegetation coverage of NNRs in the Qinghai-Tibet Plateau increased by 0.6%, from 31.5% to 32.1%, and the NPP in NNRs also showed an increasing trend in 15 years. At the same time, human disturbance dramatically decreased from 6.46% to 5.32% in NNRs of the Qinghai-Tibet Plateau due to limiting human activities in NNRs, especially in the NNRs of Qiangtang, Altun Mountains, Selin Co, and Haizi Mountain (Zhu *et al.* 2018). In addition, biomass in grasslands of the Qinghai-Tibet Plateau has displayed an overall increasing trend, which was profoundly influenced by climate change (WANG *et al.* 2018). The temperature directly influenced the starting date of the vegetation growing season, and it may expand the length of the plant growing season, which is closely related to biomass and C storage (Zhu *et al.* 2018). The C stocks of tropical shrub-grassland in NRs showed a slight decrease, which was mainly distributed in the southeast of China. Most of the NRs in this area were mainly pay attention to the wetlands and forest ecosystems, and little attention was paid to the protection of tropical shrub-grassland. The strong interference of human activities, such as urbanization, led to the fragmentation of irrigation areas, which affected the integrity of the ecosystem (Liu *et al.* 2017b). However, the protection ratio of NRs to grassland in the country was increasing, indicating that the protection of grassland ecosystems in NRs was gradually improving. Since grassland is the largest terrestrial ecosystem globally and in China, it has a large amount of ecological and economic value. The grassland restoration improved biodiversity by 32.44% and ecosystem services by 30.43% (Ren *et al.*

2016), so it is very important for China to improve protecting and managing grassland ecosystem in NRs.

#### 4.2. The Growth Rate Distribution of NRs C Storage

90% of NRs generally showed positive growth. The NRs with high growth rate of C storage were distributed in the northwest and northeast of China. Moreover, the change rate of forest and grassland C stocks in NRs was similar to the overall. From 2000 to 2015, the northeast region of China not only increased the number and area of NRs, but also strengthened the improvement and protection of NRs. At the same time, climate change also has a certain impact on vegetation biomass and C storage in NRs. Overall the frequency of drought was decreasing in Northeast China in the study period (Cong *et al.* 2017, Zhou *et al.* 2017), which means the precipitation was improving in these years. That condition was very helpful for plants growing (Yang *et al.* 2009). Especially for grassland, the precipitation had significantly positive correlation with NDVI because the precipitation could provided the required moisture for vegetation growth (Mao *et al.* 2012). Northwest China belongs to arid and semi-arid areas, and the NRs with higher C storage growth rate was mainly concentrated in the Loess Plateau regions, where the C sequestration markedly increased in the tableland of Loess Plateau during this 15 years. The mixed broadleaf-conifer forest ranked first, and the bare land and sparse vegetation also presented a few C storage (Zhang *et al.* 2019). The construction of ThreeNorth Shelter Forest Program (TNSFP) and the “Grain for Green” also have made a big contribution for forest protection (Sun *et al.* 2016b, Zhang *et al.* 2019). The increase of the forest C storage in 15 years can confirm that the NRs and afforestation policy have a certain positive effect on the protection of the ecosystem in the Loess Plateau.

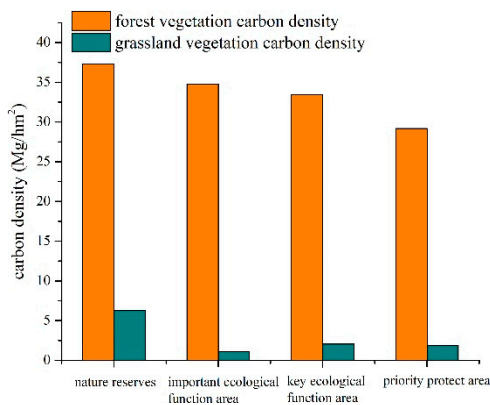
The growth rate of C stocks in eastern and southeast NRs was low, and some NRs showed a negative growth trend. We found that the management system of NRs was still imperfect, which was one of the important reasons for impeding the improvement of the efficiency of NRs in the east and southeast part of China (Xu *et al.* 2007). First, the impact of population growth and human activity disturbances on nature reserves, including decrease in the per capita ecological carrying capacity, and dramatic increase in ecological footprints (Liu *et al.* 2016). Second, the area of nature reserves limits the scope of protection, medium and small nature reserves compose 92.32% of all nature reserves. And the areas contained in nature reserves in each province are not proportional to the areas of the provinces, particularly for national NRs, with higher protection rates in Southwest and Northwest China than in other regions (Guo *et al.* 2015). Third, the conflict between economic and natural resource protection has seriously affected the construction of nature reserves. The eastern and southeastern parts are important areas for China's economic development, and the economic factors have a greater impact on the construction of nature reserves than ecological factors in these regions (Wu *et al.* 2018). Besides, The fragmentation of the nature reserves, the conflicts of responsibilities between governments at all levels and the overlapping management of different types of protected areas also impacted the development of NRs in southeast of China. It is believed that biodiversity and ecosystem conservation will be further successful after coordinating and balancing the relationships between different protected areas.

#### 4.3. The Nature Reserve Played an Important Role in Forest C Conservation in China

Our results indicated that the forest C density in NRs was higher than the outside, while the grassland showed an opposite result. In addition, with the decline of tropical seasonal rainforests C storage in both the country and NRs, the proportion of tropical monsoon forests C storage in NRs to the whole country has been rising during study period. That truth means NRs have the function of slowing down the decline of C storage in tropical monsoon forests, so that the tropical monsoon forest within NRs scope suffer less damage than the outside. And the increasing of the proportion was more than other forest types. Therefore, the nature reserves played an important role in forest carbon functions in China.



In order to improve the environmental degradation caused by industrial and economic development, China has not only established the nature reserve system, but also key ecological functional areas and biodiversity priority conservation areas. But after calculation, from the perspective of carbon density, the nature reserves were higher than other types of ecological function areas, including key ecological function areas, important ecological function areas and biodiversity priority protected area (Figure 7). The main reason of this situation was that the newly added NRs have been strictly set with boundary and managed hierarchically, including strict laws and regulations and planning purposes(Guo *et al.* 2015). Some scholars have confirmed that strict nature reserve management, that is, not allowing the use of natural resources in protected areas, can provide more value for ecosystem services. In contrast, nature reserves offer greater benefits in terms of carbon storage, carbon sequestration and recreation at the national and global levels(Liu *et al.* 2017a).



**Figure 7.** Comparison of vegetation carbon density in four kinds of protected areas in China.

**5.Conclusion**

The vegetation C storage showed a clear upward trend in NRs from 2000 to 2015, and the proportion of organic carbon stocks in NRs to total carbon storage in China’s ecosystem increased in recent decades. NRs have the function of slowing down the decline of C storage in tropical monsoon forests, so that the tropical monsoon forest within NRs scope suffer less damage than the outside. The C stock growth rate of the northeastern and western NRs was higher than that of other regions. Nature reserves played an important role in protecting forest carbon function, but do not found the same result from grassland.

Based on this situation, we recommend that strengthen the construction and management of grassland ecosystems type nature reserves in Inner Mongolia; Improve the planation of the eastern and southeastern NRs, and expand the protected area to cover more forest ecosystems; Reduce the impact of human and economic activities on NRs, balance the conflict between NRs and urban construction, control the invasive species especially in tropical rainforests and subtropical evergreen broad-leaved forests; Increase connectivity between smaller and more dispersed protected areas, and reduce ecosystem fragmentation. For decision makers, it is very important to balance the construction of various types of NRs according to the natural resources of China. Although the NRs are managed according to different grades of government, it is more important to judge the rationality of the protected areas construction on a national scale.

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**Appendix A**

Appendix A.1 Carbon Storage Calculation Model for Different Forest Vegetation Types (Mg/ha)

Vegetation type	year	Stepwise linear regression model
Temperate needle and deciduous broad-leaved mixed forest	2000	$y=96.59+222.63x_3-287.34x_4+404.88x_5-334.14x_6-217.22x_{10}+257.08x_{11}$
	2015	$y=66.31+73.33x_2+98.38x_6-145.78x_8-84.48x_{10}-65.43x_{11}$
Subtropical evergreen broad-leaved forest	2000	$y=10.049-71.307x_2+75.923x_3-59.199x_4+128.159x_5-88.66x_6+74.742x_7-150.962x_8+161.085x_9$
	2015	$y=13.748+44.422x_5-55.584x_8+26.475x_{10}+13.440x_{11}+42.723x_{12}$
Cold temperate coniferous forest	2000	$y=120.83+718.92x_3-592.93x_4+857.76x_5-1277.34x_7+678.67x_8-324.84x_9+143.85x_{11}$
	2015	$y=551.82+392.79x_1-459.45x_3-180.40x_5-524.87x_8+258.99x_{10}$
Tropical rainforest, rainforest	2000	$y=-1050.6-4307.7x_2+6206.4x_3-2296.7x_4+2915.6x_5-2783.3x_6+1340.7x_7+1433.9x_{10}-1146.5x_{11}$
	2015	$y=4109.3-804.5x_1-572.0x_2-1321.2x_3+9068.9x_4+1982.9x_6-6828.0x_7+475.7x_8+1291.4x_{10}+3422.7x_{11}-11218.2x_{12}$
Warm temperate deciduous broad-leaved forest	2000	$y=65.711-94.681x_2+168.834x_3-101.352x_8$
	2015	$y=40.05+32.01x_1+38.31x_2+32.17x_4-86.79x_5+73.47x_6+56.24x_7-117.51x_8+61.02x_9-49.29x_{10}$

Note: y represents vegetation biomass.

Appendix A.2 Carbon Storage Calculation Model for Different Grassland Vegetation Types (g/m3)

Grassland type	Steppe regionalization	Distribution area	Unitary linear model
Meadow steppe	Northeast grassland	Central part of northeast	$y = 8708.54 \text{ NDVI} - 2218.58$
Desert steppe	Inner Mongolia grassland	Xilin Gol League,	$y = 6874.37 \text{ NDVI} - 2154.14$
typical steppe		Inner Mongolia	$y = 4830.21 \text{ NDVI} - 1837.76$
Meadow steppe		Autonomous Region	$y = 7963.35 \text{ NDVI} - 3393.17$
Desert steppe	Loess Plateau grassland	Inner Mongolia, Gansu and Ningxia	$y = 5673.47 \text{ NDVI} - 463.63$
Semi-arid warm shrub	Warm temperate grassland in North China	Hebei, Shanxi and Shaanxi	$y = 10305.05 \text{ NDVI} - 2255.59$
desert steppe and montane steppe	Xinjiang grassland	Xinjiang	$y = 6916.80 \text{ NDVI} - 553.00$
Meadow steppe	Xinjiang grassland	The southern	$y = 10490.51 \text{ NDVI} - 1881.69$
Alpine meadow	Qinghai-Tibet Plateau grassland	mountain area of Urumqi in the	$y = 7485.98 \text{ NDVI} - 2301.23$
Humid tropical shrub-grassland	Southern meadow	middle section of the northern slope of the Tianshan Mountains	$y = 12418.85 \text{ NDVI} - 4353.07$
Yew grass meadow	Qinghai-Tibet Plateau grassland	Mountainous area in	$y = 66.72 \text{ NDVI} - 1142.19$
Alpine wormwood meadow		the southern suburbs of Urumqi, the	$y = 65.31 \text{ NDVI} - 780.70$
Moss meadow		northern slope of the Tianshan Mountains	$y = 70.54 \text{ NDVI} - 1374.84$
Alpine meadow			$y = 1030.06 \text{ NDVI}$

Note: y represents vegetation biomass.

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