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A Study on the Planning and Design of Campus Plant Communities Based on the Carbon Sink Capacity of Vegetation

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Abstract: The purpose of this paper is to study the planning and design of campus plant communities from the perspective of vegetation carbon sink capacity. During the research period, based on literature review and material investigation, the quantitative calculation of the carbon sink capacity of the vegetation of the campus of the case study university was carried out using the i-Tree model, and the shortcomings of the carbon sink level of the campus vegetation community were pointed out based on the calculation results. Subsequently, with the goal of improving the carbon sink capacity, the park is oriented to the planning and design of vegetation communities, and the feasibility of the program is demonstrated with the support of the data on the level of carbon sink capacity after the implementation of the program. It is hoped that this paper can provide technical reference for the managers of universities and urban landscape departments in China, and actively promote the optimization of vegetation communities, enhance the carbon sink capacity, and promote the full implementation of the goal of sustainable development.

Keywords: Carbon sink capacity; Planning and design of plant communities; i-Tree model; Annual carbon sequestration

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1. Introduction

Although advocated by the state, a large number of campus managers in China have attached great importance to the arrangement of vegetation in campus parks, aiming to create a good low-carbon space for teachers and students. However, most campuses have problems such as single species and simple layers of vegetation . At the same time, blindly planting vegetation not only wastes a lot of costs but also fails to maximize the carbon sink potential of the vegetation community. The quantitative calculation of carbon sink capacity can effectively identify low carbon sink areas in campus parks, guide campus managers to adjust the ratio of trees, shrubs and grasses, and create multi-level composite communities, thus effectively improving the carbon sink potential per unit area, breaking through the limitations of the traditional "empirical model" during the planning of vegetation communities, and enable the park to achieve the goal of low-carbon development while providing educational value for sustainable development to the student group.

1.1. Contribution of vegetation carbon sink capacity to campus environment

(1) Carbon sink mechanism and carbon sequestration efficacy

The vegetation carbon sink system in the campus will rely on photosynthesis and use chloroplasts to capture light energy, convert atmospheric carbon dioxide into carbohydrates, and store them in biomass to achieve carbon accumulation and fixation. With the multi-layered structure of trees, shrubs, and grasses on campus, a three-dimensional carbon sequestration network can be created. Among them, the huge biomass of trees can lay the foundation of carbon sinks, and the cooperation between shrubs and herbaceous plants can make use of the dense leaf area to improve the efficiency of carbon assimilation [1].

(2) Microclimate regulation and environmental optimization

The vegetation community in the campus can significantly regulate the microclimate of the campus through transpiration and the shading effect of the shrub layer. The transpiration process of plants can effectively consume heat and lower the surrounding air temperature, forming a "local cold island" effect in the campus. The evaporation of water from the surface of the vegetation leaves can effectively increase the humidity of the air and alleviate the dryness of the environment. The canopy structure can effectively weaken the solar radiation, reduce the absorption of ground heat, and reduce the load of the air-conditioning system of the campus buildings [2].

(3) Educational value and dissemination of sustainable development concepts

The campus vegetation carbon sink system is a natural "ecological classroom" for students. Students can understand the ecosystem, the carbon cycle mechanism and the ecological function of vegetation through participating in plant conservation and monitoring of carbon sink data on campus. This kind of immersion education based on the campus environment can help students to establish ecological protection awareness, cultivate low-carbon life concepts, and strengthen the penetration of the concept of sustainable development under the influence of practice and the environment [3].

1.2. Campus vegetation carbon sink capacity analysis

(1) Campus overview and vegetation communities

This paper relies on the scientific and technological research project of Chongqing Municipal Education Commission - 9/16-7 Survey on Campus Vegetation Carbon Sink Capacity of Colleges and Universities. It was launched in July 2022, focusing on the data collection and analysis of campus carbon sink capacity in a certain university campus in Chongqing. In the research stage, based on literature reading combined with on-site research, a suitable carbon sink model was selected to investigate the carbon sink capacity of the vegetation of the case campus.

At present, the vegetation community of the case university campus adopts the form of "tree-shrub-grass" composite structure, and the tree layer contains more than 1,400 suitable tree species, which together create the main skeleton of the community and assume the dominant role of the campus carbon sequestration and oxygen release function. Shrubs and herbs cover an area of 9,500 square meters, jointly constructing the bottom ecological network of the campus, and the combination of shrubs and grasses can enhance the soil and water conservation capacity through the dense root system.

(2) Calculation of vegetation carbon sink capacity based on i-Tree

This project uses the i-Tree model to calculate the vegetation carbon sink capacity of the campus, combining the aerial survey of the drone with the meteorological department to obtain the vegetation data and meteorological data of the campus, and then calculating the key results on an annual scale to lay a data foundation for the analysis of the campus vegetation carbon sink level.

2. Basic data

For the acquisition of basic data, the drone was first used to conduct aerial surveys of the vegetation distribution map on the campus, and combined with the records of the field survey, 1,200 trees with a diameter at breast height of ≥ 5cm and 8,000m^2 of shrubs and herbaceous species were recorded, and parameters such as the diameter at breast height, height of the plant, and irrigation width of the species were extracted and obtained. At the same time, the meteorological data of the campus was synchronized with the meteorological department. The average annual temperature of the campus is 16°C, the precipitation is 1200mm, and the soil is sandy loam.

2.1. Key results based on annual scale

Taking the year as the scale, using the i-Tree model and based on the hetero-rate growth equation for biomass carbon, soil pool model, and carbon sink rate formula, the calculation results of carbon sink indicators are output. Formula 1 and 2 are biomass carbon and carbon sink rate expressions, respectively, and the soil organic carbon content is 2.3 kg/m^2 -year.

(1) Formula 1: Arbor carbon stock = 0.059 × diameter at breast height^2 × tree height × wood density

(2) Formula 2: Annual carbon sequestration = biomass carbon gain + soil carbon gain

Table 1 shows the key indicators of the carbon sink level of the park's vegetation communities in 2022 on an annual scale:

Table 1. Key indicators of the carbon sink level of the park's vegetation communities in 2022

Vegetation type	Number of plants/area	Biomass carbon stock	Soil carbon stock	Annual carbon sequestration	Value of carbon sinks
Trees	1,200 trees	850.2t	420.5t	285.6t/CO_2	17136 Yuan
Shrubs/herbs	8,000m^2	120.5t	180.3t	68.2t/CO_2	4092 Yuan
Total	--	970.7t	600.8t	353.8t/CO_2	21228 Yuan

Analyzing the calculation data of the key indexes in **Table 1**, it can be concluded that in terms of the intensity of carbon sinks, the average annual carbon sequestration by the vegetation in the park is 353.8t CO_2, which can offset the average annual exhaust emissions of 76 vehicles by calculating the annual average emissions at 4.65t CO_2 per vehicle per year, and based on the carbon value of 60 yuan per ton of CO_2, equivalent to 21,000 yuan. As for the efficiency of vegetation structure, the average tree diameter at breast height of the park is 18cm, dominated by fast-growing species of poplar, accounting for more than 65%, and trailing broad-leaved trees such as balsam fir account for 15%, with 40% shrub layer coverage, 70% herbaceous coverage, and it is mainly a single lawn [4].

3. Analysis of shortcomings in carbon sink capacity

At present, the shortcomings in carbon sink capacity of the vegetation communities in the park include structural defects and functional bottlenecks.

3.1. Structural defects

From the perspective of carbon sink capacity, the structural defect of the vegetation community in this university campus is first reflected in the single vertical hierarchy. At present, the area with a complete three-layer structure of trees, shrubs and grass in the park accounts for only 25% of the campus green space area. 30% of the green space forms are concentrated in single-layer trees and pure lawns, with a leaf area index of only 2.1, lower than the ideal value of 3.5, indicating insufficient utilization of light energy. Secondly, there is an imbalance in the allocation of species. The proportion of fast-growing poplar trees (with an average annual carbon sequestration rate of 4.2kg per tree per year) is too high, while the proportion of slow-growing broad-leaved trees such as camphor trees (with an average annual carbon sequestration rate of 7.8kg per tree per year) is relatively low, resulting in the inability to fully release the carbon sink potential per unit area. The third manifestation is the weakness of the soil carbon pool. The soil organic carbon content in the lawn area of the park is 12.3g/kg, which is much lower than 18.5g/kg in the soil under the tree forest. The root distribution is relatively shallow, generally less than 20cm, further intensifying the risk of carbon loss [5].

3.2. Functional bottleneck

First, the functional bottleneck of the vegetation community in the university campus is reflected in the uneven spatial distribution of carbon sinks. According to the survey, the green space rate of the teaching area is only 22%, and the hard surface around the administrative building accounts for 80%, the carbon sink hotspot of the whole campus focuses on the peripheral forest area, which accounts for 60% of the total carbon storage of the campus, and the core area of the campus is seriously insufficient in carbon sink service capacity. Secondly, it is reflected in the lagging management measures. The school arranges the gardener to prune the shrubs frequently, which leads to the slow biomass accumulation of the shrubs, with an average annual growth of only 0.05 kg/m^2, while the long-term over-irrigation of the lawn causes the problem of shallow lawn root system, and the carbon sequestration capacity of the soil decreases by 15%-20% compared with the normal root depth [6].

4. Planning and design of campus vegetation communities with the goal of enhancing carbon sink capacity

For the shortcomings of the carbon sinking capacity of the vegetation community in the case of the campus, this study takes the chain of “Goal Orientation→Spatial Layout→Species Optimization” as the core idea, and formulates a systematic planning scheme for the vegetation community, with the aim of enhancing the carbon sinking capacity of the vegetation community.

4.1. Goal orientation

Combined with the calculation of carbon sink capacity and the analysis of shortcomings, three major goals are set: carbon sink enhancement, structural optimization, and functional synergy. Under the goal of carbon sink enhancement, the annual carbon sequestration of the campus vegetation community will be increased to 40%, i.e., 495t of CO_2 per year. Under the goal of structure optimization, the coverage of tree-shrub-grass three-layer structure should be increased to > 60%, the proportion of slow-growing broadleaf trees should be increased to 30%, and the proportion of native trees should be guaranteed to be ≥ 70%. Under the functional synergy objective, a series of ecological services such as rainwater retention and air purification are simultaneously enhanced [7].

4.2. Spatial layout

For the spatial layout of the vegetation community, the main optimization objects are four areas: the core teaching area, the living function zoning area, the peripheral ecological area, and the road corridor.

4.2.1. Layout design of core teaching area

The core teaching area mainly faces the problems of serious hardening of the surrounding ground and weak carbon sinks. In order to solve this problem, a hierarchical green space is constructed by planting tree arrays, border shrubs, and shade-tolerant herbaceous plants. The tree array selects native tree species that are in the rapid growth stage of middle-aged and young adults, such as: Duyin, Ficus microcarpa, Bilberry, etc.; the shrubs are selected from the shade-resistant and pruning-resistant varieties, such as: small-leaved poplar, octagonal gold plate, etc.; the small square in the teaching area is converted into permeable paving + trampling-resistant herbs such as dogtooth root, which can effectively increase the projected green coverage rate of the teaching area from 22% to more than 40%.

4.2.2. Layout design of living functional area

Campus living functional area is concentrated in the area of student dormitory and cafeteria, and the main problem lies in the significant heat island effect and high energy consumption of buildings. For the living service area, plant tree species with strong adsorption capacity, such as oleander and paper mulberry. The width should be guaranteed to be no less than 10 meters. Meanwhile, for the roof greening of buildings, the form of Sedum sinensis and shrubs should be adopted, with the proportion of area required to be ≥ 20%. The overall vegetation community should have a carbon sequestration capacity of ≥ 80kg/m^2, and the annual carbon sequestration target should meet 15t of CO_2.

4.2.3. Layout design of peripheral ecological zone

The main problem faced by the peripheral ecological zone lies in the single fast-growing forest, which makes it difficult to fully release the carbon sink efficiency. To solve this problem, on the one hand, replanting bushes in the forest garden, the species chosen are Lespedeza, Purple acacia, the height is controlled at 1.5–2m, and the coverage rate should be ≥ 50%. On the other hand, carbon sequestering herbs such as white clover are sown in the forest open space to enhance the soil carbon input capacity. In addition, the ratio of tree-shrub-grass should be set at 5:3:2 to ensure that the annual soil carbon increase is 2%.

4.2.4. Layout design of road corridor in the park

The main problem of the road corridor lies in the single street tree and insufficient shading carbon sink. To address this issue, on the one hand, the main roads are replaced with multi-layered street trees. The upper layer uses Sophora japonica or camphor trees, while the lower layer uses red-leaf photinia. The tree spacing is set at 6 to 8 meters. On the other hand, vertical green belts in the form of flower boxes should be added to the pedestrian crossings. The varieties can be ivy or climbing roses to ensure that the leaf area quality index is increased to 4.0 [8].

4.3. Species optimization

In the optimization stage of the species matrix for the vegetation community in the park, for the tree layer, with “high carbon sink + longevity” as the target. On the basis of ensuring that the proportion of native land is over 70%, Ficus virens, camphor trees and ginkgo trees are selected to ensure that the annual carbon sequestration potential reaches 18 to 25 tons of CO_2 per hectare. For the combination of “sand + purification”, poplar and tree can be adopted to ensure that the annual carbon sequestration potential reaches 12~18 tons of CO_2/ha.

For shrubbery, the goal is to achieve “soil stabilization + nectar source”. Native shrubs such as rhododendron and camellia bauhinia can be used to ensure that the annual carbon sequestration potential reaches 6~9 tons of CO_2/ha. For the objective of “shade tolerance + landscape”, rhododendron and heather were selected to ensure the annual carbon sequestration potential of 4~6 tons of CO_2/ha [9].

For the herbaceous layer, the goal is to achieve “carbon sequestration + low maintenance”. Aster and iris are chosen to ensure annual carbon sequestration potential of 3~5 tons CO_2/ha. For the objective of “rainwater retention + ornamental”, iris, aster, and daylily were selected to ensure the annual carbon sequestration potential of 2~4 tons CO_2/ha [10].

5. Calculation of carbon sinks after planning implementation

After implementing the above layout scheme and species matrix optimization strategy for the case university campus, the quantitative test of carbon sinks of the park's vegetation communities was carried out again after 1 year, and the test results are shown in **Table 2**.

Table 2. Carbon sinks achievements of the park's re-layout and species optimization

Indicators	Before optimization (2022)	After optimization (2024)	Enhancement amount
Carbon Sequestered per Year	353.8t CO_2	495t CO_2	+40%
Soil carbon stock	600.8t	820t	+37%
PM2.5 annual adsorption	12.5t	18.7t	+50%
Biomass carbon stock	970.7t	1350t	+39%
Leaf area index	2.1	3.8	+81%

Combined with the post-measurement data in **Table 2**, it is not difficult to see that the vegetation community based on the project "structural stratification+species rusticization" has been significantly improved. The annual carbon sequestration, soil carbon storage, and other indicators have been significantly improved.

6. Conclusion

In summary, this project quantifies the carbon sink capacity of the vegetation communities in the case campus, and points out the structural deficiencies and functional bottlenecks of the carbon sink capacity of the vegetation communities in the university campus based on the statistical data. Subsequently, this paper takes the chain of goal orientation → spatial layout → species optimization to carry out the design of the campus vegetation community planning scheme with the goal of enhancing carbon sink capacity. After the implementation of the program, the annual carbon sequestration, soil carbon storage, biomass, carbon storage and other indicators of the campus have been significantly improved after one year, which fully demonstrates the value of structural compounding, species vernacularization, and the layout of vegetation communities for improving the carbon sink capacity. The administrators of universities in China can use this paper as a planning paradigm to promote the optimization of vegetation communities in the campus, fully explore the potential of carbon sink capacity, and make technical guarantee for the creation of a good campus ecology and the implementation of the theory of sustainable development.

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