Carbon Storage of Shelterbelts in Yunnan Province and Countermeasures for Increasing Carbon Sinks

Kaidi Zhang[1,**], Jianlan Su[2,*]

[1]First authors: College of Economics and Management, Southwest Forestry University, graduate student, Kunming, China.
[2]Corresponding author: College of Economics and Management, Southwest Forestry University, A.P., Kunming, China.

Abstract. Based on the data of seven national forest inventory and the fourth second-class forest inventory in Yunnan Province, the biomass expansion factor method was used to calculate the carbon storage dynamics of shelterbelts in Yunnan Province. The results show that: 1) the carbon storage of shelterbelts in Yunnan Province increased from 8868.03×10^4 tons in 1988 to 37635.01×10^4 tons in 2018, with an average annual growth of 821.91×10^4 tons. The contribution rate of shelterbelts carbon storage to the total forest carbon storage in Yunnan Province increased from 17.59% to 41.63%, and the total average carbon density of shelterbelts showed an upward trend in fluctuation. 2) the contribution rate of carbon storage of middle-aged forest (20.20%-27.44%) was the largest, the mature forest and overmature forest was the second and third, and the contribution rate of carbon storage of young forest was the lowest. The total average carbon density of shelterbelts increased with the age classes. 3) The natural shelterbelts had been the main contributor to the carbon storage in Yunnan, and its contribution rate (between 95.80% and 99.53%) decreases gradually, while the carbon density of natural shelterbelts increases with the increase of age. Compared with natural shelterbelts, the carbon storage and density of artificial shelterbelts were at a lower level, and the total average carbon density of artificial shelterbelts is on the rise. The carbon density of artificial shelterbelts of different ages is mature forest > near mature forest > over mature forest > middle aged forest > young forest. 4) Diqing Prefecture was the main contributor of carbon storage of shelterbelts in Yunnan Province (the contribution rate is 17.65%), and the carbon storage of shelterbelts in northwest Yunnan accounts for 44.19% of the total carbon storage of shelterbelts in Yunnan Province. Yunnan province should pay attention to the maturity of middle-aged and young shelterbelts, strengthen the management of artificial shelterbelts to enhance the carbon storage capacity of Yunnan shelterbelts.

1.Introduction

Forest vegetation carbon storage accounts for 76%-98% of terrestrial carbon storage, which plays a key role in promoting regional and global carbon balance, alleviating CO_2 gas and maintaining climate[1-3]. The development of industry and the continuous expansion of human activities have caused the destruction of forests on a large scale all over the world[4]. Shelterbelts is a forest community for the purpose of preventing natural disasters, protecting production, improving environment and maintaining ecological balance, the construction of shelterbelts projects have gradually attracted the attention of all countries in the world. Shelterbelts project not only has great ecological and economic benefits, but also can bring great carbon storage benefits at lower cost[5,6]. The carbon sink benefit of developing shelterbelts is an innovative measure of eco-economic shelterbelts management, it not only determines the contribution of shelterbelts as the main force of forest resources in the field of carbon sink[7], but also contributes to the optimization and practical guidance of shelterbelts management plan[8]. Therefore, it is very important to explore the carbon sink of shelterbelts based on China's "double carbon" goal, which is a beneficial exploration to keep pace with the times and realize the multiple benefits of shelterbelts.

Shelterbelts project is not only very important for the ecological service function in the basin area, but also the key channel for increasing forest sinks in Yunnan Province. Looking at the domestic and foreign research literature, many scholars have estimated the carbon storage and density of forest vegetation in different regional scales[9] or evaluated the current situation of shelterbelts construction in China and put forward optimization suggestions[10,11]. With the continuous advancement of shelterbelt project, how to combine the national goal of "peak carbon dioxide emissions and carbon neutrality", give full play to the ecological effects of shelter-forest and tap its huge carbon sink potential has become an important issue at present. Scholars' research on shelterbelts in Yunnan Province mainly focuses on the evaluation of the effectiveness of engineering construction, and there is no estimation of carbon storage of shelterbelts in Yunnan Province[12,13]. Therefore, this paper used the national

*Corresponding author: 764278555@qq.com
**1808693045@qq.com

forest inventory data to estimation of carbon storage and density of shelterbelts in Yunnan Province, aiming at understanding the dynamic change characteristics, evaluating the carbon storage capacity, and optimizing the resource structure and sustainable management of shelterbelts in Yunnan Province.

2.Data sources and research methods

2.1 Data source

Based on the perfection degree of national forest resources inventory data in each period, this paper estimated the carbon storage and density of shelterbelts in Yunnan Province based on seven inventories data (1984-2018), and analysis the carbon storage and density of shelterbelts in various cities based on the data of the fourth second-class forest resources survey in Yunnan Province (2014-2016).

2.2 Research methods

(1) Estimation method of forest carbon storage

The biomass expansion factor method in sample plot inventory method was adopted in this paper, the calculation formula of biomass expansion factor method is as follows:

$$Ct = \sum_j^n \sum_k^m [V_{j,k} \cdot BEF_{j,k} \cdot WD_j \cdot (1 + RSR_{j,k}) \cdot CF_j] \quad (1)$$

In the formula, Ct is the carbon storage of forest vegetation (10^9 Kg), $V_{j,k}$ is the volume of a tree group and a certain age (m^3), WD_j is the basic wood density of a certain tree group (t/m^3), $BEF_{j,k}$ is the biomass expansion factor, $RSR_{j,k}$ is the ratio of underground biomass to above-ground biomass of a certain tree group, and CF_j is the carbon content (%). The parameters of dominant tree species in each stand age come from the collation and analysis of existing literature and field measured data.

(2) Estimation method of forest carbon density

Carbon density is the carbon storage per unit area of forest. The calculation formula as follows:

$$P = Ct/S \quad (2)$$

In the formula, P is the carbon density (t/hm^2); S is the woodland area of a certain tree species (hm^2).

3.Results and analysis

3.1Dynamics of carbon storage and carbon density of shelterbelts in Yunnan Province

The carbon storage of shelterbelts in Yunnan Province increased from 8868.03×10^4 tons during the third inventory to 37635.01×10^4 tons during the ninth inventory, with an average annual growth of 821.91×10^4 tons. The shelterbelts in Yunnan Province all showed carbon sinks during each inventory period, and the carbon density showed a trend of rising-falling-rising, the carbon storage and density of shelterbelts in different inventory periods in Yunnan Province are shown in Table 1.

Table 1. Carbon storage and density of shelterbelts in different inventory periods in Yunnan province.

Inventory period	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
Carbon storage(10^4t)	8868.03	12232.60	15976.00	43664.96	29317.57	34182.01	37635.01
Carbon density(t/hm^2)	55.34	67.99	53.88	45.43	50.08	53.11	55.86

During the research period, the carbon storage of shelterbelts in Yunnan Province showed an overall upward trend, it stored 17.59%, 22.92%, 25.61%, 64.00%, 38.72%, 41.28% and 38.72% of the total forest carbon storage in Yunnan Province respectively, and the carbon storage of shelterbelts increased by 28766.97 $\times10^4$ tons, accounting for 61.51% of the total increase of forest carbon storage in Yunnan Province. During the sixth inventory, the large increase of middle-aged and young shelterbelts in Yunnan Province led to a significant increase in carbon storage and a significant decrease in carbon density. During the study period, the total average carbon density of shelterbelts in Yunnan Province fluctuated in the range of 45.43 t/hm^2 - 67.99 t/hm^2, and the total average carbon density in Yunnan Province increased steadily after 2004, which shows that the carbon storage function of shelterbelts was obvious.

3.2Dynamics of carbon storage and carbon density of shelterbelts in different age classes

Forest carbon storage is closely related to forest age structure, the higher the frequency of forest disturbance, the greater proportion of young forest. During the study period, the carbon storage of middle-aged shelterbelts in Yunnan was in a high state for a long time, the proportion of total carbon storage accounted for an increasing trend (2.20%, 20.73%, 22.20%, 25.95%, 24.43%, 26.07% and 27.44%). The contribution rates of total carbon storage in mature and over-mature forests (68.90%, 53.41%, 50.74%, 40.68%, 42.31%, 41.79% and 36.37%) showed a downward trend, mainly due to the continuous reduction of their areas. The carbon storage of young shelterbelts showed a rising-falling-rising trend, during the sixth inventory, the construction of the first phase of Yangtze River shelterbelts and Pearl River shelterbelts in Yunnan Province greatly increased the area of young forests, which made the carbon storage contribution rate of it higher. The carbon storage and density of near-mature forest were in a stable state, and the contribution rate of carbon storage was between 14.07% and 17.40%.

During the study period, the total average carbon density of shelterbelts in Yunnan province increased with the increase of age classes (over-mature forest > mature forest > near-mature forest > middle-aged forest > young forest). The difference of carbon density between middle-aged forest and near-mature forest was small, and the carbon density of over-mature forest was much higher than that of other age groups. The total average carbon density of shelterbelts increased slightly (0.52 t/hm^2) during the seven times of inventory, and the decline of carbon density of mature forests indicated that it was

disturbed and declined to a greater extent, the relatively large area of young forests with low carbon density indicated that the age structure of shelterbelts in Yunnan needs to be optimized.

3.3Dynamics of carbon storage and carbon density of shelterbelts of different origin

Since the fourth national forest inventory, there were statistics on shelterbelts with different origins. The carbon storage of natural shelterbelts in Yunnan Province showed an overall upward trend during the study period, with a net increase of 23880.11×10^4 tons, accounting for 94.01% of the total increase of carbon storage of shelterbelts in Yunnan Province, with an average annual increase of 796.01×10^4 tons. From 1989 to 2018, the carbon storage of artificial shelterbelts showed a net increase trend, with net increase of 1522.29×10^4 tons. The proportion of carbon storage of natural shelterbelts in Yunnan Province to the total carbon storage of shelterbelts in the same period (99.53%, 99.45%, 97.42%, 98.67%, 96.12%, 95.80%) showed a downward trend, but the natural shelterbelts in Yunnan Province still occupied a very important position, and the carbon storage function of artificial shelterbelts was gradually improved (Figure 1). The average carbon density of natural shelterbelts in Yunnan Province is much higher than that of artificial shelterbelts in each inventory period, but the difference between them decreases gradually, from 48.88 t/hm^2 in the fourth inventory period to 25.77 t/hm^2 in the ninth inventory period.

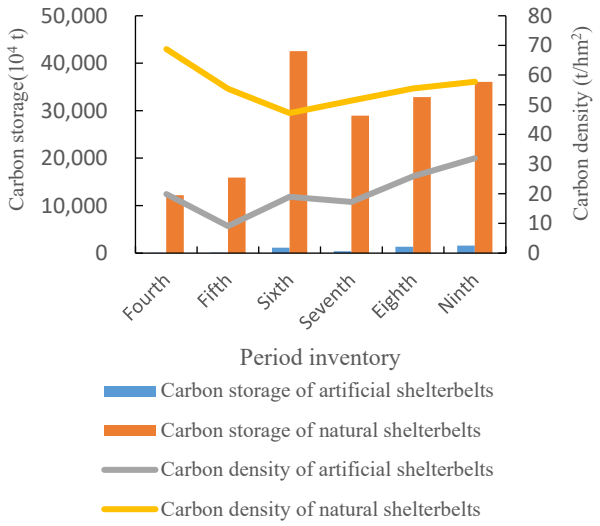

Figure 1. Carbon storage and carbon density of shelterbelts of different origins in Yunnan Province.

The carbon density of natural shelterbelts in Yunnan increased with the increase of age classes, and the carbon density of over-mature forests is much higher than that of young forests. The carbon density of artificial shelterbelts in Yunnan showed an increasing-decreasing trend with the increase of age (mature forest > near-mature forest > over-mature forest > middle-aged forest > young forest), the carbon density of over-mature forest is lower than that of middle-aged forest and near-mature forest for a long time. The carbon density of artificial shelterbelts increased rapidly with the age classes, which indicates that it has a fast carbon storage capacity, but the simple structure and the lack of competitiveness of the artificial shelterbelts make the over-mature forest lack water and nutrients, and easier to age and die.

3.4Carbon storage contribution of shelterbelts in different regions of Yunnan Province

In the fourth survey of forest resources in Yunnan Province, the total carbon storage of shelterbelts in Yunnan Province reached 24607.50×10^4 tons, of which the carbon storage of middle-aged forests was 10487.04×10^4 tons, accounting for 42.62% of the total carbon storage of shelterbelts in Yunnan Province. The carbon storage of near-mature forests and mature forests accounted for 17.50% and 17.80% of the total carbon storage of Yunnan Province, respectively, and the middle-aged forests have the highest proportion of carbon storage in most of the states and cities. From the perspective of region, the carbon storage of shelterbelts in Diqing Prefecture of Yunnan Province was the highest (4342.31×10^4 tons), accounting for 17.65% of the total carbon storage of shelterbelts in Yunnan Province, this was mainly due to the parallel flow of Jinsha River, Lancang River and Nujiang River in Diqing Prefecture. The carbon storage of shelterbelts in Yunnan ranked second to sixth respectively in Puer, Lijiang, Nujiang, Xishuangbanna and Dali, and the carbon storage of shelterbelts in Baoshan was the lowest. The carbon storage of shelterbelts in Baoshan, Lijiang, Dali, Nujiang and Diqing in northwest Yunnan accounted for 44.19% of the total carbon storage of shelterbelts in Yunnan Province.

4.Conclusions and countermeasures

4.1Conclusions

In recent years, the total carbon storage and carbon density level of shelterbelts in Yunnan Province showed an overall upward trend, and the total average carbon density of shelterbelts increased with the age classes. The carbon storage of natural shelterbelts occupies an absolute advantage in the total carbon storage of shelterbelts in Yunnan Province, and its carbon density level was higher than that of artificial shelterbelts for a long time, but the carbon density of artificial shelterbelts in Yunnan Province was on the rise, and the contribution rate of carbon storage was also increasing. The young shelterbelts in Yunnan had a large area and its carbon storage was at a general level, the carbon storage of middle-aged shelterbelts had been at a high level for a long time, while mature and over-mature forests were in a state of fluctuation, and the contribution rate of their total carbon storage had been declining in recent 20 years. The carbon storage level of shelterbelts in Diqing Prefecture was the highest, most cities showed that the carbon storage of middle-aged shelterbelts was large. The increase in the area of young shelterbelts in Yunnan province and the decrease in the area of over-mature forests indicated that the age structure needs to be optimized and the quality of shelterbelts is poor. It also shows that the shelterbelts resources in Yunnan Province

are in a relatively young state, with the tending and growth of trees, shelterbelts can contribute more to the forest carbon storage in Yunnan.

4.2Countermeasures for increasing carbon sink of shelterbelts in Yunnan Province

1) Pay attention to the tending management of middle-aged and young-aged shelterbelts, ensure the smooth maturity of middle-aged and young-aged forests, reasonable thinning, eliminating the inferior and retaining the superior. Give priority to the protection of mature forests and over-mature forests, cut them rationally, and reduce the impact of artificial management and destruction on them.

2) Strengthen the intensive and efficient management of artificial shelterbelts, carry out long-term and multi-level forestry planning, and optimize the tree species structure of artificial shelterbelts. Update aging trees in time, make full use of the rapid carbon accumulation characteristics of artificial shelterbelts and continuously improve the contribution rate of carbon storage of artificial shelterbelts.

3) Adjust the age-class structure of shelterbelts, strengthen the tending of young and middle-aged forests, and actively renew inefficient and degraded forests. Actively use digital technology to detect and analyze the status of shelterbelts resources, and contribute to the goal of “double carbon” in Yunnan.

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