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Research Article

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Examining the Purification Effect of *Euryale Ferox* On Eutrophic Rivers Along the Huaihe River

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Abstract

We conducted a comprehensive analysis to assess the purification effect of Euryale ferox, a native aquatic plant, on eutrophic rivers in rural areas along the Huaihe River. This involved simulating variations in the total nitrogen (TN), ammonia nitrogen (NH4+-N), total phosphorus (TP), chemical oxygen demand (CODCr), pH, soluble salt content (SSC), and dissolved oxygen (DO) within the eutrophic river pool. Euryale ferox was cultivated in a eutrophic river pool within rural areas along the Huaihe River. Subsequently, an extensive analysis was conducted to assess the purification effects of Euryale ferox on river ecosystems. The results indicated that Euryale ferox, an indigenous aquatic plant in the Huaihe River, exerted a beneficial purifying influence on eutrophic rivers. This plant demonstrated a robust capacity to absorb NH4+-N and TP, ranging from 95.53% to 98.45% and 99.50% to 99.65%, respectively, in the water body during its growth, thereby achieving excellent purification performance. However, the purification of Euryale ferox for TN and CODCr in eutrophic rivers remains unclear. Notably, the pH in the aquatic environment demonstrated a noteworthy increase from 11.05% to 11.61%, while the EC value increased from 21.12% to 22%. Additionally, the DO levels exhibited a substantial increase, ranging from 3.82 to 21.77 times. It is essential to acknowledge that rural rivers are subject to various influences, including river velocity, submerged vegetation, aquatic fauna, and human activities. Further observation of practical applications is vital to comprehensively understand the implications of these findings.

Keywords: Euryale Ferox, Eutrophic River, Water Purification, Comprehensive Analysis

1. Introduction

The Proposal of the Central Committee of the Communist Party of China regarding the 14th Five-Year Plan for National Economic and Social Development and the Visionary Goals for the 23rd Five-Year Plan emphasizes "Promote rural latrines, domestic garbage disposal, and sewage treatment in accordance with local conditions and carry out a comprehensive renovation of rivers and lakes to improve the environment of rural human settlements [1]." Moreover, the Report of the 20th Party Congress states "Strongly promote the prevention and control of environmental pollution. Adhere to precise pollution control and scientific pollution control to integrate water resources, the water environment, water ecological management, etc. Promote urban and rural habitat improvement [[2]. The aquatic environment in rural areas has attracted increasing attention. According to the Ministry of Housing and Urban-Rural Development 2022 statistics [3], in China, the annual rural domestic water consumption has reached 6.5×10^7 m^3, with 36.94% of townships equipped for domestic sewage treatment. Local governments allocate substantial financial resources annually to execute rural sewage treatment projects. However, after construction, the long-term operation and maintenance of these facilities have proven exceedingly challenging [4], and the establishment of a robust management assurance system has not yet been achieved [5]. Moreover, different economic development environments across regions have led to extended periods of inactivity for sewage treatment plants in certain provinces. Rural sewage is directly discharged into pits, ditches, and rivers [6], with long-term accumulation of domestic waste and reduced water body flow. Consequently, during summer, these conditions frequently lead to the formation of black smelly water bodies, subject to local residents' criticism. Although sewage treatment plants remain partially operational, a comprehensive strategy has been implemented to address the factors contributing to the formation of black odour water bodies, such as the scientific application of source control, sewage interception, desilting, dredging, ecological restoration, and water purification [6]. The selection of ecological restoration measures is based on the specific functions of the water body, including rainwater collection and storage, soil retention, purification, irrigation, and landscape [6]. Water quality enhancement is a pivotal and primary objective in the management of rural water bodies [7], and serves as an essential condition for subsequent ecological restoration efforts within river ecosystems [7]. In rural regions, most rivers are shallow water bodies dominated by eutrophication, primarily driven by high nitrogen and phosphorus levels [8]. The management of eutrophication in shallow water bodies has attracted considerable attention from various parties [9, 10, 11, 12]. Aquatic plants, renowned for their robust pollutant tolerance in eutrophic environments [13], play a vital role in nutrient and pollutant reduction through absorption, adsorption, and degradation [14]. Consequently, they contribute to the creation of a healthier ecological environment and improve the self-purification capacity of water bodies [15, 16]. The utilization of aquatic plants for water purification has become one of the most important methods for the ecological management of eutrophic rural rivers [17, 18, 19, 20].

According to available statistics, there is a diverse array of aquatic plants, comprising 61 families, 168 genera, and 741 species in China [21]. Notably, these aquatic plants are effective tools for water purification, whether used individually or in combination with species such as plantains, reeds, calamus, bitter grass, and goldfish algae [22, 23, 24,]. Among them, pink-green foxtail, plantain, and reed plants demonstrate notable proficiency in nitrogen removal [25], whereas fenugreek, duckweed, and zelchocarpus excel in phosphorus removal [26]. Aquatic plants with substantial root systems, high oxygen-secreting capacity, and microorganism-friendly surfaces offer distinct advantages for COD removal from water sources [25, 26]. It is imperative to recognize that the purifying efficacy of aquatic plants in polluted waters is also affected by several environmental factors, including light [27, 28], temperature conditions [29] water depth [30], and flow [31].

In the selection of aquatic plants, it is often observed that non-native species, such as water hyacinth [32] and algae [33], are favoured, despite their inherent challenges in control [34] and their potential to disrupt the original ecosystem dynamics [34]. China possesses a bountiful reserve of indigenous aquatic plants, noted for their abundant resources [21], with high ecological safety and water purification capacity. For example, the yellow-flowered water dragon, a native plant, exhibits an impressive removal rate of approximately 60% for total nitrogen in polluted water [35], which is 2.6 and 2.9 times that of water hyacinth and water peanut, respectively. Similarly, its removal rate for total phosphorus was approximately 25%, exceeding that of water hyacinth and water peanut by 0.7 and 1.9 times, respectively. In the Anhui Province, specifically within the Huaihe area, local water systems are abundant and extensively cultivated with *Euryale ferox*, lotus roots, wild rice, and other aquatic plants. On the afternoon of August 18, 2020, during a visit to the Mengwa flood control reservoir in Funan County, Xi Jinping, Secretary-General of Anhui Province, interacted cordially with local residents while harvesting *Euryale ferox,* emphasizing the importance of leveraging local conditions to expedite replanting efforts, minimize disaster losses, and achieve a successful autumn harvest. Previous studies have consistently demonstrated the significant water purification capabilities of Euryale ferox in various settings, including rural sewage in Hunan [24] and water bodies experiencing varying levels of eutrophication in Northeast China and other regions [36]. Additionally, *Euryale ferox* serve as valuable indicators of environmental pollution [21].

The native aquatic plant *Euryale ferox* in the Huaihe region has traditionally garnered attention for its medicinal properties [37, 38]. However, its use in the management of rural eutrophic rivers in the Anhui Province of the Huaihe region remains relatively unexplored. This study focused on hybrid *Euryale ferox* cultivated in the Huaihe area, and investigated their efficacy in purifying shallow eutrophic water bodies. The aim was to propose technical solutions and provide empirical data to support the management of eutrophic water pollution in shallow rural water bodies along the Huaihe area while also offering insights for local ecological enhancement and landscape preservation.

2. Materials and methods

2.1 Test plants and water bodies

The experiment was conducted within the garden training field of Fuyang Vocational and Technical College. This training field includes two landscape ponds, with an upstream pond of irregular dimensions and a depth of 1.3 m, covering an area of approximately 100 m2. The pool is landscaped with rye grass along its perimeter, featuring a pavilion on the north side and stones on the east side. The surroundings are adorned with spring, forsythia, willows, peach trees, and other vegetation. A water stopper is positioned on the south side, allowing water to overflow into the downstream landscape pool when the water level exceeds the stopper by 1.2 m. An inlet for tap water is positioned on the north side of the upstream landscape pond, ensuring consistent water depth in both ponds throughout the year. The upstream landscape pond has experienced prolonged eutrophication. During the experimental period, it was drained to facilitate the testing. River water from the landscape river in the courtyard of the Fuyang Vocational and Technical College was introduced into the landscape pond during the *Euryale ferox* planting phase. The primary aim of this experiment was to assess the water purification capabilities of *Euryale ferox*. Notably, the experiment was not designed for river flow rates, not adding water to the landscape pond or applying fertilizers to replicate the conditions in rural rivers along the Huaihe region. In June 2022, *Euryale ferox* seedlings were procured from Fuyang City, Funan County, and Fuyang County *Euryale ferox* Planting Professional Cooperatives. Each plant exhibited uniform height and biomass, and a gradual pseudo-planting technique was used to decelerate the seedlings after planting. The selected planting pot was a dragon pot measuring 600 mm in diameter and 380 mm in height. These pots were filled with a substrate derived from river sludge originating in a village in Wanghua Town, Funan County, characterized by sandy ginger-black soil with a soil capacity of approximately 1.42g/cm^3.

2.2 Experimental procedure

In late May 2022, *Euryale ferox* were planted by filling dragon tanks with sludge, extending to a depth of 50 cm, and subsequently placing them in a sewage pond. A total of 18 pots were strategically positioned based on the *Euryale ferox* density and irregular shape of the landscape pond. On June 15, 2022, slow-growing *Euryale ferox* were transplanted, and the pond was filled with water sourced from the landscape river of the school. The initial concentrations of the test water were as follows: total nitrogen (TN) ranged from 0.544 to 0.566 mg•L^{-1}, ammonia nitrogen (NH_4^+-N) ranged from 0.112 to 0.24 mg•L^{-1}, total phosphorus (TP) ranged from 0.232 to 0.242 mg•L^{-1}, chemical oxygen demand (CODCr) ranged from 9.605 to 15.99 mg•L^{-1}, pH ranged from 7.51 to 7.58, soluble salt content (EC) ranged from 516 to 518 us·cm^{-1}, and dissolved oxygen (DO) ranged from 0.819 to 1.214 mg•L^{-1}. These concentrations were close to those found in rural rivers within the Huaihe region. The experimental period spanned from June 15, 2022, to September 15, 2022, totalling a 90-day testing cycle. In mid-July, the padded section of the dragon tank was removed, and water quality samples from the landscape pond were collected and analysed at 15-day intervals. At the end of the experiment, the landscape pond was maintained at a water depth of 50 cm, and the decomposing plants were removed. Water samples were extracted from a depth of 3 cm from the water surface, and 500 mL samples were collected from three distinct locations in the landscape pond, designated as Sites I, II, and III. The experimental process was divided into a pre-growth period (June 15 to June 30), mid-growth period (June 30 to July 30), late growth period (July 15 to August 15), harvest period (August 15 to August 30), and decay period (August 30 to September 15).

2.3 Detection methods

TN concentrations were detected using alkaline potassium persulfate digestion UV spectrophotometry (HJ636-2012). TP concentrations were assessed using ammonium molybdate spectrophotometry (HJ671-2013). COD levels were quantified using the dichromate method (HJ828-2017), and NH_3-N concentrations were determined via nano-reagent spectrophotometry (HJ535-2009). Additionally, pH values were measured using a photometric method (HJ535-2009) and an acidimeter.

The removal rate (ρ, %) of each index was calculated as follows:

$\rho=(\rho_0-\rho_i)/\rho_0\times 100\%$.

where ρ_0 represents the initial measured mass concentration of the site, mg•L^{-1}; and ρi represents the last measured mass concentration of the site, mg•L^{-1}.

2.4 Data analysis

Microsoft Excel was used to calculate and plot the data, and SPSS22.0 statistical analysis software was applied to analyse the data.

3 Results and analysis

3.1 Purification effect of Euryale ferox on TN and NH4+-N in water bodies

The influence of *Euryale ferox* on the purification of TN in eutrophic water bodies (Fig. 1) exhibited a pattern of increase-decrease-increase during the Euryale ferox growth period. Specifically, during the pre-growth phase of *Euryale fero*x, the TN content of the water body initially increased. Subsequently, during the rapid growth phase of Euryale ferox, the TN content substantially decreased, indicating the efficacy of *Euryale ferox* in TN removal from eutrophic water bodies. As *Euryale ferox* growth decelerated in the later stage, the TN content in the water body demonstrated an increasing trend. From the harvesting period to plant failure, the TN content experienced a slight decrease followed by an increase, eventually reaching its peak value. Throughout the entire Euryale ferox growth period, variations in TN content within the water body remained minimal, fluctuating within the range of 0–0.42%.

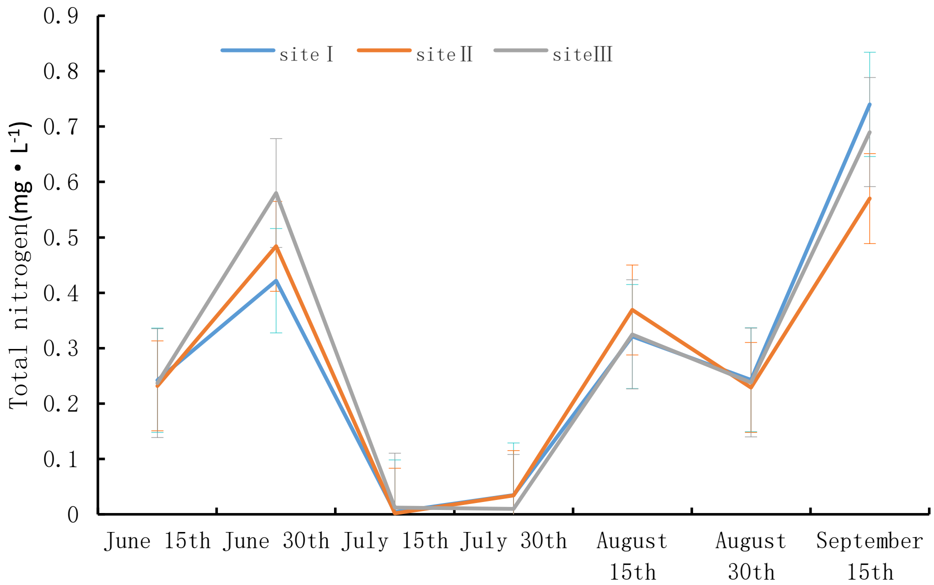

Figure 1: Dynamics of total nitrogen at each sampling point

The NH_4^+-N removal effect of the *Euryale ferox* is evident in Fig. 2, demonstrating their remarkable capacity to purify NH_4^+-N from eutrophic water bodies. During the pre-growth phase of *Euryale ferox*, there was a rapid decrease in NH_4^+-N content within the water body. Throughout the middle, late, and harvest growth periods, the NH_4^+-N content remained consistently low, maintaining a go-flat state. Subsequent to the decay of the *Euryale ferox* plant body, the NH_4^+-N content increased again. When considering the period from *Euryale ferox* planting to harvesting, *Euryale ferox* exhibited an impressive NH_4^+-N purification efficiency, ranging from 95.53% to 98.45%, indicative of their robust purification capability.

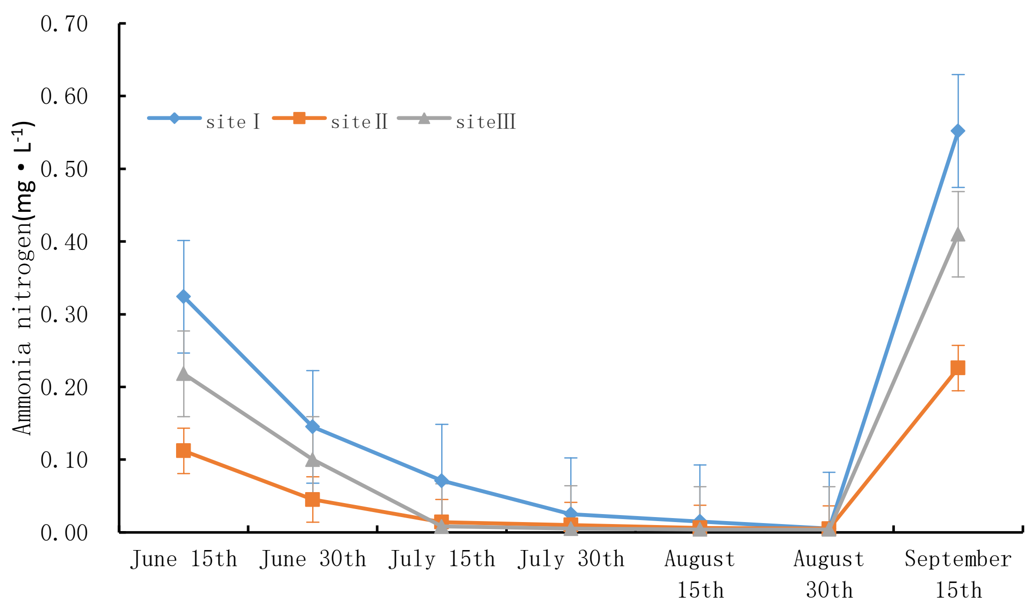

Figure 2: Dynamics of ammonia nitrogen at each sampling point

3.2 Purification effect of *Euryale ferox* on TP and CODCr in water bodies

The purification effect of *Euryale ferox* on TP in eutrophic water bodies (Fig. 3) indicates a highly pronounced removal effect. During the pre-growth period of *Euryale ferox*, there was a steep decline in TP content within the water body. Subsequently, from the middle of the growth period until decay, the TP content in the water body remained consistently low, maintaining a flat state. The effect of the plant on TP purification in eutrophic waters was remarkable, ranging from 99.50% to 99.65%, underscoring its potent purifying capacity.

During the analysis of the purifying effect of *Euryale ferox* on COD_{Cr} in eutrophic water bodies (Fig. 4) showed that the COD_{Cr} content initially increased during the pre-growth period. Subsequently, as the *Euryale ferox* grew, the COD_{Cr} content increased slightly, followed by a rapid decline. During the harvesting phase of *Euryale ferox*, the COD_{Cr} content increased. After the decay of the Euryale ferox plants, the COD_{Cr} content decreased again. Throughout the entire test period, involving Euryale ferox, the COD_{Cr} content in the pools exhibited relatively minimal fluctuations.

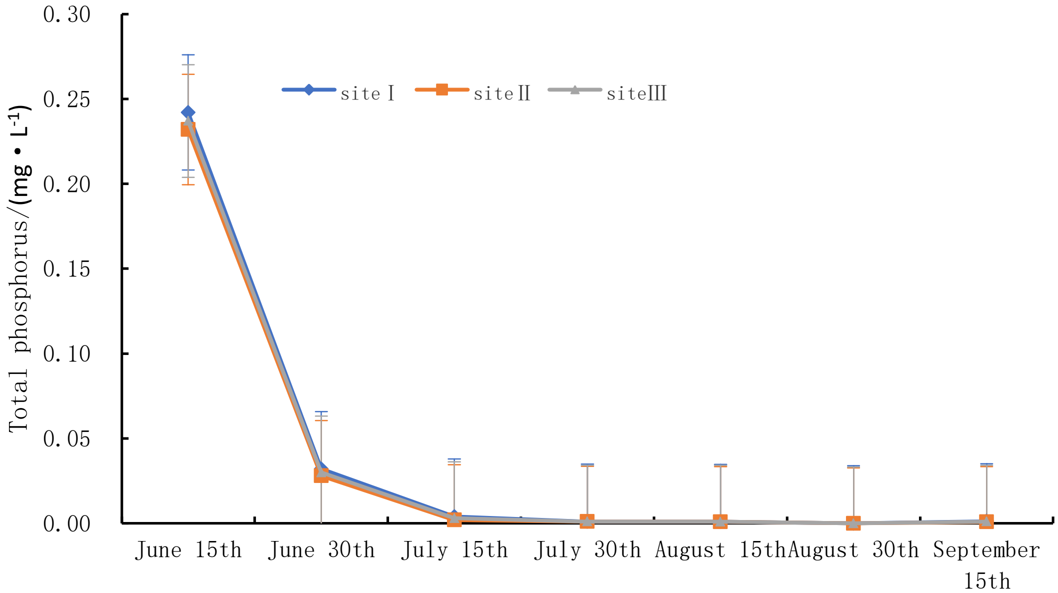

Figure 3: Dynamics of total phosphorus at each sampling point

Examination of the purifying effect of *Euryale ferox* on COD_{Cr} in eutrophic water (Fig. 4) revealed that the COD_{Cr} content initially increased during the pre-*Euryale ferox* growth period. Subsequently, it exhibited a rapid decline with the growth of the Euryale ferox, followed by a slight increase and another rapid decrease. During the harvesting period of *Euryale ferox*, the COD_{Cr} content increased again but decreased again after the decay of Euryale ferox plants. The overall variation in the COD_{Cr} content in the pools remained relatively insignificant throughout the test period involving *Euryale ferox*.

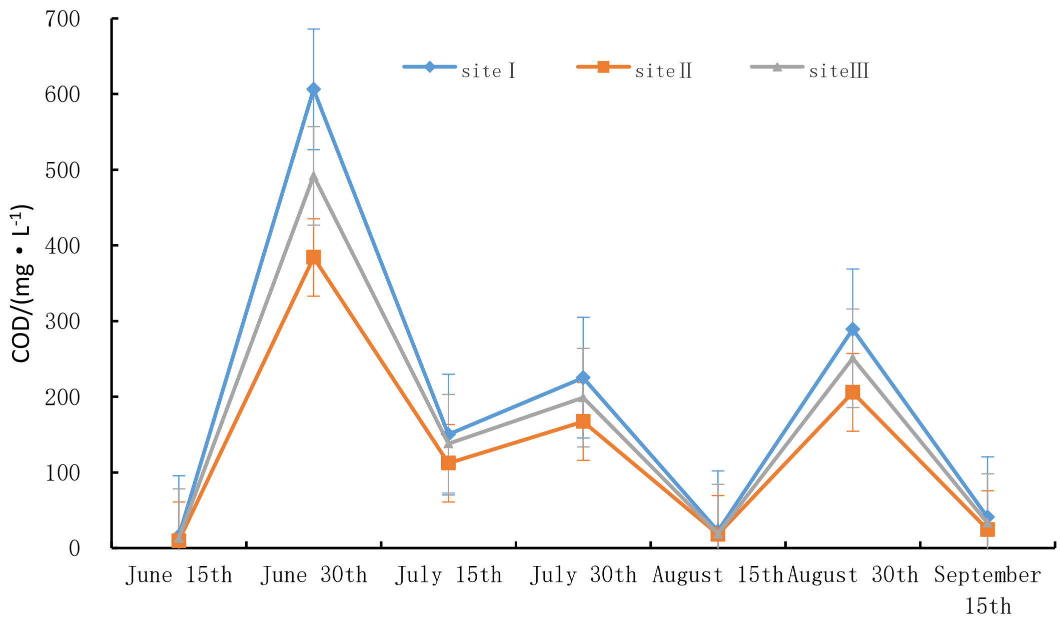

Figure 4: Dynamics of COD at each sampling point

3.3 Effect of *Euryale ferox* on pH, EC, and DO in water bodies

Analysing the impact of *Euryale ferox* on pH levels in eutrophic water bodies (Fig. 5), after *Euryale ferox* planting, the pH in eutrophic water initially began to rise during the pre-growth phase. Subsequently, during the middle growth period of the *Euryale ferox*, the pH exhibited a slight decline, followed by another increase. During the late growth period, the pH decreased again. It peaked at the time of the *Euryale ferox* harvest. After the decay of Euryale ferox plants, the pH of the pool decreased again. Across the entire growth process of *Euryale ferox*, there was a general trend of pH elevation, with an increase ranging from 11.05% to 11.61% when calculated from *Euryale ferox* planting to harvest.

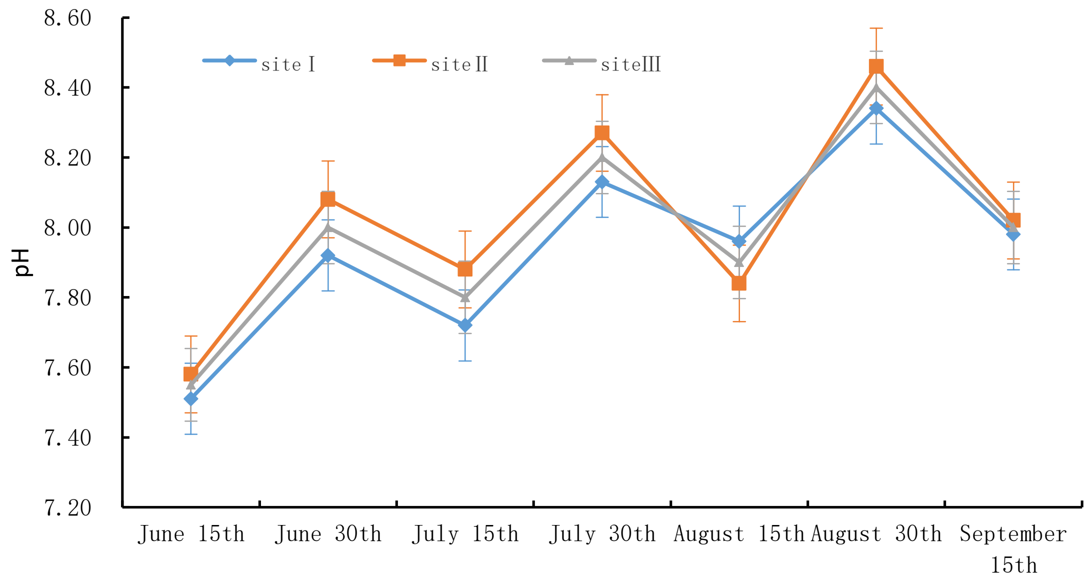

Figure 5: Dynamics of pH at each sampling point

Analysis of the impact of *Euryale ferox* on EC values in eutrophic water bodies (Fig. 6) revealed that *Euryale ferox* initiated an increase in EC values during the pre-planting period. However, the EC values in pools experienced a slight decrease during the mid-growth period. Subsequently, during the late growth period, the EC values increased again, followed by a decrease during the harvesting period. During the decay period, the EC values increased to higher levels. Based on the entire period from *Euryale ferox* planting to harvest, there was an overall increasing trend in EC values, with increases ranging from 21.12% to 22%.

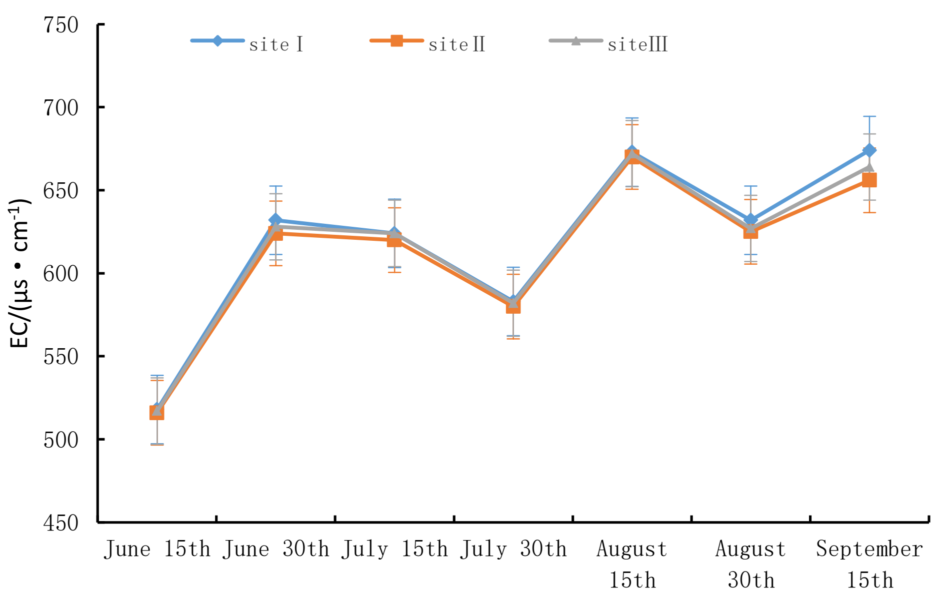

Figure 6: Dynamic change of EC value at each sampling point

During the analysis of the impact of *Euryale ferox* on DO levels in eutrophic waters (Fig. 7), DO exhibited a consistent upward trend throughout the growth of the *Euryale ferox*, reaching its peak during the late growth phase. However, upon harvesting and transitioning to the decay period, the DO levels began to decrease linearly. Calculations based on the period from *Euryale ferox* planting to harvesting indicated a substantial increase in DO, ranging from 3.82 to 21.77 times.

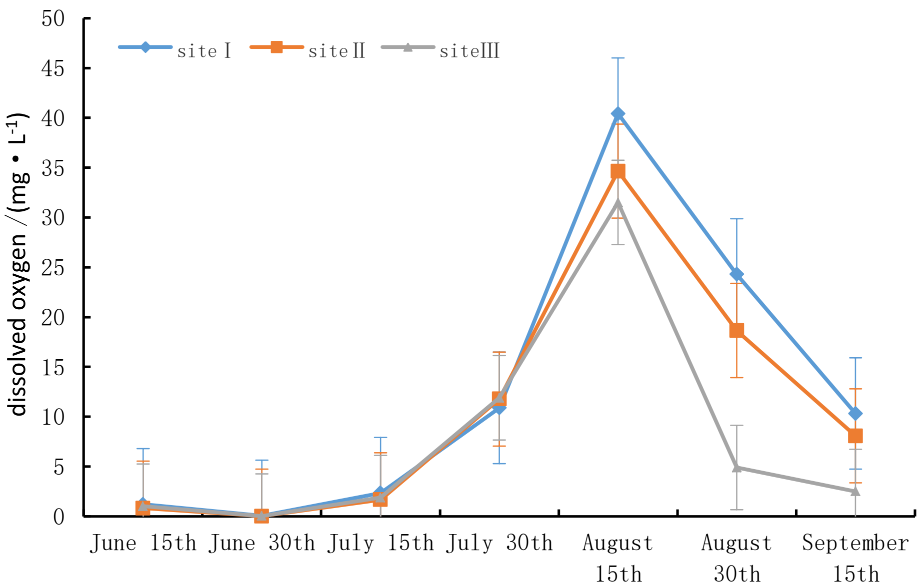

Figure 7: Dynamics of dissolved oxygen at each sampling point

4. Discussion

4.1 Analysis of TN and NH4+-N removal in water bodies by *Euryale ferox*

In eutrophic water bodies, nitrogen removal primarily involves processes such as plant uptake, ammonia nitrogen volatilisation, and denitrification facilitated by inter-root microorganisms [39]. During the initial growth period of *Euryale ferox*, the TN in the water tended to increase, which may be attributed to the nitrogen nutrient exchange occurring between the substrate and water, leading to the release of nitrogen from the substrate into the water [40]. Notably, as *Euryale ferox* grow more rapidly during the summer in eutrophic waters, their capacity to absorb and utilise total nitrogen intensified, resulting in a substantial reduction in TN content [40]. This phase demonstrated an efficient removal of TN from the water, ranging from 85.34% to 95.78%, consistent with the findings of Yan [29]. In the later stages of *Euryale ferox* growth, the uptake of TN by the Euryale ferox decreased. As external factors such as precipitation and surface runoff contribute nitrogen to the open water body [26], the TN content exhibited an upward trend, which was substantiated by the concurrent increase in EC values within the water body. During the later period, the decay and decomposition of *Euryale ferox* plants led to an increase in nitrogen and phosphorus nutrient concentrations. The significant increase in TN content in the water body corresponded with changes in ammonia and nitrogen levels, which was consistent with a previous study [29]. During the application of *Euryale ferox* for eutrophic water purification, TN and TP can be transferred to plants through uptake processes and subsequently removed from water upon plant harvest.

Throughout the growth of *Euryale ferox*, the primary nitrogen source in eutrophic waters is ammonia nitrogen [41]. When multiple forms of nitrogen are absorbed concurrently, *Euryale ferox* exhibit a preference for NH_4^+-N [42]. The change in NH_4^+-N content demonstrates that Euryale ferox rely on ammonia nitrogen from growth to harvest. The decline in the NH_4^+-N content indicates that Euryale ferox require ammonia nitrogen throughout their growth. Notably, ammonia nitrogen decreased because volatilisation became more pronounced only when the pH of the water body exceeded 8.0, and the ammonia-to-ammonium ion ratio reached 1:1 [43]. During the pre-growth period, the pH of the water body experienced rapid elevation, surpassing 8.0 during the pre-growth period and reaching 8.27 during the peak growth period. This increase in pH can contribute to ammonia nitrogen volatilisation. During this period, external environmental factors introduced the effluents. However, the majority of the external nitrogen existed as NO_3—N [26], with the NH_4^+-N content remaining relatively stable. In an aerobic environment, NH_4^+-N reacts with dissolved oxygen to produce nitrite [44]. With the DO data, the water body experienced a DO peak during the *Euryale ferox* growth period. This peak facilitated the reaction with NH_4^+-N, thereby maintaining a low ammonia nitrogen content in the water body. Subsequently, as the *Euryale ferox* decayed, nutrients from the plant body re-entered the water body, leading to an increase in nutrient salt concentrations [45] and a subsequent increase in ammonia nitrogen content. This was further corroborated by the increase in EC of the water body during the decay period.

4.2 Analysis of TP and COD removal in water bodies by *Euryale ferox*.

A significant portion of phosphorus in the water body exists in the form of insoluble phosphates [46]. The removal of TP requires the conversion of insoluble phosphate into organic components. Oxygen availability in the root zone facilitates the action of phosphorus-colonizing bacteria responsible for phosphorus degradation in the effluent [47]. Dissolved oxygen data have consistently increased since the establishment of *Euryale ferox*, leading to continuous oxygen release by plants. Consequently, TP reduction occurred under the influence of poly phosphorus bacteria, which is consistent with the experimental results. During the pre-growth period of *Euryale ferox*, the conditions were conducive, with nutrient-rich water and a suitable climate. During this period, the collaboration of nitrogen nutrients accelerated TP removal by the *Euryale ferox*. The primary phosphorus uptake by Euryale ferox was concentrated in the pre-growth period, which is consistent with the findings of the study by [48]. Overall, the *Euryale ferox* exhibited a notably high TP removal rate from the water body throughout the experiment, which was in line with previously reported results.

COD_{Cr} removal by aquatic plants is closely related to microbial degradation and the DO [46, 49]. This indicates that anaerobic degradation occurs when there are varying DO concentrations in water bodies. Anaerobic degradation occurs when the DO levels are below 0.20 mg/L. Anoxic degradation occurs when DO range from 0.20 to 1.0 mg/L, whereas aerobic degradation dominates when DO exceeds 1.0 mg/L [50]. In the initial stages of the experiment, *Euryale ferox* growth was low, resulting in reduced microbial activity and relatively low DO concentrations in the water body. Consequently, COD_{Cr} levels in the water body rapidly increased during the initial growth period. However, as the *Euryale ferox* biomass expanded and their root systems developed, the DO concentration significantly increased and sufficient oxygen was released, thereby providing an optimal environment for microbial activity and enhancing their effectiveness. During this period, the COD_{Cr} levels in the water demonstrated a downward trend throughout the growth period, albeit with occasional fluctuations attributed to external environmental factors.

4.3 Analysis of the effect of *Euryale ferox* on DO in the water body

DO depletion in water bodies primarily occurs through physical, chemical, and biological processes [51]. Under hydrostatic conditions, physical consumption is notably slow [51], with changes in the DO concentration primarily driven by chemical reactions and biological activities within the water body. In the initial stage of *Euryale ferox* growth, the increase in local air and water temperatures, substrate decomposition, and *Euryale ferox* growth collectively consumed oxygen from the water, leading to a decrease in DO concentration. Throughout the middle and late stages of *Euryale ferox* growth, *Euryale ferox* released oxygen through their respiratory tissues. Throughout this period, microorganisms in the water body exhibited enhanced activity, leading to oxygen consumption. Despite this microbial activity, the DO concentration curve continued to steadily rise, signifying robust *Euryale ferox* growth and increased oxygen release during this growth period. The net increase in aquatic plant biomass remains a critical factor influencing purification capacity [34]. Following the transition into the harvesting period, the *Euryale ferox* growth rates decelerated, resulting in a linear decline in water DO levels. The magnitude of this decrease in DO was directly correlated with the growth status of aquatic plants, which is consistent with previous research findings [52].

5. Conclusion

(1) Native aquatic plants, such as *Euryale ferox*, exhibit notable purification effect on eutrophic rivers, with a preference for selecting native species with substantial biomass increase and rapid growth for cultivation.

(2) *Euryale ferox* demonstrated remarkable purification effectiveness by absorbing 95.53% to 98.45% of NH_4^+-N and 99.50% to 99.65% of TP from the water body during their growth stages.

(3) Although the purification effect of Euryale ferox on TN and COD_{Cr} in eutrophic water bodies may not be evident, they induced significant changes in the water body, including a 11.05% to 11.61% increase in pH, a 21.12% to 22% increase in EC values, and a substantial 3.82 to 21.77-time increase in DO levels.

The results of this study indicated that *Euryale ferox*, a native aquatic plant, can absorb nitrogen and phosphorus nutrients from eutrophic water bodies. Moreover, the presence of aquatic vegetation improves the nitrogen and phosphorus removal efficacy of water bodies, particularly in conjunction with the removal of exogenous pollutants [34]. These experimental results offer valuable insights into the potential restoration of eutrophic water bodies and the application of ecological engineering to rural river ecosystems. Prioritization of native aquatic plants with high biomass and rapid growth is recommended when selecting suitable candidates for ecological restoration [34]. It is imperative to acknowledge that the aquatic environment of rural rivers is intricate and influenced by certain factors, such as river flow, submerged aquatic vegetation, aquatic fauna, and human activities. Consequently, further observations and evaluations are required for practical implementation.

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