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IMPROVING THE WASTE WATER QUALITY OF CATFISH FARMING POND THROUGH PHYTOREMEDIATION PROCESS BATCH CULTURE SYSTEM USING VARIOUS TYPES OF LOCAL HYDROMACROPHYTES

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Abstract: This study aimed to determine the effectiveness of the batch culture phytoremediation model conducted in a 30 L bucket with sand and gravel as a substrate in reducing pollutants from post-harvest catfish farming ponds. This true experimental study used a completely randomised design with the treatments of hydromacrophytes of emergent, floating, submerged, and polycultures of the three hydromacrophytes and controls without hydromacrophytes. Each treatment was repeated three times. The effectiveness of this model was monitored using physicochemical water parameters, Chironomidae density, and the biotic index of diatom [Trophic Diatom Index (TDI) and Percentage of Pollution Tolerant Value (%PTV)]. After incubation, monitoring was done on days 10, 15, 20, and 25. The results showed that the phytoremediation process had successfully reduced the suspended solid and nitrate levels in the water starting from day ten after incubation. The levels of Biochemical Oxygen Demand (BOD) and Total Kjeldahl Nitrogen (TKN) decreased significantly after 25 days. The level of organic matter pollution based on the %PTV and density of Chironomidae was significantly reduced after 15 days of incubation. However, the phosphate level was still high, and the water trophic status was hypereutrophic. The most effective treatment for the phytoremediation process in this study is submerged hydromacrophytes.

Keywords: Artificial feed, macrophyte, pond, remediation, wastewater.

Introduction

The community often cultivates catfish because it has several advantages, including easy cultivation, high nutrition, and relatively cheap selling value (Sitio *et al*., 2017; Nurrohim, 2021). Catfish can survive in water conditions with poor quality, so their growth is relatively faster than other fish (Caesar *et al*., 2021). Gondosuli Village is located east of the Gondang district, Tulungagung regency, East Java, Indonesia, with an area of 1.71 km^2, the livelihood of most of the population as catfish farmers. From an area of 9.87 hectares of the pond each year, fish farmers in Gondosuli Village can produce fish as much as 3,860 tonnes/year.

The age of catfish ready to harvest is 3 to 4 months. Catfish farming is done using semi-intensively farming techniques that rely on artificial feed. Artificial feed is generally in the form of pellets with nutritional content such as protein, carbohydrates, fats, minerals, and vitamins (Dewanggani *et al*., 2021). Catfish farmers in Gondosuli provide feed regularly every morning and evening. This residual feed will decrease the quality of pond water, which can be sourced from organic and nutrient pollution and highly suspended solids. From the preliminary study, it was found that there was a change in the colour of the pond water from clear before being used for fish cultivation to green in catfish farming ponds aged 1-2 months, brown colour in pond water with catfish having an age of 2-3 months and red water in ponds with fish that ready to harvest about 3-4 months old. Research results of Febriansyah and Retnaningdyah (2021) in the catfish pond of Gondosuli found that the pond water containing catfish aged 3-4 months had the worst water quality with turbidity values of 1827 NTU, conductivity 174.8 S/cm, water transparency of 4 cm, DO 0.2 mg/L and BOD 795.34 mg/L.

This low water transparency indicates that the waters are eutrophic to hyper-eutrophic, with very high nutrient levels. These can also be seen from monitoring the pond water quality using the plankton biotic index as a bioindicator. The value of the trophic diatom index in this pond was more than 75, indicating poor water quality with water nutrition status was hypereutrophic, while based on the index of Percentage Pollution Tolerant Value (%PTV), indicating catfish ponds water were also has been polluted with heavy levels of organic pollution indicated by the value of %PTV in ponds with catfish aged 3-4 months was 70.83% (Febriansyah & Retnaningdyah, 2021). After harvesting, pond water is discharged directly into the existing drainage channel and enters the river. The water, with the status of eutrophic to hypereutrophic and also the high level of organic matter content in general, can trigger eutrophication events in rivers and beaches which in turn can trigger algae blooms in river waters, reservoirs, and also in the oceans (Yang *et al*., 2017; Hao *et al*., 2020).

Based on the above, it is necessary to manage the catfish farming pond wastewater in Gondosuli, which is proven to contain high organic matter and nutrients. Many studies have been carried out to control the high levels of organic matter and nutrients in water bodies through the process of absorption and storage by organic matter in sediments, plant (hydromacrophytes), and microbes uptake, as well as denitrification processes (Waller *et al.,* 2018; Deng *et al*., 2020). In order to improve the quality of catfish farming pond wastewater before being discharged into the drainage, it is necessary to conduct a phytoremediation process. In this research, we carried out a phytoremediation process-based batch culture system using various kinds of local emergent, floating, and submerged aquatic plants (hydromacrophytes) and polycultures of the three types of hydromacrophytes. This phytoremediation process is carried out in a greenhouse. Emergent hydromacrophytes such as *Fimbristylis* sp., *Typha* sp., *Scirpus* sp., *Acorus calamus*, *Colocasia esculenta*, *Cyperus alternativeolius,* and *Ipomoea aquatica* have a function to precipitate suspended particles. Hydromacrophytes with floating leaves, such as *Nymphaea* sp., *Azolla* sp, and *Marsilea crenata,* also have a function to precipitate suspended particles and commonly were ornamental plants. The submerged hydromacrophytes such as *Hydrilla verticilata*, *Utricularia* sp., and *Vallisneria* sp. can filter water pollutants.

The selection of hydromacrophytes in the phytoremediation process of this study was based on the success of previous studies that have been carried out both at the greenhouse scale, pond scale, and in situ scale in irrigation canals (Vidayanti *et al*., 2012; Prahardika *et al*., 2013; Sundari *et al*., 2013; Ivansyah & Retnaningdyah, 2013; Retnaningdyah, 2017; Retnaningdyah *et al*., 2017; Retnaningdyah & Arisoesilaningsih 2018a; 2018b; Retnaningdyah & Arisoesilaningsih, 2019a; 2019b). The success and safety of the results of the phytoremediation process were determined by monitoring the improvement of water quality as reflected in the physical and chemical parameters of the water. In addition, monitoring of water quality resulting from the phytoremediation process was also carried out through the biotic index of Diatom, namely TDI and %PTV, as well as the density of Chironomidae, which, based on the results of previous studies, has been known to be effective as a bioindicator of water quality (Wu *et al*., 2014; Retnaningdyah *et al*., 2017; Retnaningdyah & Arisoesilaningsih, 2018b; 2019a; 2019b).

Materials and Methods

Research Design

This true experimental study using a completely randomised design (Anderson & McLean, 2018) was conducted in the glass house of the Biology Department, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya, Malang. The treatment is the type of hydromacrophyte covering five levels, namely emergent (*Scirpus* sp., *Acorus calamus*, *Marsilea crenata*), floating (*Ipomoea aquatica*, *Azolla* sp.), submerged (*Vallisneria* sp., *Hydrilla verticilata*), polycultures of the three hydromacrophytes, and controls that were not planted with hydromacrophytes. The research was repeated three times for each treatment at the same time. The study used a bucket that could hold 30 L of water. Each bottom of this bucket was given a substrate in the form of sand and gravel with a height of 5 cm each.

Hydromacrophytes used in this research were planted in those buckets and added to groundwater. The initial hydromacrophytes planted in each treatment bucket were 25% of the surface area and, during this research, were allowed to grow until coverage reached 70%. The coverage of the plants will be maintained in the range of 50-70%. If there is an excess cover, harvesting will occur in the treatment tank. Hydromacrophytes harvesting is also carried out if plant parts are getting old or yellowing (Retnaningdyah *et al*., 2017; Retnaningdyah & Arisoesilaningsih, 2019a).

Moreover, after the plant's steady growth, the groundwater was replaced with 25 L wastewater treatment from catfish farming pond water taken from Gondosuli Village, Gondang District, Tulungagung Regency, East Java, Indonesia. When replacing groundwater with wastewater from the catfish farming pond used for this treatment, we put an artificial substrate in the form of ceramics with an area of 10 x 10 cm^2 placed in each treatment tank. This artificial substrate was used for monitoring diatoms and Chironomidae as bioindicators of water quality improvement. Water quality monitoring was started after the incubation period for the phytoremediation process was ten days. The dependent variable in this research was the improvement in the water quality indicated by some water physics chemical parameters, densities of Chironomidae as bioindicator of organic pollution, and biotic indices of diatoms including Trophic Diatom Index (TDI) as an indicator of water nutrition status and also the percentage of Pollution Tolerant Values (%PTV) that indicated the level of pollution of organic substances in the water.

Monitoring the Improvement of the Water Quality in the Phytoremediation Model

The effectiveness of the phytoremediation model for each treatment was determined by its ability to improve water quality as reflected in some water physics chemical and biological parameters (diatoms and Chironomidae). The water physics and chemical quality was monitored, i.e., pH, DO (Dissolved Oxygen), conductivity, TSS (Total Suspended Solid), temperature, nitrate, orthophosphate, TP (Total Phosphate), TKN (Total Kjeldahl Nitrogen), and BOD (Biochemical Oxygen Demand). Water quality monitoring was carried out for each treatment every five days on 10, 15, 20, and 25 days after incubation. The phytoremediation model was successful if a significant decrease was found in each observed physics and chemical parameter (except DO). The method of measuring water physics chemical parameters was carried out according to Clesceri *et al*. (1998), as seen in Table 1.

The improved water quality resulting from the phytoremediation process was also monitored from the density of Chironomidae and diatoms in the artificial substrate. Chironomidae and diatom sampling was done by cleansing each side of the artificial substrate with a brush and water and then inserting it into a flacon bottle and preservatives in 10 drops of 4% formaldehyde and five drops of saturated $CuSO_4$. Diatom identification was based on Lange-Bertalot *et al*. (2017) and Bellinger and Sigee (2015). The data from the identification and calculation of diatom density are then used to determine the biotic index of diatoms.

Data Analysis

The data from the measurement of physics and chemical parameters and the density of Chironomidae in each treatment were compiled and then calculated the average value for each parameter between treatments and monitoring time. The level of water pollution can also be known by comparing the average value of water quality obtained with the Water Quality Standard based on Indonesian government regulation No.

Table 1: Environmental factors measured in research and methods of measurement

No.	Parameters	Unit	Tool/Methods
I. Analysis in the Field			
1.	Temperature	°C	Digital thermometer
2.	pH	-	pH meter
3.	Conductivity	mS/cm	Conductivity meter
4.	Dissolved oxygen	mg/L	DO meter
II. Analysis in the Laboratorium			
1.	Nitrate	mg/L	Brucine methods
2.	BOD	mg/L	Potentiometric
3.	TSS	mg/L	TDS meter
4.	Orthophosphate	mg/L	Stannous chloride
5.	Total Kjeldahl Nitrogen	mg/L	Macro Kjeldahl methods
6.	Total phosphate	mg/L	Ascorbic acid

22/2021 concerning Water Quality Management and Water Pollution Control. Whereas the data of diatom composition and abundance were used to calculate the Trophic Diatom Index (TDI) to indicate the nutrient status of the water and the percentage of pollution tolerant values (%PTV) to estimate the organic pollution (Lobo *et al*., 2016; Oeding & Taffs, 2017). The differences in water quality parameters (physics, chemical, and biology) between phytoremediation treatments in this research were seen using a biplot from principal component analysis, which the PAST software program analysed.

Results and Discussion

Improving the Water Quality from Catfish Farming Pond in the Batch Culture Phytoremediation Process Using Various Types of Local Hydromacrophytes

Post-harvest pond water has an average pH value of 7.58. Planting local hydromacrophytes floating, emergent, or submerged in batch culture for 25 days increased the pH value from 7.90 to 8.50 after incubating for 25 days (Figure 1). This increase in pH value indicates a photosynthetic process from hydromacrophytes used for this research (Retnaningdyah & Arisoesilaningsih, 2018b). The pH value of the pond water for catfish cultivation and the results of the phytoremediation process in this study still meet the water quality standards based on the provisions of Indonesian government regulation No. 22/2021 concerning water quality management and water pollution control class I to III, ranging between 6-9. However, several treatments still did not meet the provisions of the international irrigation water quality standard from FAO of 6.5-8.4.

A decrease followed the pH value increase in the water's electrical conductivity. Post-harvest catfish pond water in Gondosuli Village has an average conductivity value of 117.7 mS/m. The conductivity value of this water decreased to 63.2-79.2 mS/m or 0.632-0.792 dS/m in all treatments of phytoremediation after 25 days of incubation (Figure 1). The decrease in conductivity value in the phytoremediation process has met the FAO irrigation water quality standard, which requires 0-3 dS/m. This conductivity value can be used to describe the dissolved salt content (salinity), which will determine water availability for plants. A TDS value of less than 450 mg/L with a conductivity of fewer than 0.7 dS/m indicates no salinity problem in the irrigation water so that it can be used for all crops (without restrictions). Meanwhile, if the TDS value is 450-2000 mg/L, it is included in the slight to moderate degree of restriction on use (Shakir *et al*., 2017).

The phytoremediation process in all treatments, from the incubation time for ten days to 25 days, increased dissolved oxygen levels in the waters on post-harvest water (Figure 1). DO levels in catfish culture pond water average 0.21 mg/L. The low level of DO in the catfish farming pond in Gondosuli village is strongly influenced by the level of organic matter in the water. The monitoring results of Febriansyah and Retnaningdyah (2021) showed that the level of organic matter pollution in the catfish farming pond in Gondosuli village was in the high category (795.34 mg/L). The phytoremediation process in this study using various hydromacrophytes increased DO levels to 2.14-4.77 mg/L. The minimum dissolved oxygen required for Class III agricultural activities is 3 mg/L. The low DO value in this process indicates that the oxygen produced by the photosynthesis process can only be used for respiration for organisms in the treatment area.

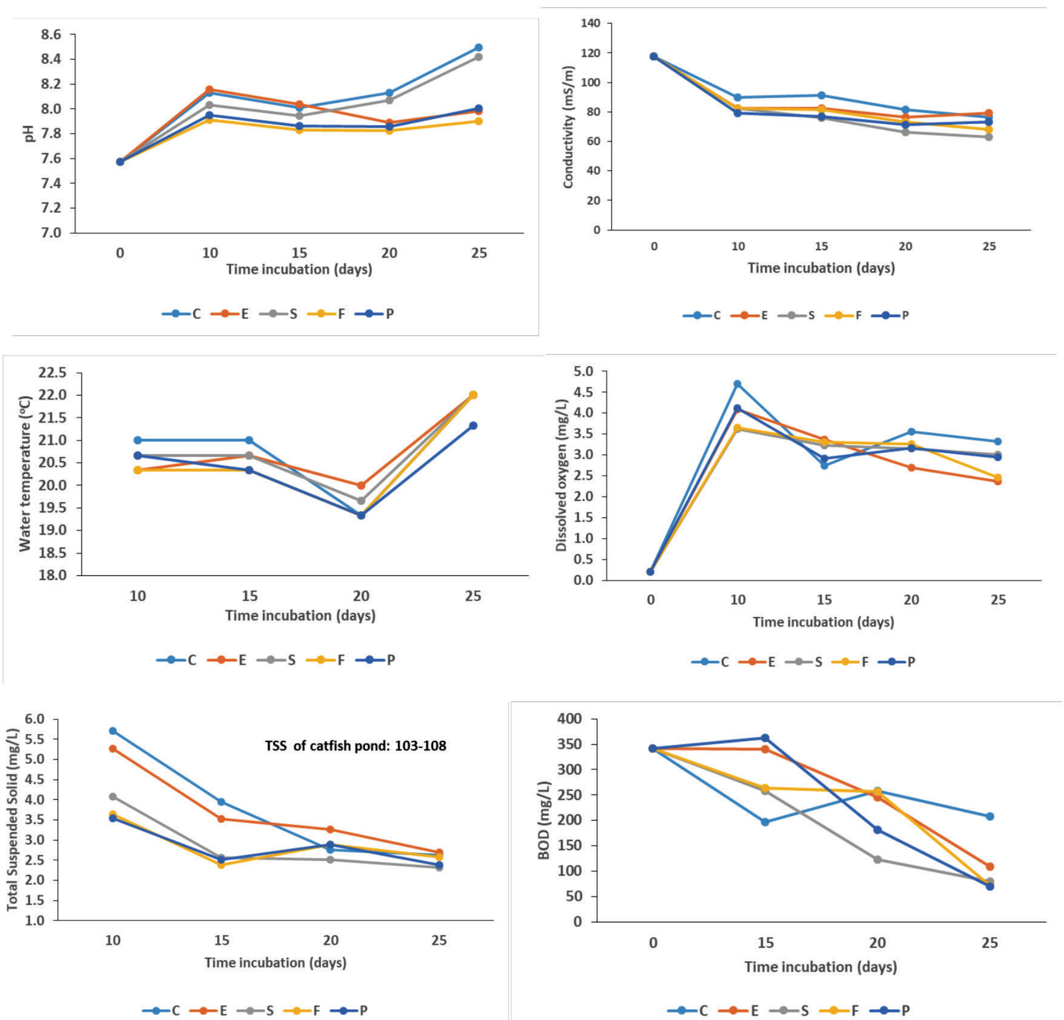


Figure 1: Monitoring the water physics and chemical quality of catfish farming pond water in the phytoremediation process using emergent, floating, submerged, polyculture, and without hydromacrophytes on days 0 (post-harvest catfish pond water), 10, 15, 20, 25 after incubation (Note: n = 3; C = control; E = emergent; S = submerged; F = floating leaf; P = polyculture)

Planting hydromacrophytes as emergent, submerged, floating leaf or polyculture in all treatments starting from ten days of incubation has significantly reduced suspended solids, as reflected by a decrease in TSS levels (Figure 1). The results showed that planting some hydromacrophytes impacts the sedimentation process of suspended solids in water. Total suspended solids (TSS) decreased from 103.03 mg/L (post-harvest catfish pond water) to 2.32-2.70 mg/L after incubation for 25 days. Control treatment without planting hydromacrophytes but given gravel and sand substrate was also able to reduce suspended solids. The value of TSS complies with Class I and II quality standards based on Indonesian government regulation with a maximum limit of level 50 mg/L. The temperature of the treatment water during the phytoremediation process did not differ significantly, ranging from 19-22^{o}C. These results showed that the glass house environment during phytoremediation treatment has a relatively stable temperature.

Fish feed residues provided by farmers impact increasing organic matter (Febriansyah & Retnaningdyah, 2021). The presence of organic matter in the waters can be shown from the BOD (Biochemical Oxygen Demand) value. The phytoremediation process by planting hydromacrophytes in the form of emergent, submerged, floating, or polyculture of all types after 15 days of incubation has reduced BOD levels in post-harvest catfish farming pond water. The average BOD level of post-harvest catfish farming pond water is 341.3 mg/L. This level decreased to 70.67-208.00 mg/L after 25 days of incubation and continued to decrease to 8.63-17.20 mg/L after 30 days of incubation (personal observation). Control treatment without hydromacrophytes but given the substrate of sand and gravel was also able to reduce BOD levels indicating a bioremediation process by microbes in the treatment. Thus, all treatments in this study have not improved irrigation water quality from class IV to class III, which requires a minimum BOD value of 6 mg/L.

If decomposed by microbes, high organic matter in catfish culture ponds will impact increasing nutrient levels in the water. The level of nutrients in the waters can be reflected in the levels of dissolved phosphate, nitrate, Total Phosphate (TP), and Total Kjeldahl Nitrogen (TKN). Besides filtering suspended solids and reducing organic pollution, this phytoremediation process can also reduce nutrients such as phosphorus and nitrogen in the waters (Chen *et al*., 2017; Retnaningdyah & Arisoesilaningsih, 2018b; 2019a). Nitrate levels in post-harvest catfish farming ponds averaged 0.41 mg/L. This level decreased in the phytoremediation process after 15 days of incubation to 0.17-0.31 mg/L, then rose slightly at 20-day incubation to 0.41-0.78 mg/L and decreased again after 25 days of incubation, which was to 0.12-0.24 mg/L except for control and polyculture treatments ranging from 0.42-0.50 mg/L. This phytoremediation process reduced TKN levels from 11.07-21.95 mg/L to 1.20-1.32 mg/L after incubation for 25 days (Figure 2). This result follows the results of other studies, which show that some hydromacrophytes have also been proven to reduce dissolved N and P in polluted water (Sundari *et al*., 2013; Retnaningdyah & Arisoesilaningsih, 2018b; 2019a).

The phytoremediation process in post-harvest pond water decreased dissolved phosphate from 3.93 mg/L to 2.09-3.71 mg/L after 25 days of incubation. Similarly, total phosphate levels in all treatments increased during the 25-day phytoremediation process, from 12.16-25.02 mg/L to 14.63-40.05 mg/L (Figure 3). According to Dar (2021), TKN levels between 0.5-1.1 mg/L are included in the category of eutrophic waters, whereas more than 1.1 mg/L are included in the hypereutrophic category. Thus the phytoremediation process has improved the water quality from hypereutrophic to eutrophic. Meanwhile, based on the TP level, wastewater quality is still included in the hypereutrophic category. Based on the water quality standard set by the Indonesian government number 22/2021, the total phosphates of one mg/L is the maximum limit for Class III water, and five mg/L is the maximum limit for Class IV water.

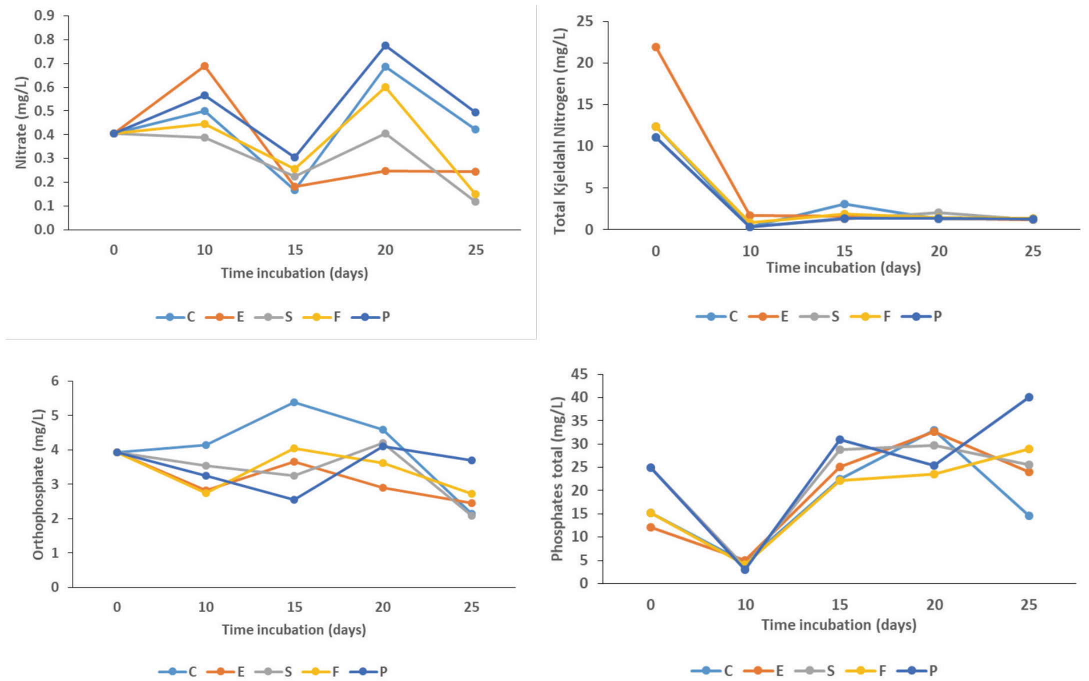


Figure 2: Monitoring nutrient levels in catfish farming pond water in the phytoremediation process using emergent, floating, submerged, polyculture, and without hydromacrophytes on days 0 (post-harvest catfish pond water), 10, 15, 20, 25 after incubation (Note: n = 3; C = control; E = emergent; S = submerged; F = floating leaf; P = polyculture)

Thus, based on this total phosphates content, the water resulting from the phytoremediation process still does not meet class IV water.

The results showed that the phytoremediation process, although able to reduce the levels of several water quality parameters, still does not meet the specified quality standard values. It is probably due to the non-optimal growth of hydromacrophytic plants. Another thing that might need to be considered is the density or coverage of hydromacrophytic plants used for the phytoremediation process. This study used a variety of local hydromacrophytes that were submerged, floating, and emergent with a hydromacrophyte coverage area in the bucket between 50% to 70%. In addition, the phytoremediation process should also be pursued using the continuous culture method.

Improving the quality of catfish farming pond wastewater after the phytoremediation process using emergent hydromacrophytes (*Scirpus* sp., *Acorus calamus*, *Marsilea crenata*), floating leaf (*Ipomoea aquatica*, *Azolla* sp.), submerged (*Vallisneria* sp., *Hydrilla verticilata*), and polycultures of these three groups of hydromacrophytes can also be seen from the results of monitoring diatoms as bioindicators of water quality. In this research, we use biotic indices of diatoms, including Trophic Diatom Index (TDI) that indicates water nutrition status and percentage Pollution Tolerant Value (%PTV) as bioindicators of organic pollution in waters (Wu *et al*., 2014). The monitoring results showed that *Navicula* sp., *Nitzchia* sp. and *Gomphonema* sp. are always dominant in all treatments. These three diatom species are indicators of high organic pollution in the waters (Schuch *et al*., 2015). The results of the calculation of the %PTV index value (Figure 3) can be seen that the batch culture phytoremediation process using local hydromacrophytes for 25 days was still not able to reduce the high level of organic matter pollution in catfish farming pond water, as indicated by the %PTV value of more than 60.

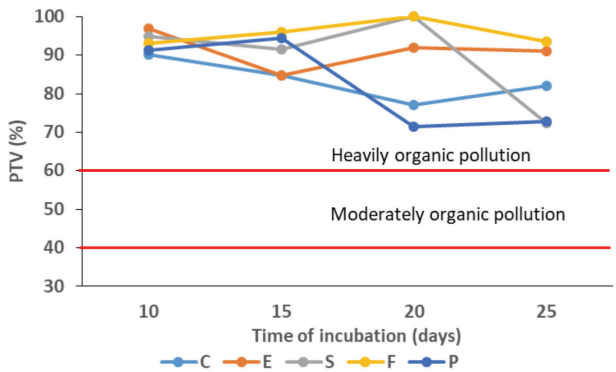


Figure 3: Index of percentage pollution tolerant value (% PTV) of catfish farming pond wastewater in the phytoremediation process using emergent, floating, submerged, polyculture and without hydromacrophytes on days 10, 15, 20, 25 after incubation (Note: n = 3; C = control; E = emergent; S = submerged; F = floating leaf; P = polyculture)

Although the status of the level of organic pollution is categorised as heavy organic pollution, there is a tendency to decrease the value of %PTV with the longer incubation time. In the post-harvest treatment of catfish farming pond wastewater, the initial %PTV index value was 91-97%, then decreased to 72-94 after incubation for 25 days. This result is different from a similar batch culture phytoremediation process in irrigation water contaminated with organic matter and contaminated with synthetic pesticide (Prevathon), which can reduce the level of organic matter pollution from heavy organic pollution to moderately and slightly organic pollution (Retnaningdyah & Arisoesilaningsih, 2018b; 2019a). This difference may be caused by the level of organic matter contamination of the catfish farming pond wastewater, which is much higher, indicated by a higher BOD value than the BOD level of polluted irrigation water in previous studies.

The level of organic matter pollution in the waters can also be seen from the density of Chironomidae as a bioindicator (Serra *et al*., 2017; Retnaningdyah & Arisoesilaningsih, 2019b). The results of observations on the density of Chironomidae during the research can be seen in Figure 4. Based on these observations, it can

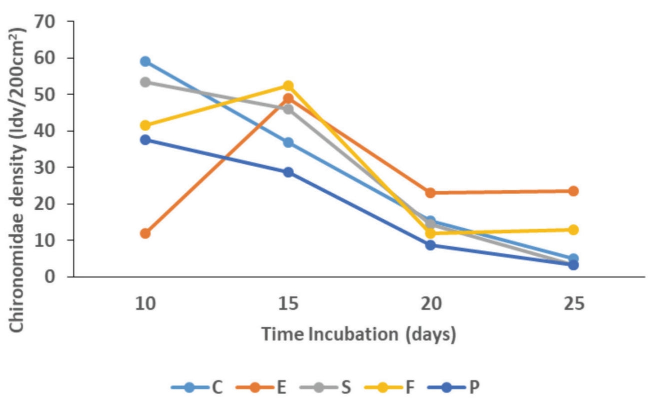


Figure 4: Density of Chironomidae of catfish farming pond wastewater in the phytoremediation process treatment using emergent, floating, submerged, polyculture hydromacrophytes and without hydromacrophytes on days 10, 15, 20, 25 after incubation (Note: n = 3; C = control; E = emergent; S = submerged; F = floating leaf; P = polyculture)

be seen that the density of Chironomidae, which initially ranged from 12-59 individuals/200 cm^2, decreased to 3-24 individuals/200 cm^2 after incubation for 25 days. These results showed that the phytoremediation process using several local hydromacrophytes that have been carried out in this study has an impact on improving water quality during the phytoremediation process, especially by reducing the level of organic matter pollution in catfish farming pond wastewater used for treatment.

The phytoremediation process in this study has not improved the nutritional status of catfish farming pond wastewater. The nutritional status of catfish farming pond wastewater at the hypereutrophic level category is shown by the TP and TKN levels and the results of monitoring the TDI index. Meanwhile, in phytoremediation treatment, the TDI value which originally ranged from 67-75, dropped to 68-73. It indicates a slight improvement in water quality from hypereutrophic to eutrophic and mesotrophic status (Figure 5).

These results were similar to previous studies in that the phytoremediation process using local hydromacrophytes could only increase one level of nutritional status. However, other researchers have widely recommended the role of hydromacrophytes as a filter of sediment and toxic substances, reducing phosphorus and nitrogen and purifying eutrophic water and organic pollutants in the water bodies. The removal of total nitrogen and phosphates is the synergistic effect of plant roots and microorganisms (Retnaningdyah, 2017; Retnaningdyah *et al.,* 2017; He *et al.,* 2019; Su *et al.,* 2019; Retnaningdyah & Arisoesilaningsih 2019b; Azeez 2021).

The Effectivity of Batch Culture System Phytoremediation Using Some Emergent, Submerged, and Floating Leaves of Local Hydromacrophytes for Improving the Wastewater Quality from Catfish Farming Pond

The effectiveness of the phytoremediation process with a batch culture system through the cultivation of emergent, floating leaf and submerged hydromacrophytes can be seen from the improvement in water quality after incubating the phytoremediation process for some time incubation. Suppose the phytoremediation process can effectively improve water quality. In this case of study, there will be differences in water quality based on physics, chemicals, and biology (diatoms and Chironomidae as bioindicators of water quality) between the differences in the incubation time of the phytoremediation process and or can be compared with the control treatment without the use of hydromacrophytes. Differences in water's physics, chemical and biological quality

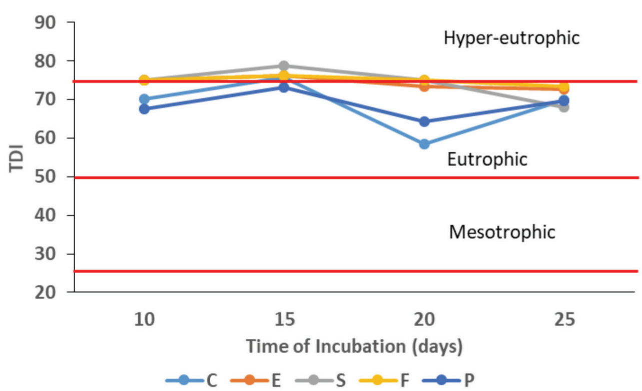
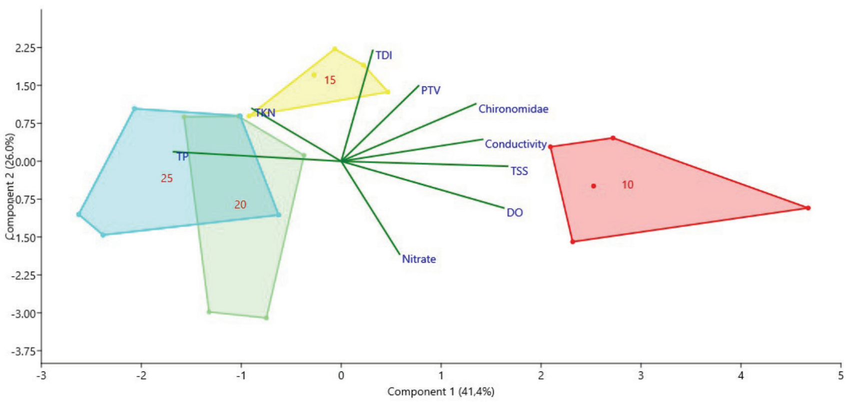


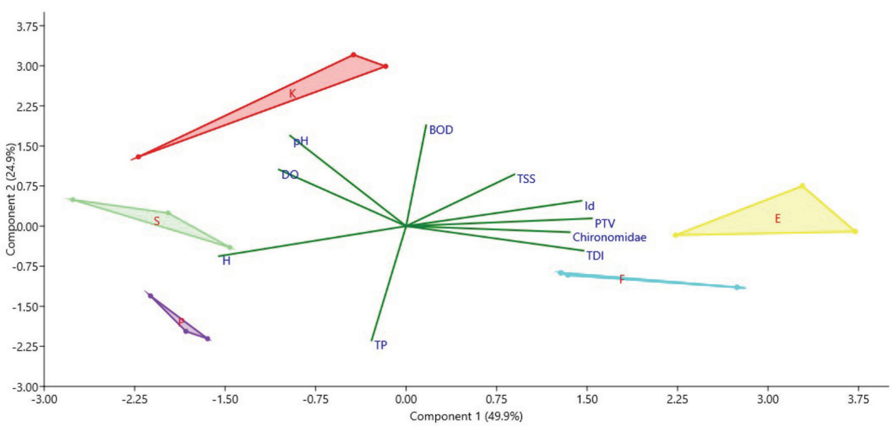
Figure 5: Trophic Diatom Index (TDI) value of catfish farming pond water in the phytoremediation process using emergent, floating, submerged, polyculture, and without hydromacrophytes on days 0 (pond water), 10, 15, 20, 25 after incubation (Note: n = 3; C = control; E = emergent; S = submerged; F = floating leaf; P = polyculture)

due to several phytoremediation processes with incubation times ranging from 10 to 25 days can generally be seen from the water quality grouping based on PCA Biplot analysis, as shown in Figure 6.

Based on PCA Biplot analysis on the phytoremediation process of catfish farming pond water [Figure 6 (a)], it can be seen that the phytoremediation process for ten days after incubation still had the worst water quality, which is characterised by the highest values of several parameters such as nitrate levels, TSS, conductivity and also have a high level of organic matter pollution indicated by the high value of BOD, %PTV biotic index and also a high density of Chironomidae. Incubation time for ten days also had high nutrient content, as reflected in the high TDI value. However, with the longer incubation time of the phytoremediation process, the water quality significantly improved, as seen from the shift in the treatment group in the incubation period from 15 days to 25 days [Figure 6 (a)].



(a)



(b

Figure 6: Improvement of water quality during the phytoremediation process in the treatment of catfish farming pond wastewater using various types of hydromacrophytes between incubation times (a) and between types of hydromacrophytes after 25-day incubation (b) according to biplot analysis using Principal Component Analysis (PCA) (Note: n = 3; C = control; E = emergent; S = submerged; F = floating leaf; P = polyculture)

The phytoremediation process significantly reduced suspended solids (TSS) and nitrate levels and %PTV and Chironomidae densities starting on day 15 after incubation and consistently decreasing until 25 days of incubation (Figure 6). The conductivity value tended to decrease in the post-harvest catfish farming pond water treatment, while the TDI value decreased after an incubation period of 20 days. Until the end of the incubation period (day 25), the phytoremediation process did not significantly reduce TP. While the levels of TKN and BOD decreased significantly after the phytoremediation process for 25 days [Figure 6 (a)].

Based on biplot analysis using PCA, it can be concluded that the batch culture phytoremediation process using various emergent hydromacrophytes (*Scirpus* sp., *Acorus calamus*, *Marsilea crenata*), floating leaf macrophytes (*Ipomoea aquatica, Azolla* sp.), submerged (*Vallisneria* sp., *Hydrilla verticilata*), polycultures of the three hydromacrophytes, as well as controls that were not planted with hydromacrophytes after incubation 25 days had been able to improve water quality based on several physics chemical water parameters. It is the best time that can be recommended to remediate post-harvest catfish pond wastewater.

The results of the biplot analysis 25 days after incubation [Figure 6 (b)] showed an increase in water quality in post-harvest catfish pond wastewater with a phytoremediation process using local hydromacrophytes. The treatment with the best results recommended was submerged hydromacrophyte, characterised by increased DO, pH, and H' according to biplot analysis using PCA [Figure 6 (b)]. BOD and TSS can be reduced in this treatment, and Chironomidae, PTV, and TDI were also smaller than in other treatments. Hydromacrophytes that are completely submerged in water are known to have high efficiency in phytoremediation through their ability to produce oxygen directly, which will be transported to the underground tissue and can then come out of the roots to oxidise the surrounding substrate so that effectively improve the aeration process in water (Retnaningdyah, 2019).

Conclusion

Based on those results, it can be concluded that the minimum incubation time for the phytoremediation process of post-harvest catfish farming pond water using a batch culture system using local hydromacrophytes was 25 days, and the best treatment was submerged hydromacrophytes, which is characterised by lower values of all physical and chemical parameters. However, incubation for 25 days can still not reduce the TP level, so the water status is still hypereutrophic. Due to the phytoremediation process, the DO and pH levels have partially met the standard quality values set by the government based on Indonesian government regulation No. 22/2021, which has set the minimum DO level for agricultural activities to 3 mg/L and pH ranging between 6-9.

Thus, to reduce the levels of TP, it is necessary to further experiment research with the phytoremediation process using continuous culture accompanied by an increase in the coverage and density of hydromacrophytes. With this continuous culture phytoremediation model, it is expected that the DO level of the water will be higher due to the presence of water currents so that it can further improve the performance of phytoremediation agents, and the overall water quality will increase.

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