

## Original Article

# Phytoremediation of some freshwater aquatic ornamental plants to treat wastewater from Indonesian shortfin eel, *Anguilla bicolor*

Hany Handajani<sup>\*1</sup>, Widanarni<sup>2</sup>, Tatag Budiardi<sup>2</sup>, Mia Setiawati<sup>2</sup>, Soni Andriawan<sup>1,3</sup>

<sup>1</sup>Department of Aquaculture, Faculty of Agriculture and Animal Science, University of Muhammadiyah Malang, Malang, East Java, 65144, Indonesia.

<sup>2</sup>Aquaculture Science Department, Faculty of Fisheries and Marine Sciences, IPB University, Bogor, West Java, Indonesia.

<sup>3</sup>Biotechnology Development Center, University of Muhammadiyah Malang, Malang, East Java, 65144, Indonesia.

**Abstract:** This study evaluated the ability of freshwater ornamental aquatic plants to treat wastewater from *Anguilla bicolor* culture and the effects on growth performance. Over 60 days, plants including *Cryptocoryne beckettii*, *Bacopa serpyllifolia*, *Echinodorus amazonicus*, *Echinodorus palaefolius*, and a control group were tested. The average weight of *A. bicolor* was  $7.01 \pm 0.18$  g, with a stocking density of  $4 \text{ g L}^{-1}$ . The *A. bicolor* were maintained in 48 L aquariums with a recirculating system, using aquatic plants as phytoremediators, in a semi-outdoor laboratory to ensure adequate light. The feed protein content was 45.30%, and feeding occurred three times daily. The results showed that the aquatic plants efficiently removed nutrients from the water. *Echinodorus palaefolius* was the most effective, removing 23.33% of total ammonia nitrogen (TAN), 33.25% nitrite, 47.40% nitrate, and 43.92% phosphate. This species also promoted the highest specific growth rate ( $1.14 \pm 0.10\%$ ), biomass ( $22.67 \pm 1.65$  g), and physiological response in *A. bicolor*, with the lowest feed conversion ratio ( $1.97 \pm 0.17$ ). In conclusion, *Echinodorus palaefolius* effectively improved water quality and growth performance in *A. bicolor*, demonstrating its potential as a phytoremediator for sustainable aquaculture.

### Article history:

Received 15 April 2025

Accepted 1 January 2026

Available online 25 April 2026

### Keywords:

Nutrient removal efficiency

Phytoremediation

*Anguilla bicolor*

Recirculation

## Introduction

Indonesian shortfin eel, *Anguilla bicolor*, is a valuable export commodity in Indonesia (Nafsiyah et al., 2018). They are found in diverse regions of Indonesia, including the south coast of Java, the west coast of Sumatra, the east coast of Borneo, the coast of Sulawesi, and the shores of the Moluccas and New Guinea. The intensification of *A. bicolor* culture entails increased feed utilization and greater wastewater generation (Nawir et al., 2015). The accumulation of waste in an aquaculture system degrades water quality parameters, thereby directly affecting the physiological processes, behavior, growth, and mortality of reared fish (Bureau and Hua, 2010; Davidson et al., 2016). According to Brune et al. (2003), approximately 25% of the total nitrogen in feed is utilized for growth, 60% is excreted in  $\text{NH}_3$  form, and 15% is excreted in feces. In the feed, 37%-72% of nitrogen is converted to ammonia via

excretion or bacterial mineralization (Dauda et al., 2018). Crab et al. (2007) explained that 33% of feed nitrogen could be excreted and recycled. On average, 60-90% of nitrogen and 25-85% of phosphorus are excreted in metabolic waste (Van Rijn, 2013).

Maintaining water quality within an acceptable range reduces waste accumulation. According to Ahmad et al. (2021), aquaculture requires water as a rearing medium, thereby increasing the risk of environmental degradation. Phytoremediation and recirculation are approaches for maintaining water quality within the tolerable range (Ghaly et al., 2005; Qu et al., 2017). The principle of the recirculation system is water recycling (Twarowska et al., 1997; Deviller et al., 2004; Metaxa et al., 2006; Han et al., 2021), and its advantages are minimizing water usage, buffering pH level, and reducing inorganic materials, such as ammonia and nitrite (Suzuki et al., 2003; Tseng and Wu, 2004; Romano and Sinha, 2020).

\*Correspondence: Hany Handajani  
E-mail: handajani@umm.ac.id

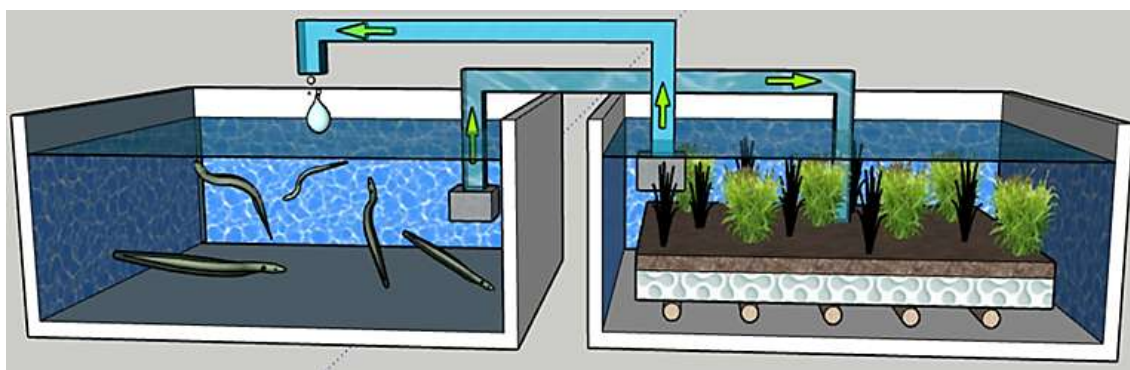


Figure 1. Recirculation design on *Anguilla bicolor* culture with phyto remediation application.

Phyto remediation uses plants to remediate environmental pollutants, including elevated nitrogen and organic contaminants in soils, water, and sediments (Newman and Reynolds, 2004; Dickinson et al., 2009). The advantages of using the phyto remediation system are low-cost production (Jasrotia et al., 2017), natural process, plant synergy, and simple technology (Russell, 2005; Nootong et al., 2013; Paz-Alberto and Sigua, 2013). Several phyto remediation studies have been conducted using water hyacinth, *Eichhornia crassipe* (Liao and Chang, 2004; Madikizela, 2021; Singh et al., 2022), *Pistia stratiotes* (Madhurina et al., 2014), *Hydrilla verticillata* (Rahman and Hasegawa, 2011), and *Lemna perpusilla* (Mkandawire and Dudel, 2007; Zhou et al., 2023).

Combining the recirculation system with phyto remediation resulted in efficient water use and acceptable water quality. However, most studies on phyto remediation have used vegetables such as *Ipomoea aquatica*, *Amaranthus* spp., and *Solanum lycopersicum* (Borguini et al., 2013). Accordingly, further research on the use of ornamental aquatic plants for phyto remediation is warranted (Nakbanpote et al., 2016). The ornamental aquatic plant has greater economic value and nutrient-absorption capacity than the common vegetable (Sharma et al., 2016). Hence, potential ornamental aquatic plant species for reducing nitrogen and phosphorus waste must be evaluated. Therefore, this study aimed to assess the role of several ornamental aquatic plant species in the phyto remediation of wastewater from an *A. bicolor* recirculating system and their effects on its growth

performance.

### Materials and Methods

This study was conducted at the University of Muhammadiyah Malang Fishery Laboratory for three months. Water quality was measured in the Water Quality Laboratory, blood profile analysis was conducted in the Biology Laboratory, and proximate analysis was performed in the Nutrition Laboratory.

**Fish and plant screening:** The experimental aquarium was 40×30×30 cm and was equipped with a recirculation system. The foundation of the aquarium was constructed with a double bottom, a PVC pipe as a buffer, soft gauze, and a gutter for the Dacron, and sand as the media for the aquatic plant (Fig. 1). There was no water discharge; thus, water was added to maintain the water height caused by evaporation.

Fish was obtained from fish farms in Tulungagung, East Java, Indonesia. The average weight of *A. bicolor* was 7.01±0.18 g. The 342 elvers were adapted for 30 days in a 100×100×100 cm tank. Subsequently, the 15 elvers were treated for 60 days at a stocking density of 4 g L<sup>-1</sup> in an aquarium (40×30×30 cm) (Harianto et al., 2014). During the study, the elvers were fed a commercial paste feed with a protein content of 45.3%. The feeding method was satiation, and the feeding frequency was three times daily at 7.00, 13.00, and 19.00.

Some studies suggest that various aquatic plants are effective phyto remediators, each contributing uniquely to nutrient uptake and water-quality improvement in sustainable aquaculture systems. For instance, *Vallisneria spiralis* (Eelweed), *Lilaeopsis* sp.

(Grassworts), and *Hygrophila difformis* (Water wisteria) demonstrate high rates of ammonia, nitrate, and phosphate uptake, enhancing water quality through robust growth (Zhang et al., 2009; de Winton et al., 2013; Zhou et al., 2018; Tang et al., 2021). *Microsorium pteropu* (Java fern), *Cryptocoryne becketti* (Water trumpet), *Echinodorus amazonicus* (Amazon sword plant), and *E. palaefolius* (Mexican sword plant) are particularly effective in reducing total ammonia nitrogen (TAN) and phosphate, with *E. palaefolius* achieving notable clarity and nutrient balance (Handajani et al., 2018; Rosen, 2000; Handajani et al., 2021; Zakia et al., 2023). *Bacopa serpyllifolia* (Bacopa "Japan") can act as a natural adsorbent, demonstrating high efficacy in removing pollutants such as phenols and oils from wastewater (Mokif and Abdulhusain, 2022). Smaller species, such as *Eleocharis parvula* (Small Spikerush) and *Hemianthus callitrichoide* (Dwarf baby tears), have been identified as hyperaccumulators of heavy metals, including arsenic (As), copper (Cu), and zinc (Zn) (Othman et al., 2015; Nurfitri et al., 2017). Together, these plants support sustainable aquaculture by reducing nutrient loads and enhancing habitat structure.

This study employed ornamental aquatic plants as phytoremediators commonly featured in aquascapes. Preliminary research involved rearing the above-mentioned plants for two weeks using wastewater from Nile tilapia aquaculture. After this period, four species demonstrated satisfactory growth: *C. beckettii* (T1), *B. serpyllifolia* (T2), *E. amazonicus* (T3), and *E. palaefolius* (T4), which were considered treatments, with a control group without any plant. The aquatic plants were sourced from Batu, Malang, East Java, Indonesia. Before the experiment began, the plants were acclimated to a recirculating water system for 14 days to ensure optimal growth conditions. Subsequently, each species was established at a stocking density of approximately 80 g wet weight per aquarium (40×30×30 cm). These tanks were exposed to natural sunlight throughout the study, providing consistent natural light for photosynthesis.

#### **Data collection and experimental parameters**

**Nutrient removal efficiency (NRE):** Subsequently, weekly water-quality analyses were conducted on the influent and effluent of each treatment system. Water samples were analyzed for concentrations of total ammonia-nitrogen (TAN), nitrite-nitrogen (NO<sub>2</sub>-N), nitrate-nitrogen (NO<sub>3</sub>-N), and orthophosphate (PO<sub>4</sub>-P) using the Nessler Reagent method, the diazotization method, the cadmium reduction method, and the ascorbic acid method, respectively (Enduta et al., 2011). Before analysis, all samples were filtered through a fiberglass filter (Whatman paper) with a pore size of 0.45 µm. The resulting solutions were analyzed using a spectrophotometer. The removal efficiency for the parameters was calculated using the equation: Removal efficiency (%) = (Influent – Effluent) / Influent × 100.

**Production performance of aquatic ornamental plants:** All aquatic plants were weighed every two weeks during the study to estimate the mean wet weight and relative growth rate for 60 days of rearing. At the beginning and end of the study, total N and P in plant tissues were analyzed to determine nitrogen and phosphorus retention. Analyzing nitrogen retention in plants begins with collecting consistent tissue samples, such as leaves and stems. The plant samples were dried at 60-70°C to remove moisture and ground into a fine powder to ensure consistent nitrogen and phosphate analysis. Nitrogen content was determined using the Kjeldahl method (Kainama et al., 2021). This method involved digesting a 5 g sample with 20 mL of concentrated sulfuric acid (98%) and a catalyst, thereby converting organic nitrogen to ammonium. Moreover, phosphate concentration was determined using the molybdenum blue method (method 995.11) with a UV spectrophotometer (UV-2450, Shimadzu, Kyoto, Japan) (Trung Quang et al., 2024). Nitrogen and phosphate retention were calculated by comparing final and initial levels, thereby providing a measure of nitrogen uptake and utilization over time. Using the formulas of Nitrogen Retention (g) = Final nitrogen (g) – Initial nitrogen (g), and Phosphate Retention (g) = Final phosphate (g) – Initial phosphate (g).

**Water quality analysis:** Water quality measurements

were conducted over 60 days. Temperature, pH, and dissolved oxygen (DO) were measured daily. In contrast, alkalinity, total ammonia nitrogen (TAN), nitrite (NO<sub>2</sub>-N), nitrate (NO<sub>3</sub>-N), orthophosphate (PO<sub>4</sub>-P), and total suspended solids (TSS) were measured every two weeks, as described by Goddek and Vermeulen (2018) and Flickinger et al. (2019). Measurements of TAN, NO<sub>2</sub>-N, NO<sub>3</sub>-N, and PO<sub>4</sub>-P were performed using a spectrophotometer, in accordance with APHA (2006).

**Growth performance of Indonesian shortfin eel:** The data on production performance included survival rate (SR), weight gain (WG), daily weight gain (DWG), specific growth rate (SGR), and feed conversion rate (FCR) (Nhan et al., 2019). Daily records were done on *A. bicolor* feed intake and survival rates. Satiation feeding was implemented on the first day of each sampling period to calibrate the daily feeding rate relative to fish body weight. Five fish in each tank were randomly selected and weighed every two weeks to estimate the mean body weight, assess fish production, and adjust feeding levels as necessary. The survival rate was recorded at 7-day intervals. Growth performance parameters were calculated using the formula (Enduta et al., 2011)

WG (g) = Final weight (g) – Initial weight (g)

DGW (g d<sup>-1</sup>) = (Final weight (g) – Initial weight (g))/culture period (d)

SGR (% d<sup>-1</sup>) = (ln mean final weight - ln mean initial weight)/culture period (d)

FCR = culture period (d) / Total wet weight gain (g)

SR (%) = Final number of eel / Initial number of eel × 100

Meanwhile, protein retention (PR) and lipid retention (LR) were analyzed using proximate analysis (Horwitz et al., 1970). The crude protein content of the fish samples was analyzed by the Kjeldahl method, and crude lipid content was measured by extraction, a widely recognized and reliable method for isolating lipids from tissue samples (Kim and Lee, 2005; Pratama et al., 2020) using the formulas of PR (%) = (Initial fish protein (g) - Final fish protein (g)) / Protein consumption (g) × 100, and LR (%) = (Initial fish fat (g) - Final fish fat

(g)) / Fat consumption (g) × 100, respectively.

**Physiological responses of Indonesian shortfin eels to the treatments:** Physiological responses to the treatments (blood glucose, blood profile, and serum protein) were also evaluated (Braun et al., 2010; Lee et al., 2013). Briefly, blood samples were collected from the caudal vein using heparin as the anticoagulant. Erythrocytes and leukocytes were counted using a hemocytometer under the microscope at 400× (Braun et al., 2010), and formulas of  $N = n \times 10^4$ , where n = Erythrocyte total in the 80 areas of a hemocytometer, and N = Erythrocyte total in 1 ml of blood; WBCs in 1 mm of blood = (Numbers of cells counted)/(Numbers of 1 sq. mm. counted) × Dilution. A hematocrit tube containing ¾ of the blood sample was centrifuged at 5000 rpm for 5 min to determine hematocrit (Ht), as described by Hudson et al. (2008), using the formula of Hematocrit (%) = length of RBC column (100) / total length of the blood column. The concentration of haemoglobin (Hb) was determined following the cyanmethemoglobin method. In this method, 20 mL of blood was diluted with 1.0 mL of Drabkin solution before the photometric reading at 540 nm. The total plasma protein calculation followed the method of Lawrence and Amadeo (2010), using the Biuret reagent as the standard. Blood plasma (up to 100 mL) was diluted to 500 mL with Biuret reagent in a test tube to prepare the sample solution, and the Biuret reagent without a sample was used as the blank. The mixture was incubated for 30 min, and the absorbance was measured at 540 nm using a spectrophotometer (Cecil 2000, UK). Glucose was measured using the Wedemeyer and Yasutake (1977) method. A blood sample was collected in the Eppendorf tube and centrifuged at 2,500 rpm for 20 min to separate blood plasma. Furthermore, 0.05 µL of blood plasma was added to 3.50 mL of ortho-toluidine colour reagent in glacial acetic acid. The mixture was boiled in water for 15 minutes and then cooled to room temperature. The glucose concentration was measured using a spectrophotometer at 635 nm. The absorbance value was converted to mg 100 mL<sup>-1</sup> plasma glucose levels. Protein (g 100 mL) / Glucose (g 100 mL) = Au × Cs /

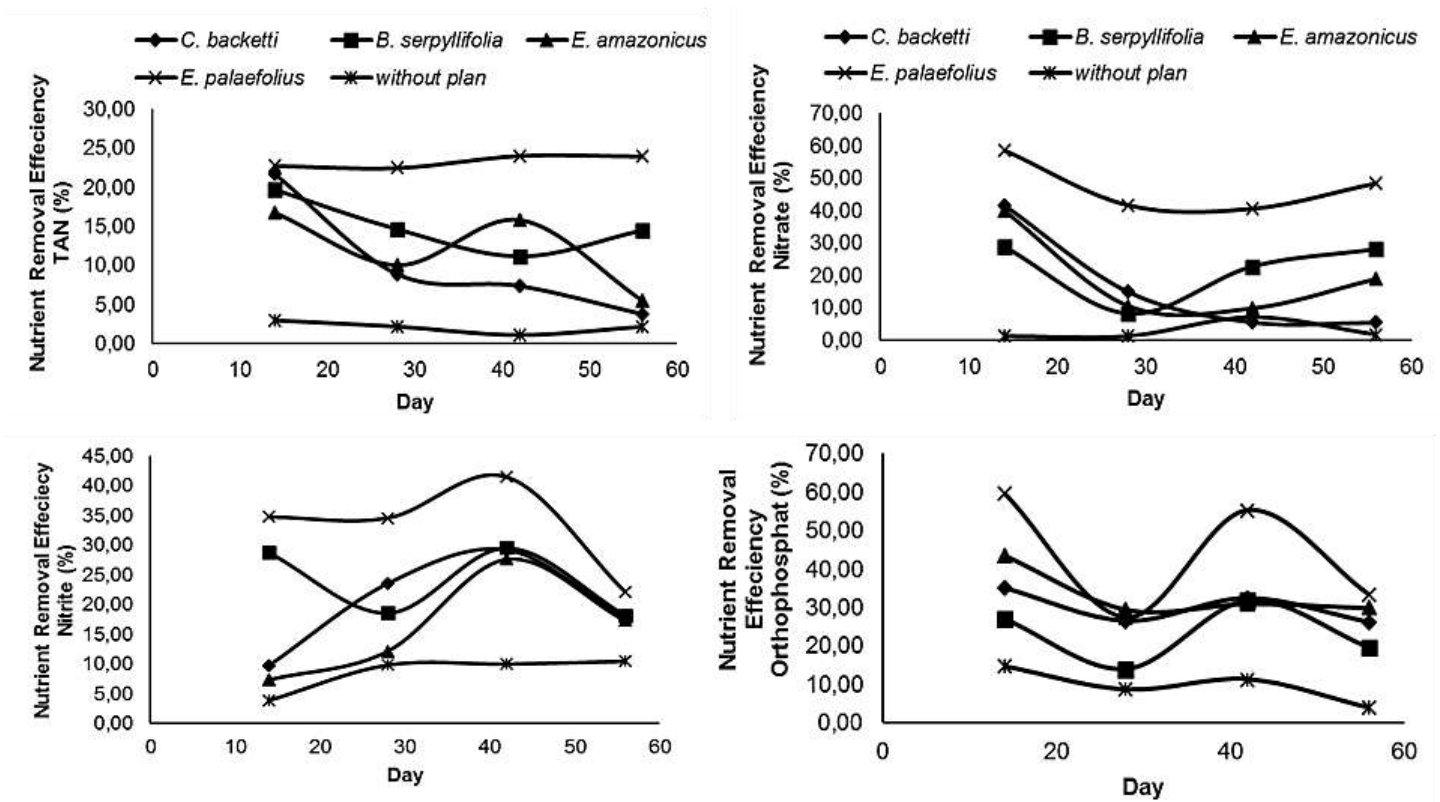


Figure 2. Nutrient removal efficiency, percentage of TAN (a), Nitrite (b), Nitrate (c), and phosphate (d) in each treatment (%).

As, where Au = Absorbance of unknown, As = Absorbance of standard, and Cs = Concentration of standard.

**Data analysis:** Data are presented as mean ± standard error and analyzed using one-way analysis of variance (ANOVA), followed by Duncan post hoc comparisons. Assumptions of normality and homogeneity of variance were checked using the Kolmogorov-Smirnov test. In all cases, results were considered significant at the 0.05 level. Data processing and analysis were managed using Microsoft Excel 2013 and SPSS 21.

**Results**

**Nutrient removal efficiency (NRE):** The analysis of total ammonia nitrogen (TAN), nitrate, nitrite, and phosphate removal efficiencies across four examined plant species, namely *C. beckettii* (T1), *B. serpyllifolia* (T2), *E. amazonicus* (T3), and *E. palaefolius* (T4) and a control group (T0) provides insight into the comparative effectiveness of each species over 56 days (Fig. 2). Based on the results, T4 demonstrated the highest and most stable TAN removal efficiency,

beginning at 22.79% on day 14 and maintaining high values through day 56 (23.97%). This TAN removal efficiency ( $P < 0.05$ ) suggests that T4 is the most effective for sustained nitrogen retention, while T1 and T3 showed a marked decline in TAN removal efficiency over time ( $P > 0.05$ ). The control group, without plants, exhibited low TAN removal efficiency, ranging from 1.09 to 3.00%, underscoring the positive effect of plant presence on nitrogen retention. In addition, T4 excelled in nitrate removal, achieving 58.67% on day 14 and maintaining high efficiency through day 56 (48.51%) (Fig. 2b). This consistency indicates that T4 is the most reliable species for nitrate removal over time ( $P < 0.05$ ). In contrast, T1 and T3 showed a steep decline in nitrate removal efficiency from day 28 onward, dropping below 10% by day 42, whereas T2 exhibited variable but moderate-to-high efficiency, reaching 28.15% on day 56. The control group consistently showed minimal nitrate removal, with values mainly below 8%, highlighting the role of plants in enhancing nitrate removal efficiency.

The data on nitrite removal efficiency (Fig. 2c)

Table 1. Aquatic ornamental plant's performances toward four treatments for 60 days.

Parameter	<i>C. backetti</i> (T1)	<i>B. serpyllifolia</i> (T2)	<i>E. amazonicus</i> (T3)	<i>E. palaefolius</i> (T4)
Initial weight (g)	80.00±0.44 <sup>a</sup>	80.00±0.04 <sup>a</sup>	80.01±0.85 <sup>a</sup>	80.00±1.41 <sup>a</sup>
Final weight (g)	84.33±1.20 <sup>a</sup>	86.00±1.15 <sup>ab</sup>	89.34±1.22 <sup>b</sup>	102.67±1.04 <sup>c</sup>
Weight gain (g)	4.33±1.23 <sup>a</sup>	6.00±1.15 <sup>a</sup>	9.33±1.45 <sup>a</sup>	22.67±1.65 <sup>b</sup>
Relative growth rate (g.day <sup>-1</sup> )	0.07±0.02 <sup>a</sup>	0.10±0.00 <sup>a</sup>	0.16±0.00 <sup>ab</sup>	0.38±0.00 <sup>b</sup>
Nitrogen retention (g)	2.59±1.22 <sup>a</sup>	9.60±0.61 <sup>b</sup>	11.12±1.34 <sup>c</sup>	21.47±2.97 <sup>d</sup>
Phosphorus retention (g)	1.42±0.13 <sup>a</sup>	0.62±0.05 <sup>a</sup>	3.97±0.84 <sup>b</sup>	6.36±1.08 <sup>c</sup>

Different superscripts in the same row indicate a significant difference in 5% of a significant level (Duncan multiple range tests). If the superscript is 'b', it is no different from 'ab'.

further illustrates the superior performance of T4, which achieved the highest efficiency, peaking at 41.49% on day 42 and remaining above 22% throughout the study. T1 and T2 demonstrated moderate nitrite removal efficiencies, peaking at approximately 29%, whereas T3 showed lower, more variable performance, reaching 27.67% on day 42. The control group exhibited minimal nitrite removal, reinforcing the positive impact of the plants, particularly *E. palaefolius*, in removing nitrites from the environment.

Lastly, Figure 2d illustrates phosphate removal efficiency across species. T4 again displayed the highest and most consistent performance, beginning at 59.64% on day 14 and ending at 33.33% on day 56, indicating strong phosphate-removal capabilities. T3 also performed relatively well, with efficiency ranging from 43.66% on day 14 to 29.94% on day 56 ( $P<0.05$ ). T1 and T2 exhibited moderate removal efficiency, peaking at approximately 32% ( $P>0.05$ ). The control group without plants showed negligible phosphate removal, underscoring the efficacy of these species, particularly T4, in reducing phosphate levels. The data suggest that *E. palaefolius* consistently outperforms other species in TAN, nitrate, nitrite, and phosphate retention and removal efficiencies, making it the most effective choice for sustained nutrient management.

**Production performance of aquatic ornamental plants:** Table 1 provides an overview of the performance of four aquatic ornamental plant species, namely *C. backetti* (T1), *B. serpyllifolia* (T2), *E. amazonicus* (T3), and *E. palaefolius* (T4) in terms of growth and nutrient retention over 60 days. The

initial plant weights were statistically similar across all treatments, averaging approximately 80 g. However, *E. palaefolius* (T4) exhibited significantly higher final weight (102.67±1.04 g), weight gain (22.67±1.65 g), and relative growth rate (0.38±0.00 g/day) than the other species, suggesting superior growth potential ( $P<0.05$ ). Additionally, *E. palaefolius* retained the highest nitrogen (21.47±2.97 g) and phosphorus (6.36±1.08 g), indicating enhanced nutrient absorption. These results suggest that *E. palaefolius* is the most effective species among those tested for promoting growth and nutrient retention in aquatic environments.

**Water quality analysis:** The water quality parameters for a 60-day eel rearing experiment revealed significant effects of four different aquatic ornamental plants, namely *C. backetti* (T1), *B. serpyllifolia* (T2), *E. amazonicus* (T3), and *E. palaefolius* (T4), compared to a control group without plants (T0). The results show that plants generally improved water quality, although the magnitude of the effect varied among species (Table 2).

The temperature remained relatively stable across all treatments, with a narrow range from 28.67±0.33°C in the control group to 29.33±0.33°C in the tank with *E. amazonicus* (T3). This similarity suggests that the plants did not significantly influence water temperature and that external environmental conditions were the primary regulator of temperature ( $P>0.05$ ). Dissolved oxygen (DO) levels varied significantly, with T1 showing the lowest concentration at 4.23±0.23 mg L<sup>-1</sup>. In contrast, the other planted treatments, especially T4 at 5.50±0.21 mg L<sup>-1</sup>, maintained significantly higher DO levels,

Table 2. The result of water quality analysis for 60 days of eel rearing.

Parameter	<i>C. backetti</i> (T1)	<i>B. serpyllifolia</i> (T2)	<i>E. amazonicus</i> (T3)	<i>E. palaefolius</i> (T4)	No plant (T0)	Optimum (reference)
Temperature ( $^{\circ}$ C)	29.17 $\pm$ 0.17 <sup>a</sup>	29.33 $\pm$ 0.17 <sup>a</sup>	29.33 $\pm$ 0.33 <sup>a</sup>	29.00 $\pm$ 0.29 <sup>a</sup>	28.67 $\pm$ 0.33 <sup>a</sup>	28-33 (Luo et al., 2013)
Dissolved oxygen (mg L <sup>-1</sup> )	4.23 $\pm$ 0.23 <sup>a</sup>	4.93 $\pm$ 0.23 <sup>b</sup>	5.40 $\pm$ 0.25 <sup>b</sup>	5.50 $\pm$ 0.21 <sup>b</sup>	5.40 $\pm$ 0.15 <sup>b</sup>	> 4 (Saputra et al., 2016)
pH	7.50 $\pm$ 0.00 <sup>a</sup>	7.50 $\pm$ 0.06 <sup>a</sup>	7.30 $\pm$ 0.00 <sup>a</sup>	7.27 $\pm$ 0.12 <sup>a</sup>	7.33 $\pm$ 0.12 <sup>a</sup>	6-8 (Tseng and Wu, 2004)
Alkalinity (mg L <sup>-1</sup> )	54.67 $\pm$ 9.33 <sup>a</sup>	106.00 $\pm$ 38.15 <sup>c</sup>	87.33 $\pm$ 14.25 <sup>b</sup>	71.33 $\pm$ 17.68 <sup>b</sup>	94.00 $\pm$ 8.08 <sup>c</sup>	58-123 mg L <sup>-1</sup> (Luo et al., 2013)
Total suspended solid (mg L <sup>-1</sup> )	2.60 $\pm$ 0.62 <sup>a</sup>	5.83 $\pm$ 1.25 <sup>b</sup>	2.49 $\pm$ 0.38 <sup>a</sup>	2.41 $\pm$ 0.52 <sup>a</sup>	3.53 $\pm$ 0.28 <sup>a</sup>	< 10 mg L <sup>-1</sup> (Suzuki et al., 2003)
Total ammonia nitrogen (mg L <sup>-1</sup> )	0.25 $\pm$ 0.01 <sup>a</sup>	0.22 $\pm$ 0.01 <sup>a</sup>	0.25 $\pm$ 0.01 <sup>a</sup>	0.25 $\pm$ 0.01 <sup>a</sup>	0.25 $\pm$ 0.01 <sup>a</sup>	<0.25 mg L <sup>-1</sup> (Tseng and Wu, 2004)
Nitrite (mg L <sup>-1</sup> )	0.07 $\pm$ 0.01 <sup>b</sup>	0.05 $\pm$ 0.00 <sup>ab</sup>	0.05 $\pm$ 0.01 <sup>a</sup>	0.04 $\pm$ 0.00 <sup>a</sup>	0.06 $\pm$ 0.00 <sup>ab</sup>	<0.1 mg L <sup>-1</sup> (Tseng and Wu, 2004)
Nitrate (mg L <sup>-1</sup> )	27.23 $\pm$ 0.22 <sup>a</sup>	37.99 $\pm$ 0.51 <sup>b</sup>	42.86 $\pm$ 0.37 <sup>c</sup>	49.95 $\pm$ 0.97 <sup>d</sup>	52.88 $\pm$ 0.14 <sup>e</sup>	< 50 mg L <sup>-1</sup> (Ghaly et al., 2005)
Phosphate (mg L <sup>-1</sup> )	6.98 $\pm$ 0.42 <sup>a</sup>	6.65 $\pm$ 1.03 <sup>a</sup>	7.25 $\pm$ 1.08 <sup>ab</sup>	8.99 $\pm$ 0.34 <sup>ab</sup>	9.45 $\pm$ 0.37 <sup>b</sup>	<15 mg L <sup>-1</sup> (Suzuki et al., 2003)

Different superscripts in the same row indicate a significant difference in 5% of a significant level (Duncan multiple range tests). If the superscript is 'b', it is no different from 'ab'.

like the control group (5.40 $\pm$ 0.15 mg L<sup>-1</sup>) ( $P>0.05$ ). The elevated DO levels in treatments with T2, T3, and T4 suggest these plants may have improved aeration or oxygen retention in the water, creating a more favorable environment for eel rearing.

In addition, the pH levels remained relatively consistent, showing minor variation across treatments. This suggests that the presence of plants had a minimal impact on pH, keeping it within an optimal range for eel growth. Alkalinity exhibited noticeable variation across treatments. The T2 recorded the highest alkalinity at 106.00 $\pm$ 38.15 mg L<sup>-1</sup>, while T1 had the lowest at 54.67 $\pm$ 9.33 mg L<sup>-1</sup>. The T0 also maintained relatively high alkalinity at 94.00 $\pm$ 8.08 mg L<sup>-1</sup>. These differences indicate that certain plant species may enhance the water's buffering capacity, potentially helping to stabilize pH by neutralizing acidic or basic compounds. Although Total suspended solids (TSS) were suitable for eel culture, TSS were highest in T2 (5.83 $\pm$ 1.25 mg L<sup>-1</sup>), while other treatments, including T3, T4, and T1, had lower TSS levels, averaging around 2.4 to 2.6 mg L<sup>-1</sup> ( $P>0.05$ ). The control group (T0) had a moderate TSS level (3.53 $\pm$ 0.28 mg L<sup>-1</sup>). The elevated TSS in the *B. serpyllifolia* group suggests that this plant may shed more particulate matter into the water, potentially increasing organic loading in the tank environment.

Total ammonia nitrogen (TAN) concentrations remained fairly stable (no significant) across all treatments, ranging from 0.22 $\pm$ 0.01 to 0.25 $\pm$ 0.01 mg

L<sup>-1</sup>. This indicates that ammonia removal was not a major differentiating factor among the plant species tested, and all plants-maintained TAN within a safe range for eel health ( $P>0.05$ ). Nitrite levels slightly varied across treatments, with T1 exhibiting the highest nitrite concentration at 0.07 $\pm$ 0.01 mg L<sup>-1</sup>. In contrast, T3 and T4 had significantly lower nitrite levels (0.05 $\pm$ 0.01 and 0.04 $\pm$ 0.00 mg L<sup>-1</sup>, respectively), suggesting that these species may contribute to improved nitrogen cycling by reducing the accumulation of potentially toxic nitrite in the water. Nitrate concentrations were highest in the control group (52.88 $\pm$ 0.14 mg L<sup>-1</sup>), indicating limited nitrate removal in the absence of plants. All the planted treatments performed better than T0 and T1, which was an outlier, reducing the lowest nitrate removal among the planted groups (27.23 $\pm$ 0.22 mg L<sup>-1</sup>), highlighting *C. backetti* as particularly effective in reducing nitrate levels and potentially enhancing nitrogen balance in the rearing system.

Phosphate concentrations varied, with T1 and T2 demonstrating lower phosphate levels (6.98 $\pm$ 0.42 and 6.65 $\pm$ 1.03 mg L<sup>-1</sup>, respectively), while T3 and T4 showed slightly higher phosphate values, ranging from 7.25 $\pm$ 1.08 to 8.99 $\pm$ 0.34 mg L<sup>-1</sup>. The control group had the highest phosphate concentration (9.45 $\pm$ 0.37 mg L<sup>-1</sup>). These results indicate that *C. backetti* and *B. serpyllifolia* may effectively reduce phosphate, likely through uptake and incorporation

Table 3. Growth performance of Indonesian shortfin eel for 60 days of rearing.

Parameter	<i>C. backetti</i> (T1)	<i>B. serpyllifolia</i> (T2)	<i>E. amazonicus</i> (T3)	<i>E. palaefolius</i> (T4)	No plant (T0)
Survival rate (%)	100.00±0.00 <sup>a</sup>	100.00±0.00 <sup>a</sup>	100.00±0.00 <sup>a</sup>	100.00±0.00 <sup>a</sup>	100.00±0.00 <sup>a</sup>
Weight gain (g)	68.27±13.89 <sup>ab</sup>	66.70±11.66 <sup>ab</sup>	79.77±12.31 <sup>ab</sup>	101.73±10.63 <sup>b</sup>	52.47±17.87 <sup>a</sup>
Daily weight gain (g.day <sup>-1</sup> )	0.19±0.02 <sup>ab</sup>	0.19±0.02 <sup>ab</sup>	0.20±0.02 <sup>ab</sup>	0.23±0.02 <sup>b</sup>	0.18±0.04 <sup>a</sup>
Specific growth rate (%)	0.81±0.14 <sup>ab</sup>	0.82±0.11 <sup>ab</sup>	0.94±0.12 <sup>ab</sup>	1.14±0.10 <sup>b</sup>	0.65±0.17 <sup>a</sup>
Feed consumption (g)	159.00±1.73 <sup>a</sup>	156.00±0.00 <sup>a</sup>	157.00±1.00 <sup>a</sup>	156.00±3.46 <sup>a</sup>	154.00±1.00 <sup>a</sup>
Feed conversion ratio	2.58±0.62 <sup>ab</sup>	2.50±0.46 <sup>ab</sup>	2.09±0.39 <sup>ab</sup>	1.57±0.17 <sup>a</sup>	3.57±0.95 <sup>b</sup>
Protein retention (%)	30.72±2.93 <sup>ab</sup>	33.41±1.31 <sup>ab</sup>	35.80±1.16 <sup>bc</sup>	41.29±2.02 <sup>c</sup>	26.93±3.30 <sup>a</sup>
Lipid retention (%)	32.21±4.23 <sup>a</sup>	42.24±1.99 <sup>b</sup>	44.24±2.72 <sup>b</sup>	53.97±1.18 <sup>c</sup>	31.22±2.40 <sup>a</sup>
Coefficient of variance (%)	11.18±1.12 <sup>a</sup>	10.64±1.46 <sup>a</sup>	10.68±0.22 <sup>a</sup>	10.90±0.46 <sup>a</sup>	9.67±1.22 <sup>a</sup>

Different superscripts in the same row indicate a significant difference in 5% of a significant level (Duncan multiple range tests). If the superscript is 'b', it is no different from 'ab'.

into plant biomass, thereby helping to limit excess nutrient accumulation in the system.

Overall, the findings suggest that including plant species can improve various aspects of water quality in aquaculture systems. *Echinodorus palaefolius* performed exceptionally well in nitrate and nitrite reduction and in maintaining higher dissolved oxygen levels, making it a strong candidate for enhancing environmental conditions in eel rearing. *Bacopa serpyllifolia* showed potential in alkalinity enhancement and phosphate reduction, while *E. amazonicus* demonstrated balanced performance across multiple water quality parameters.

#### Production performance of *A. bicolor*

**Growth performance and nutrient utilization:** The survival rate, biomass, daily growth, specific growth rate, feed consumption, feed percentage, feed conversion, protein retention, lipid retention, and coefficient of variance are presented in Table 3. During the earning period, each treatment outperformed the control group. This was explained by higher average biomass, daily growth, specific growth rate, feed efficiency, and protein retention, and by a lower coefficient of variation ( $P<0.05$ ). The T4 showed the best growth performance, feed conversion ratio, feed efficiency, and total biomass (1.14%, 1.57, 65.54%, and 101.73 g, respectively). On the other hand, it increased efficiency by 20.18 to 47.92%. The specific growth rate of *A. bicolor* ranged from 19.75% to 42.89% across all aquatic plant treatments, compared with 0.65% in the control group.

The total consumed feed during the study was 154-159 g, with 7.24% of N content. The *A. bicolor* feed consumption in each treatment was 175.67 g (T1), 170.67 g (T2), 184 g (T3), 205.67 g (T4), and 185.33 g (T0). The nitrogen content in the dish biomass was 11.63% (T1), 11.69% (T2), 11.88% (T3), 12.01% (T4), and 11.26% (T0). The T4 treatment maintained the highest N, thereby promoting *A. bicolor* biomass production up to 205.67 g. On the contrary, the most increased deposit or sediment of nitrogen could be found in the case of no aquatic plant treatment.

**The physiological response of *A. bicolor*:** The physiological responses of *A. bicolor* to various plant treatments, including *C. backetti* (T1), *B. serpyllifolia* (T2), *E. amazonicus* (T3), and *E. palaefolius* (T4), were evaluated in comparison to a control group without any plant intervention (T0). The data underscore the effects of each plant species on critical hematological and biochemical parameters. Hematocrit values differed significantly across treatments ( $P<0.05$ ), with T4 exhibiting the highest level (27.12±0.14%), indicating enhanced oxygen-carrying capacity and a favorable physiological status. Moreover, T2 also showed elevated levels (26.70±0.17%), slightly above the control (26.21±0.81%). In contrast, T1 (25.87±0.39%) and T3 (25.97±0.21%) displayed lower values, suggesting less efficient oxygen transport. These results suggest *E. palaefolius* may notably improve oxygen transport and physiological performance in *A. bicolor*.

Erythrocyte counts, an indicator of red blood cell

Table 4. Physiological observation of *Anguilla bicolor* toward four various treatments.

Parameter	<i>C. backetti</i> (T1)	<i>B. serpyllifolia</i> (T2)	<i>E. amazonicus</i> (T3)	<i>E. palaefolius</i> (T4)	No plant (T0)
Hematocrit (%)	25.87±0.39 <sup>a</sup>	26.70±0.17 <sup>b</sup>	25.97±0.21 <sup>ab</sup>	27.12±0.14 <sup>c</sup>	26.21±0.81 <sup>b</sup>
Erythrocyte (10 <sup>6</sup> cells mL <sup>-1</sup> )	7.70±0.41 <sup>c</sup>	7.53±0.14 <sup>a</sup>	7.63±0.31 <sup>b</sup>	8.03±0.41 <sup>d</sup>	7.69±0.44 <sup>b</sup>
Hemoglobin (g/%)	6.63±0.15 <sup>b</sup>	6.80±0.10 <sup>b</sup>	6.33±0.06 <sup>a</sup>	7.20±0.10 <sup>c</sup>	6.77±0.16 <sup>b</sup>
Leucocyte (10 <sup>4</sup> cell mL <sup>-1</sup> )	6.30±0.37 <sup>b</sup>	5.84±2.57 <sup>a</sup>	6.43±0.77 <sup>b</sup>	6.35±0.51 <sup>b</sup>	6.89±0.67 <sup>c</sup>
Glucose (mg dL <sup>-1</sup> )	33.50±1.57 <sup>b</sup>	22.50±1.58 <sup>a</sup>	22.90±0.70 <sup>a</sup>	38.07±2.93 <sup>c</sup>	52.50±1.21 <sup>d</sup>
Total protein (mg L <sup>-1</sup> )	31.70±1.61 <sup>b</sup>	23.20±1.28 <sup>a</sup>	29.83±1.23 <sup>b</sup>	25.00±1.66 <sup>a</sup>	32.20±1.78 <sup>b</sup>

Different superscripts in the same row indicate a significant difference in 5% of a significant level (Duncan multiple range tests). If the superscript is `b`, it is no different from `ab`.

abundance, also showed significant variation across treatments ( $P < 0.05$ ). T4 had the highest erythrocyte count ( $8.03 \pm 0.41 \times 10^6$  cells mL<sup>-1</sup>), indicating a potential benefit in promoting erythropoiesis or sustaining red blood cell levels. In contrast, T2 exhibited the lowest erythrocyte count ( $7.53 \pm 0.14 \times 10^6$  cells mL<sup>-1</sup>), followed closely by T3 ( $7.63 \pm 0.31 \times 10^6$  cells mL<sup>-1</sup>). The control group ( $7.69 \pm 0.44 \times 10^6$  cells mL<sup>-1</sup>) and T1 ( $7.70 \pm 0.41 \times 10^6$  cells mL<sup>-1</sup>) displayed intermediate erythrocyte levels, highlighting the comparatively superior efficacy of *E. palaefolius* in supporting red blood cell health in *A. bicolor*. Leucocyte counts, an indicator of immune response, exhibited notable variation. The control group (T0) exhibited the highest leucocyte count ( $6.89 \pm 0.67 \times 10^4$  cells mL<sup>-1</sup>), possibly indicative of an immune response to environmental stressors in the absence of plant intervention. T3 and T4 experienced similar leucocyte levels ( $6.43 \pm 0.77$  and  $6.35 \pm 0.51 \times 10^4$  cells mL<sup>-1</sup>, respectively), suggesting a stable immune status. Interestingly, T2 exhibited the lowest leucocyte count ( $5.84 \pm 2.57 \times 10^4$  cells mL<sup>-1</sup>), which may reflect reduced immune activation, potentially due to the plant's stress-relieving effects.

Hemoglobin concentration, a crucial marker for oxygen transport efficiency, also varied significantly among the groups. T4 demonstrated the highest hemoglobin level ( $7.20 \pm 0.10$  g/%), signifying improved oxygen-carrying capacity. In contrast, T3 had the lowest hemoglobin concentration ( $6.33 \pm 0.06$  g/%), suggesting reduced oxygen transport efficiency in this treatment. The hemoglobin levels of the control group and T1 ( $6.77 \pm 0.16$  and

$6.63 \pm 0.15$  g/%, respectively) were comparable, while T2 showed a moderately high hemoglobin concentration ( $6.80 \pm 0.10$  g/%). Glucose concentrations, a key indicator of stress, revealed substantial differences among treatments. The control group showed the highest glucose level ( $52.50 \pm 1.21$  mg dL<sup>-1</sup>), suggesting heightened stress in the absence of plants. T4 had a lower glucose level ( $38.07 \pm 2.93$  mg dL<sup>-1</sup>), yet it remained higher than that observed in T2 and T3, which had significantly lower glucose levels ( $22.50 \pm 1.58$  and  $22.90 \pm 0.70$  mg dL<sup>-1</sup>, respectively). These results suggest that *B. serpyllifolia* and *E. amazonicus* may help mitigate stress-induced hyperglycemia, possibly through their calming effects on fish physiology.

Total protein levels were highest in the control group ( $32.20 \pm 1.78$  mg L<sup>-1</sup>), followed by T1 ( $31.70 \pm 1.61$  mg L<sup>-1</sup>), potentially reflecting a stress response in the absence of plant-derived mitigation effects. T3 also exhibited a relatively high protein concentration ( $29.83 \pm 1.23$  mg L<sup>-1</sup>). Conversely, T2 and T4 demonstrated lower total protein levels ( $23.20 \pm 1.28$  and  $25.00 \pm 1.66$  mg L<sup>-1</sup>, respectively), possibly indicating reduced metabolic demands due to decreased stress in the presence of these plant species. As a result, this study demonstrates that incorporating aquatic plants such as *E. palaefolius*, *B. serpyllifolia*, and *E. amazonicus* into *A. bicolor* rearing environments can enhance health and reduce stress. *Echinodorus palaefolius* notably improved hematological parameters, while the others effectively lowered stress markers. Using these plants in aquaculture supports better physiological resilience and growth in *A. bicolor*.

## Discussions

Wastewater is a mixture of water with many chemicals (organic and inorganic matter) and heavy metals, which are contributed by domestic, commercial, and industrial activities (Dixit et al., 2011; Haris et al., 2021). Phytoremediation technology can address both organic and inorganic pollutants, although plant uptake varies with each pollutant (Poschenrieder and Coll, 2003; Anerao et al., 2022). Roots and foliar absorption are the uptake pathways for inorganic contaminants, primarily radionuclides, heavy metals, and nutrients, in aquatic plants (Dhir, 2013).

**Nutrient removal efficiency (NRE):** The current study's water quality in aquaculture, based on a phytoremediation system, was within the tolerable range due to the use of aquaculture waste as a nutrient source (Enduta et al., 2011; Akinbile and Yusoff, 2012). In the case of nitrates, *E. palaefolius* is the best recommended for reducing nitrate concentration compared with other plants. Our study revealed that *E. palaefolius* experienced a reduction in phosphate concentration during *A. bicolor* cultivation. It assumed the explanation of the *E. palaefolius*'s higher ability to utilize P compared to other aquatic plant treatments. It suggested that *E. palaefolius* could be applied to reduce P concentration in aquaculture. The NRE value, TAN, nitrite, nitrate, and orthophosphate for all aquatic plant treatments in the 2nd week were higher than in the following two weeks. It was caused by a higher nutrient requirement in the early stage of the study than in the following weeks.

According to Perdana et al. (2018), *E. palaefolius* can take up nitrate to stimulate its growth (as indicated by fresh buds and larger leaves) and serve as a substrate for denitrification, namely carbon and energy (from decaying basal stalks), thereby diminishing nitrate. *Eichhornia palaefolius*'s ability to utilize N and P was higher than that of other aquatic plant treatments due to its abundant, longer root system. It provided a larger surface area for microbes to absorb pollutants and greater assimilation of pollutants into plant tissues (Dhir, 2013). Microbes in the rhizosphere accelerate biodegradation and simultaneously absorb contaminants and nutrients

(Enduta et al., 2011). Based on this, we suggested that ornamental aquatic plants, particularly *E. palaefolius*, are suitable for phytoremediation to reduce nitrate levels in wastewater culture.

Generally, phosphorus is more likely required to support the generative development of the plant (Młodzińska and Zboińska, 2016). In a similar study, *E. palaefolius* reduced the phosphate concentration of greywater by 69.07% (Rakhmatika et al., 2017). In addition, *E. palaefolius* also reduced phosphate content in liquid laundry waste (Siswandari, 2016). The NRE value in this study was considered higher than the maximum N absorption by *Lemna* spp., which has been reported to reach up to 50 % (Mkandawire and Dudel, 2007). The study by Enduta et al. (2011) showed that spinach's NO<sub>3</sub> and PO<sub>4</sub> utilization efficiencies were 79.17 and 75.36%, respectively, whereas *Brassica chinensis*'s NO<sub>3</sub> and PO<sub>4</sub> utilization efficiencies were 56.67 and 66.67%, respectively. Water spinach (*Ipomoea aquatica*) was evaluated for its effectiveness in reducing nitrate levels in Nile tilapia rearing (50.15%; Djokosetiyanto and Sunarma, 2006).

**Production performance of aquatic ornamental plants:** Aquatic plants grow by absorbing nutrients from the culture waste in the recirculation system (Gosselin et al., 2018). The excellence of the recirculation and phytoremediation was directly related to the aquatic plant's ability to utilize aquaculture waste. Generally, retention time is used in lake ecology to assess how eutrophication operates (O'Hare et al., 2018). According to Qu et al. (2017), *E. palaefolius* has developed the capacity to retain root, nitrogen, and phosphorus in water and other organic matter, which are removed directly by the rhizosphere adsorption mechanism. Rhizoremediation, a remediation technology, can eliminate or reduce pollutants and contaminants in the rhizosphere of aquatic plants through microbial activity (Liu et al., 2014; Ngoc et al., 2016; Zhang et al., 2016). Water hyacinths contain approximately 1.78% of nitrogen in overflow areas with a nitrogen content of 2.40 mg L<sup>-1</sup> (Su et al., 2018). The nutrient content in stems and roots is usually smaller than in

the leaf (Abdelhamid and Gabr, 1991).

The variation in N retention was certainly linked to variation in plant biomass, which increases both plant biomass and N retention (Johnson et al., 2016). In addition, nitrogen retention in freshwater ecosystems substantially affects ecosystem processes, and nitrogen's inhibitory role in aquatic systems is increasingly recognized (Saunders and Kalff, 2001). This study's results were also considered relatively improved compared with the previous study (El-Shafai et al., 2007), which reported 14%-20% nitrogen retention using *L. gibba* in a recirculation system. Based on this, our study recommends *E. palaefolius* for use in aquaculture.

Phosphorus plays a crucial role in biological processes, including the synthesis of biomolecules, the maintenance of membrane structures, and the production of high-energy molecules (Malhotra et al., 2018). It also supports cell division, enzyme activation or inactivation, and carbohydrate metabolism (Razaq et al., 2017). In our study, *E. palaefolius* absorbed the highest phosphorus concentration (6.36 g) among the groups. The present study assumed that the highest phosphorus retention is represented by better plant growth. According to Hinsinger (2001) and Zapata and Zaharah (2002), phosphorus is an essential nutrient for plant growth and is required for optimal plant production and quality. Based on this, we suggested that *E. palaefolius* is recommended to reduce N and P in the wastewater from *A. bicolor* culture.

**Water quality analysis:** Over the past two decades, water quality control using aquatic plants has been established in Europe (Thiebaut, 2008). The results for water quality parameters across treatments indicated an optimal range that supports eel growth, except for the T0 treatment. The present study found that temperature, pH, Alkalinity, TSS, NO<sub>2</sub>, NO<sub>3</sub>, and PO<sub>4</sub> across all treatments were comparably tolerable to the control group, except for DO and TAN.

El-Shafai et al. (2007) reported that the nitrate concentration in eel rearing using the recirculation system was <0.5 mg L<sup>-1</sup>. Suzuki et al. (2003) reported that the nitrate concentration in the recirculation

system used for eel rearing was approximately 40.8 mg L<sup>-1</sup>. Ghaly et al. (2005) recommended maintaining NO<sub>3</sub> concentrations below 50 mg L<sup>-1</sup> because higher concentrations can cause algal blooms, which require longer periods and also cause a decline in pH (Ebeling et al., 2006). In addition, the rise in nitrate, followed by a loss of ammonium, as water passes through the growing medium, may indicate nitrification (Berndtsson et al., 2009). Phosphorus is an essential nutrient required by plants (Vaillant et al., 2004). Orthophosphate (PO<sub>4</sub>-P) is an inorganic water-dissolved compound that the plant can directly utilize (Alori et al., 2017). Orthophosphate is not poisonous to aquatic organisms (Simplício et al., 2017). However, a high orthophosphate concentration can induce massive algal growth and oxygen depletion, potentially causing fish mortality (Ebeling et al., 2006). As a result, Suzuki et al. (2003) suggested an orthophosphate concentration <15 mg L<sup>-1</sup>. Based on this, the study recommended ornamental aquatic plants for phytoremediation to maintain water quality tolerable for *A. bicolor*.

#### **Production performance of *A. bicolor*:**

**Growth performance and nutrient utilization:** Based on the production performance of *A. bicolor*, the use of various aquatic plant species for phytoremediation decreased the feed conversion ratio from 3.57 (control group) to 1.57-2.58. Another phytoremediation study by Omitoyin et al. (2017) showed that duckweed reduced the feed conversion rate of *Oreochromis niloticus* by 1.59. According to Gettys et al. (2008), aquatic plants have numerous benefits, including providing excellent habitat for many fish and increasing fish diversity, as well as supporting feeding, growth, health, and reproduction. Assuming 100% nitrogen content, the nitrogen mass equilibrium in this study is illustrated in Figure 2. According to Nootong et al. (2013) and Nootong et al. (2011), in a balanced nitrogen condition in an aquaculture system, nitrogen assimilation in fish biomass varied between 25 to 35% of total nitrogen input without considering the species of the fish.

**The physiological response of *A. bicolor*:** Blood parameters, including hematocrit, erythrocyte count,

hemoglobin, leucocyte count, glucose, and total protein, were measured to assess the physiological response of *A. bicolor* following phytoremediation. Haematological parameters are precise tools for evaluating fish health (Bhaskar and Rao, 1984; Schütt et al., 1997; Norousta and Mousavi-Sabet, 2013) and physiological responses to environmental stress (Jawad et al., 2004). Normal blood glucose of a fish ranges from 29 mg dL<sup>-1</sup> to 43 mg dL<sup>-1</sup> (Tavares-Dias et al., 2007). This study indicated that the eels' physiological condition was significantly better than that of the control treatment. The blood glucose level at T0 (control) was not acceptable, indicating a stress condition. The blood profile parameters across all treatments were within the acceptable range. The hematocrit ranged from 25.87 to 27.12%, and the leucocyte count ranged from 5.84×10<sup>4</sup> to 6.89×10<sup>4</sup> cells mL<sup>-1</sup>. Commonly, the hematocrit level ranged from 24-36%, and the leucocyte level ranged from 3.60×10<sup>4</sup> to 7.58×10<sup>4</sup> cells mL<sup>-1</sup> (Ren et al., 2005). In the current study, *E. palaefolius* exhibits the highest levels of waste and nutrient absorption, supporting its growth. Moreover, the environment itself did not negatively affect the physiological condition of *A. bicolor*. It explained the high level of efficiency and growth performance.

### Conclusion

The ornamental aquatic plant could reduce the waste from intensive culture of *A. bicolor*. The Mexican sword plant, *E. palaefolius*, achieved the highest waste utilization. The growth performance of the *A. bicolor* in the recirculation system using phytoremediation was greater than the control treatment, and the greatest production was retrieved in the *E. palaefolius* treatment as a phytoremediator. Moreover, this knowledge could be applied to the culture of *A. bicolor* and potentially to other species. *E. palaefolius* needs to be considered as a recommended plant to eliminate ammonia nitrogen (TAN), nitrite (NO<sub>2</sub>-N), nitrate (NO<sub>3</sub>-N), and orthophosphate (PO<sub>4</sub>-P) in the water.

### Acknowledgements

The authors gratefully acknowledge the Indonesian Ministry of Research and Technology of Higher Education for research grant aid.

**Ethical statement:** This experiment was conducted in accordance with the Ethics Clearance Committee of the Health Research, University of Muhammadiyah Malang, Indonesia, for the care and use of fish and ornamental aquatic plants.

### References

- Abdelhamid A.M., Gabr A.A. (1991). Evaluation of water hyacinth as a feed for ruminants. *Archiv für Tierernaehrung*, 41(7-8): 745-756.
- Ahmad A., Abdullah S.R.S., Hasan H.A., Othman A.R., Ismail N.I. (2021). Aquaculture industry: Supply and demand, best practices, effluent and its current issues and treatment technology. *Journal of Environmental Management*, 287: 112271.
- Akinbile C., Yusoff M.S. (2012). Assessing water hyacinth (*Eichhornia crassipes*) and lettuce (*Pistia stratiotes*) effectiveness in aquaculture wastewater treatment. *International Journal of Phytoremediation*, 14(3): 201-211.
- Alori E.T., Glick B.R., Babalola O.O. (2017). Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Frontiers in Microbiology*, 8: 971-971.
- Anerao P., Kaware R., Khedikar A.K., Kumar M., Singh L. (2022). Phytoremediation of persistent organic pollutants: Concept challenges and perspectives. In: V. Kumar, M.P. Shah, S.K. Shahi (Eds.), *Phytoremediation technology for the removal of heavy metals and other contaminants from soil and water*. Elsevier. pp: 375-404.
- APHA. (2006). *Standard methods for the examination of the water and wastewater*. 22nd ed. American Public Health Association, Washington, D.C. (US). 1195 p.
- Berndtsson J.C., Bengtsson L., Jinno K. (2009). Runoff water quality from intensive and extensive vegetated roofs. *Ecological engineering*, 35(3): 369-380.
- Bhaskar B., Rao K. (1984). Influence of environmental variables on haematological ranges of milkfish, *Chanos chanos* (Forsk.), in brackish water culture. *Aquaculture*, 83(1-2): 123-136.
- Borguini R.G., Bastos D.H.M., Moita-Neto J.M., Capasso F.S., Torres E.A.F.D.S. (2013). Antioxidant potential of

- tomatoes cultivated in organic and conventional systems. *Brazilian Archives of Biology and Technology*, 56(4): 521-529.
- Braun N., de Lima R.L., Baldisserotto B., Dafre A.L., de Oliveira Nuñez A.P. (2010). Growth, biochemical and physiological responses of *Salminus brasiliensis* with different stocking densities and handling. *Aquaculture*, 301(1-4): 22-30.
- Brune D., Schwartz G., Eversole A., Collier J.A., Schwedler T.E. (2003). Intensification of pond aquaculture and high rate photosynthetic systems. *Aquacultural Engineering*, 28: 65-86.
- Bureau D.P., Hua K. (2010). Towards effective nutritional management of waste outputs in aquaculture, with particular reference to salmonid aquaculture operations. *Aquaculture Research*, 41(5): 777-792.
- Crab R., Avnimelech Y., Defoirdt T., Bossier P., Verstraete W. (2007). Nitrogen removal techniques in aquaculture for a sustainable production. *Aquaculture*, 270(1-4): 1-14.
- Dauda A.B., Ajadi A., Tola-Fabunmi A.S., Akinwole A.O. (2018). Waste production in aquaculture: Sources, components and managements in different culture systems. *Aquaculture and Fisheries*, 4(3): 81-88.
- Davidson J., Barrows F.T., Kenney P.B., Good C., Schroyer K., Summerfelt S.T. (2016). Effects of feeding a fishmeal-free versus a fishmeal-based diet on post-smolt Atlantic salmon *Salmo salar* performance, water quality, and waste production in recirculation aquaculture systems. *Aquacultural Engineering*, 74: 38-51.
- de Winton M., Jones H.F.E., Edwards T., Özkundakci D., Wells R., McBride C.G., Rowe D.K., Hamilton D.P., Clayton J., Champion P. (2013). Review of best management practices for aquatic vegetation control in stormwater ponds, wetlands, and lakes (Vol. 1). Auckland Council.
- Deviller G., Aliaume C., Nava M.A.F., Casellas C., Blancheton J.P. (2004). High-rate algal pond treatment for water reuse in an integrated marine fish recirculating system: effect on water quality and sea bass growth. *Aquaculture*, 235(1): 331-344.
- Dhir B. (2013). *Phytoremediation: Role of aquatic plants in environmental clean-up*. Springer.
- Dickinson N.M., Baker A.J.M., Doronila A., Laidlaw S., Reeves, R.D. (2009). Phytoremediation of inorganics: realism and synergies. *International Journal of Phytoremediation*, 11(2): 97-114.
- Dixit A., Dixit S., Goswami C. (2011). Process and plants for wastewater remediation: A review. *Scientific Reviews and Chemical Communications*, 11: 71-77.
- Djokosetiyanto D., Sunarma A. (2006). Changes of ammonia, nitrite and nitrate at recirculation system of red tilapia (*Oreochromis* sp.) rearing. *Jurnal Akuakultur Indonesia*, 5(1): 13-20.
- Ebeling J.M., Timmons M.B., Bisogni J. (2006). Engineering analysis of the stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia-nitrogen in aquaculture systems. *Aquaculture*, 257(1-4): 346-358.
- El-Shafai S.A., El-Gohary F.A., Naser F.A., Van der Steen P., Gijzen H.J. (2007). Nitrogen recovery in an integrated system for wastewater treatment and tilapia production. *The Environmentalist*, 27(2): 287-302.
- Enduta A., Jusoh A., Ali N.A., Wan Nik W. (2011). Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system. *Desalination and Water Treatment*, 32(1-3): 422-430.
- Flickinger D.L., Costa G.A., Dantas D., Moraes-Valenti P., Valenti W.C.J.A.R. (2019). The budget of nitrogen in the grow-out of the Amazon river prawn (*Macrobrachium amazonicum* Heller) and tambaqui (*Colossoma macropomum* Cuvier) farmed in monoculture and in integrated multitrophic aquaculture systems. *Aquaculture Research*, 50(11): 3444-3461.
- Gettys L.A., Haller W.T., Petty D.G. (2008). *Biology and control of aquatic plants: A best management*. Aquatic Ecosystem Restoration Foundation, Marietta, Georgia.
- Ghaly A., Kamal M., Mahmoud N. (2005). Phytoremediation of aquaculture wastewater for water recycling and production of fish feed. *Environment International*, 31(1): 1-13.
- Goddek S., Vermeulen T. (2018). Comparison of *Lactuca sativa* growth performance in conventional and RAS-based hydroponic systems. *Aquaculture International*, 26(6): 1377-1386.
- Gosselin J.R., Haller W.T., Gettys L., Griffin T., Crawford E. (2018). Effects of substrate nutrients on growth of three submersed aquatic plants. *Journal of Aquatic Plant Management*, 56: 39-46.
- Han N., Zhang J., Hoang M., Gray S., Xie Z. (2021). A review of process and wastewater reuse in the recycled paper industry. *Environmental Technology and Innovation*, 24: 101860.
- Handajani H., Adhywirawan G., Andriawan S., Prasetyo

- D., Mavuso B.R. (2021). Evaluation of efficiency of *Echinodorus palaefolius* (JF Macbr.) Involved in the *Clarias gariepinus* (Burchell, 1822) culture for water quality recovery and fish growth support. *Jordan Journal of Biological Sciences*, 14(5): 959-964.
- Handajani H., Widanarni W., Budiardi T., Setiawati M., Sujono S. (2018). Phytoremediation of Eel (*Anguilla bicolor bicolor*) rearing wastewater using amazon sword (*Echinodorus amazonicus*) and water jasmine (*Echinodorus palaefolius*). *Omni-Akuatika*, 14(2): 43-51.
- Harianto E., Budiardi T., Sudrajat A.O. (2014). Growth performance of 7-g *Anguilla bicolor bicolor* at different density. *Jurnal Akuakultur Indonesia*, 13(2), 120-131.
- Haris M., Shakeel A., Hussain T., Ahmad G., Ansari M.S., Khan A.A. (2021). New trends in removing heavy metals from industrial wastewater through microbes. *Removal of emerging Contaminants Through Microbial Processes*, 183-205.
- Hinsinger P. (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. *Plant and soil*, 237(2): 173-195.
- Horwitz W., Chichilo P., Reynolds H. (1970). Official methods of analysis of the Association of Official Analytical Chemists. Official methods of analysis of the Association of Official Analytical Chemists.
- Hudson H., Brauer P., Scofield M., Petzel D. (2008). Effects of warm acclimation on serum osmolality, cortisol and hematocrit levels in the Antarctic fish, *Trematomus bernacchii*. *Polar Biology*, 31(8): 991-997.
- Jasrotia S., Kansal A., Mehra A. (2017). Performance of aquatic plant species for phytoremediation of arsenic-contaminated water. *Applied Water Science*, 7(2): 889-896.
- Jawad L.A., Al-Mukhtar M., Ahmed H. (2004). The relationship between haematocrit and some biological parameters of the Indian shad, *Tenuulosa ilisha* (Family Clupeidae). *Animal Biodiversity and Conservation*, 27(2): 47-52.
- Johnson C., Schweinhart S., Buffam I. (2016). Plant species richness enhances nitrogen retention in green roof plots. *Ecological Applications*, 26(7): 2130-2144.
- Kainama H., Sohilit H.J., Souisa C.J. (2021). Qualitative Protein Hydrolyzed from *Nerita undata* in supralittoral rocks and mezolittoral zone of Hasa Cape using TLC. *Indonesian Journal of Chemical Research*, 9(2): 118-123.
- Kim L.O., Lee S.-M. (2005). Effects of the dietary protein and lipid levels on growth and body composition of bagrid catfish, *Pseudobagrus fulvidraco*. *Aquaculture*, 243(1): 323-329.
- Lawrence A., Amadeo J. (2010). Textbook of clinical chemistry, theory, analysis correlations. Mosby/Elsevier.
- Lee J.-S., Cheng H., Damte D., Lee S.-J., Kim J.-C., Rhee M.-H., Suh J.-W., Park S.-C. (2013). Effects of dietary supplementation of *Lactobacillus pentosus* PL11 on the growth performance, immune and antioxidant systems of Japanese eel *Anguilla japonica* challenged with *Edwardsiella tarda*. *Fish and Shellfish Immunology*, 34(3): 756-761.
- Liao S.-W., Chang W.-L. (2004). Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan. *Journal of Aquatic*, 42: 60-68.
- Liu X., Xu H., Wang X., Wu Z., Bao X. (2014). An ecological engineering pond aquaculture recirculating system for effluent purification and water quality control. *CLEAN-Soil, Air, Water*, 42(3): 221-228.
- Luo M., Guan R., Li Z., Jin H. (2013). The effects of water temperature on the survival, feeding, and growth of the juveniles of *Anguilla marmorata* and *A. bicolor pacifica*. *Aquaculture*, 400: 61-64.
- Madhurina M., Bidisha M., Shekhar M., Sankar C., Amitawa G., Arunabha M. (2014). Study on the phytoremediation potential wastewater-A case study in Indian context. *International Research Journal of Environment Sciences*, 3(1): 83-89.
- Madikizela L.M. (2021). Removal of organic pollutants in water using water hyacinth (*Eichhornia crassipes*). *Journal of Environmental Management*, 295: 113153.
- Malhotra H., Sharma S., Pandey R. (2018). Phosphorus nutrition: plant growth in response to deficiency and excess. In: *Plant Nutrients and Abiotic Stress Tolerance*. Springer. pp: 171-190.
- Metaxa E., Deviller G., Pagand P., Alliaume C., Casellas C., Blancheton J.P. (2006). High rate algal pond treatment for water reuse in a marine fish recirculation system: Water purification and fish health. *Aquaculture*, 252(1): 92-101.
- Mkandawire M., Dudel E.G. (2007). Are *Lemna* spp. effective phytoremediation agents. *Bioremediation, Biodiversity and Bioavailability*, 1(1): 56-71.
- Młodzińska E., Zboińska M. (2016). Phosphate uptake and allocation - a closer Look at *Arabidopsis thaliana* L. and *Oryza sativa* L. *Frontiers in Plant Science*, 7: 1198-1198.

- Mokif L.A., Abdulhusain N.A. (2022). A low cost material for treatment wastewater contained petroleum pollution. IOP Conference Series: Earth and Environmental Science, 1088(1): 012014
- Nafsiyah I., Nurilmala M., Abdullah A. (2018). Nutrient composition of Eel *Anguilla bicolor bicolor* and *Anguilla marmorata*. Jurnal Pengolahan Hasil Perikanan Indonesia, 21(3): 504-512.
- Nakbanpote W., Meesungnoen O., Majeti P. (2016). Chapter 9 - Potential of ornamental plants for phytoremediation of heavy metals and income generation. In: Bioremediation and Bioeconomy. pp: 177-217.
- Nawir F., Utomo N.B.P., Budiardi T. (2015). The growth of eel fed with different protein level and protein-energy ratio. Jurnal Akuakultur Indonesia, 14(2): 128-134.
- Newman L.A., Reynolds C.M. (2004). Phytodegradation of organic compounds. Current Opinion in Biotechnology, 15(3): 225-230.
- Ngoc P.T.A., Meuwissen M.P.M., Le T.C., Bosma R.H., Verreth J., Lansink A.O. (2016). Adoption of recirculating aquaculture systems in large pangasius farms: A choice experiment. Aquaculture, 460: 90-97.
- Nhan H.T., Tai N.T., Liem P.T., Ut V.N., Ako H. (2019). Effects of different stocking densities on growth performance of Asian swamp eel *Monopterus albus*, water quality and plant growth of watercress *Nasturtium officinale* in an aquaponic recirculating system. Aquaculture, 503: 96-104.
- Nootong K., Nurit S., Powtongsook S. (2013). Control of inorganic nitrogen and suspended solids concentrations in a land-based recirculating aquaculture system. Engineering Journal, 17(1): 49-60.
- Nootong K., Pavasant P., Powtongsook S. (2011). Effects of organic carbon addition in controlling inorganic nitrogen concentrations in a biofloc system. Journal of the World Aquaculture Society, 42(3): 339-346.
- Norousta R., Mousavi-Sabet H. (2013). Comparative characterization of blood cells and hematological parameters between the mature and immature Caspian Vimba, *Vimba vimba persa* (Teleostei, Cyprinidae). Aquaculture, Aquarium, Conservation and Legislation, 6(3): 232-240.
- Nurfitri A., Masayuki S., Koichiro S. (2017). Phytoremediation of heavy metal-polluted mine drainage by *Eleocharis acicularis*. Environmental Science Indian Journal, 13(1): 131.
- O'Hare M.T., Baattrup-Pedersen A., Baumgarte I., Freeman A., Gunn I.D., Lázár A.N., Sinclair R., Wade A.J., Bowes M.J. (2018). Responses of aquatic plants to eutrophication in rivers: a revised conceptual model. Frontiers in Plant Science, 9(451): 1-13.
- Omitoyin B.O., Ajani E.K., Okeleye O.I., Akpoilih B.U., Ogunjobi A.A. (2017). Biological treatments of fish farm effluent and its reuse in the culture of Nile tilapia (*Oreochromis niloticus*). Journal of Aquaculture Research and Development, 8(2): 469-478.
- Othman R., Hatta F.A.M., Ramya R., Hanifah N.A. (2015). Phytoremediation model system for aquaculture wastewater using *Glossostigma elatinoides* and *Hemianthus callitrichoides*. International Journal of Sustainable Energy and Environmental Research, 4(1): 1-7.
- Paz-Alberto A.M., Sigua G.C. (2013). Phytoremediation: a green technology to remove environmental pollutants. American Journal of Climate Change, 2(1): 71-86.
- Perdana M., Sutanto H., Prihatmo G. (2018). Vertical Subsurface Flow (VSSF) constructed wetland for domestic wastewater treatment. IOP Conference Series Earth and Environmental Science, 148(1): 012025.
- Poschenrieder C., Coll J.B. (2003). Phytoremediation: principles and perspectives. Contributions to Science, 333-344.
- Pratama W.W., Nursyam H., Hariati A.M., Islamy R.A., Hasan V. (2020). Proximate analysis, amino acid profile and albumin concentration of various weights of Giant Snakehead (*Channa micropeltes*) from Kapuas Hulu, West Kalimantan, Indonesia. Biodiversitas Journal of Biological Diversity, 21(3): 1196-1200.
- Qu J., Zhang Q., Jia C., Liu P., Yang M. (2017). The study of recirculating aquaculture system in pond and its purification effect. IOP Conference Series: Earth and Environmental Science, 67(1): 012028.
- Rahman M.A., Hasegawa H. (2011). Aquatic arsenic: phytoremediation using floating macrophytes. Chemosphere, 83(5): 633-646.
- Rakhmatika S., Joko T., Nurjazuli N. (2017). Differences of constructed wetlands recirculating free water surface and subsurface flow system *Echinodorus palaefolius* for reducing phosphat greywater case study: Kelurahan Gedawang, Kecamatan Banyumanik. Jurnal Kesehatan Masyarakat, 5(1): 482-488.
- Razaq M., Zhang P., Shen H.-l. (2017). Influence of nitrogen and phosphorous on the growth and root morphology of *Acer mono*. PLoS One, 12(2): e0171321.
- Ren T., Koshio S., Teshima S.I., Md M.I., Alam S.,

- Panganiban Jr A., Moe Y.Y., Kojima T., Tokumitsu H. (2005). Optimum dietary level of L-ascorbic acid for Japanese eel, *Anguilla japonica*. Journal of the World Aquaculture Society, 36(4): 437-443.
- Romano N., Sinha A.K. (2020). Husbandry of aquatic animals in closed aquaculture systems. In: Aquaculture Health Management. Elsevier. pp: 17-73.
- Rosen D.J. (2000). *Cryptocoryne beckettii* (Araceae), a new aquatic plant in Texas. SIDA, Contributions to Botany, 19(2): 399-401.
- Russell K. (2005). The use and effectiveness of phytoremediation to treat persistent organic pollutants. US Environmental Protection Agency Office of Solid Waste and Emergency Response Technology Innovation and Field Services Division Washington, DC.
- Saputra A., Budiardi T., Supriyono E. (2016). Production performance of eel *Anguilla bicolor bicolor* with the addition of calcium carbonate. Jurnal Akuakultur Indonesia, 15(1): 56-62.
- Saunders D., Kalff J. (2001). Nitrogen retention in wetlands, lakes and rivers. Hydrobiologia, 443(1-3): 205-212.
- Schütt D.A., Lehmann J., Goerlich R., Hamers R. (1997). Haematology of swordtail, *Xiphophorus helleri*. I: blood parameters and light microscopy of blood cells. Journal of Applied Ichthyology, 13(2): 83-89.
- Sharma A., Aggarwal N.K., Saini A., Yadav A. (2016). Beyond biocontrol: water hyacinth-opportunities and challenges. Journal of Environmental Science and Technology, 9(1): 26-48.
- Simplício N., Muniz D., Rocha F., Martins D., Dias Z., Farias B., Oliveira-Filho E. (2017). Comparative analysis between ecotoxicity of nitrogen-, phosphorus-, and potassium-based fertilizers and their active ingredients. Toxics, 5(1): 2-15.
- Singh J., Kumar V., Kumar P., Kumar P. (2022). Kinetics and prediction modeling of heavy metal phytoremediation from glass industry effluent by water hyacinth (*Eichhornia crassipes*). International Journal of Environmental Science and Technology, 19(6): 5481-5492.
- Siswandari A.M. (2016). Phytoremediation of laundry phosphat wastewater using *Echinodorus paleaefolius* and *Equisetum hyemale* as biological knowledge resources. University of Muhammadiyah Malang Press.
- Su W., Sun Q., Xia M., Wen Z., Yao Z. (2018). The resource utilization of Water Hyacinth (*Eichhornia crassipes* [Mart.] Solms) and its challenges. Resources, 7(3): 46-55.
- Suzuki Y., Maruyama T., Numata H., Sato H., Asakawa M. (2003). Performance of a closed recirculating system with foam separation, nitrification and denitrification units for intensive culture of eel: towards zero emission. Aquacultural Engineering, 29(3-4): 165-182.
- Tang H., Dai Y., Fan Y., Song X., Wang F., Liang W. (2021). Effect of *Vallisneria spiralis* on water quality and sediment nitrogen at different growth stages in eutrophic shallow Lake Mesocosms. Polish Journal of Environmental Studies, 30(3): 2341-2351.
- Tavares-Dias M., Barcellos J., Marcon J., Menezes G., Ono E.A., Affonso E.G. (2007). Hematological and biochemical parameters for the pirarucu *Arapaima gigas* Schinz, 1822 (Osteoglossiformes, Arapaimatidae) in net cage culture. Electronic Journal of Ichthyology, 2: 61-68.
- Thiebaut G. (2008). Phosphorus and aquatic plants. Springer, Dordrecht. pp: 31-49.
- Trung Quang P., Lan Anh Thi N., Nhung Thi D., Thao Thi T. (2024). Determination of phosphorus additives in instant noodle samples by Phosphorus-31 nuclear magnetic resonance (P-NMR). Vietnam Journal of Science, Technology and Engineering, 66(3): 39-45.
- Tseng K.-F., Wu K.-L. (2004). The ammonia removal cycle for a submerged biofilter used in a recirculating eel culture system. Aquacultural Engineering, 31(1-2): 17-30.
- Twarowska J.G., Westerman P.W., Losordo T.M. (1997). Water treatment and waste characterization evaluation of an intensive recirculating fish production system. Aquacultural Engineering, 16(3): 133-147.
- Vaillant N., Monnet F., Sallanon H., Coudret A., Hitmi A. (2004). Use of commercial plant species in a hydroponic system to treat domestic wastewaters. Journal of Environmental Quality, 33(2): 695-702.
- Van Rijn J. (2013). Waste treatment in recirculating aquaculture systems. Aquacultural Engineering, 53: 49-56.
- Wananda A.Z.J., Setyawan Y.A., Setiani F.S., Wulandari I.N.E., Andriawan S. (2022). Local synbiotic from *Amorphophallus muelleri* Bl. and *Bacillus* sp. to boost *Litopenaeus vannamei* non-specific immune responses [Article]. AACL Bioflux, 15(1): 489-501.
- Wedemeyer G.A., Yasutake W. (1977). Clinical methods for the assessment of the effects of environmental stress on fish health (Vol. 89). U.S. Fish and Wildlife Service.

- Zakia D.W., Prasetyo H.D., Latuconsina H. (2023). Phytoremediation of a combination of Water Clover (*Marsilea crenata*) and Java Fern (*Microsorium pteropus*) for fecal wastewater. *Jurnal Ilmiah Mahasiswa Sains Unisma Malang*, 1(2): 56-65.
- Zapata F., Zaharah A. (2002). Phosphorus availability from phosphate rock and sewage sludge as influenced by the addition of water soluble phosphate fertilizer. *Nutrient Cycling in Agroecosystems*, 63(1): 43-48.
- Zhang C., Chen X., Wei B., Li Z., Liu S., Li Q. (2009). Study on removal efficiency of nitrogen and phosphorus from sewage by aquatic macrophytes under two cultivation modes. *Southwest China Journal of Agricultural Sciences*, 22: 786-790.
- Zhang S., Li M., Cheng J., Xu Z., Chen J. (2016). Response and environmental assessment of two Chinese conventional carps to water quality regulation in recirculating aquaculture. *Aquacultural Engineering*, 74: 180-185.
- Zhou Y.-W., Xu X.-G., Han R.-M., Zhou X.-H., Feng D.-Y., Li Z.-C., Wang G.-X. (2018). Effect of nutrient loadings on the regulation of water nitrogen and phosphorus by *Vallisneria natans* and its photosynthetic fluorescence characteristics. *Huan Jing Ke Xue = Huanjing Kexue*, 39(3): 1180-1187.
- Zhou Y., Stepanenko A., Kishchenko O., Xu J., Borisjuk N. (2023). Duckweeds for phytoremediation of polluted water. *Plants*, 12(3): 589-608.