# CAPACITY OF FOREST CARBON SEQUESTRATION DRIVEN BY NPP INCREASING IN CHINA


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**ABSTRACT:**

Forest ecosystem could significantly sequestrate some atmospheric $CO_2$ and, therefore, partly mitigate current pressure on global warming. The carbon sequestration capacity of forest ecosystem is determined by both the NPP increase trend and turnover time. In order to estimate the capability of forest C sequestration in China, a carbon turnover model, which bases on NPP increase trend monitored by remote sensing and carbon turnover time derived from forest observed data, was designed. Modelled results illustrated that China forest is an apparent carbon sink with a magnitude of 0.052 PgC a-1, in which about 0.034 PgC a-1 in plant tissues and the other of 0.018 PgC a-1 in soil. The further analysis on carbon sequestration efficiency (CSE) indicated that the CSE value is controlled by carbon turnover time.


## 1. INTRODUCTION

Since industry revolution, burning of fossil fuel and landuse change have released a lot of greenhouse gas $CO_2$, which results in global warming and a series of environmental problems （Solomon et al,2007） How to mitigate the increasing rate of $CO_2$ effectively is not only a science problem, but also a political and economical problem(Young., 2003).Because of the regrowth of forest can absorb $CO_2$ effectively, much attention has be paid to forest fixed C (Fang et a,2007). It is an effective measurement for alleviating global warming (Andrasko,1990;Brown et al,1996). With the sign of Kyoto Protocol and the implement of policy to reply global warming, research and application of forest C sink has been given a lot of attention (Cannell et al,1999;Dai et al,2004) .

Forest ecosystem exchange C with atmosphere by photosynthesis and respiration. If C absorbed is larger than released, forest ecosystem can be called carbon sink, otherwise, it is carbon source.

There are many factors influenced ecosystem C sink, such as climate change(Dai et al,1993), $CO_2$ fertilization(Cramer et al,2001), N sedimentation(Holland et al,1997)and landuse change(Houghton et al,1999).Because there is a large spatial heterogeneity of ecosystem and the difference of affection factors, a lot of uncertainties of ecosystem C sink research exist(Denman et al,2007).Results showed that no matter the simulation method based on progress model(Cao et al,2003;Wang et al,2007) or on forest checked data(Liu et al,2000;Fang et al,2007) ,there are a lot of differences for carbon sink estimation.

Two major factors determined the capacity of C sink of forest ecosystem: increase trend of NPP and C turnover time(Luo et al,2003).Forest growth and regrowth lead to more and more C enter the ecosystem, so it is a external driven factor for C sequence. While the carbon sink efficiency is determined by carbon turnover time(Luo et al,2003). With the same NPP increase trend, the longer of the carbon turnover time, the higher of the forest carbon sequence and carbon sink efficiency is. This paper based on NPP increase trend driven forest ecosystem carbon turnover model, simulates the annual change of forest carbon sink from 1982~1999, estimates the capability of sequence C by vegetation and soil, and discuses the efficiency of carbon turnover time to forest carbon sink efficiency .

## 2. METHOD AND DATA

### 2.1 Model structure

The structure of carbon turnover model based on NPP increase trend is as figure 1.For each kind of forest, there are 3 layers: arbor, shrub and herb. NPP after revise（$NPP_m(\varepsilon_a^*)$） is distributed to arbor, shrub and herb pool based on distribution ratio（$\alpha_t$、$\alpha_{sh}$ $\alpha_h$）. NPP entered arbor is further distributed to stem, leaf and root according to ratio （$\alpha_s$、$\alpha_l$、$\alpha_r$）. Carbon entered ecosystem, part is form biomass（$q_t$、$q_{sh}$、$q_h$、$q_s$、$q_l$、$q_r$）, and the other is deviate from the carbon pool, the rate of which is determined by turnover time （$\tau_t$、$\tau_{sh}$、$\tau_h$、$\tau_s$、$\tau_l$、$\tau_r$）.Vegetation litter fall entered litter and soil organic matter（$q_{soc}$）, part is form soil carbon sink , the other is released to


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atmosphere by heterotrophic respiration.Its rate is based on soil carbon turnover time （$\tau_{soc}$）.

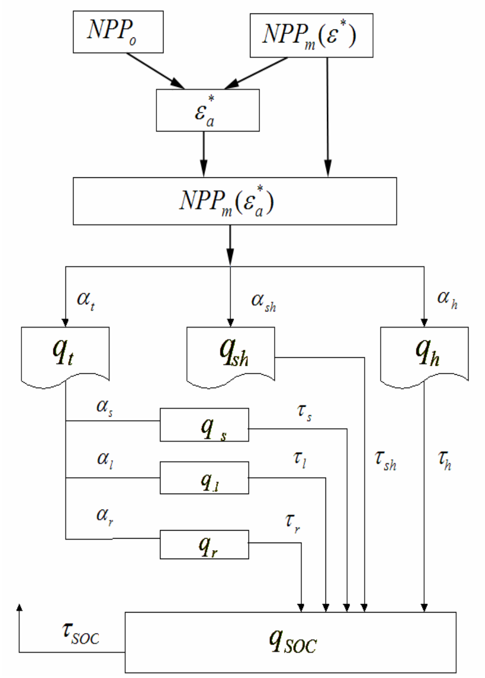


Fig.1 The forest ecosystem carbon turnover model driven by NPP increasing trend

Since the late 1970s, Chinese government has implemented several large forest ecological programs(Shen,2000) .At the same time , Fang(Fang et al,2001)have showed that Chinese forest carbon sink increase from 1980s. This paper supposing that 1982 is a balance point, simulates the annual change and accumulation of forest carbon sink from 1982 to 1999 based on formula 1~6.

$$\frac{dq_t}{dt} = \alpha_t \cdot NPP - q_t / \tau_t \tag{1}$$

$$\frac{dq_h}{dt} = \alpha_h \cdot NPP - q_h / \tau_h \tag{2}$$

$$\frac{dq_{sh}}{dt} = \alpha_{sh} \cdot NPP - q_{sh} / \tau_{sh} \tag{3}$$

$$\frac{dq_s}{dt} = \alpha_t \cdot \alpha_s \cdot NPP - q_s / \tau_s \tag{4}$$

$$\frac{dq_l}{dt} = \alpha_t \cdot \alpha_l \cdot NPP - q_l / \tau_l \tag{5}$$

$$\frac{dq_r}{dt} = \alpha_t \cdot \alpha_r \cdot NPP - q_r / \tau_r \tag{6}$$

### 2.2 Parameter determination

NPP increase trend and intensity is the external driven factor of ecosystem. Determining the quantity and trend of NPP is the key for ecosystem carbon sink stimulation. CASA model based on remote sensing data is used in different spatial scale. It can stimulate both the spatial distribution and change of local scale NPP very well(Potter et al,1993;Piao et al,2005;Zhu et al,2006). In CASA model, NPP is the function of APAR, maximum light-use efficiency variable $\varepsilon^*$ , light-use efficiency stressed temperature $T_\varepsilon$ and moisture $W_\varepsilon$ .

$$NPP = fAPAR \cdot PAR \cdot \varepsilon^* \cdot T_\varepsilon \cdot W_\varepsilon \tag{7}$$

Where… $fAPAR$ = the absorbed ratio of PAR by vegetation, and it is calculated by remote sensing data NDVI.

In CASA model, $\varepsilon^*$ is the most important parameter for the precision of CASA estimated NPP(Peng et al,2000). It usually change with vegetation kind (Ruimy et al,1999;Zhu et al,2006).

It is very important to determine $\varepsilon^*$ of different vegetation kinds for the absolute amount of annual NPP increase trend estimation. However, the annual change of vegetation kind is small in spatial distribution, so the relative trend of NPP will not change (Piao et al,2005). Piao (Piao et al,2005) stimulated NPP increase trend of different ecosystem from 1982 to 1999 in China by CASA model whose $\varepsilon^*$ is a constant（$\varepsilon^*$ = 0.405 gC MJ-1）.

Because the driven factor of forest carbon sink is NPP increase trend, here we combine the NPP increase trend of Piao(2005) with NPP observed data from 1266 forest sample plots of Luo (Luo et al,1996), revise $\varepsilon^*$ of CASA model（$\varepsilon_a^*$）, attain revised NPP （$NPP_m(\varepsilon_a^*)$）and its annual change to drive carbon turnover model, such as figure1

$$\varepsilon_a^* = \varepsilon^* \times \frac{NPP_o}{NPP_m(\varepsilon^*)} \tag{8}$$

Where… $\varepsilon^*$ =the maximum light-use efficiency variable （0.405 gC MJ-1），

$NPP_0$ =the observed NPP in sample plot，

$NPP_m(\varepsilon^*)$ = the stimulated perennial annual NPP by $\varepsilon^*$.

In this research, carbon distributed ratio and turnover time are attained by observed data, in which carbon distributed ratio is attained by plot observed data of Luo, and turnover time of each pool is estimated by carbon storage and flux data of vegetation and soil by Luo(1996) and Wang(2003).

## 3. RESULTS AND DISCUSSION

### 3.1 Maximum light-use efficiency variable $\varepsilon^*$

$\varepsilon^*$ after revising (Tabel.1) indicates that, for different forests, $\varepsilon^*$ has a lot of discrepancies. $\varepsilon^*$ of EBF and DBF is largest, reach to 0.896 and 0.853 respectively. It is consistent with Zhu's result(Zhu et al,2006) and nearer to Peng's result(Peng et al,2000) which shows that $\varepsilon^*$ in Guangdong is get to 1.25gC MJ-1, larger than $\varepsilon^*$ of CASA. It illustrates that revised $\varepsilon^*$ can reduce the differences of the stimulated NPP and observed NPP. At the same time, NPP increase trend is consistent with Piao's result(Piao et al,2005).

| Code | Forest kind | number | $\varepsilon^*$ | $\varepsilon_a^*$ |
|---|---|---|---|---|
| 1 | EBF | 260 | 0.405 | 0.896 |
| 2 | DBF | 301 | 0.405 | 0.853 |
| 3 | ENF | 613 | 0.405 | 0.846 |
| 4 | DNF | 48 | 0.405 | 0.695 |
| 5 | BNMF | 22 | 0.405 | 0.639 |

Table 1 The maximum light-use efficiency of major forest ecosystem in China

EBF, evergreen broadleaf forests; DBF, deciduous broadleaf forests; BNMF, broadleaf and needleleaf mixed forests; ENF, evergreen needleleaf forests; DNF, deciduous needleleaf forests

### 3.2 Forest carbon sink and annual change

The stimulated result of ecosystem carbon sink in China forest indicates that NPP increase trend is corresponded closely with forest carbon sink. NPP monitored by remote sensing increases obviously (Figure2a), which makes the accumulated NPP enter the ecosystem increase markedly (Figure2b). It leads to the annual(Figure2c) and accumulated(Figure2d) change of forest ecosystem carbon sink. So NPP incensement is the essential factor driven China forest carbon sink. In different forests, the carbon sink of ENF and EBF is largest for its largest area and increase trend, while DNF and BNMF is smallest.

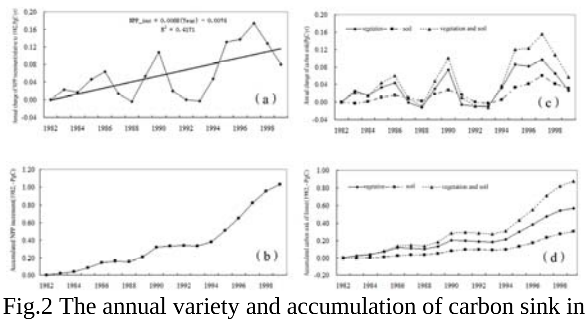

Fig.2 The annual variety and accumulation of carbon sink in forest ecosystem

From 1982 to 1999, accumulated forest carbon sink is 0.876 PgC, annual average is 0.052 PgC. Besides, carbon sink of vegetation is 0.034 PgC, of soil is 0.018 PgC. For vegetation, the carbon sink of arbor is largest（0.032 PgC $a^{-1}$）, next is shrub（0.002 PgC $a^{-1}$）, the herb is smallest(0.0002 PgC $a^{-1}$). Because the turnover time is short, carbon distributed to herb put into the soil carbon pool quickly (Figure3a). For different tissue of arbor, carbon sink of stem is largest（0.023PgC $a^{-1}$）, account for 72% of the total. Next is root（0.006 PgC $a^{-1}$）, which is 19% of the total. The carbon sink of leaf is smallest（0.003 PgC $a^{-1}$）, only 9%(Figure 3b). The carbon sink of arbor root is smaller than of stem. It is consistent with the fact that NPP distributed to stem is larger than to the root(Luo,1996).

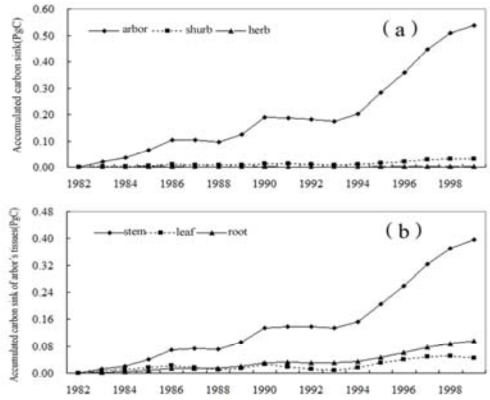


Fig.3 The cumulative carbon sequestration of forest（a）vegetation (b) organ of arbor

Table 2 is the comparation of stimulated vegetation carbon sink with the results of other researchers. The estimated value of this research is higher tan Fang(2001), Liu(2000) and Piao's(2005) results based on forest observed data, which is between 0.019~0.029 PgC $a^{-1}$, but lower than Fang's (2007)result（0.075 PgC $a^{-1}$）. The canopy density of forest changes from 30% to 20% may lead to the carbon sink estimation on the high side(Fang et al,2007). Compare with forest carbon sink estimated by other models, this result is consistent with Wang's(2007), which estimates China forest carbon sink by InTEC model. The change scale of it is 0.011~0.055 PgC $a^{-1}$.

| Researcher | Vegetation carbon sink（PgC $a^{-1}$） |
|---|---|
| Author | 0.034 |
| Liu（2000） | 0.027 |
| Fang（2001） | 0.021 |
| Piao (2005) | 0.019 |
| Fang（2007） | 0.075 |
| Cao (2003) | 0.07 |
| Wang (2007) | 0.011~0.055 |

Table 2 The comparison of forest vegetation carbon sink

For total forest ecosystem of China, carbon sink is major in root, stem and leaf of vegetation. The carbon sink of soil is only half of the vegetation（53.8%）. But in the USA, carbon sink in soil is 2/3 of the sink in vegetation(Wang et al,2007). In Europe, soil carbon sink is 30% (Janssens et al,2003) .The soil carbon sink in China forest is similar to in the USA. Huang et al(2006). research the change trend of organic carbon in cropland of China, results showed that, in the last 20 years, the soil organic carbon in the cropland increase 0.31~0.40 PgC, annual average is 0.016 to 0.02 PgC $a^{-1}$, which is equivalent to the carbon sequenced in forest soil. Given the area of cropland（166.73× 106ha）is larger than forest（124.29×106ha）, carbon sequenced in forest soil is about 1.2 ~1.6 times of the cropland in unit area.

### 3.3 Forest carbon sequestration efficiency

Besides NPP increase trend, carbon turnover time is another significant reference for carbon sink(Luo et al,2003) .For forest ecosystem, carbon sequestration efficiency (CSE )means the carbon sink produced by unit NPP.

Results showed that, the CSE of EF is larger than of DF, the largest is in ENF and the smallest is in DNF. From large to small, the CSE is ENF > BNMF > EBF > DBF > DNF. The further analysis indicates that, CSE of forest is controlled by carbon turnover time obviously. There is a markedly linear relationship between them（R2＝0.91）. That is the longer of the carbon turnover time, the higher of the vegetation CSE(Figure 4).

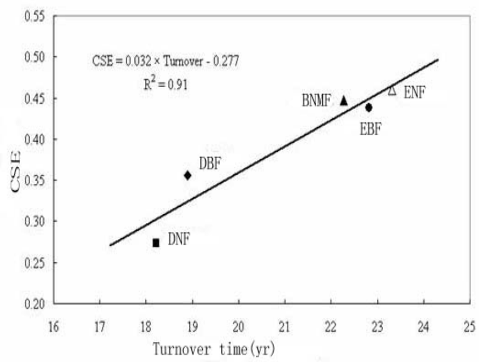


Fig. 4 The relationship between carbon sink efficiency and carbon turnover time of forest vegetation

## 4. RESULTS

This paper use monitored forest ecosystem NPP increase trend based on remote sensing and carbon turnover time model driven by NPP increase trend, estimate average carbon sink and annual change of China forest ecosystem. Results indicate that, NPP increase trend is corresponded with forest carbon sink closely. NPP increase is the essential factor driven forest carbon sink in China. Form 1982 to 1999, the annual average carbon sink of forest ecosystem in China is 0.052 PgC $a^{-1}$, of which, carbon sink in vegetation is 0.074 PgC $a^{-1}$, in soil is 0.018 PgC $a^{-1}$.In different forests, the attribution of ENF and EBF is largest, while the smallest is in DNF and BNMF. CSE analysis shows that, CSE of forest vegetation is controlled by carbon turnover time, from largest to smallest, the CSE is ENF > BNMF > EBF > DBF > DNF. That is to say, when NPP increase trend is unchanged, the carbon sink of ENF is largest, of DNF is smallest.

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