processes

Article

Coordinated Development of Water Environment Protection and Water Ecological Carbon Sink in Baiyangdian Lake

Yanli Li, Jinxu Lv and Lijun Li *

School of Economic & Management, Shijiazhuang Tiedao University, Shijiazhuang 050043, China; lyl56857@sohu.com (Y.L.); lifen_6754@sohu.com (J.L.)
* Correspondence: lilj@stdu.edu.cn or llhtddx123@126.com

Abstract: "The Hebei Xiongan New Area Planning Outline" states that the carbon sink of the water body should be improved and the quality of Baiyangdian water should be improved by cleaning the sludge, but the treatment of endogenous pollution in the water body will release a large amount of carbon dioxide, which will reduce the carbon sink of Baiyangdian, which makes the improvement of water body quality and increasing carbon sink conflicting. In order to realize the coordinated development of Baiyangdian water quality improvement and carbon sink increase, this paper establishes the calculation model of the amount of sludge to be cleared to improve the unit water quality and the amount of carbon dioxide released by clearing the silt using the release flux and diffusion flux of nitrogen and phosphorus elements in the water body, and the relationship between the content of nitrogen and phosphorus elements, the depth of Baiyangdian sludge excavation and the amount of carbon dioxide released: as the content of nitrogen and phosphorus elements in the water decreases, the depth of sludge excavated to improve the unit water body increases, and the amount of carbon dioxide released gradually increases. As the nitrogen and phosphorus content in the water decreases, the depth of dredged sludge to improve the quality of the water body increases, the carbon dioxide released gradually increases, and when the nitrogen and phosphorus concentration reaches 0.18 g/m^3 and 0.6 g/m^3 respectively, the carbon dioxide released will increase exponentially. Thus, we propose countermeasures to improve the water quality of Baiyangdian and increase the carbon sink capacity: we can improve the water quality by reasonable dredging before the water quality reaches poor category 3; we can achieve the dual goals of improving the water quality and increasing the carbon sink by increasing the reed planting area.

Keywords: Baiyangdian Lake; water quality; water carbon sink

check for updates

Citation: Li, Y.; Lv, J.; Li, L. Coordinated Development of Water Environment Protection and Water Ecological Carbon Sink in Baiyangdian Lake. *Processes* **2021**, *9*, 2066. https://doi.org/10.3390/pr9112066

Academic Editors: Zhiqiang Sun, Sheng Yang and Yi Man

Received: 11 October 2021
Accepted: 11 November 2021
Published: 18 November 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Baiyangdian is located in Baoding City, Hebei Province, with a longitude of 115°45′–116°07′ E and a latitude of 38°44′–38°59′ N. It has a water area of 366 square kilometers and is the largest freshwater lake in the North China Plain. "Hebei Xiong'an New District Planning Outline" pointed out that the scope of dredging should be reasonably delineated, the ecological dredging of the lake should be realized scientifically and orderly, the internal pollution should be eliminated, the ecological environment of aquatic animals at the bottom of the water body should be repaired, the environmental quality of the lake should be improved, and the water quality of Baiyangdian should be gradually restored to III-IV category [1]. At the end of 2018, Xiong'an New Area had completed the treatment of livestock and poultry breeding, domestic waste cleaning and renovation in Dianzhong village and dianbian village, garbage cleaning politics within two kilometers on both sides of the river, treatment of industrial wastewater discharge standard, industrial solid waste and hazardous waste cleaning and renovation, toilet renovation of Dianzhong village and dianbian village, and upgrading of sewage treatment plant, etc., which is expected to be further improved The water quality of Baiyangdian Lake needs to start from the direction of internal pollution control. "Hebei xiong'an New District Planning Outline" states that carbon emissions should be strictly controlled, carbon sink space should be protected, and carbon sink capacity should be enhanced. Baiyangdian is the lung of North China and a huge carbon pool, including water carbon sink, reed carbon sink, aquatic animal carbon sink, etc. Aquatic organisms absorb carbon dioxide from the air during growth, and their bodies settle in the sludge after death. Part of the carbon re-enters the carbon cycle under the action of microorganisms and other animals, and part of the carbon stays in the sludge and becomes a carbon sink [2]. The dredging and cleaning of eutrophic algae and other operations to eliminate endogenous pollution to improve water quality will reduce the content of nitrogen, phosphorus and other polluting elements in the water while re-emitting their fixed carbon into the air, increasing carbon emissions, and reducing carbon sinks in the sediment, which is inconsistent with the goal of improving carbon sink capacity. [3].

Robert Bueya Suami, Luca Giorgio Bellucci, Agnieszka Baran et al. studied the relationship between organic matter content in sludge and water pollution, and they suggested that cleaning up sludge can reduce the content of nitrogen and phosphorus in water [4–6]. Qin Yong, Kenneth Fortino et al. studied the relationship between organic matter and carbon sinks in sludge [2,7]. But they did not consider the contradiction between sludge cleaning and carbon sink reduction. The paper starts by reconciling the contradiction between endogenous pollution and carbon sink of water bodies. Based on the actual situation of Baiyangdian sludge and reeds, the paper explores the reasonable scope of dredging by calculating the carbon sink reduced by reducing the unit nitrogen and phosphorus concentration in the water body by dredging activities and the carbon sink increased and carbon and nitrogen absorbed by increasing the reed area and provides suggestions for the coordinated development of improving the quality of Baiyangdian water bodies and enhancing the carbon sink capacity.

2. Theoretical Basis and Research Scope

2.1. The Water Quality of Baiyangdian Lake

At present, the water quality of Baiyangdian is class IV, which is slightly polluted and slightly eutrophicated. The reasons that affect the quality of water body include natural pollution and man-made pollution. Man-made pollution is mainly caused by human life and production activities, including industrial wastewater pollution, agricultural pollution, domestic sewage pollution and water pollution caused by urban domestic garbage. At the end of 2018, Xiong'an New Area had completed the treatment of livestock and poultry breeding, domestic waste cleaning and renovation in Dianzhong village and dianbian village, garbage cleaning politics within two kilometers on both sides of the river, treatment of industrial wastewater discharge standard, industrial solid waste and hazardous waste cleaning and renovation, toilet renovation of Dianzhong village and dianbian village, and upgrading of sewage treatment plant, basically realized the control of man-made pollution.

The natural pollution is mainly caused by changes of natural laws and the pollution of water source by minerals in soil to water, including sand content, plant nutrients and sludge. When there are a lot of oxyge-consuming pollutants in water, aerobic microorganisms will biodegrade these pollutants and consume dissolved oxygen in water at the same time, which makes oxygen consuming microorganisms unable to survive and the anaerobic microorganisms proliferate rapidly, leading to the deterioration of the water body and the inability of aquatic organisms to survive [8].

The oxygen consumption process of the degradation of oxygen-consuming organic pollutants by sediment conforms to first-order kinetic reaction, and the oxygen consumption rate increases with the increase of sand content. Plant nutrients refer to the algae and aquatic plants that seriously interfere with the purification of water quality, which can increase the biochemical oxygen demand, and the excessive nutrients in the water body will cause eutrophication. Sludge includes sediment, animal and plant corpses and feces. The sediment mainly comes from a large amount of mineral-free precipitation in water caused by soil erosion, sandstorm, and debris flow. Such sediment will weaken the sunlight of aquatic organisms, cover fish holes, hinder the growth of water organisms, thereby affecting the quality of water bodies [9]. There are a lot of aquatic animal and plant corpses and fish manure in the sludge bottom. Fish growth 1 kg can produce 162 g organic manure, including protein 50 g, lipid 31 g and carbohydrate 81 g, total nitrogen 30 g and 7 g total phosphorus [10]. Nitrogen, phosphorus, and various metal elements are indispensable elements for life. Animals and plants contain a large amount of nitrogen and phosphorus elements. These animal and plant corpses lead to a large amount of nitrogen and phosphorus in the sludge bottom.

Fish feces and aquatic organism corpses sink into the sediment by sedimentation, making the sludge become an important storage reservoir for elements such as nitrogen and phosphorus in the Baiyang Lake water body [2]. At present, the accumulation of nitrogen and phosphorus in the sludge is too high, and it is released to the overlying water body by diffusion, which becomes the internal pollution of Baiyangdian water body. Even if the external pollution is controlled, the sludge can still have a great impact on the water quality of Baiyangdian Lake. Therefore, cleaning the sludge in the lake is one of the effective ways to improve the quality of the water body.

2.2. Baiyangdian Carbon Sink

Wetlands, forests, and oceans are listed as the three major ecosystems in the world, accounting for about 6.4% of the earth's surface area, providing a living environment for 20% of the same species on the earth, with irreplaceable ecological functions and enjoying the reputation of "kidney of the earth" [3]. Wetlands generally have high primary productivity, Vegetation can act as a carbon sink through photosynthetic absorption of carbon dioxide in the atmosphere, aquatic organisms can sequester carbon through growth, and aquatic organisms become sludge after precipitation to achieve carbon sequestration. The total area of Baiyangdian is 366 square kilometers, and the average annual water storage capacity is 1.32 billion cubic meters. The carbon sink of Baiyangdian Wetland includes reed carbon sink, aquatic carbon sink and water carbon sink [11].

Reed carbon sink refers to the process, activity and mechanism of reed absorbs and stores carbon dioxide from the atmosphere. Through photosynthesis, reed absorbs carbon dioxide from the atmosphere and fixes it in vegetation and soil in the form of biomass, thus reducing the concentration of carbon dioxide in the atmosphere. The reed in Baiyangdian Lake is not allowed to be harvested after it is mature. When the reed withers, the above-water part will wither naturally in the water, part of the carbon will re-enter the carbon cycle under the action of microbial decomposition, and the remaining part will become sludge partial precipitation to realize "permanent carbon fixation" [12].

Aquatic biological carbon sink refers to the process, activity, and mechanism by which aquatic organisms absorb and store carbon dioxide during their growth. A large amount of organic matter brought in by surface runoff is decomposed into inorganic substances by microorganisms and then absorbed and utilized by algae and aquatic plants [3]. Aquatic animals accumulate carbon in their bodies by preying on various animals and plants, so as to achieve the effect of carbon fixation. After the death of aquatic organisms, some of the corpses are called the food of other organisms, and the carbon in them enters the carbon cycle, and the remaining carbon is precipitated into sludge [13].

Water carbon sink refers to the process, activity and mechanism of absorbing and storing carbon dioxide from the atmosphere through water. The amount of carbon dissolved in water is related to temperature, pH, and water volume, but temperature and pH are difficult to be interfered with artificially, so the volume of water can be increased to increase carbon sink. The main body of water carbon sink is Baiyangdian Lake.

2.3. Research Content and Scope

In the surface water environmental quality standards, except for nitrogen and phosphorus, the limit values of other metal elements and all kinds of pollution elements in the three kinds of standards change slightly, only phosphorus and nitrogen change greatly. Table 1 shows the standard limits of some basic items of surface water environmental quality standards [14]. Metal elements and other pollution elements are mainly caused by human factors. At present, Xiong'an has strengthened the control of pollution, and its control is not related to the reduction of carbon sink, so it is not considered. One of the main causes of phosphorus and nitrogen production is internal pollution. Since the sludge is mainly half-decayed animal and plant corpses, its phosphorus and nitrogen contents are high, which is the main source of phosphorus and nitrogen in the water body, and there is a large amount of organic matter in the sludge. Cleaning up the sludge will cause organic matter to re-enter the carbon cycle and become a carbon source. Therefore, the scope of the study is to reduce the amount of carbon sink by dredging to reduce the content of phosphorus and nitrogen in water.

Table 1. Standard limits for basic items of environmental quality standards for surface water.

Standard Value	Class II	Class III	Class IV
Ammonia Nitrogen≤	0.5	1.0	1.5
TP≤	0.1	0.2	0.3
TN≤	0.5	1.0	1.5
CU≤	1.0	1.0	1.0
Z≤	1.0	1.0	2.0
F≤	1.0	1.0	1.5
As≤	0.05	0.05	0.1
Hg≤	0.00005	0.0001	0.0001

3. Analysis on the Contradiction between Water Quality and Carbon Sink

The contradictions between endogenous pollution control of water quality and carbon sink is mainly the contradiction between cleaning algae and carbon sink, contradiction between cleaning sludge and carbon sink, and contradiction between reducing nitrogen and phosphorus in water and reed carbon sink.

In order to control the eutrophication of water body, it is necessary to regularly clean the eutrophic aquatic plants. The cleaned algae will be decomposed by microorganisms and made into feed to re-enter the carbon cycle, reducing the carbon sink of Baiyangdian Lake (Figure 1). However, in order to avoid eutrophication of Baiyangdian Lake, it is unavoidable to clean the algae, and the contradiction with the carbon sink of Baiyangdian Lake is irreconcilable, so the impact of cleaning up the algae on the carbon sink is not considered [2].

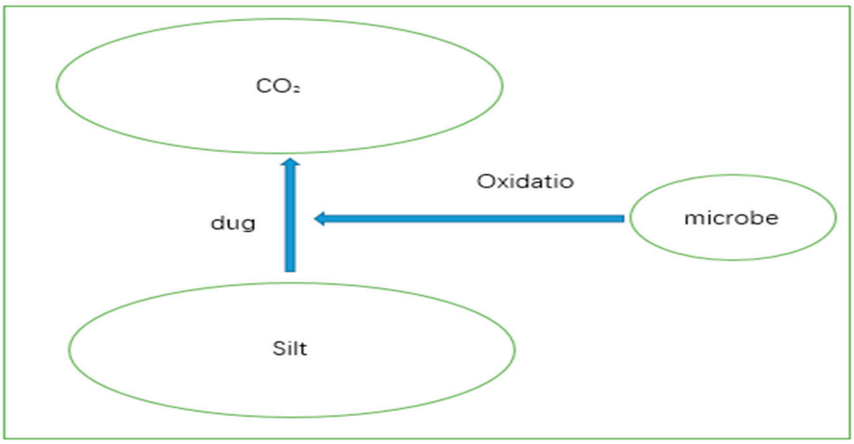


Figure 1. The relationship between sludge mining and carbon dioxide release.

Sludge mainly affects water quality by releasing and diffusing pollutant elements into the water body. By increasing the oxygen consumption rate of itchy microorganisms and reducing the oxygen content in water to make the water eutrophicated, so it is necessary to clean up the sludge [8,10]. However, the sludge itself is a huge carbon pool. There are dead bodies of animals and plants in the sludge. If it is salvaged, the carbon in the carcasses will be decomposed by microorganisms and re-enter the carbon cycle, which will reduce the carbon fixation in Baiyangdian Lake.

Reeds grow above the surface of the water and cannot form dominant groups in the water. The sediments are fine in grain size, and the contents of nitrogen, phosphorus and organic matter are also high, the soil is fertile, which is conducive to the growth and development of reed and is conducive to the carbon storage and carbon fixation capacity of reed [15]. However, the higher content of nitrogen, phosphorus and organic matter are not conducive to the improvement of water quality, which contradicts the improvement of water quality in Baiyangdian Lake. The higher content of nitrogen, phosphorus, and organic matter in the sludge contributes to the growth of reeds, salvaging the sludge will destroy the environment for the growth of reeds, reduce the carbon sequestration efficiency of reeds, which is not conducive to the role of Baiyangdian as a carbon sink [16].

In order to avoid eutrophication in Baiyangdian Lake, it is unavoidable to clean up algae, and the contradiction with carbon sink in Baiyangdian Lake is irreconcilable. Therefore, the carbon sink caused by algae-cleaning is not calculated. The concentration of nitrogen and phosphorus required for the growth of reed is above 40 and 5 mg/L, and the nitrogen and phosphorus in sludge are much higher than this value. Therefore, in class IV~II water quality goals, the reduction of nitrogen and phosphorus has little impact on the growth of reed, which can be ignored [17]. Silt removal is an effective but not the only way to improve water quality. A model for calculating the amount of carbon dioxide released per unit of water quality improvement is established, and the optimal cleaning range of sludge is found from the perspective of carbon sinks through the calculation results.

3.1. Research Hypothesis

Liu Xin, Yang Xiaoxuan and others calculated the TN and TP content of Baiyangdian sludge by establishing simulation models: the contents of TN and TP in different areas of Baiyangdian Lake are different, and the differences are large, which are 1230.8~9959.0 and 344.4~915.4 mg/kg respectively [13,18]. For the convenience of calculation, the average value of nitrogen and phosphorus content in the model is 0.79 g/kg and 44 g/kg, ignoring the uneven distribution of nitrogen and phosphorus [19].

The concentration of nitrogen and phosphorus in the interstitial water near the sludge-water interface and near the water side is approximately equal to the concentration of nitrogen and phosphorus in the interstitial water of the surface sludge bottom and the water body [20].

Since the content of nitrogen and phosphorus in the sediment is much higher than that in the water, and the deposition amount of nitrogen and phosphorus in the water body is less than the release and diffusion amount of nitrogen and phosphorus in the sludge, so in the process of nitrogen and phosphorus precipitation-release-diffusion, the process of nitrogen and phosphorus deposition in water body is ignored, and only the release and diffusion process of nitrogen and phosphorus in sludge is considered.

The impact of the reduction of nitrogen, phosphorus, and various metal elements on the growth of reeds is not considered.

3.2. Modeling

The decrease of a certain element content in water body means the decrease of release flux and diffusion flux [10,12]. According to the decrease of the element in the water body, the percentage of the decrease in the emission flux is calculated:

$$\alpha = [(V \times \Delta i)/(S \times T)]/v \quad (1)$$

where α is the reduction of release flux ($mg/m^3 * d$), V is the volume of Biangbiang Lake (m^3), Δi is the amount of change of nitrogen and phosphorus concentration in the water body (mg/m^3), S is the sludge area (m^2), T is the time interval (days) of sludge cleaning, and v is the original release flux ($mg/m^3 * d$).

According to the calculation formula of release flux and the change of release flux, the change of element concentration in sludge can be calculated [13,14].

$$\alpha F = \theta \times D \times \frac{dC}{dZ} \tag{2}$$

F is the release flux of elements ($mg/m^3 * d$), θ is the porosity of sludge bottom, D is the diffusion coefficient of elements at the sludge-water interface, and dC/dZ represents the concentration gradient of elements at the sludge-water interface.

After obtaining the element content in the sludge bottom, according to the relationship between the depth of the sludge bottom and the element content, the depth of the sludge to be cleaned is obtained, and the volume of the sludge to be cleaned is obtained [15,16]. According to the sludge density and organic matter content, the amount of carbon dioxide released is calculated.

$$C = S \times h \times \rho \times \omega \times \mu \times \frac{44}{12} \tag{3}$$

C is the amount of carbon dioxide released (g). S is the area of sludge bottom (m^2), h is the height of sludge to be cleaned (m), ρ is the density of sludge (kg/m^3), ω is the content of organic matter in sludge (g/kg), μ is the content of carbon in organic matter (dimensionless).

3.3. Calculation Results and Analysis

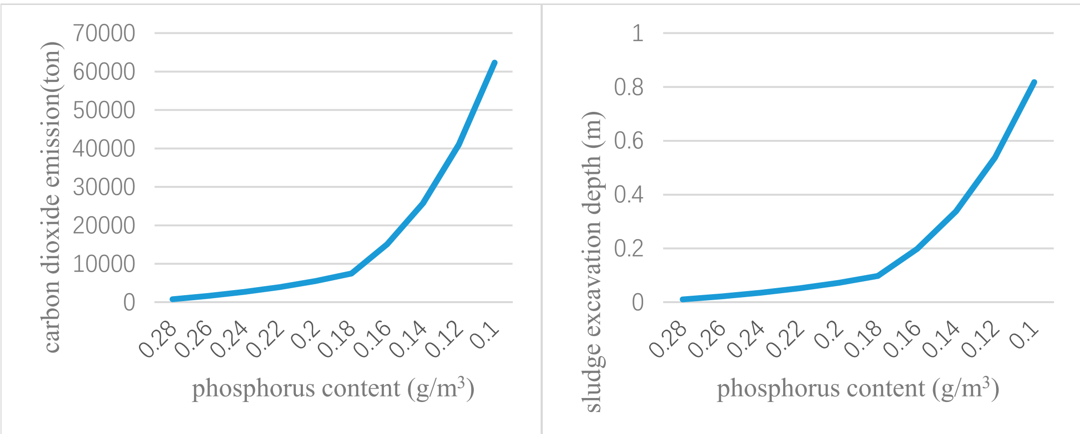
The sediment layer of Yangqin lake is rich in organic matter, and the sludge bottom is rich in semi-decomposed organic matter of animal and plant residues. Xiong Chunhui and Xue Peiying used sampling to count the depth of the sludge in Baiyangdian: The area with sediment is 200.84 km^2, accounting for 68.8% of the total Lake area, and the area without sediment is 91.27 km^2, accounting for 31.2% of the total Lake area [20]. The total phosphorus content, total nitrogen content and organic matter content of surface sediment are about 0.79 g/kg, 1.44 g/kg and 20.3 g/kg respectively [21].

For the content of nitrogen and phosphorus in the water body, the carbon dioxide released per unit content and the depth of sludge to be excavated are calculated at the interval of 0.02 and 0.1 g/m^3 respectively, and the above data is brought into the model to obtain the calculation results (Table 2).

Table 2. Relationship between element content and carbon dioxide emission in water.

p	CO_2 (ton)	Depth (m)	n	CO_2 (ton)	Depth (m)
0.28	799.94923	0.0105	1.4	838.0420554	0.011
0.26	1676.0841	0.022	1.3	1752.269752	0.023
0.24	2704.5903	0.0355	1.2	2818.868732	0.037
0.22	3961.6534	0.052	1.1	4114.024636	0.054
0.2	5523.459	0.0725	1	5713.923105	0.075
0.18	7466.1929	0.098	0.9	7694.749781	0.101
0.16	15,084.757	0.198	0.8	10,056.50466	0.132
0.14	25,750.747	0.338	0.7	13,027.74468	0.171
0.12	40,987.875	0.538	0.6	16,151.35598	0.212
0.1	62,319.855	0.818	0.5	23,769.92012	0.312

The relationship between carbon dioxide release and elemental phosphorus content is shown in Figure 2a, with the decrease of phosphorus content in water, the depth of excavation increases with the decrease of phosphorus concentration of 0.02 g/m^3 (Figure 2b), which leads to the increase of dredged sludge volume and the increase of carbon dioxide concentration. This is because the phosphorus content decreases with the increase of sludge depth. When the phosphorus content in the water is higher than 0.18 g/m^3, the carbon dioxide emitted by reducing the unit phosphorus concentration tends to be consistent and close to a straight line. This is because the soil excavated within this concentration range is located within 0.1 m depth, and the TP content in the bottom of the soil decreases in the depth of 0.0~0.1 m, and the downward trend tends to be consistent. When the phosphorus content in the water is lower than 0.18 g/m^3, the carbon dioxide emitted by reducing the unit phosphorus concentration increases exponentially. This is because the depth of the soil excavated in the sub concentration range is below 0.1 m, and the TP content in the bottom of the soil has an inflection point near the depth of 0.1 m, which shows a slight downward trend, leading to the need to excavate more soil. The distribution thickness of sludge bottom is mainly 0.05~0.4 m, and the part with excavation depth greater than 0.4 m is calculated by using existing data, which has no practical significance.



(**a**) (**b**)

Figure 2. Relationship between phosphorus content and carbon dioxide emission (**a**) and dredging depth (**b**).

The relationship between carbon dioxide release and elemental nitrogen content is shown in Figure 3a, as the nitrogen content in the water decreases, the depth of excavation is increased for every 0.1 g/m^3 reduction in the nitrogen concentration in the water (Figure 3b), resulting in an increase in the volume of sludge excavated and an increase in the concentration of carbon dioxide released. The reason is that as the depth of the sludge increases, the nitrogen content in the sludge continues to decrease. When the nitrogen content in the water is lower than 0.6 g/m^3, the carbon dioxide emission and the depth to be excavated increase exponentially.

This is because the TN content in the sediment decreases rapidly in the depth of 0.0~0.2 m. When the nitrogen content in the water is lower than 0.6 g/m^3, the exponential change trend of carbon dioxide emission and excavation depth is strengthened. This is because the nitrogen concentration tends to be stable at the depth of 0.2 m, and the decrease trend is not obvious, so more sludge needs to be excavated.

When the concentration of nitrogen and phosphorus in water reaches 0.9 g/m^3 and 0.18 g/m^3 (Figure 4) [22], the excavation depth of reducing unit interval phosphorus and reducing unit interval nitrogen element is similar to carbon dioxide emission. When nitrogen and phosphorus exceed this value, the carbon dioxide released by reducing phosphorus content per unit interval is higher than that of nitrogen element, the effect began to weaken rapidly. Therefore, the best advantage of improving water quality by cleaning sludge is that when the concentration of nitrogen and phosphorus reaches 0.9 g/m^3 and

0.18 g/m^3, it is inferior to class III water quality. When the concentration of nitrogen and phosphorus in water exceeds this value, the carbon dioxide released increases exponentially and the opportunity cost is too high.

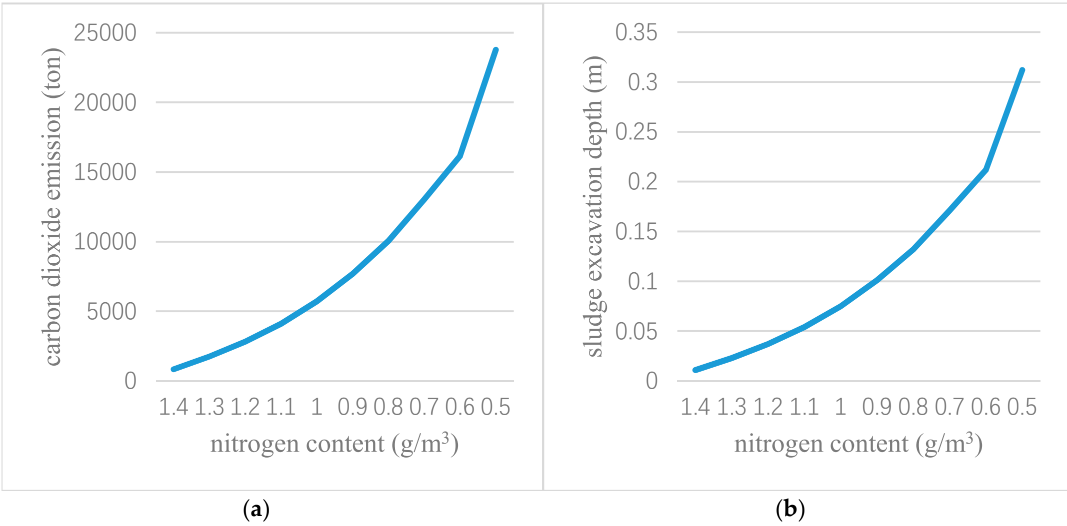


Figure 3. Relationship between nitrogen content and carbon dioxide emission (**a**) and sludge excavation depth (**b**).

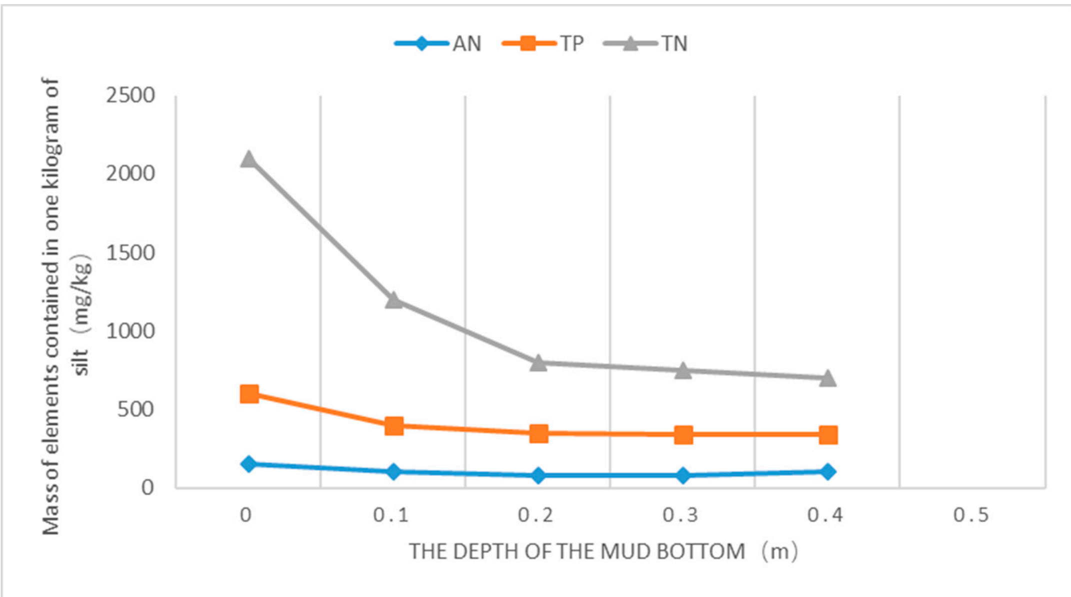


Figure 4. The relationship between the element content of the sludge bottom and the depth of the sludge bottom.

4. Research on the Coordinated Development of Water Environmental and Carbon Sinks

4.1. Expanding the Planting Area of Reeds

Reeds not only absorbs carbon dioxide in the air through photosynthesis, but also absorbs nitrogen and phosphorus during growth and development. The carbon sequestration capacity of Phragmites australis in Baiyangdian is 2.52–3.44 kg/m^2, with an average of 2.9 kg/m^2, which is 1.7–3.4 times of that of terrestrial vegetation in China and 2.0–4.0 times of that of global vegetation. Increasing the planting area of reeds by 100 square meters can increase carbon sinks by an average of 290 kg [23].

Reed needs to absorb nutrient elements such as nitrogen, phosphorus, and organic matter in the growth process. Nitrogen is an essential element for plant growth and development.

The synthesis of proteins and nucleic acids and the normal exercise of their functions require a large amount of nitrogen, nitrogen is also an important component of chlorophyll.

The content of phosphorus in plants is second only to carbon, nitrogen, and potassium, and mainly exists in the form of phosphoric acid, phospholipid, and other organic substances. It is widely involved in the process of photosynthesis, respiration, energy storage and transmission, and plays an important role. According to relevant research, a square meter of reed can absorb 18.91 g of nitrogen and 1.25 g of phosphorus [24].

Planting reed can not only achieve carbon sequestration, but also absorb nitrogen, phosphorus, and other elements in water, improve water quality. Higher content of nitrogen and phosphorus is conducive to the growth and development of reed, which is conducive to higher carbon storage and carbon fixation capacity [18]. In addition, roots of submerged plant can absorb suspended particles in the water, increase the transparency of water body, which is conducive to submerged plants and other organisms that need to use light to obtain more energy; the growth of aquatic plants also provides a place for aquatic animals to lay eggs and live; a large number of microorganisms and soil will be attached to the stems under the water surface and the dead branches and leaves in the plant belt, and there are also a large number of microorganisms in the soil, which can degrade the nutrients in the river water, and provide a carrier for the growth of microorganisms. Therefore, without affecting the light in the water, a moderate increase in the growth area of reeds can not only absorb nitrogen and phosphorus in the water, reduce the content of nitrogen and phosphorus in the water to improve water quality, but also increase the amount of carbon fixation of reed, forming more reed carbon sink.

4.2. Reasonably Cleaning up Silt

According to the calculation results, before the concentration of nitrogen is reduced to 0.9 g/m^3 and the concentration of phosphorus is reduced to 0.18 g/m^3 [25], the carbon dioxide released and excavation depth per unit phosphorus concentration and unit nitrogen concentration are about the same. When the concentration is exceeded, the carbon dioxide released by reducing the concentration of phosphorus element is higher than that of nitrogen, and the carbon dioxide released by reducing the content of phosphorus is higher than that of nitrogen. At this time, the effect of removing sludge per unit depth on reducing phosphorus concentration began decay rapidly. Therefore, the best way to improve the water quality by cleaning the sludge is that when the concentration of nitrogen and phosphorus reaches 0.9 g/m^3 and 0.18 g/m^3, it is inferior to class III water quality. The water quality can be improved by dredging before the water quality reaches the inferior category III. When the water quality reaches grade III, the opportunity cost will increase rapidly.

The distribution of nitrogen and phosphorus content in Baiyangdian Lake sediments is not uniform. The content of TN and TP ranges from 1230.8 to 9559.0 and 344.4 to 915.4 mg/kg [26], respectively. Due to the intensive human activities in the North estuary area and the middle part of the river, the content of nitrogen and phosphorus in the sediment is high, and the endogenous nitrogen and phosphorus load is high in this area. The content of nitrogen and phosphorus in the sludge in this area is relatively high, the amount of sludge to be cleaned up per unit water quality in this area is relatively less, the cleaning cost and carbon emission are less, the opportunity cost and marginal cost are low, and the income is high. Therefore, this area should be regarded as the key area of dredging.

5. Conclusions

Basing on the calculation of carbon dioxide released by dredging to improve water quality, combining with the actual situation of Baiyangdian Lake and the growth of reed, aiming at the contradiction between improving water quality, cleaning internal pollution and carbon sink, the following conclusions are drawn:

1. As the nitrogen and phosphorus concentration in the water column decreases, the amount of carbon dioxide released by using dredging to reduce the nitrogen and

phosphorus content per unit gradient increases exponentially, mainly due to the fact that the nitrogen and phosphorus content in the silt decreases with increasing silt depth, and the decreasing trend continues to diminish.

2. The best advantage of improving water quality by dredging is when the concentration of nitrogen and phosphorus elements reaches 0.9 g/m^3 and 0.18 g/m^3, i.e., poor III water quality. The water quality can be improved by dredging before the water quality reaches poor III, when the water quality reaches poor III and then use the method of dredging, the opportunity cost will increase rapidly.
3. Without affecting the amount of light in the water, the planting area of reed can be increased, which can not only achieve the goal of improving water body, but also enhance the ability of carbon sink.

Author Contributions: Methodology, J.L.; writing—original draft preparation, L.L.; writing—review and editing, Y.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Social Science Foundation of Hebei Province grant number HB20LJ005. And the APC was funded by Social Science Foundation of Hebei Province.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The study did not report any data.

Acknowledgments: Social Science Foundation of Hebei Province "Research on Public Participation Carbon Methodology in Xiongan New Area Based on Comprehensive Carbon Control Theory" (No: HB20LJ005).

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

α	The reduction of release flux (mg/m^3 * d)
V	The volume of Baiyangdian Lake (m^3)
Δi	The amount of change of nitrogen and phosphorus concentration in the water body (mg/m^3)
s	The sludge area (m^2)
t	The time interval (days) of sludge cleaning
v	The original release flux (mg/m^3 * d)
F	The release flux of elements (mg/m^3 * d)
θ	The porosity of sludge bottom
D	The diffusion coefficient of elements at the sludge-water interface
dC/dZ	The concentration gradient of elements at the sludge-water interface
C	The amount of carbon dioxide released (g)
S	The area of sludge bottom (m^2)
h	The height of sludge to be cleaned (m)
ρ	The density of sludge (kg/m^3)
ω	The content of organic matter in sludge (g/kg),
μ	The content of carbon in organic matter (dimensionless)

References

1. The Hebei Provincial Committee of the Communist Party of China Hebei Provincial People's Government. *Outline of the Plan for the Xiong'an New Area of Hebei Province (N.Hebei Daily, 2018-04-22 (002)*; The Hebei Provincial Committee of the Communist Party: Shijiazhuang, China, 2018.
2. Qin, Y. Sediment Organic Carbon Burial Effect of River Step Damming and Its Influence Mechanism. Ph.D. Thesis, Shanghai University, Shanghai, China, 2020.
3. Lian, W.; Li, J. Talk about the river sludge removal and sludge treatment technology. Hehai University, Xi'an University of Technology, China Dredging Association, Shanxi Provincial Water Resources Association. In Proceedings of the 2021 9th China Water Ecology Conference Paper Collection, Xi'an, China, 1–4 November 2021; Hehai University, Xi'an University of Technology, China Dredging Association, Shanxi Provincial Water Resources Society. Beijing Water Consulting Co., Ltd.: Beijing, China, 2021; p. 6.

4. Suami, R.B.; Sivalingam, P.; Al Salah, D.M.; Grandjean, D.; Mulaji, C.K.; Mpiana, P.T.; Breider, F.; Otamonga, J.-P.; Poté, J. Heavy metals and persistent organic pollutants contamination in river, estuary, and marine sediments from Atlantic Coast of Democratic Republic of the Congo. *Environ. Sci. Pollut. Res.* **2020**, *27*, 192–195. [CrossRef] [PubMed]
5. Bellucci, L.G.; Cassin, D.; Giuliani, S.; Botter, M.; Zonta, R. Sediment pollution and dynamic in the Mar Piccolo of Taranto (southern Italy): Insights from bottom sediment traps and surficial sediments. *Environ. Sci. Pollut. Res.* **2016**, *23*, 201–205. [CrossRef] [PubMed]
6. Baran, A.; Mierzwa-Hersztek, M.; Gondek, K.; Tarnawski, M.; Szara, M.; Gorczyca, O.; Koniarz, T. The influence of the quantity and quality of sediment organic matter on the potential mobility and toxicity of trace elements in bottom sediment. *Environ. Geochem. Health* **2019**, *41*, 108–110. [CrossRef] [PubMed]
7. Fortino, K.; Whalen, S.C.; Smoak, J.M. Patterns in the percent sediment organic matter of arctic lakes. *Hydrobiologia* **2016**, *777*, 345–350. [CrossRef]
8. Wang, H.; Bai, J.; Liu, S.; Tian, K.; Zhao, Y.; Li, C. Characteristics of temporal and spatial changes of water quality in Baiyangdian Lake in the past 30 years. *J. Agric. Environ. Sci.* **2020**, *39*, 1051–1059.
9. Chen, Z.; Zhao, D.; Li, M.; Tu, W.; Luo, X.; Liu, X. A field study on the effects of combined biomanipulation on the water quality of a eutrophic lake. *Environ. Pollut.* **2020**, *265*, 115091. [CrossRef] [PubMed]
10. Wang, D.; Men, B.; Zhang, M. On the water-solid interlock zone and scientific dredging planning in shallow lakes: Taking Baiyangdian in Xiong'an New District as an example. *Acta Sci. Circumstantiae* **2020**, *40*, 1550–1559.
11. Liu, X.; Shi, B.; Meng, J.; Zhou, Y.; Ke, X.; Wang, T. Characteristics of temporal and spatial changes of baiyangdian water eutrophication and sediment pollution. *Environ. Sci.* **2020**, *41*, 2127–2136.
12. Lin, N. Rehabilitation and management of Baiyangdian ecological environment in Xiong'an New District. *Technol. Wind* **2019**, *4*, 110.
13. Yang, X.; Zhang, R.; Mao, X.; Wang, R.; Meng, H.; Liu, D.; Tian, X.; Yang, Y. Spatial-temporal distribution and eutrophication analysis of nitrogen and phosphorus in Baiyangdian water body. *Jiangsu Agric. Sci.* **2018**, *46*, 370–373.
14. *GB 3838-2002, Surface Water Environmental Quality Standards*; Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2002.
15. Zhang, F. *Research on the Purification Law and Effect of Dominant Submerged Plants in Baiyangdian on Eutrophic Water Body*; Hebei Agricultural University: Baoding, China, 2012.
16. Liu, C.; Li, A.; Li, B.; Wang, J.; Zhang, Y.; Liu, S. Dynamic characteristics of reed biomass and nitrogen and phosphorus reserves in Baiyangdian wetland. *Acta Sci. Circumstantiae* **2012**, *32*, 1503–1511.
17. Zhang, Y.; Cui, B.; Lan, Y.; Han, Z.; Wang, T.; Zhang, Y. The contents of nitrogen and phosphorus in rhizomes of reeds at different ages in Baiyangdian. *Wetl. Sci.* **2013**, *11*, 286–291.
18. Li, L.; Wang, G.; Qin, P.; Zhao, J.; Wan, Z.; Ai, S.; Cheng, Y.; Lu, S. The water environment of Baiyangdian and its treatment and protection countermeasures. *Sci. Technol. Rev.* **2019**, *37*, 14–25.
19. Zhang, Z. *Baiyangdian Lake Sediment Pollution Characteristics and Disturbance Release Research*; Hebei University: Baoding, China, 2013.
20. Xiong, C.; Zhang, R.; Wu, X.; Feng, L.; Wang, L. Assessment of the distribution and pollution of nutrients and heavy metals in the surface sediments of Lake Luan. *Environ. Sci.* **2016**, *37*, 925–934.
21. Li, Y.; Chen, H.; Sun, W. "River-Lake" Sediment Heavy Metal Environmental Characteristics and Source Analysis. *Environ. Sci.* **2020**, *41*, 2646–2652.
22. Jin, L.; Li, L.; Zhou, Y.; Liu, C. The phytoplankton community and water quality evaluation of three typical waters in Baiyangdian Lake. *J. Hebei Univ.* **2017**, *37*, 329–336.
23. Li, B.; Liu, C.; Wang, J.; Zhang, Y. Study on carbon storage and carbon sequestration function of typical vegetation reed in Baiyangdian wetland. *Acta Agri. Environ. Sci.* **2009**, *28*, 2603–2607.
24. Alemayehu, T.; Mebrahtu, G.; Hadera, A.; Bekele, D.N. Assessment of the impact of landfill leachate on groundwater and surrounding surface water: A case study of Mekelle city, Northern Ethiopia. *Sustain. Water Resour. Manag.* **2019**, *5*, 1641–1649. [CrossRef]
25. Elemile, O.O.; Raphael, D.O.; Omole, D.O.; Oloruntoba, E.O.; Ajayi, E.O.; Ohwavborua, N.A. Assessment of the impact of abattoir effluent on the quality of groundwater in a residential area of Omu-Aran, Nigeria. *Environ. Sci. Eur.* **2019**, *31*, 16. [CrossRef]
26. Sarkar, B.; Islam, A. Drivers of water pollution and evaluating its ecological stress with special reference to macrovertebrates (fish community structure): A case of Churni River, India. *Environ. Monit. Assess.* **2019**, *192*, 21–29. [CrossRef] [PubMed]