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Methodology and calculation of carbon sink in Baiyangdian water body

Lijun Li, Kaiyang Sun, Yanli Li*

School of Economics and Management, Shijiazhuang Railway University, Shijiazhuang 050043, China, email: lyl56857@163.com

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ABSTRACT

In the past 10 y, it has been one of the main directions of the international scientific and business circles to compensate the carbon emission in the economic development by increasing the ecosystem carbon pool. The research and application of the water body carbon sink methodology of Baiyangdian is an important link connecting the ecological function and economic value of Baiyangdian. This paper combines the actual situation of Baiyangdian waters, comprehensively considering the size of carbon sinks and the convenience of data acquisition, using reed carbon sinks, aquatic organisms carbon sinks, and water-soluble carbon sinks to reflect the carbon sink capacity of Baiyangdian water bodies. Research and application of reeds, aquatic organisms, and water-soluble carbon sink methodology, respectively. Based on the methodology and relevant data, the carbon sink amount of Baiyangdian water body was estimated. The results showed that the water-soluble carbon sink amount of Baiyangdian water body at the present stage was higher than the carbon sink amount at the full water level, which indicates that the annual water injection of Baiyangdian is higher than the ecological water demand in normal state due to the expansion of water area; Baiyangdian water body has great potential for carbon sinks, and the annual carbon sink is considerable, which is the key factor to achieve regional carbon neutrality.

Keywords: Baiyangdian water body; Carbon sink measurement; Methodology; Carbon neutralization

1. Introduction

Baiyangdian, as the largest wetland-type freshwater lake in North China, not only has the function of regulating and storing flood, purifying water quality, and adjusting regional climate, but also has the function of wetland biodiversity protection in North China and ecological environment stability in North China Plain, which plays an irreplaceable role in the overall ecological pattern of Beijing, Tianjin, and Hebei.

Baiyangdian water body carbon sink is an important part of Baiyangdian Wetland carbon sink system, which plays an important role in absorbing greenhouse gases such as CO_2 and promoting regional sustainable development. Baiyangdian is an important part of the blue–green space in the Xiong'an New District. Under the background of carbon trading and carbon market, giving full play to the function of Baiyangdian's water body carbon sink is the basic premise for Xiong'an New District to build a model city of ecological civilization in the new era, and it is also the realistic basis for achieving regional carbon neutralization and near-zero emissions.

2. Basic principles of water carbon sink

The understanding of water bodies can be divided into narrow water bodies and broad water bodies. Article 3, paragraph 6 of the General Provisions of Water Law in Germany defines narrow water bodies as: the whole and important reaches (surface water body) of a surface water body or coastal water body and the separated underground water reserves (underground water

* Corresponding author.

body) within the scope of one or more underground water sources [1]. In the broad sense, the water body defined by Professor Cai Shouqiu refers to the water ecosystem formed by water, aquatic organisms, and other substances in the water, as well as the water bank bottom [2].

Carbon sink refers to the process, activity, or mechanism of removing greenhouse gases from the atmosphere and fixing them to other carbon pools to reduce the amount of greenhouse gases in the atmosphere. The distribution of "sources" and "sinks" is influenced by external factors such as latitude, site conditions, surface cover, and time, and there is a general phenomenon of conversion between "sources" and "sinks" [3]. The mechanism of action of carbon sinks in water can be roughly divided into two types. The first is that CO_2 dissolves in water and chemically reacts with water to form carbonic acid. The second is to use aquatic plants to convert carbon dioxide in the atmosphere into organic matter through photosynthesis. Under the action of the food chain, the organic matter is transferred in the organism and plays a role in carbon fixation [4]. The excreta of aquatic animals (feces and nitrogen excreta, etc.) can also be used by lower organisms or fish. After the aquatic organisms die, their residues are transformed into humus and peat through humification and peatification, and are stored in the mud bottom in this form [5]. The basic principle of water carbon sink is shown in Fig. 1 below.

3. Baiyangdian water body carbon sink methodology

According to the basic principle of water body carbon sink and combined with the characteristics of Baiyangdian water, in order to facilitate data acquisition and carbon sink measurement, this paper divides the carbon sink methodology of Baiyangdian water body into reed carbon sink methodology, water-soluble carbon sink methodology, and aquatic organisms carbon sink methodology.

3.1. Methodology of carbon sinks for reed

Whether the reed wetland is a source or sink of greenhouse gases depends mainly on the balance between net CO_2 absorption and CH_4 release. It is generally believed that methane has a greater global warming potential than CO_2 [6]. HansBrix found in the study of the Vejleme Nature Reserve and the Reed wetland in Europe that the reed wetland was a net carbon source in the growing season and released a small amount of CO_2 and CH_4 in winter. The methane emission is about 4% of the fixed CO_2 in photosynthesis, accounting for only 9% of the fixed carbon in wetland, combined with the global warming potential and molar ratio analysis of CH_4 and CO_2, it shows that the reed wetland ecosystem has shown a net carbon sink effect within a few decades of stable growth [7].

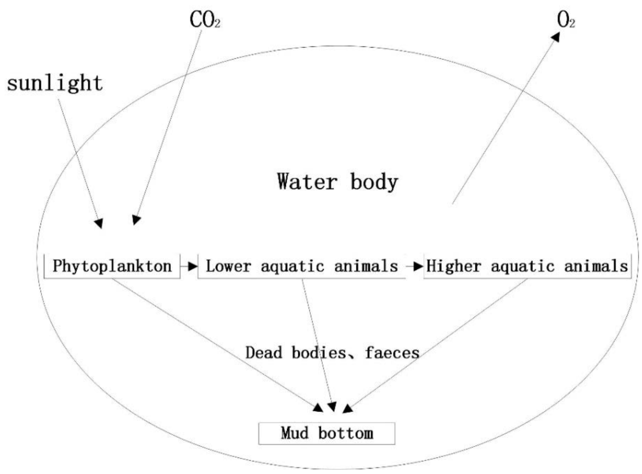

Fig. 1. Basic principles of water carbon sink.

3.1.1. Project accounting boundary

The accounting boundary of reed carbon sinks refers to the geographic range of reed carbon sinks in Baiyang Lake, measured in square meters.

3.1.2. Calculation of carbon sink of reed

The reed growth of Baiyangdian begins at the end of March every year and finally ends at the end of October each year. The main growth period is from June to August. During the growth period, the reed absorbs CO_2 through photosynthesis during the day and releases CO_2 through respiration at night, during this period, the reed is both a carbon source and a carbon sink. After the growth period, reeds stopped photosynthesis, and only acted as a carbon source. During the growth period, reed showed different photosynthetic characteristics in different months and absorbed different amounts of CO_2.

$$B_{\overline{\mathrm{Pn}}} = A_{\mathrm{RREED},t} \times N_{\mathrm{REED}} \times \int_{4}^{10} \mathrm{Pn} \quad (1)$$

In Eq. (1): $B_{\overline{\mathrm{Hn}}}$ is the average net absorption of CO_2 during the growth period of reed (g); $A_{\mathrm{RREED},t}$ is the area of reed planting in the t year (m^2); N_{REED} refers to trees planted with reed plants per unit area (plant/m^2); $\int_{4}^{10} \mathrm{Pn}$ is the net absorption of CO_2 in different months during the growth period (g/m^2 d).

$$B_{\overline{\mathrm{Hn}}} = A_{\mathrm{RREED},t} \times N_{\mathrm{REED}} \times \int_{10}^{12} \mathrm{Hn} \times \int_{12}^{4} \mathrm{Hn} \quad (2)$$

In the Eq. (2): $B_{\overline{\mathrm{Hn}}}$ is the average net absorption of CO_2 during the growth period of reed (g); $A_{\mathrm{RREED},t}$ is the area of reed planting in the t year (m^2); N_{REED} refers to trees planted with reed plants per unit area (plant/m^2); $\int_{10}^{12} \mathrm{Hn} \times \int_{12}^{4} \mathrm{Hn}$ is the CO_2 emissions in different months during the non-growth period (g/m^2 d).

Reed carbon sink:

$$\mathrm{XARFS} = \left(B_{\overline{\mathrm{Pn}}} - B_{\overline{\mathrm{Hn}}} \right) \quad (3)$$

In Eq. (3): XiongAn reed carbon sinks (XARFS) is the carbon sink of reed (g).

3.2. Methodology of carbon sinks for aquatic organisms

Baiyangdian is rich in aquatic organisms and species diversity. There are studies showing that a total of 43 species of zooplankton have been identified in Baiyangdian water body in the three seasons of 2019 [8]. Zooplankton as a primary consumer is a key link in the aquatic food chain. Under the action of food chain, the organic matter generated by photosynthesis is transferred down and fixed into aquatic organisms.

3.2.1. Project accounting boundary

The accounting boundary of aquatic biological carbon sink refers to the geographical scope of aquatic biological carbon sink activities in Baiyangdian, in square meters.

3.2.2. Calculation of biomass of newly released aquatic organisms

Calculate the newly released aquatic biomass based on the data monitored by the participants during the crediting period (t) of the newly released aquatic organisms in different years (t) and the data collected by the carbon sink carbon measurement department:

$$B_{\text{NPAO},t,i} = N_{\text{NPAO},i,t} \times \int_{b\text{AO}}^{\bullet} \left(L_{\text{AO},i}, W_{\text{AO},i}\right) \quad (4)$$

In Eq. (4): $B_{\text{NPAO},t,i}$ is the newly released i-th aquatic biomass in year t (g); $N_{\text{NPAO},i,t}$ is the number of the newly released i-th aquatic organism in year t (piece/m^3); $\int_{b\text{AO}}^{\bullet}\left(L_{\text{AO},i}, W_{\text{AO},i}\right)$ is a function of the biomass and length and weight of the single aquatic organism in the i-th (g/piece); $L_{\text{AO},i}$ is the mean length (cm) of aquatic organisms newly released to the i in year t. $W_{\text{AO},i}$ is the average weight (g/piece) of aquatic organisms newly released to the i in year t.

3.2.3. Calculation of new input aquatic biological carbon storage

The carbon storage of newly invested aquatic organisms is to use the carbon content of aquatic organisms to convert the newly invested aquatic organisms into carbon storage, and then use the molecular weight (44/12) ratio of CO_2 and C to convert the carbon storage (g/C) into carbon dioxide equivalent (g):

$$C_{\text{NPAO},t} = \sum_i \frac{44}{12} \times B_{\text{NPAO},t,i} \times \text{CF}_{\text{AO},i} \quad (5)$$

In Eq. (5): $C_{\text{NPAO},t}$ is the newly input aquatic biomass carbon storage in year t (g); $B_{\text{NPAO},t,i}$ is the newly released i-th species of aquatic biomass in year t (g); $\text{CF}_{\text{AO},i}$ is the carbon content in the biomass of the ith aquatic organism (g/g).

3.2.4. Calculation of carbon sequestration of dead aquatic organisms

Aquatic organisms of all ages have a certain mortality rate, part of the carbon in aquatic organisms enters the carbon cycle again through other aquatic organisms and microorganisms, and the remaining carbon is fixed by becoming sediment. Since the carbon that re-entered the carbon cycle when the aquatic organism died has been included in the carbon sink in the past, the carbon that entered the carbon cycle should be subtracted when the aquatic organism died.

Carbon sequestration of dead aquatic organisms:

$$C_{\text{DAO},t,i} = \frac{44}{12} \times \left(\beta_i\right) \sum_{L}^{1\le L\le t} \left\{ \text{PN}_L \times \left(1-\alpha_{i,t+1-L}\right) \times \prod_{j=1}^{j\le t-L} \alpha_{i,j} \right\} \quad (6)$$

In Eq. (6): $C_{\text{DAO},t,i}$ is the carbon sequestration (g) of the death of the i-th aquatic organism in year t; β_i is the carbon sequestration efficiency of the corpse of the i-th aquatic organism, which is dimensionless; L is the year of aquatic organism input from the project application cycle, dimensionless; PN_L is the input of the i-th aquatic organism in year L (piece); $\alpha_{i,j}$ is the survival rate of the i-th aquatic organism of the age j, dimensionless.

3.2.5. Calculation of living aquatic biomass

$$B_{\text{AO},t,i} = A_{\text{AO},t} \times H_{\text{AO}} \times N_{\text{AO},t,i} \times \int_{b\text{AO}}^{\bullet} \left(L_{\text{AO},i}, W_{\text{AO},i}\right) \quad (7)$$

In Eq. (7): $B_{\text{AO},t,i}$ is the i-th aquatic biomass in the t-year water area (g); $A_{\text{AO},t}$ is the water area in the year t (m^2); H_{AO} is the average depth of the water in year t (m); $N_{\text{AO},t,i}$ is the number of the i-th aquatic organism in the unit water volume in year t (piece/m^3); $\int_{b\text{AO}}^{\bullet}\left(L_{\text{AO},i}, W_{\text{AO},i}\right)$ is a function of the biomass and length and weight of the single aquatic organism in the i-th (g/piece); $L_{\text{AO},i}$ is the mean length (cm) of aquatic organisms newly released to the i in year t. $W_{\text{AO},i}$ is the average weight (g/piece) of aquatic organisms newly released to the i in year t.

3.2.6. Calculation of carbon reserves of living aquatic organisms

The carbon storage of aquatic organisms is to use the carbon content of aquatic biomass to convert the aquatic biomass into carbon storage, and then use the molecular weight (44/12) ratio of CO_2 and C to convert the carbon storage (g/C) into carbon dioxide equivalent (g):

$$C_{\text{AO},t} = \sum_i \left(\frac{44}{12} \times B_{\text{AO},t,i} \times \text{CF}_{\text{AO},i} \right) \quad (8)$$

In Eq. (8): $C_{\text{AO},t}$ is the carbon storage of aquatic organisms in year t (g); $B_{\text{AO},t,i}$ is the i-th species of aquatic biomass in year t (g); $\text{CF}_{\text{AO},i}$ is the carbon content of the i-th aquatic organism (g/g).

3.2.7. Calculation of carbon sink of aquatic organisms

$$\text{XAAOCS} = C_{\text{AO},t2} - C_{\text{AO},t1} - C_{\text{NPAO},t} + \sum_i C_{\text{DAO},t,i} \quad (9)$$

In Eq. (9): Xiongan quantitative organizations carbon sinks (XAAOCS) is the carbon sink of aquatic organisms (g); $C_{\text{AO},t2}$ is the carbon storage of aquatic organisms in the $t2$ year (g); $C_{\text{AO},t1}$ is the carbon storage of aquatic organisms in the $t1$ year (g); $C_{\text{NPAO},t}$ is the newly input carbon storage of aquatic organisms in year t (g); $C_{DAO,t,i}$ is the carbon fixation of the i-th species of aquatic organisms in year t (g).

3.3. Methodology of carbon sink for water-soluble

Baiyangdian has a vast water area, rich in water, which can dissolve a large amount of CO_2, and has considerable water-soluble carbon sink potential.

3.3.1. Project accounting boundary

The calculation boundary of water-soluble carbon sink is that the volume of water in Baiyangdian water area is more than 1 m^3, and the volume of lakes, ditches, etc., is in cubic meters.

3.3.2. Calculation of water-soluble carbon sink

$$\text{XAWCS} = \text{WA}_t \times H_t \times \delta_i \times \gamma_i \times 1{,}000 \quad (10)$$

In Eq. (10): Xiongan water carbon sinks (XAWCS) is the water carbon sink (g); WA_t is the water area in the T year (m^2); H_t is the average depth in the T year (m); δ_i is the solubility of CO_2 in water at normal temperature and pressure, dimensionless; γ_i is the mass of CO_2 per unit volume (g).

4. Estimate of carbon sink of Baiyangdian water body

According to the carbon sink methodology of Baiyangdian water body, the carbon sink amount of Baiyangdian is estimated at the current stage and at the stage of full water level in the future. Based on the total amount of carbon sink in Baiyangdian water body = reed carbon sink + aquatic organism carbon sink + water-soluble carbon sink, the total amount of reed carbon sink, aquatic organism carbon sink, and water-soluble carbon sink in Baiyangdian water body at the stage of occurrence and future full water level were calculated respectively, and then estimate the total amount of carbon in Baiyangdian water body.

4.1. Estimation of carbon sink of reeds in Baiyangdian

The Baiyangdian reed root system is well-developed, and more than 50% of its biomass comes underground. Experiments have shown that Baiyangdian reeds have a maximum net CO_2 emissions of 0.178 g/m^2 h at night in October, 50% of which was taken to represent CO_2 released by respiration of reed root. According to the survey data, as of 2018, the area of reeds in Baiyangdian was 125,000 mu. The amount of CO_2 released by respiration of Baiyangdian Reed during non-growth period:

$$12.5 \times 10{,}000 \times 666.67 \times 0.178 \times 50\% \times 24 \times 30 \times 6 = 32{,}040\ t \quad (11)$$

Similarly, during the whole growing season, the average daily net CO_2 absorption of reed in Baiyangdian is 4.89 g/m^2 d [9]. The amount of CO_2 absorbed by the net photosynthesis of Baiyangdian reed during the growing period:

$$12.5 \times 10{,}000 \times 666.67 \times 4.89 \times 30 \times 6 = 73{,}350\ t \quad (12)$$

Annual net carbon sink of Baiyangdian reed:

$$73{,}350 - 32{,}040 = 41{,}310\ t \quad (13)$$

According to the survey data, the Baiyangdian water area was 270 km^2 by 2019. According to the outline of the plan for the Xiongan new area in Hebei province, "Haidian district has gradually been restored to about 360 km^2". That is, the Baiyangdian area will expand by 33% in 2035. Suppose the reed expands by 30%.

Annual net carbon sink of reed at full water level of Baiyangdian:

$$41{,}310 \times 30\% + 41{,}310 = 53{,}730\ t \quad (14)$$

The calculation data of this methodology does not consider the amount of CO_2 released by the burning of reed biomass due to natural fires and the CO_2 released by reeds for other purposes.

4.2. Estimation of carbon sinks of aquatic organisms in Baiyangdian

The aquatic organisms in Baiyangdian water are complex and diverse. Considering the convenience of data calculation and the difficulty of data acquisition, the carbon sink amount of microorganisms, and primary consumers in the water is ignored, and the newly released senior consumer fish is adopted to represent the carbon sink amount of aquatic organisms.

According to the survey data, in 2018, the government department of Anxin County delivered silver carp and bighead carp to Baiyangdian, with sizes ranging from 64 to 395 g/tail, 48.0795 million catties, and 2,457,600 tails; 40 million tails of blue shrimp seedlings with a discharge length of more than 1 cm; grass carp, 60.7–485 g/tail, 562.479 kg, 779,250 tails; the Xiong County government department released 30.927 kg of grass carp to Baiyangdian.

A total of 593.406 kg of grass carp was put in. According to the weight of the grass carp, it can be known as the first-age fish. The average specification at the time of release was 360 g/tail, 1 y-old fish can grow to 3.5 kg a year, with a conservative value of 3 kg after 1 y, and an increase of 2.6 kg within a year. Each 100 g of grass carp contains 15.5–26.6 g of protein and 1.4–8.9 g of fat. The average value is 21% of protein and 6.2% of fat. The protein and fat carbon content is calculated as 50%. The survival rate of fry is calculated according to 40%.

Annual carbon sink of grass carp:

$$593{,}406/2 \times (2.6/0.36) \times 40\% \times 27.2\% \times 50\% \times 44/12 = 427.428\ t \quad (15)$$

A total of 480.795 kg of silver carp and bighead carp were put in, with an average size of 97.82 g/ tail, which can grow to 0.8 kg after 1 y and an increase of 0.7 kg within 1 y. Silver carp and bighead carp contain 15.3 g protein and 0.9 g fat per 100 g. The protein and fat carbon content is calculated as 50%. The survival rate of fry is calculated according to 40%.

Annual carbon sink of silver carp and bighead carp:

$$480,795/2 \times (0.7/0.1) \times 40\% \times 16.2\% \times 50\% \times 44/12 = 199.914\ t \quad (16)$$

40 million tails of green shrimps with a length of more than 1 cm are put in. The average weight of green shrimps about 1 cm is 0.5 g. After 1 y, the weight is about 4.5 g, and the annual growth is 4 g. Green shrimp molt takes 13–15 times in a lifetime, and its growth and development is accomplished by molting, Its life is generally 14–18 months. The number of peeling was about 11 times a year, assuming that the molting weight is 1 g on average, and the partial protein per 100 g of green shrimp can be 16.4 g, assuming that the total protein of 100 g of green shrimp is 32.8 g, and the survival rate of green shrimp in China is 20%.

Annual carbon sink of green shrimp:

$$40,000,000 \times (4 \times 32.8\% + 11) \times 20\% \times 50\% \times 44/12 = 180.576\ t \quad (17)$$

The annual carbon sink amount of aquatic organisms is:

$$180.576 + 199.914 + 427.428 = 807.918\ t \quad (18)$$

The biomass released by Baiyangdian is different every year and the growth rate of newly-added fish varies with the age of the fish. Ignoring the effects of the annual stocking rate and the growth rate of the fish, it is assumed that the density of fish and shrimp in the water remains the same, and the stocking species remain unchanged. The aquatic biomass was amplified in the same proportion.

Annual net carbon sink of aquatic organisms at full water level of Baiyangdian:

$$807.918 \times 33\% + 807.918 = 1,074.5\ t \quad (19)$$

4.3. Estimation of water-soluble carbon sink in Baiyangdian

Ecological water demand refers to a certain amount, time, and water quality of freshwater flow or water level necessary to maintain aquatic ecosystems to maintain human culture, economy, sustainable production, and life and human well-being [10,11]. In order to maintain the ecosystem in Baiyangdian, Baiyangdian needs to add water to the lake every year, such as "Yinhuangjidian", "Yinyuejidian", etc. Therefore, the amount of CO_2 dissolved in the annual replenishment water of Baiyangdian is used to represent the increment of dissolved carbon sink amount of Baiyangdian.

For the convenience of calculation, the amount of carbon dioxide dissolved in 1 m^3 of water in Baiyangdian is approximately replaced by the amount of carbon dioxide dissolved in one cubic meter at normal temperature and pressure. Some experiments have shown that CO_2 gas close to 0.7 standard volume can be dissolved at most per volume of water at room temperature and pressure [12]. The mass of CO_2 in a standard volume is about 1.8 g. According to the relevant data from the Water Resources Department of Hebei Province, by 2019, Baiyangdian had received more than 350 million m^3 of ecological water.

Baiyangdian water-soluble carbon sinks in 2019:

$$3.5 \times 10^9 \times 1,000 \times 0.7 \times 1.8 \times 10^{-6} = 441,000\ t \quad (20)$$

Studies have shown that from the perspective of flux, the minimum ecological water demand of Baiyangdian is 135 million m^3, the suitable water demand is 240 million m^3, and the maximum ecological water demand is 620 million m^3. The research results have supported the current stage of Baiyangdian ecology water replenishment. Assuming that the ecological water demand of Baiyangdian will expand in the same proportion when the water level is full in the future, the appropriate water supplement required is 320 million m^3 [13].

At the full water level of Baiyangdian, the water-soluble carbon sink amount is:

$$3.2 \times 10^9 \times 1,000 \times 0.7 \times 1.8 \times 10^{-6} = 403,200\ t \quad (21)$$

According to the above calculations, the annual carbon sink of Baiyangdian water body is shown in Table 1 below:

As can be seen from Table 1, in the total carbon sink of Baiyangdian water body, the water-soluble carbon sink accounted for the largest proportion, followed by the reed carbon sink, and the aquatic biological carbon sink accounted for the smallest proportion. The annual carbon sink of the water body in Baiyangdian at this stage is higher than the annual carbon sink in the full water stage in the future, the main reason is that the water-soluble carbon sink in Baiyangdian is larger at this stage. According to the outline of the plan for the Xiongan New Area in Hebei Province, the area of Baiyangdian district has been gradually restored to 360 km^2 [14–17]. At this stage, the water area of Baiyangdian is about 270 km^2. In order to expand the water area of Baiyangdian, the annual water injection volume of Baiyangdian at the present stage is higher than the ecological water demand under normal conditions. Therefore, the water-soluble carbon sink volume of Baiyangdian at the present stage is higher than that at the future full water level. There is a large gap between the carbon sink of aquatic organisms in Baiyangdian and the carbon sink of reed and water-soluble. The main reason is that in the calculation process, only the carbon sink of newly released fish is involved, while the carbon sink of other organisms in the water is ignored [18]. The actual carbon sink of aquatic organisms in Baiyangdian is higher than that calculated in this paper. The total amount of calculations shows that the current and future full-water stage Baiyangdian water bodies have considerable annual carbon sinks, and have great carbon sink capacity and green economic development potential.

5. Conclusions

In this paper, in the process of calculating the carbon sinks in Baiyangdian water body, for the convenience of calculation, some important factors affecting the carbon sinks in Baiyangdian water body, such as temperature changes, the types of aquatic organisms, and the nutritional level of water bodies have been ignored. In addition,

Table 1
Annual carbon sink estimation of Baiyangdian water body

	At this stage	Full water stage
Reed carbon sink	41,310 *t*	53,730 *t*
Aquatic organisms carbon sink	807.918 *t*	1,106.8 *t*
Water-soluble carbon sink	441,000 *t*	403,200 *t*
Total	483,117.918 *t*	458,004.5 *t*

in the calculation of the future full water level carbon sinks in Baiyangdian water body. Using the expansion ratio of the water area as a reference, the carbon sink of the water body will be increased year-on-year, ignoring factors such as human interference in the water body of Baiyangdian. Make the measurement results deviate from the real situation. The calculation results show that Baiyangdian has a great potential of carbon sink in water body. Therefore, strengthening the ecological environment protection and ensuring the carbon sink capacity of Baiyangdian water body not only conforms to the development planning of ecological civilization construction in Xiongan New Area, but also reflects the concept of green development, which plays a crucial role in promoting regional carbon offset and carbon neutralization.

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