

Review

Review on ecological response of aquatic plants to balanced harvesting

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Abstract: Macrophytes are the main primary producers in lake ecosystems and are the main transmitters of material and energy flows in lake ecosystems, directly influencing the structure and function of lake ecosystems. Balanced harvesting of aquatic plants is a cost-effective scientific management approach to maintain ecosystem health. The article defines "balanced harvesting" as an aquatic plant harvesting technique to optimize the structure of aquatic plant communities, maintain the normal function of ecosystem material cycle and energy flow, and enhance the stability and resilience of the system. The ecological significance of balanced harvesting in regulating the evaporation coefficient of the subsurface, reducing the accumulation and release of endogenous nutrient loads in lakes, delaying the evolutionary process of marshification, inhibiting biological filling, increasing biodiversity and system stability, and improving the environment of water bodies under the natural laws of adapted aquatic plants is reviewed. The way, time and method of balanced harvesting of aquatic plants in Baiyangdian, a grass-type lake in the north, were analyzed. In order to provide an important reference for wetland ecological restoration and protection, maintaining the health of the aquatic ecosystem, and making the lake environment sustainable.

Keywords: Aquatic plants; balanced harvesting; ecosystems; stability

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1. Introduction

Harvesting is one of the most important management measures for wetland plants, which is the process of manually or mechanically collecting and transporting aquatic plants from the water to the shore at different intensities. Proper harvesting facilitates the growth of aquatic plants and also avoids secondary pollution of water bodies when it declines at a later stage. The harvested aquatic plants can be rationally developed and used as resources to increase local economic income by producing organic fertilizers[1], feed for animals, construction materials, fire retardant materials, handicrafts, ecological black carbon and biomass for power generation[2,3].

At present, domestic and foreign scholars have paid attention to and studied the effects of harvesting methods and harvesting time on the growth and development of aquatic plants, structural wetland optimization and improvement of ecological functions [4,5], but the final conclusions are inconsistent. After Zhifeng and others first proposed balanced harvesting ecological water conservancy technology, in order to better play the scientific role of balanced harvesting, based on this "Eleventh Five-Year Plan" Baiyangdian China National Water Pollution Control and Management Science and Technology Major Project Group innovated the concept of balanced harvesting water body nitrogen and phosphorus balance, grass and algae balance. In 2020, the Standing Committee of the Hebei Provincial People's Congress promulgated Article 67 of the Baiyangdian Ecological Environment Management and Protection Regulations, which clearly states that "the Xiongnu New Area Management Committee shall strengthen the management

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of the Baiyangdian reed field and lotus ponds and their aquatic vegetation, make scientific use of reeds and bushes, balance harvesting, improve the self-purification capacity of the sediment and prevent pollution." The subject group of Science and Technology Major Special Project for Water Pollution Control and Management innovated the concept of balanced harvesting of water body nitrogen and phosphorus balance and grass and algae balance. For the first time, balanced harvesting has been raised to the level of a law.

"Balanced harvesting" is an aquatic plant harvesting technique to optimize the structure of aquatic plant communities, maintain the normal function of ecosystem material cycle and energy flow, and enhance the stability and resilience of the system, in order to achieve the expected benign ecological balance. In this study, from the perspective of balanced harvesting control technology, the ecological effects of balanced harvesting in regulating the evaporation coefficient of the substratum, reducing the accumulation and release of endogenous nutrient loads in lakes, increasing biodiversity and system stability, and delaying the evolution of marshification are sorted out in four aspects, which provide a basis for the study of aquatic population morphology, aquatic ecosystem restoration, biological regulation of grass-algae balance and marshification, with a view to providing an important reference for lake wetland. It is expected to provide an important reference for ecological restoration and protection of lake wetlands.

2. Water saving effect

In 2010, Yang Zhifeng et al. proposed the balanced harvesting ecological water conservation technology and applied for a patent for the invention. On the basis of stable physiological and ecological parameters such as vegetation community biomass and leaf area index, balanced harvesting technology is used to adjust the composition ratio of water consumed by vegetation and substratum evapotranspiration in the ecosystem to reduce ineffective evapotranspiration and achieve ecological water conservation, while the plant residue left in place after harvesting also plays a good role in covering water conservation. For example, in the northern shallow grass-type lake Baiyangdian, where *Phragmites australis* cover up to 18 km², accounting for 18% of the total precipitation area, evapotranspiration is greater than evaporation from the water surface during the growing season from April to August. After 20% balanced harvesting of *Phragmites australis*, the water consumption from untreated is 44 mm/d will to 38 mm/d, and the ecological water saving efficiency is 13.6% [6].

3. Effects on plant growth and development

The effects of harvesting on the growth and development of tidewater plants and submerged plants have been thoroughly studied by domestic and foreign scholars.

The balanced harvest management model of tappers mainly affects the growth and development of tappers indirectly by influencing changes such as enzyme activity within the soil [7]. The American ecologist J. H. Connell et al. proposed the light disturbance theory hypothesis in 1978, suggesting that a moderate frequency of disturbance can maintain high species diversity [8]. Significant changes in plant height, density, cover and biomass occurred under different intensities of disturbance [9]. The chemosensory effect of *Phragmites australis* was stronger and species monoculture was higher once. Balanced harvesting promotes good growth of *Phragmites australis*, increases the net photosynthetic rate of leaves, and facilitates the uptake of N and P from the surrounding environment by *Phragmites australis* [7]. *Phragmites australis* have high fiber content and tough stalks, and after the end of their life cycle, if not harvested, the dieback can still maintain a special standing form. It takes 5 years for *Phragmites australis* to decay and release, and standing dieback has a significant impact on the rejuvenation and growth of *Phragmites australis* communities and is maintained for a longer period of time. Balanced harvesting highly significantly affected *Phragmites australis* spring regrowth, increased chlorophyll content in water, and reduced total nitrogen and phosphorus content in the surface layer of the substrate

compared to no harvesting control [10,11]. In addition to affecting the rejuvenation rate of *Phragmites australis*, the stand dieback can also lead to population degradation, causing the *Phragmites australis* plants to become short and "hairy". For example, the density, height, diameter, and above-ground biomass of *Phragmites australis* plants in Baiyangdian increased significantly after harvesting and management compared to the untreated community [7], as shown in Figure 1.

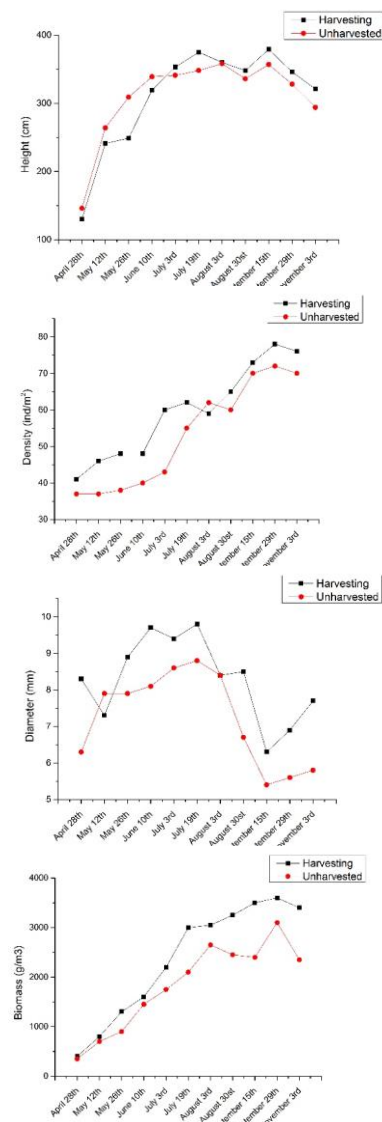


Figure 1. Effects of *Phragmites australis* harvesting management on density, height, diameter and aboveground biomass in Baiyangdian

Balanced harvesting management patterns also had significant effects on the growth and development of submerged plants. High intensity and high frequency of harvesting reduced the number of branches and branch length of *Hydrilla verticillata* and inhibited later asexual reproduction. Different harvesting intensities resulted in different relative growth rates of *Myriophyllum spicatum* dry weight, and the higher the harvesting intensity, the longer the plant re-recovery time, but all eventually recovered completely. Moderate harvesting intensity will promote *Elodea nuttallii* branching and growth [12]. Harvesting has a significant impact on *Potamogeton crispus* branching and limits the formation of canopy. *Potamogeton crispus* recovered in the short term after low intensity harvesting, while the recovery time became longer with moderate to high intensity harvesting [13]. Harvesting management was carried out in March–May, when *Potamogeton crispus* growth rate is fastest, and the number of sprouts, location and number of lateral shoots, and biomass of *Potamogeton crispus* decreased significantly with increasing harvesting intensity, indicating that *Potamogeton crispus* regrowth capacity was inhibited after harvesting treatment, which effectively controlled the overgrowth problem [14].

4. Purification effect on water bodies

The use of aquatic plants to absorb nutrients and take away nutrients from water by harvesting plants after the growth period is a simple, efficient and low cost method to remediate polluted water bodies and prevent secondary pollution.

As the main primary producer in the lake, aquatic plants are an important part of the ecosystem. During photosynthesis, they assimilate and absorb nutrients such as nitrogen and phosphorus from the water and sediment to promote their own growth, and the assimilation rate is positively correlated with plant growth rate and nutrient level in the water body [15]. While aquatic plants only absorb nutrients from sediments, submerged plants can absorb nutrients from the surrounding water column and substrate, and the substrate is the main source of nutrients [16]. Empirical models of the relative contribution of substrate and open water to aquatic plant phosphorus predict that more than 50% of phosphorus is supplied by substrate, while nitrogen supplied to aquatic plants can come from both substrate and open water. More than 70% of the phosphorus assimilated by submerged plants comes from the substrate [16]. The ratio of nutrient salt uptake from the substrate and surrounding waters is related to the root-to-crown ratio of submerged plants: some submerged plants have severely degraded or even disappeared root systems such as *Hydrilla verticillata*, *Ceratophyllum demersum*, *Potamogeton crispus*, etc. Most of these plants have large canopies, and the uptake of phosphorus is mainly through the uptake of phosphorus in the overlying water by the stems and leaves, while the uptake of phosphorus in the sediment is less [17–19]; some submerged plants have well-developed root systems and can uptake phosphorus in both the sediment and the overlying water through the roots and stems and leaves, such as *Vallisneria spiralis*. At the same time, these plants can form thick mats, which can act as a natural physical barrier and reduce the release of phosphorus from the sediment to the overlying water [20].

Comparative experiments between harvested and unharvested aquatic plants found that the organic matter, total nitrogen, and total phosphorus contents in the substrate above 40 cm in the *Phragmites australis* harvested area were lower than those in the unharvested area [21]. In addition to taking away the nitrogen and phosphorus nutrients from the plants, harvesting aquatic plants also improved the light conditions in the wetland and promoted the decomposition and transformation of nitrogen and phosphorus nutrients, so that the total nitrogen and phosphorus contents in the substrate of the plant-harvested area were significantly lower than those in the unharvested area [21]. The balanced harvesting of *Potamogeton crispus* can effectively control the accumulation and release of endogenous nutrients in the lake, reduce the growth of algae, and maintain the stability of

Potamogeton crispus populations, which is of great practical importance to the purification of lake water quality [22]. For example, in the experiment of periphyton harvesting in Baiyangdian *Phragmites australis* in mid-May in spring, the pollutants and water transparency (SD) of the harvested treated water bodies were significantly improved compared with the unharvested water bodies, especially the best effect after 31 days, see Figure 2.

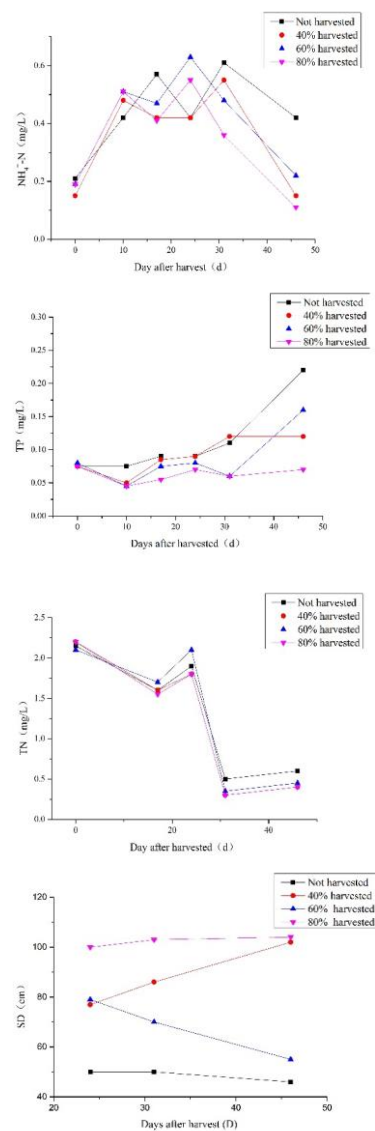


Figure 2. Effects of Baiyangdian *Potamogeton crispus* harvesting on ammonia nitrogen, total phosphorus, total nitrogen and transparency of water bodies.

Most scholars believe that the optimal harvest time is when the nutrient salt content of aquatic plant stems and leaves is highest [16], and the optimal harvest time can be determined by the maximum amount of nutrients assimilated by aquatic plants in the water column and substrate with reference to the maximum sustained yield of the logistic Stee growth model[23]. In addition, one study found that multiple harvests harvested 3.62 times more plant biomass than one harvest; multiple harvests could take away 3.78 and 6.72 times more total nitrogen and total phosphorus than one harvest [24].

5. Maintaining ecosystem stability

5.1. Retard swampy succession

Lake marshification is an inevitable process of lake succession, and plant residues are an important factor for the thickening of the lake bottom mud layer. Shallow lakes enjoy good habitat for aquatic plant growth and reproduction due to shallow water depth, and without harvesting management, after the continuous growth and death of aquatic plants or wet plants, the residues sink to the bottom of the lake and are not fully decomposed due to lack of oxygen, forming peat, resulting in the shrinking of the lake surface, shallow water depth and the spread of wet bog plants, so the bogging of shallow lakes is mainly of the bog plant band invasion type, and the large aquatic plant The primary productivity of large aquatic plants is directly related to the accumulation and decomposition of their residues on the lake bottom, which plays an important role in the swampification process.

Marsh vegetation is divided into stem and leaf overspreading type and root overspreading type, for example, the dominant marsh vegetation in Baiyangdian Taitian area is mainly *Phragmites australis* and *Nelumbo nucifera*. The spread of large vascular plants, siltation of residues, and crowding of water body space have resulted in the swamping of lakes. At the end of 2007, the accumulation of plant residues in Baiyangdian *Phragmites australis* increased by 400 g/m² which was double of that in 1997, and the overall accumulation of *Phragmites australis* residues showed an increasing trend year by year. About 8.5×10^4 t (dry weight) of submerged plants are deposited on the lake bottom every year in the Wuliang Su Sea, and about 20.5×10^4 t of macrophyte residues are deposited on the lake bottom, with a biological filling effect of 9 ~ 13 mm/a. The average substrate thickness of siltation on the lake bottom is 360 mm, and the area of the Wuliang Su Sea shrinks from 660 km² in the 1950s to 293 km² [25]. The significant reduction of biofilling effect was significant in the Wulansu Sea by using a hydrophyte harvester to reasonably harvest submerged plants and stop *Phragmites australis* spreading, which could reduce the biofilling rate from 7 ~ 13 mm/a to 2 ~ 3 mm/a [26].

5.2. Influence on homeostatic transitions in shallow water lakes

Bachmann classified the structural types of lake ecological homeostasis by comparative limnology into clear water homeostasis with macrophytes (grass-type) as the main primary producer and turbid water homeostasis with planktonic algae (algal-type) as the main primary producer [27]. Grass-type clear-water lakes and algal-type turbid-water lakes are different stages in the lake succession process, and they are mutually inhibited by each other [28]. With the intensification of harvesting, the role of aquatic plants in inhibiting the release of nutrients from the substrate decreases, while the uptake of aquatic plants is reduced, and phytoplankton are subject to a reduced role of nutrient limitation and gradually develop into the dominant primary producers of the lake. Grass-type lakes have a tendency to gradually transform from a clear water grass-type steady state dominated by benthic plants to a turbid water algal-type steady state dominated by phytoplankton [29], resulting in eutrophication of the water column, which can lead to significant changes in the physicochemical properties, aquatic plant community structure,

benthic community structure and ecological structure of the water column. Therefore, ensuring that lakes maintain grass-type clear water homeostasis is the key to the management of lake eutrophication [27].

Aquatic plants control algae mainly by using competition between benthic and pelagic algae for light, nutrients and other resources as well as chemosensitive substances released by plants into the environment, while secondary metabolites secreted by algae (mainly *Cyanobacteria*) into the environment also exert chemosensory effects on macrophytes, such as alkaloids, fatty acids, peptides, ketones alcohols and terpenoids [30]. The fundamental driver of ecological homeostasis in different lakes is the chemosynthesis of aquatic plants. The term "chemosensory" was introduced by the German scientist Molisch in 1937 as a phenomenon in which chemosensory substances produced during plant growth inhibit the growth, development and exclusion of other plants [25]. In 1995, Cross reported for the first time the chemosensory effects of dozens of different submerged plants [28]. There are more aquatic plants with algae control chemosensory ability [28]. Based on the chemosensory algae control ability, Sabine classified aquatic plants into three categories: 1) high activity, such as *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Acorus calamus*, *Cabomba caroliniana*; 2) moderate activity, such as *Elodea nuttallii*, *Najas marina*, *Myriophyllum verticillatum*; 3) low or no activity, such as *Lemna minor*, *Chara globularis*, *Potamogeton crispus*, *Potamogeton pectinatus*. Algae showed selective variability to algae control chemosensitive substances, and in general, *Bacillariophyta* and *Cyanobacteria* were effectively inhibited, while *Chlorophyta* was insensitive. Symbiotic algae are more tolerant than planktonic algae. The inhibition of algae only occurs when the biomass of submerged plants with chemosensory activity reaches a certain level, and the impact of chemosensory effects is greater with higher cover [28]. For example, in Baiyangdian Dujiadian, planting of different cover *Charophyceae* enclosures was carried out, in which *Charophyceae* with 50%, 70% and 80% cover had a better effect on the regulation of phytoplankton in the water column, in which *Charophyceae* with 80% cover had the best effect on the regulation of Chl-a in the water column [31], see Figure 3.

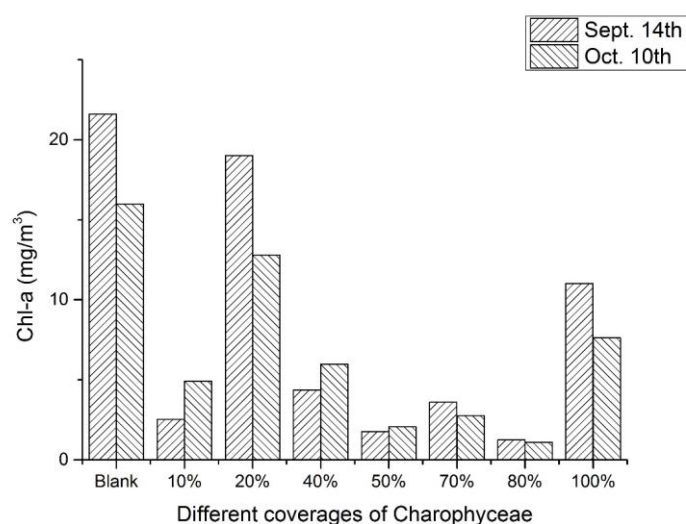


Figure 3. Variation of water quality Chl-a concentration in different cover *Charophyceae* enclosures.

In order to inhibit the spread of algae in the Ulansu Sea, it was found that the annual harvest of submerged plants should not exceed 60% of the production of the whole lake, and it is not appropriate to harvest in the water below 0.7 m depth, and the rest of the lake is harvested sequentially using the method of harvesting in strips or blocks at intervals, and 30% of the water plants are temporarily retained in the harvesting area, which can reasonably maintain the active role of submerged plants in the water ecosystem [32].

5.3. Influence on ecosystem stability

5.3.1. Influence on primary productivity perpetuates reproduction

Asexual reproduction is more developed than sexual reproduction in aquatic plants, and most submerged plants rely mainly on asexual reproduction [33]. The timing of harvesting had little effect on species that relied on underground tubers and rhizomes for the following year's population recovery, but had a greater effect on the formation of special nutritional propagules at maturity. *Potamogeton pectinatus* Sexual reproduction has both surface and underwater bubbles for pollination; seed production is large, but seed germination is low, less than 6%, and seed propagation contributes little to population recovery, with its main role being remote dispersal and maintaining a durable seed bank. *Potamogeton pectinatus* has an extensive and efficient asexual reproduction system that can be propagated by breaking plants, rhizomes, aboveground tubers, underground tubers, aboveground stem nodes, and leaf axil bases, and population recovery is mainly from underground tubers and rhizomes [34], so the timing of harvesting has little effect on this type of plant. The propagule of *Potamogeton crispus* is stone buds, the maturity of stone buds is about May, the colonial buds fall into the bottom of the lake after maturity and enter the dormant period, the water temperature is the main factor affecting the dormancy and germination of *Potamogeton crispus* colonial buds, when the water temperature is higher than 25 ~ 30°C, the colonial buds are in the dormant state, in early October, when the water temperature is lower than 20 ~ 25°C, the colonial buds germinate, the harvest has a greater impact on such plants, so the harvest should be shaken as much as possible, so that the stone buds enter the water body to ensure the development of plants in the second year. The asexual reproduction of *Ceratophyllum demersum* is also more developed than the sexual reproduction. In autumn, when the light is shortened and the temperature drops, the terminal buds become dormant, the tips of the lateral branches stop growing, the leaves become dense into leaf clusters, the color becomes dark green, the cuticle thickens, and accumulates starch and other nutrients, becoming a special nutrient propagule, the plant becomes brittle, the terminal buds fall off easily, sink in the mud dormant over winter, and sprout into new plants in the following spring. Too many harvests can reduce the depression of plants and damage the ecosystem; too few harvests have limited biomass control, so a reasonable number of harvests needs to be considered [35].

5.3.2. Improving local biodiversity

Balanced harvesting will form "grass windows" of different patch sizes [36], providing light and space for the growth of propagules, dormant shoots and juveniles in the lower layers, and may also affect the species composition of the community, providing ecological niches for some opportunistic species, which are usually invaded by pioneer species with strong dispersal ability first, and may occur as a result of colorful competition, usually by harvesting. Species that are more resistant or recover more quickly dominate after harvest, increasing local biodiversity.

5.3.3. Provide habitat for other trophic levels

As primary producers of the ecosystem, aquatic plants provide habitat for other trophic levels in addition to providing carriers for ecosystem flow energy, material cycling and information transfer. Submerged plants are sensitive to external disturbances, and incorrect harvesting intensity and excessive harvesting frequency can have a large impact

on their communities and may lead to imbalance in grass-based lake ecosystems [37]. Appropriate upper clipping harvesting of macrophytes would avoid resuspension of sediments caused by uprooted removal of plants [38], and unreasonable harvesting would decrease macrophyte cover and productivity of the entire ecosystem [38,39], resulting in a decrease in the area of active and juvenile fish living areas for sinking mucilaginous egg-producing fish, such as *Cyprinus carpio*, *Carassius auratus*, *Megalobrama amblycephala* and *Silurus asotus*.

Zooplankton is an important indicator of the ecological health of water bodies, and the more copepods and branchial horn zooplankton are present, the more stable the ecological structure [40]. For example, *Potamogeton crispus* harvesting experiments with different harvesting intensities were conducted in typical reclaimed water recharge type rivers in Beijing, and the results showed that different *Potamogeton crispus* harvesting intensities had less effect on zooplankton. The overall number of copepods and branchiopods zooplankton was low, and the number of copepods decreased by 20%–70% after *Potamogeton crispus* harvesting treatment. *Potamogeton crispus* harvesting and more frequent harvesting can reduce the structural complexity of river submerged plant communities, resulting in higher nutrient levels in the water column, which is not conducive to the growth of copepod zooplankton in reclaimed water channels at this time [14], see Figure 3.

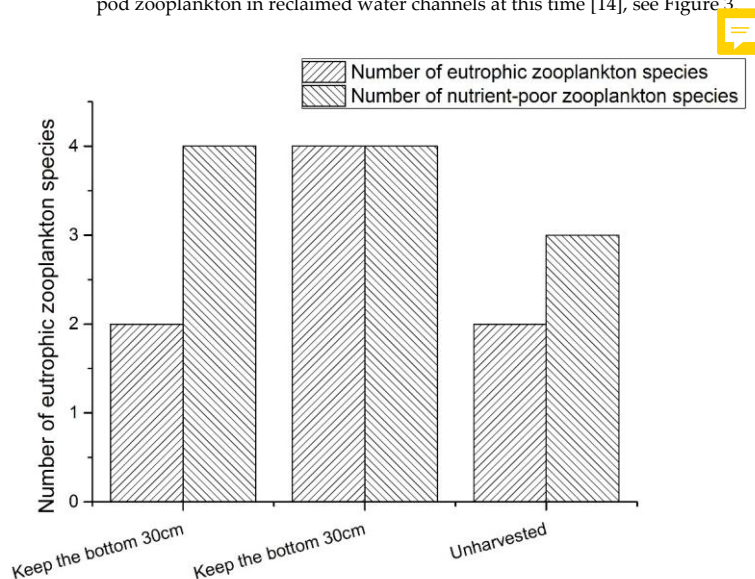


Figure 4. Number of zooplankton species of different trophic types under different harvesting intensities.

Submerged plant harvesting and harvesting methods can have a large impact on benthic fauna, and after over-intensive harvesting *Potamogeton crispus*, the benthic community structure changes from originally clean species as the dominant species to medium fouling species as the dominant species [14].

There is also a large impact of aquatic plant harvesting on birds. When the reeds are harvested in winter, the wetlands of lakes in northern China are all resident birds, with little change in species numbers. However, in addition to resident birds, southern Chinese lakes also have a high number of wintering and traveling birds with a large impact, and strong anthropogenic disturbance at harvest time results in a significant reduction in the

number of bird species. After harvest is complete, the sparser reed stump sites and exposed bare ground provide the habitat needed for species increase. For example, the number of species of birds varied significantly in winter for the month before harvest (20 species), the month of harvest (11 species), and the month after harvest (17 species) in Taihu National Wetland Park A [41].

6. Discussion

6.1. Ways of balanced harvesting

Balanced harvesting of aquatic plants is divided into 2 ways at the operational level: first, full harvesting during the decay period; second, thinning during the growth period.

Full harvesting during plant decay is an effective way to reduce summer pollution loads. With the establishment of Xiong'an New Area, the ecological restoration and protection work of Baiyangdian has been accelerated to achieve a breakthrough of full precipitation category III in 2021. The indexes that affect the precipitation area cannot reach the standard stably are mainly COD, and the time is mainly concentrated in summer and autumn. As the aquatic plant growth period has obvious seasonality, *Potamogeton crispus* decay release contribution is mainly concentrated in May–June, the Chinese New Year of the lunar calendar, which coincides with the time of *Potamogeton crispus* decay release as the starting time. The large amount of organic matter released into the water in spring *Potamogeton crispus* coupled with the increased release of substrate and increased algal density in summer caused the summer Baiyangdian COD to fail to meet the standard stably. Other dominant species of aquatic plants such as *Potamogeton pectinatus*, *Myriophyllum spicatum* and *Nelumbo nucifera* are mainly concentrated in late September and early October. A study of typical months of aquatic plant decay release found that spring *Potamogeton crispus* COD release accounted for about 90% of the annual release of aquatic vegetation, other fall death decay aquatic plant release period mainly concentrated in late September, early of October, due to the release of less, and with the lower temperature algae density decreases, the reduction of substrate release has not caused less impact on the precipitation water quality assessment.

Balanced harvest management such as thinning and removal during the aquatic plant growth period can increase ecosystem stability. In 2021, the water quality in the precipitation area will improve significantly, and as the transparency of the water body increases, the cover of marsh grass will be as high as 90% in spring, and the species will be single and extremely dominant, and the overgrowth of marsh grass will affect the driving of boats and the growth of fish, and will also cause poor ecosystem stability. Studies have shown that the lowest nitrogen and phosphorus concentrations in water, low percentage of cyanobacteria, and water ecosystem stability were observed when the cover of Baiyangdian sediment plants were thinned and planted at 50% [42].

5.2. Timing of balanced harvesting

The growth rhythm of plants varies from region to region, and the growth cycle of plants in the same region also varies. Balanced harvesting time mainly considers the plant growth cycle. Baiyangdian is a typical northern grass-type lake wetland with high primary productivity. The dominant species of water-holding plants are mainly : *Phragmites australis*, *Nelumbo nucifera*; The dominant species of submerged plants are mainly: *Potamogeton crispus*, *Potamogeton pectinatus*, *Ceratophyllum demersum* ; Most aquatic plants have a growth cycle of spring growth, summer growth, and fall failure, such as *Phragmites australis*, *Potamogeton pectinatus*, and *Nelumbo nucifera*. A few aquatic plants are winter-growing, spring-growing, and summer-defeated, such as *Potamogeton crispus*. The life cycle table of Baiyangdian aquatic plants is shown in Figure 3.



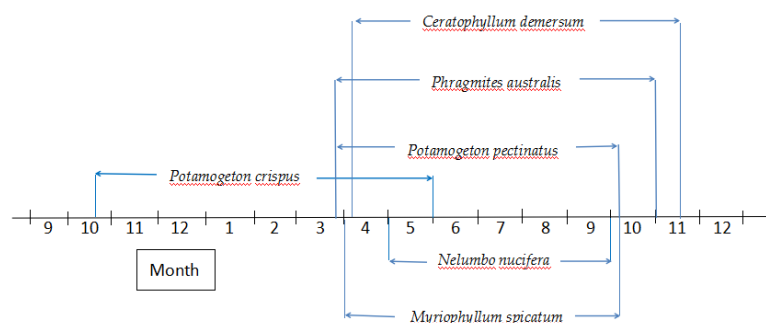


Figure 3. Life cycle table of aquatic plants in Baiyangdian Lake.

In late September and early October, the propagules of *Potamogeton crispus* began to germinate and grow slowly at the bottom of the lake. Entering the Baiyangdian into the freezing period in December, surviving and growing slowly under the ice. Plants reaching 1 m in height in January of the following year. A rapid growth period after the thawing of the ice in March, with a rapid increase in biomass. Biomass reaches its maximum in mid-May, spikes begin to emerge and stand up out of the water, and the seeds of *Potamogeton crispus* mature and produce a large number of stone shoots. At the end of May the decay and release period is entered, and the stone shoots and seeds sink to the bottom of the lake, with a decay period of about 1 month. Therefore, a full harvest should be conducted in mid to late May, with proper thinning management from March to May. With the restoration of Baiyangdian water quality, it is expected that the dominance of the dominant species of marsh grass will further increase in spring, and the stability of the ecosystem will remain poor. In spring (May) mints should continue to be harvested in a balanced manner throughout the precipitation range with a view to reducing the impact of mints decay release on Baiyangdian water quality assessment, while artificial interventions such as thinning out and planting are used to increase the diversity of submerged plants.

Potamogeton pectinatus germination at the end of March, the peak growth period is from June to September, when the accumulation of nitrogen and phosphorus in the plant is the greatest. In early October, the plants enter the decay period, decaying in large quantities and floating above the water surface, at which time the decaying residues release large amounts of nitrogen and phosphorus into the water. Therefore, *Potamogeton pectinatus* should be harvested in mid to late September to relocate the plant body out of the water body to prevent secondary pollution of the water body.

Nelumbo nucifera is a heat-loving plant. At the beginning of July, in the early growth stage. September, when the plant reaches a stable stage of growth and ceases to grow. Decay gradually begins in early October. The lotus should be harvested in mid to late September.

Phragmites australis is a widely temperate plant, germinating early, starting to germinate at the end of March and turning yellow and decaying at the end of October. Due to the large C/N and high cellulose content of *Phragmites australis* plant, it is slow to decay and release. Combined with the natural conditions of Baiyangdian, *Phragmites australis* is harvested from November to March when it turns yellow[43], and it is easy to collect on water in time when the water level is high.

At the end of August and the beginning of September, *Myriophyllum spicatum* enters the decay stage, but due to the low biomass, its companion species *Ceratophyllum demersum* and dominant species *Potamogeton pectinatus* rapidly replace its ecological niche, when the thinning of submerged plants should be carried out and the species harvesting is not easy.

Ceratophyllum demersum wider water temperature requirements, but more sensitive to ice, freezing in the ice within a few days, November into the decay and death period, but due to the low temperature of the water column, decomposition is not obvious, to the next year in April (water temperature to more than 8 degrees) only gradually decomposition, should be in line with the miner plant growth period thinned out for local small-scale harvesting.

In addition, balanced harvesting needs to consider other factors, such as fish spawning periods. Baiyangdian fish resources are rich [44], aquatic plants provide good habitat for fish, and most spawning fish on grasses spawn in the warm spring and summer months, with the main spawning period being from April to May-July to August. The dominant species of fish in Baiyangdian, such as carp, are mainly found at about 25°C. According to the water temperature of Baiyangdian is mainly concentrated at the end of June, the hatching of fish fry overlaps with the harvesting and thinning of aquatic plants, so it is necessary to avoid the fish spawning concentration when harvesting.

5.3. Methods of balanced harvesting

The methods of aquatic plant removal are divided into: fire, mowing, chemical and biological regulation. Fire can only be used to remove the remnants of water-holding plants, which is fast but causes air pollution and leads to waste of resources [45]. Chemical methods refer to the use of herbicides, etc., which may cause organic pollution of water bodies. Physical mowing and biological control are the main ways of balanced harvesting, physical mowing refers to the use of manual mowing, simple mechanical mowing and large mechanical mowing. Biological control refers to the use of herbivorous fish, protection or enhancement of natural enemies (such as parasites, predators, pathogens or competing species), etc. to keep the target species at a more desirable population size and growth state. In 2017, the Xiongnu New Area started a pilot reed harvest. In 2020, based on the experimental harvest, a large-scale local reed harvest will be carried out, mainly by mechanical harvesting on ice when Baiyangdian freezes, which is approximately 10 times more efficient than manual harvesting [46].

6. Conclusion and outlook

The introduction of the concept of balanced harvesting defines a scientific and beneficial harvesting approach for maintaining the health of aquatic ecosystems. It corroborates the theoretical hypothesis of mild disturbance in terms of the morphology of populations under different harvesting intensities, water ecological restoration, grass-algae balance, and marshyness, and provides technical support for scientific management of aquatic plants to maintain the ecosystem restoration and maintenance of grass-type lakes, and their sustainable development.

Chinese aquatic plant-related standards are only found in gardens, urban wetlands and other areas, specifying the cultivation, establishment, fertilization, water level control, pest control and removal of decaying plants of aquatic plants. Standards related to control and balanced harvesting techniques for aquatic plants in natural water bodies such as lakes and rivers are still blank. At present, the implementation of control and balanced harvesting of aquatic plants in lakes is seen in Wuliang Suhai and Baiyangdian, which have accumulated a lot of experience in aquatic plant control and balanced harvesting technology, but there are still shortcomings in the control objectives and technical specifications. Therefore, it is necessary to pay continuous attention to the control and balanced harvesting techniques of aquatic plants in shallow herbaceous lakes to guide the management of timely, appropriate and suitable harvesting of aquatic plants.

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