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Carbon Sequestration Capacity of The Forest

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The potential of forest carbon sink in the next 50 years is predicted by using the ninth inventory data of forest in Shanxi Province under the background of the forest resource utilization trends and business models in recent years. The method of the volume derived biomass is used, and the natural and artificial forest is distinguished. The results show that, taking the year 2015 as the base period, the carbon sink of the newly planted dominant tree species will reach 6,269.73×10^{4}t in 2065, the carbon sink of the original vegetation is 2,469.73×10^{4}t, and the comprehensive carbon sink reach 8,739.47×10^{4}t; so the new afforestation achieved by adding a certain area of forest land (even if the area is small, only 2.40%) contributes much more than the original forest vegetation. It is necessary to continuously increase new afforestation area to exert its carbon sink function on the basis of ensuring effective management of existing forest vegetation.

1. Introduction

The forest carbon sequestration as an important part in most provinces and regions of China is included in the carbon emission trading system (Yap et al., 2018). The methods have been adopted of the volume derived biomass, the stock volume and the average biomass in extensive research literatures (Jenkins et al., 2001). There are two aspects of content that the carbon storage and carbon density have been made comparison firstly, and secondly, the changes of carbon sink potential and carbon flux have been studied for the regional forest stand by collecting data through field sampling (Zhang et al., 2018). In the regions, which concentrates in Guangdong Province (Zhang et al., 2010), Heilongjiang Province (Ren and Xia, 2017), Shanxi Province (Wang et al., 2014), Jiangsu Province (Yang et al., 2014), Shaanxi Province (Cao et al., 2014) and Tibet (Liu et al., 2017). The optimal carbon sequestration mode and predicted the carbon trends have been predictive analysed in future years of different management plans under the premise of unchanged business model scenarios basing on the regional management characteristics and forest stand growth conditions (Gower et al., 2001). In addition, forest carbon sinks potential of forest types were analysed by Qiu et al. (2018). At the same time, the model was established to predict carbon storage changes in future years, which explain the intrinsic relationship between the stand growth period, stand age, and biomass density and forest stock volume (Xu et al., 2010).
The study constructs models to estimate values more accurately and realistically. And the models have applied by different sub-tree species, sub-stand species, sub-stand age level, and regional forest vegetation growth cycle and management characteristics (Nepal et al., 2012).

2. Methods and Model

2.1 Data

In 2015, the ninth forest resource inventory was carried out in Shanxi Province, and the forest stock volume was 20.50%. The total area of arbor forest vegetation (abbreviated to AFV) was 236.32×10^4 hm^2, and the total stock volume was 12,780.13×10^4 m^3. Among them, the natural forest area was 138.69×10^4 hm^2, the stock volume was 8,811.25×10^4 m^3, the artificial forests area was 97.63×10^4 hm^2, and the stock volume was 3,968.87×10^4 m^3.

2.2 Models

2.2.1 Forest biomass model (Forest storage volume calculation)

The Volume source biomass method uses the intrinsic relationship between biomass and stock volume. It measures the biomass density and total biomass of dominant tree species.
The formula, with this comprehensive biomass B_z of n dominant tree species, is as follows:

$$B_z = \sum_{i=1}^{n} (a_i v_i + b_i) X_i \quad (1)$$

B is the biomass density of the dominant tree species ($t.hm^{-2}$), B_z is the comprehensive biomass (t), i is a single dominant tree species, (i = 1, 2, ... n), and X is the area (hm^2), V is the unit stock volume ($m^3.hm^{-2}$), which is divided into two types: the natural and the planted forests, a and b are constants, the values are determined comprehensively according to the results measured by Fang (1996), and the data from Lu et al. (2012) and Yu et al. (2008) in study in Shanxi Province.
2.2.2 Forest biomass model (Forest stand age calculation)
The carbon sink potential of forest vegetation is predicted from two aspects. One is the carbon stock changes in the original forest vegetation ecological cycle process; the other is the carbon sink ability of new afforestation. The relationship between biomass density and growth year of the tree species is as follows:

$$B = w \big/ \left(1 + k e^{-ut}\right) \quad (2)$$

B is the biomass density, w, k and u are constants (Xu Bing, 2010). This formula is used to estimate the range of biomass density of forest vegetation (for each stand age level), and estimate the approximate age based on the different stand age levels of the regional forest vegetation. At the same time, the time required to transform from the previous stand age level to the next stand age level is estimated based on actual unit stock volume and biomass density, then the carbon storage and carbon density is measured.
There is a certain gap between the data of each stand age level within the range of stand age. The mean value is obtained by the measured data of current regional inventory report. The boundary of the upper and lower limits is available according to the above formula (2).
2.2.3 Calculation method of carbon sinks potential in Shanxi Province
(1) Comprehensive carbon storage estimation method
The total biomass B_z of a single dominant tree species is the product of biomass density multiplied by the area X, and then multiplied by the carbon content coefficient ρ, the formula for the comprehensive carbon storage is as follows:

$$C_z = \sum_{i=1}^{n} B_{zi} X_i \rho_i \quad (3)$$

C_z the sum of the current carbon storage of n dominant tree species, ρ_i is the carbon content coefficient of the i dominant tree species, which is divided into the natural and planted forest. Because of the difference in carbon content between the two types of forest, the carbon content coefficient of the single dominant tree species is replaced by this average of the natural and the planted forest. The carbon density C_c is obtained by the ratio of carbon storage to the corresponding forest vegetation area.
(2) Carbon storage calculation method for new afforestation plan
The annual net increase in the area of regional new afforestation is drawn from previous data reports on forest resource inventory, the main dominant tree species of specific new afforestation from the reports are known as well. It made assumptions that there are m tree species in the new afforestation plan, and the new afforestation quota (update) area of the h tree species is X_h. This based on the newly added area of 10 years, that is, the 10 annual net increase areas, where t is 5, and the predicted result of 50 years is measured. Therefore, the formula of carbon storage of the new afforestation in 50 years, which the carbon storage of each single dominant tree species in each period of new afforestation, is as follows:

$$C_z(t) = [a_h v_h(t) + b_h] X_h(t) \rho_h (h = 1, 2 ... m; t=1,2...5) \quad (4)$$

The new afforestation land area in each period is set to a given quota, which is a fixed value, this area is the same. The stock volume is the similar within different time periods with the same stand age level. The formula that the comprehensive carbon sinks of new afforestation in each period is as follows:

$$C_z' = \sum_{t=1}^{5}\sum_{h=1}^{m}[(t-0)C_{zh}(1)+(t-1)C_{zh}(2)+(t-2)C_{zh}(3)+(t-3)C_{zh}(4)+(t-4)C_{zh}(5)]$$
$$s.t\ \ (t-1)\le 0,\rightarrow (t-1)=0;(t-2)\le 0,\rightarrow (t-2)=0$$
$$(t-3)\le 0,\rightarrow (t-3)=0;(t-4)\le 0,\rightarrow (t-4)=0 \qquad (5)$$

(3) Expression formula of carbon sinks potential of different base periods

There are two aspects of carbon sink potential, one is the net increment in the carbon sink of the original AFV; the other is the carbon sink of the new afforestation area in the new afforestation. If the current period is the base period, the carbon sink after t years are the total carbon storage minus the carbon storage in the base period, namely the carbon sink potential is:

$$\Delta C = (C_z + C_z')_t - (C_z + C_z')_0 \qquad (6)$$

3. Empirical results

3.1 Biomass, carbon storage and carbon density of AFV

There are the proportion of natural forest area, unit stock volume and measurement coefficient of dominant tree species in the growth situation of forest vegetation in Shanxi Province. The coefficient of carbon content of dominant tree species referred to Wang (2014) analysis results in the field survey of dominant tree species in Shanxi Province.

Table 1: Characteristics of carbon storage and carbon density of dominant tree species in Shanxi Province (unit: 10^4t; t.hm^{-2})

Dominant species & types	Carbon stock	Carbon density	Dominant species & types	Carbon stock	Carbon density
All	7,183.03	30.4	Broad-leaved forest	4,450.16	33.65
Natural forest	5,099.44	36.77	Natural broad-leaved forest	3,460.62	41.1
Artificial forest	2,083.59	21.34	Artificial broad-leaved forest	989.54	20.59
Young forest	1,715.88	21.75	Quercus	1,414.47	38.63
Mid-maturation forest	2,533.49	30.47	Betula	218.15	33.72
Near-mature forest	1,821.33	41.78	Carpinus turczaninowii	62.82	18.05
Mature forest	849.04	42.67	Ulmus pumila	19.3	13.69
Over-mature forest	273.84	25.4	Styphnolobium japonicum	255.23	12
Coniferous forest	2,237.87	25.77	Tilia tuan	11.37	23.68
Natural coniferous forest	1,258.62	29.62	Populus	623.5	24.69
Artificial coniferous forest	979.25	22.08	Salix	44.3	34.89
Picea asperata	173.43	68.55	Quercus variabilis	170.75	40.18
Larix principis-rupprechtii	404.08	38.71	Soft broad-leaved forest	42.96	20.85
Pinus sylvestris	8.11	17.63	Hard broad-leaved forest	25.58	10.79
Pinus tabulaeformis	1,305.33	23.04	Mixed broad-leaved forest	1,553.19	57.48
Pinus armandii	16.31	50.98	Coniferous broad-leaved mixed forest	495.01	28.75
Pinus bungeana	75.77	23.98	Natural coniferous broad-leaved mixed forest	380.2	31.66
Cupressus funebris	157.8	16.4	Artificial coniferous broad-leaved mixed forest	114.8	22.04
Coniferous mixed forest	97.02	26.58			

The unit stock volume of natural coniferous forest is generally higher than that of natural broad-leaved forest and artificial coniferous forests. It's the same case for the broad-leaved forest. The natural tree species in coniferous forest are mainly spruce (Picea asperata), lacebark pine (Pinus bungeana), cypress (Cupressus funebris) and mixed coniferous tree species; the natural forest in broad-leaved forest are mainly robur (quercus), birch (betula), hornbeam (Carpinus turczaninowii), oriental oak (Quercus variabilis), other soft and hard broad-leaved tree species. There are differences in the average carbon content coefficients of different tree species. There are also slight differences between natural forests and artificial forests. Except for the carbon content of individual tree species such as birch, whose carbon coefficient is above 0.5, the coefficients of the other tree species are all between 0.46 and 0.48, which the mean difference is relatively small.
It is estimated that the carbon storage and carbon density of the sub-stand, sub-stand age and sub-forest species of the dominant tree species in Shanxi Province are shown in Table 1.
By the ninth forest inventory data, the carbon storage of the aboveground part of the AFV in Shanxi Province (excluding economic forest) totaled 7,183.03×10^4t, concentrated in natural forest, with carbon storage of 5,109.44×10^4t, mainly broad-leaved forest, the carbon storage is 3,460.62×10^4t. The carbon density of spruce (Picea asperata), armand pine (Pinus armandii), robur (quercus) and mixed broad-leaved tree species is higher among the species. The carbon storage of forest with different stand ages is ranked as: half-mature forest > near-mature forest > young forest > mature forest > over-mature forest. Generally, it is basically consistent with previous research conclusions, which gradually increases with the increase of stand age level.

3.2 Estimation of carbon sequestration potential of AFV in Shanxi Province in the next 50 years

3.2.1 Carbon sequestration potential of existing AFV

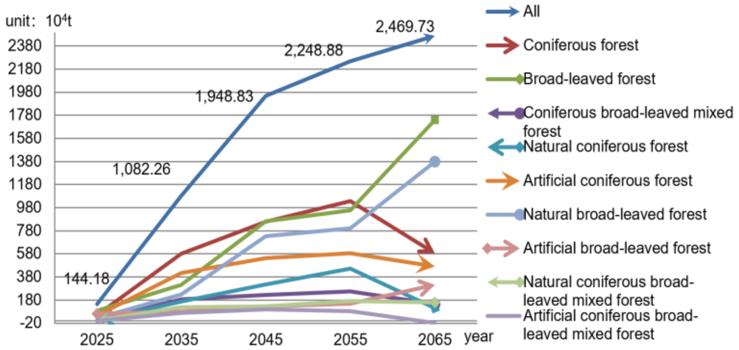

Figure 1: Trends of carbon source sinks of different forest stands of current arbor vegetation in Shanxi Province

Taking the ninth forest resource inventory as the base period(for year 2015) and every ten years as a node to calculate the change of carbon storage, it was found that the ecological circulation of AFV in Shanxi Province had play a role in carbon sink in the next 50 years. The carbon sink effect of broad-leaved forest, planted coniferous forest, natural coniferous forest, mixed forest and planted mixed forest were weakened during the period of 2055, especially for the planted mixed forest which acted as the carbon source during the year 2065. On condition that it takes for year 2055 as the base period, carbon sources function becomes dominant. In addition, the function of carbon sink in broad-leaved forest, natural broad-leaved forest and natural mixed forest are enhanced continuously.

3.2.2 Carbon sinks potential of artificial forest of new forestland

According to the data of the ninth inventory report, arbor forest land is taken as the total area of new afforestation to achieve regional new afforestation plan, which is an average net increase area of 5.68×$10^4$$hm^2$.$a^{-1}$. Based on the principle of matching site with trees, it determines major dominant tree species, and matches the area ratio of existing afforestation to allocate new afforestation areas. The carbon storage of each stand age level is calculated by measuring unit stock volume of each stand age level and the biomass, and combining with the intrinsic relationship of biomass density – stand age, the results are shown in Figure 2.
The new afforestation in Shanxi Province mainly have north China larch (Larix principis-rupprechtii), Chinese pine (Pinus tabulaeformis), black locust (Robinia pseudoacacia), poplar (Populus), mixed tree species and other coniferous and broad-leaved tree species, the carbon sink ability of the dominant tree species is ranked from high to low as: poplar (Populus) > Chinese pine (Pinus tabulaeformis) > north China larch (Larix principis-rupprechtii) > black locust (Robinia pseudoacacia) > mixed tree species > other coniferous tree species > other soft broad-leaved tree species. Therefore, if reasonable management forest were selected to achieve

optimal carbon sequestration, the tree species of Populus and Pinus tabulaeformis were the best choices, which are also two tree species with largest proportion in new afforestation in current Shanxi Province.

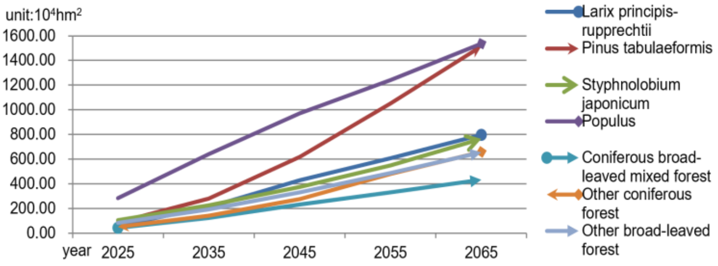

Figure 2 Trends of carbon source sinks of different forest stands of AFV in Shanxi Province

3.2.3 Comprehensive carbon sink potential development trend

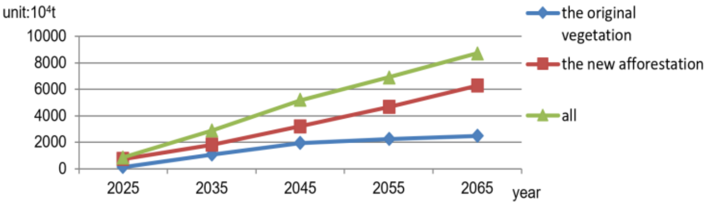

Figure 3 Trends of comprehensive carbon sinks potential of AFV in Shanxi Province

Choosing the new afforestation for obtaining carbon sinks is the optimal scheme. Among them, the carbon sinks potential of the new afforestation and the original vegetation were respectively obtained by the cumulative carbon sink amount and increment in the corresponding base period. However, there's a difference between those two. The carbon sinks of new afforestation only account for 2.27% of the existing AFV area, but its potential carbon sinks were far greater than the existing forest land in the next 50 years.

4. Conclusions

4.1 Situation of carbon storage

The total carbon storage of the aboveground part of the AFV in Shanxi Province (excluding the dead plants) is 7,183.03×10^4t, of which the natural forest is 5,109.44×10^4t, and the planted forest is 2,089.59×10^4t. The situation of sub-stand age is: half-mature forest (2,533.49×10^4t) > near-mature forest (1,821.33×10^4t)> young forest (1,715.88×10^4t)> mature forest (849.04×10^4t) > over-mature forest (273.84×10^4t); broad-leaved forest (4,450.16×10^4t) > coniferous forest (2,237.87×10^4t) > mixed forest (495.01×10^4t). Among single dominant tree species, Aobur (Quercus) has the highest carbon storage, followed by Chinese pine (Pinus tabulaeformis), the next are poplar (Populus) and Chinese scholar tree (Styphnolobium japonicum), at the same time, the carbon storages of north China larch (Larix principis-rupprechtii), cypress (Cupressus funebris), birch (Betula) and oriental oak (Quercus variabilis) are relatively high.

4.2 Situation of carbon density

The natural forest density (36.77t.hm^{-2}) of AFV in Shanxi Province is greater than that of the planted forest (21.34t.hm^{-2}). In addition to the carbon density of over-mature forest, the carbon density increases with the increase of stand age. From the perspective of stand type, broad-leaved forest > mixed forest > coniferous forest, and in both situations, the natural forest is larger than planted forest; in terms of single dominant tree species, the carbon density of spruce (Picea asperata), armand pine (Pinus armandii), robur (quercus), willow (Salix), oriental oak (Quercus variabilis) and mixed broad-leaved tree species is relatively high.

4.3 Situation of carbon sinks potential

Assume there will be no large-scale deforestation in the next 50 years, and the comprehensive carbon sink will reach 8,739.47×10^4t. Among them, the carbon sink of the original AFV will reach 2,469.73×10^4t in the 50 years, and the carbon sink of the new afforestation in the newly planted arbor tree species will be a major contributor to the carbon sink amount, reaching 6,269.73×10^4t. The increase of stand age makes a large number of vegetation reach the level of mature forest and over-mature forest, and their carbon sink potential is weakened. Their carbon sink effect is gradually replaced by the carbon source effect, that is, in a long period, the carbon stock of forest vegetation is increasing, but the growth of forest trees is accompanied by carbon release, if the forest vegetation is not harvested or updated, the comprehensive carbon sink potential will decrease.

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