The use of aquatic plants as organic absorbent in coal mining void used for aquaculture

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Abstract. Water quality is one of the factors that strongly affect the cultured fish. Aquaculture practices in coal mining void often face mass death of their cultured fish due to water quality deterioration. The use of aquatic plants is aimed to improve the water quality of the fish cage in coal mining void and especially to improve the organic matter. Water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiote*) and water fern (*Salvinia molesta*) were applied into the fish cages in coal mining void. The water quality from each cage was examined every day for a two weeks period, to identify the pattern. The results showed that the plants are potential agents for improving the water quality and the organic matter in the fish cages in post coal mining void.

Key Words: *Eichhornia crassipes*, *Pistia stratiote*, *Salvinia molesta*, phytoremediation, water quality.

Introduction. Aquaculture practice using floating cage in post-coal mining voids in East Kalimantan is still increasing nowadays. Half of the supply of carps and tilapias in East Kalimantan come from the voids. However, an interesting phenomenon occurs in the cultivation area, namely the sudden mass death of the cultivated fish that usually occurs 2-3 times a year. A study conducted by Pagoray et al (2013) detected a significant decrease of water quality in the void during the mass death of the fish. Depletion of pH, DO, and increased concentrations of toxic compounds, such as NH_3, H_2S and NO_3, were pointed as the cause of the mass deaths. Besides being characterized by a low pH, acid mine water also contain metals with high concentrations, so that it can adversely affect the health of the environment and humans (Juari 2006). There are some methods which can be applied to eliminate the water quality problem. One of them is the bioremediation method using aquatic plant (phytoremediation).

Phytoremediation is a bioremediation process using certain plants in order to eliminate or remove the contaminants from soil and water. Besides, plants can also be used as an oxygen supplier as well as for absorbing excessive organic and inorganic matters in the water (Xiang et al 2009). Some invasive plants are well known for their high potential of nutrient removal (Lu et al 2010) and hyper accumulators (Wickramasinghe & Jayawardane 2015). The remediation process carried out by Azarpila et al (2013) proved the effectiveness of *Azolla* sp. and *Lemna* sp. in reducing nitrate and phosphate levels in urban waste to 83% from the level at the start of the trial. Aquatic plants are also reported as having a high potential in reducing heavy metals in the water (El-Gendy et al 2011; Tatar et al 2019).

Plants must be able to tolerate a high level of compound in the root tissue and the canopy, and have a high rate of translocation of compounds, such as heavy metals, so that the accumulation power in the canopy is higher than in the root (Juhaeti et al 2005). Plants such as water hyacinth (*Eichhornia crassipes*) or water lettuce (*Pistia stratiotes*) have been widely used in the phytoremediation process, either to remove pollutants such as heavy metals (Setyaningsih 2007), petroleum, pesticides or to absorb organic matters (Adabayo et al 2011; Lu et al 2010; Ugya et al 2015). *E. crassipes* can absorb phosphates from laundry waste within 5 days (Hardyanti et al 2007). An experiment conducted by Wickramasinghe & Jayawardane (2015) proofed that *E. crassipes*, *P. stratiotes*, and *Salvinia molesta* could improve BOD, COD, nitrate, phosphate and total coliform in textile waste water. These plants can also effectively absorb cadmium, nickel and zinc.

The preliminary study of three invasive aquatic plants in the laboratory showed significant results in improving the quality of water originated from post-coal mining void (Pagoray et al 2016). An experiment conducted by Saha et al (2017) revealed that *E. crassipes* significantly enhance the water quality of industrial mines waste water. Therefore, this study aimed to apply the plants in a floating cage to post-coal mining voids in order to determine the effectiveness of the plants in improving or absorbing the organic matter.

Material and Method

Description of the study sites. The experiment was conducted in one of the coal mining voids in Samarinda that has been used for aquaculture. *E. crassipes*, *P. stratiote*, and *S. molesta* were collected from natural ponds. The plants were cleaned using tap water and acclimated in clean water prior experiment.

Experimental design. Fish cages were set-up in the void. The three plants were applied separately in the cages (250 g $cage^{-1}$) with one control (without plants) and five replications. The experiment was conducted for 15 days. Rotten leaves were picked to avoid decomposition that might deteriorate the water quality and replaced with fresh stocks. The portion of replacement was based on the portion of the rotten leaves that were picked. Water samples from all treatments and replications were collected and analyzed daily for water quality properties, including water temperature, dissolved oxygen, carbon dioxide, pH, ammonia, nitrate nitrite, and phosphate.

Data analysis. The collected data were analyzed using one-way ANOVA and also compared with standard criteria (Regional Regulation of East Kalimantan no. 2 of 2011 on Water Quality Management and Water Pollution Control).

Results

The water temperatures in the experimental media ranged from 28 to 30^{o}C (Figure 1A). The highest value was detected in the control media (without plants), while the lowest values were mostly found in the media with *S. molesta*. There were significant differences between the control and the plant treatments.

The dissolved oxygen levels (DO) in the experimental media ranged from 3.72 to 7.26 mg L^{-1} (Figure 1B). Initial DO levels in the media ranged from 3.72 to 3.84 mg L^{-1}, which was quite low for the aquatic biota life. Yet, on day 2, DO levels have begun to show improvement and continued to increase until day 4. The levels then slightly fluctuated every day, but never approached the initial DO level. On day 10, DO levels began to increase again until they reached their peak on day 12, before sharply dropping again the next day. Levels of CO_2 during the experiment ranged from 7.19 to 27.17 mg L^{-1} (Figure 1C). The lowest CO_2 value was detected on day 15 and the highest was detected on day 1. Moderate daily fluctuations occurred during the study, although CO_2 levels tended to decrease over time.

The water pH values during the study ranged from 6.51 to 7.38 (Figure 1D), where the lowest value was detected on day 4 and the highest was detected on day 15. The pH range during this study still fulfilled the standard criteria. The degree of acidity during the first day of the study ranged from 7.04 to 7.16. No significant daily pH movement was detected, except at the beginning of the experiment, when there was a pH decrease from day 1 to day 2 in the control treatment and in the treatment with *S. molesta*, and from day 1 to day 4 in the treatments with *E. crassipes* and *P. stratiotes*.

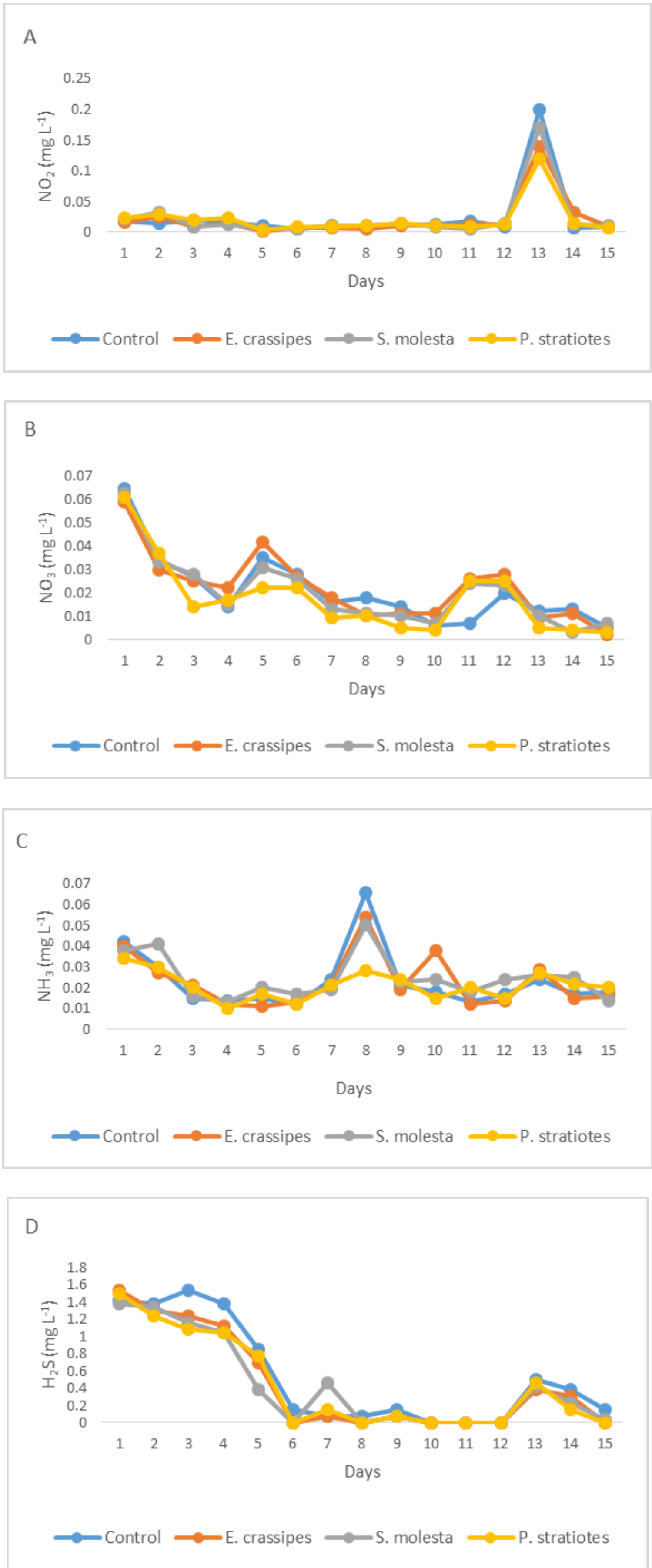

Figure 1. The dynamic of water quality in post coal mining void experimental media: A-temperature; B-dissolved oxygen (DO); C-carbon dioxide (CO_2); D–pH.

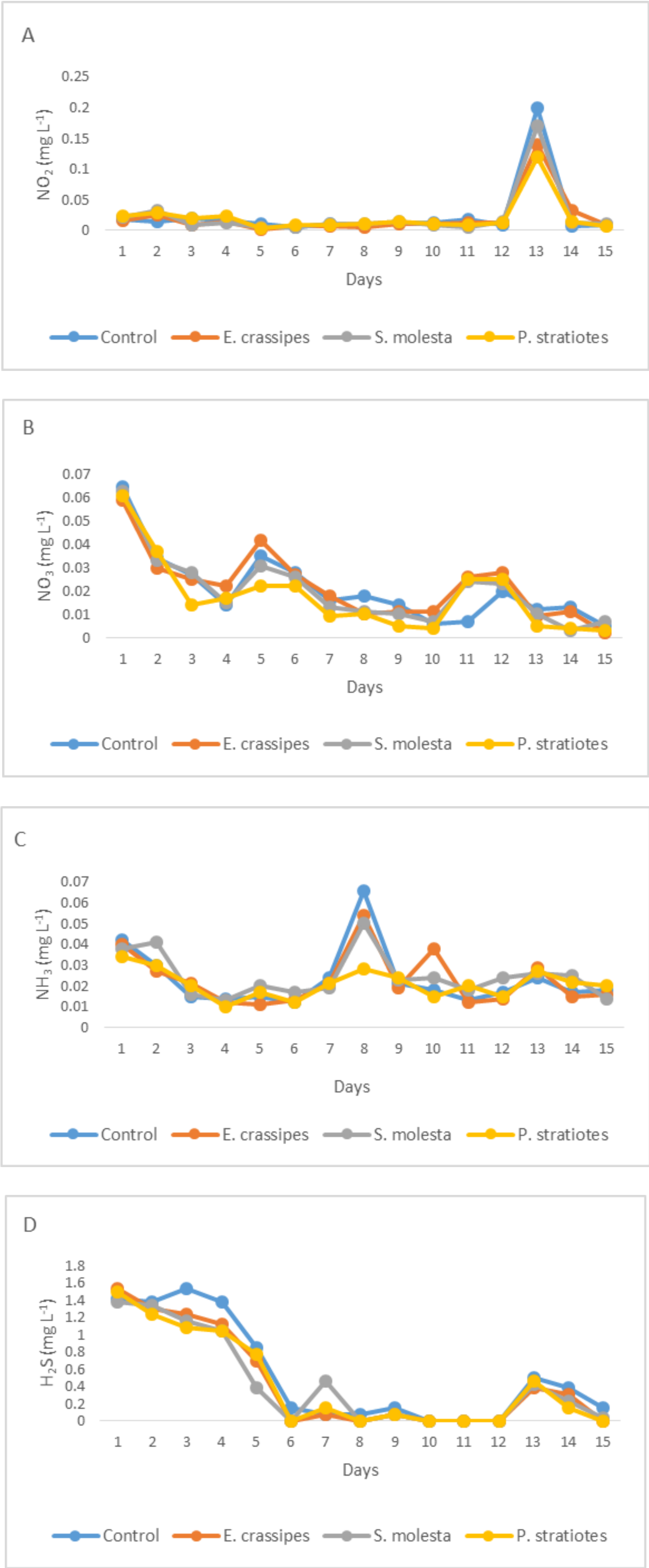

Figure 2. The dynamic of water quality in experimental media in post coal mining void: A–nitrite (NO_2); B–nitrate (NO_3); C-ammonia (NH_3); D–hydrogen sulfide (H_2S).

Nitrite levels ranged from 0.016-0.024 mg L^{-1} (Figure 2A), still meeting the standard criteria. In general, NO_2 levels slightly decreased until day 12. Fluctuation of NO_2 occurred in all treatments from day 12 to day 14, where the range of NO_2 levels increased to 0.012-0.2 mg L^{-1} on day 13. The highest increase at that time occurred in the control treatment. The NO_2 level then decreased sharply on the 14th day to reach a safe level matching the quality standard. Nitrite levels in treatment plants were significantly lower than in control.

Nitrate levels during the study ranged from 0.002 to 0.065 mg L^{-1} (Figure 2B), where the lowest levels were detected on day 15 in the media with *E. crassipes*, while the highest levels were detected on day 1 in the control treatment. Nitrate levels during the study period were still in the safe range for fish life. There was a significant decrease in NO_3 levels at the end of the study. The levels of NO_3 on the first day ranged from 0.059 to 0.065 mg L^{-1} and the levels decreased to reach the range of 0.002-0.007 mg L^{-1} on the last day of the study.

The range of ammonia (NH_3) levels during the study were 0.010-0.066 mg L^{-1} (Figure 2C), where the lowest level occurred on day 4 in the media with *P. stratiotes* and the highest level was found on day 8 in the control treatment. On day 1, NH_3 levels were still at unsafe levels for fish, with a range of 0.034-0.042 mg L^{-1}. The levels then decreased to the safe level until day 4, before increasing and fluctuating to the end of experiment. Sharp fluctuations occurred on day 8 and 9, where NH_3 levels in all treatments increased sharply to dangerous levels for fish life, before decreasing again until the end of the study. The levels of hydrogen sulfide (H_2S) at the beginning of the experiment ranged from 1.382 to 1.536 mg L^{-1} (Figure 2D). The levels in the three treatment plants continued to decline until they reached 0 mg L^{-1} on day 6. Very smooth fluctuations occurred the next day until day 9, and then they reached again 0 mg L^{-1} until the 12th day.

Discussion. Temperature is one of the parameters that may affect the ecosystem's variables. The absence of plants in the control media caused sunlight to penetrate directly into the waters rising the water temperature more than in the media with aquatic plants. Floating aquatic plants can grow both vertically and horizontally by increasing their photosynthesis surface area (Gupta et al 2015).

In the media with *P. stratiotes*, DO levels were slightly higher compared to other aquatic plants, suggesting that the plant photosynthesizes well in post-mining pond water. Shah et al (2010) found that DO levels increased up to 100% in the water containing 75% dye waste, after applying *E. crassipes*. Rather sharp daily fluctuations of DO on day 12 and 13 are thought to be indications of an upwelling phenomenon, given that some other water quality parameters experienced the same pattern. Yet, DO levels at that time did not endanger fish life. There were significant differences detected between control and plant treatments, as well as among plant treatments. Some aquatic plants are proven to be able to stabilize water temperatures in closed waters, enhancing the water mixing and preventing stratification (Gupta et al 2015).

Similar to DO levels, the CO_2 levels on day 13 and 14 experienced quite sharp fluctuations. These fluctuations may indicate the occurrence of an upwelling which brings some chemical compounds including CO_2 from the bottom column to the surface. Among the three water treatment plants, the media with *P. stratiotes* has the lowest CO_2 levels. This indicates an efficient use of CO_2 by the *P. stratiotes*. CO_2 concentrations in all the aquatic media with plants were significantly lower than in the control. During the plants photosynthesis, the CO2 levels in the water media can be depleted and the dissolved oxygen increases, thus the waters become aerobic (Gupta et al 2015; Reddy et al 1981). *P. stratiotes* has been proved to increase the water quality of waste water (Lu et al 2010; Jaikumar 2012).

The pH of the water in experimental media seemed to remain unaffected by the aquatic plants. There were no significant differences between the media with aquatic plants and the control media (no plants). Stripping overburden, excavation of its own coal, and waste material causes the disclosure of soil/rocks containing sulfide minerals, including pyrite and marcasite. The sulfide minerals then react with oxidants and water to form acid mine water. Acid mine water will erode the soil and rocks resulting in the dissolution of various metals (Marganingrum & Noviardi 2010). Nutrients absorbtion may cause a reduction of the pH value (Cholik at al 1986). *E.crassipes* releases H+ ions, which reveals an ability to change alkaline water into pH neutral (Mahmood et al 2005).

The decrease in NO_3 levels until the end of this study demonstrated the ability of these three types of aquatic plants to absorb inorganic materials contained in a post-coal mine pond. Ammonia can also result from: the feces of aquatic biota as a waste of the metabolic activity, the atmospheric diffusion and deposition, the domestic and industrial waste (Effendi 2000). A previous study revealed that *P. stratiotes* and *S. molesta* significantly reduce nitrat levels of the textile wastewater by 78.9% and 79.5%, respectively (Wickramasinghe & Jayawardane 2018). All three plants are able to absorb nutrients so as to prevent the decomposition of organic and inorganic compounds through chemical processes by environmental factors (Hermawati et al 2005). In order to absorb water as well as contaminants, *E. crassipes* utilize their root in which the carboxyl component stimulates the cations exchage (Sidek et al 2018).

During the study, NH_3 concentrations in the media with *P. stratiotes* were generally at the lowest levels among the treatments. In addition, when there were sharp fluctuations in other treatments, only the media with *P. stratiotes* showed moderate fluctuations. *P. stratiotes* have been known as fast nutrient adsorbants, capable of enhancing the microbial activity (Sidek et al 2018). The application of *E. crassipes* and *P. stratiotes* to the wastewater decreased the ammonia level by about 58% (Victor et al 2016). *E. crassipes* had a distinctively greater capacity of nitrogen and phosphorus removal during summer and rainy seasons. *P. stratiotes* were seen to reduce H_2S levels faster in post-mining ponds than other plants. Long and thick roots are the influential factor in the process of reshaping nutrient absorption in the waters (Mc Cormack & Guo 2014).

Conclusions. In general, *E. crassipes*4 *S. molesta* and *P. stratiotes* are effective to improve water quality of the fish cage in post-coal mining voids. These three aquatic plants species can increase the dissolved oxygen content and reduce the content of organic matter (NO_2, NH_3 and H_2S). There was an indication of upwelling on the 13^{th} day, which slightly decreased the water quality, yet the condition improved again the next day until the end of the research.

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