JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(9), 277–287
https://doi.org/10.12911/22998993/152047
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.06.17
Accepted: 2022.07.12
Published: 2022.08.01

Characterization of Three Selected Macrophytes – An Ecological Engineering Approach for Effective Rehabilitation of Rawapening Lake

Munifatul Izzati[1*], Tri Retnaningsih Soeprobowati[1,2], Syarif Prasetyo[3]

[1] Departement of Biology, Faculty of Sciences and Mathematics, Universitas Diponegoro, Prof. Jacob Rais Street, Tembalang Semarang, 50275, Central Java, Indonesia

[2] School of Postgraduate Studies, Universitas Diponegoro, Imam Bardjo SH Street No. 5 Semarang, 50241, Central Java, Indonesia

[3] Vocational School of Universitas Diponegoro, Prof. Sudarto Street, Tembalang, Kec. Tembalang, Semarang City, Central Java 50275, Indonesia

* Corresponding author's e-mail: munifatulizzati3@gmail.com

ABSTRACT

Rawapening is one of Indonesia's national priority lakes, which is experiencing environmental damage and urgently needs rehabilitation. The decline in water quality is caused by sedimentation and organic and inorganic waste that triggers eutrophication. Rehabilitation of Lake Rawapening is important to improve the health of freshwater resources. The ecological engineering approach is the most appropriate choice to rehabilitate these water conditions. The character of the macrophyte is the key factor for successful rehabilitation. Three macrophytes, *Hydrilla verticillata* (L. f.) Royle, *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* D.Mitch., charactierized. Their characteristics, including growth rate, salt tolerance, dissolved oxygen production and consumption, nutritive value, and preferred food by herbivore fish were evaluated. The results indicated that *H. verticillata* has the highest growth rate, is the most tolerant to salinity change, produces more oxygen, has the highest nutritive value, and is the most preferred food for herbivore fish. *H. verticilata* is recommended as the best candidate to be used as a forcing function to drive the Rawapening lake into more economic and environmentally valuable for a resident. As the other two species also have high nutritive value, they can be recommended as a source of feed for animals as well. For better management, these two macrophytes required more often regular removal. Other economic and environmental values can also be achieved from *E. crassipes* and *S. molesta.*

Keywords: rawapening, *Hydrilla verticillata*, *Eichhornia crassipes*, *Salvinia molesta,* rehabilitation.

INTRODUCTION

Water quality is currently experiencing a decline and has been a concern and the main focus of the Sustainable Development Goals (SDGs). The Indonesian government has established policies in the National Medium-Term Development Plan (RPJMN) for the restoration, and conservation of water resources and their ecosystems through revitalizing lakes one of them is Rawapening lake (RPJMN, 2020).

Rawapening is a 2,667 hectares of a semi-natural lake located in Semarang Regency, Central Java Province, Indonesia. Utilization of Lake Rawapening, in addition to aquaculture activities, includes irrigation, duck farming, peat mining, hydroelectric power (PLTA), tourism and also drinking water sources (Prasetyo et al., 2022; Soeprobowati, 2017). As one of the national priority lakes, Rawapening is a lake with environmental damage that urgently needs to be rehabilitated. The decline in environmental quality that plagued Lake Rawapening includes sedimentation, organic waste, a decrease in water quality standards, and also the occurrence of eutrophication. Eutrophication is water pollution caused by the entry of nutrients, especially phosphorus, and excessive nitrogen into aquatic ecosystems, thereby increasing primary productivity and causing the dominance of floating vegetation in wetlands (Prasetyo et al., 2021a; Grasset et al., 2016).

The existence of Lake Rawapening as a freshwater ecosystem is very important to be protected. This is in accordance with the opinion of Mohd Izam et al., (2021), who stated that freshwater ecosystems have economic value and important environmental functions. However, freshwater ecosystems are among the most threatened ecosystems in the world (Va´ri et al., 2022). The increasing demand for water resources poses a challenge to its sustainable management. The maintenance of freshwater ecosystems needs to meet human needs (Mathiews 2015). Using an ecological engineering approach, the management of the water ecosystem will meet its function in fulfilling human needs and at the same time maintain an ecological balance for the sustainability of the ecosystem. Ecological engineering is the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both (Mitsch, 2012). Schönborn (2021) has redefined that ecological engineering should always involve integrated ecological principles and processes, using an existing organism for a holistic approach to solving ecosystem problems. One of the key concepts in ecological engineering approaches is using one of the existing organisms as a „forcing function" to ensure the self-designing process direction to meet the main goals of the management (Mitch, 2012).

One of the best candidates to force and direct the process in water ecosystem management corresponds to macrophytes. Macrophytes play an important role in ecological functioning, particularly in determining the structure and function of freshwater ecosystems (Al-Abbawy et al., 2020). The presence or absence of certain macrophyte species leads to certain environmental states (Soloviy, 2019). Therefore, it plays a very important role in the rehabilitation of the freshwater ecosystem. The success in water ecosystem rehabilitation is influenced by the character of each macrophyte. The type of macrophyte such as submerged, emerged, or floating leave will determine the success rate of rehabilitation according to the desired target. Many studies have revealed the important role of submerged macrophytes in the remediation and management of polluted aquatic ecosystems by choosing the most suitable aquatic macrophyte species. Several aquatic plant characteristics, such as growth rate, salinity tolerance, oxygen production and consumption, their nutritive value, and preferred food will determine effectiveness in ecosystem management. The specific character of macrophytes to be used as a forcing function for the direction of Rawapening lake rehabilitation has not been studied. In this study, the specific character of three selected characters taken from Rawapening lake was evaluated. The submerged, emerging, and floating type macrophyte were chosen to be considered as a determinant for freshwater ecosystem rehabilitation.

MATERIAL AND METHODS

Three species of macrophytes tested in this study are *Hydrilla verticillata* (L.f.) Royle, *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* D. Mitch. these three species are chosen in accordance with their morphological and habitat differences. Besides, these three macrophytes are the most abundant in Rawapening lake. The macrophyte chosen in this study is taken from Rawapening lake, Central Java, Indonesia (Figure 1).

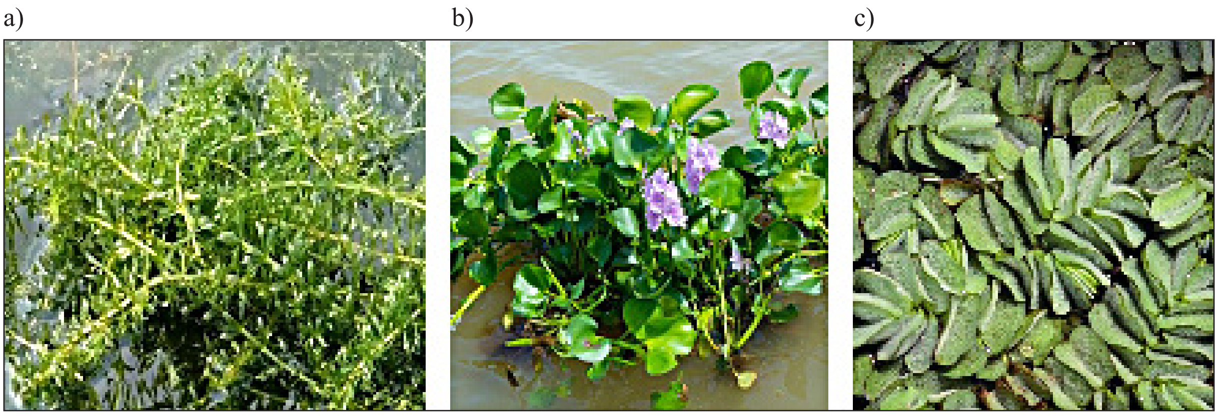

Figure 1. Macrophyte species in Rawa Pening Lake used in this study include a) *H. verticillata*, b) *E. crassipes* and, c) *S. molesta*

Methods

Macrophyte specific growth

To assess the specific growth rate of macrophytes, the three macrophyte species, namely *H. verticillata*, *E. crassipes,* and S. molesta, were cleaned and brought to the laboratory in plastic containers. The macrophytes were then grown and reared in glass aquaria in size of 50 cm (length) × 40 cm (width) × 40 cm (height). As much as 1 kg of macrophytes was used as the initial weight, which was then placed into a glass aquarium that had already been filled with 80% water volume. macrophytes were then reared for 3 weeks. Their growth rate was measured by weighing their fresh biomass every week.

Macrophyte salt tolerance

Evaluation of macrophyte salt tolerance was carried out by growing the macrophytes in glass aquariums measuring 50 cm (length) × 40 cm (width) × 40 cm (height) filled with 80% of the volume of water with different levels of salinity. Salinity series ranged from 0 ppt (control), 2 ppt, 3 ppt, and 4 ppt. The salinity of the medium was determined using a refractometer. The salinity tolerance of each macrophyte was determined by its survival and growth ability by evaluating the increase in fresh biomass of each macrophyte once a week for four weeks.

Dissolved oxygen profile

The oxygen profile performed by the macrophyte was evaluated by determining the capability of oxygen supply by each macrophyte species in water. Oxygen production by macrophytes was calculated from the difference between dissolved oxygen of media with and without macrophytes, which was done under full sunlight. The amount of oxygen produced is determined by the following formula:

Oxygen production (ppm) = *DO in the media with macrophyte – DO in the media without macrophyte* (this is held during the day under full sunlight) (1)

The oxygen consumption is measured by calculating the differences between dissolved oxygen in the medium with and without macrophytes under dark conditions. The dark condition was provided by covering the media using a black plastic sheet. Oxygen consumption is determined by the following formula:

Oxygen consumption (ppm) = *DO without macrophyte – DO with macrophyte* (under dark conditions) (2)

Nutritive value

The nutritive value of each macrophyte was determined by air-drying them and grinding a fine powder using an electric blender. The following procedure is performing the proximate analysis that will determine the crude protein (CP) using the Kjeldahl method (Kordi, 2010). The dried sample was boiled in sulfuric acid, then diluted with water and neutralized with sodium hydroxide, then continued by distillation. The crude protein content in the dried macrophyte was determined using the Kjeldahl method. The digestion was performed in sulfuric acid (H_2SO_4), 96%, at 130°C for 15 min and continued at 420°C for 75 minutes until the solution changed its color into light green. Then, it was distilled using a boric acid solution (40%) and titrated with standard 0.1N Chloric acid until the solution changed from green to pinkish. The blank solution without a sample is used to calculate *N* content in the blank solution. The crude *N* is calculated using the following formula:

$$\%N = \frac{\text{ml HCl (sample solution} - \text{blank solution)}}{\text{Weight of sample (g)} \times 1000} \times (N\ \text{HCl} \times 14.008 \times 100) \quad (3)$$

$$\text{Protein nitrogen} = \frac{(b-a) \times 0.1 \times 14.00}{Ws} \times 100\ \frac{6.25}{1000} \quad (4)$$

where: *Ws* – weight of sample, *a* – volume (ml) of 0.1N H_2SO_4 used in blank titration, *b* – volume (ml) of 0.1N H_2SO_4 used in sample titration, 14.00 – atomic weight of nitrogen, 1000 = the conversion of mg Nitrogen/100 g to nitrogen/100 g sample, 6.25 = the protein-nitrogen conversion factor for fish and its by-product).

The crude fat content in macrophytes is calculated by dissolving the sample in ether solution. The fat dissolved in the ether is dried, then weighed, and calculated as the percentage of fat content in the dry sample. The crude fiber quantification in the dried macrophyte was conducted by hydrolysis with sulfuric acid (H_2SO_4) 0.128 M and the basic hydrolysis with potassium hydroxide (KOH) 0.223 M. The cold extraction was conducted in acetone solution and dried at 100°C for an hour to reach its constant weight. Then, it was cooled in a desiccator and weighed (W1), it was then dried back in a muffle at 550°C for 3 hours, and weighted again after cooling in a desiccator. Thus, weight after ash was obtained (w2). The crude fiber percentage was calculated following the equation:

$$\% \text{ Crude fiber} = 1 + \frac{(W1 - W2)}{W0} x\ 100 \quad (5)$$

where: *W1* – the sample dried weight after hydrolysis, *W2* – the sample weight after drying in a desiccator/ash weight), *W0* – initial sample dried weight).

Macrophyte preferred by herbivorous fish

This experiment was performed by introducing these three macrophytes to herbivorous fish, the spot gourami (*Osphronemus gourami*). The three fish were chosen to each have 10 grams. Then, each fish was given 5 grams of each macrophyte fresh biomass. The proportion of left-over biomass was weighed and determines the proportion of the consumed macrophyte biomass.

RESULTS AND DISCUSSION

Macrophyte specific growth rates

On the basis on observations made on the growth rate of macrophytes, it was found that *H. verticillata* had a higher growth rate than *E. crassipes* and S. molesta. There was a significant difference in the growth rate between the three test species, namely $p<0.05$. The specific growth rate of *H. verticillata* was about 76% per month, *E. crassipes* 56% per month, and *S. molesta* was only 3% per month (Figure 2). The higher the growth rate, the faster rehabilitation will take place. Therefore, it will be more efficient.

The three species chosen in this study have distinct ecological types. *H. verticillata* is a submerged macrophyte, *E. crassipes* is an emerged macrophyte, while *S. molesta* is a floating macrophyte. The environmental requirement for the growth of these three different types of macrophytes is specific. A study by Prasetyo et al. (2021a) indicated that *E. crassipes* in mesocosms resulted in a high growth rate already. Nevertheless, the results from this study indicated that *H. verticillata* grows faster than *E. crassipes* and *S. molesta*. According to Wahl et al. (2020), the presence of submerged plants has greatly enhanced the stability of the karst carbon sink. As submerged macrophytes, the growth of *H. verticillata* is regulated by substrate grain size (Li et al., 2012) and the availability of dissolved inorganic carbon (Freitas and Thomaz 2011). According to Wang et al. (2020), the growth of *H. verticillata* is remarkably promoted by the carbonic acid (H_2CO_3) concentration in the water. The higher growth rate of *H. verticillata* may explain that the nutrient concentration in Rawapening lake favors the growth of this submerged macrophyte species.

The growth of *E. crassipes* and *S. molesta* was lower than that of *H. verticillata*. This probably happened because the levels of P and N were much more deposited in the sediment than in the lake body water solution, the accumulation of elements in the sediment was utilized by *H. verticillata*. This condition is in line with the opinion of Henry-Silva et al. (2008) who stated that nitrogen and phosphorus limit the growth of *E. crassipes* and *S. molesta.*

In terms of the growth rate character, it is recommended to use *H. verticillata* as an agent for the rehabilitation of Rawapening Lake. The higher the growth rate, the faster the rehabilitation process will take place. As Rawapening Lake is a eutrophic lake that is loaded with higher nutrients, the fast growth of *H. verticillata* will help absorb nutrients more efficiently. Therefore, the problem of eutrophication will be resolved more quickly.

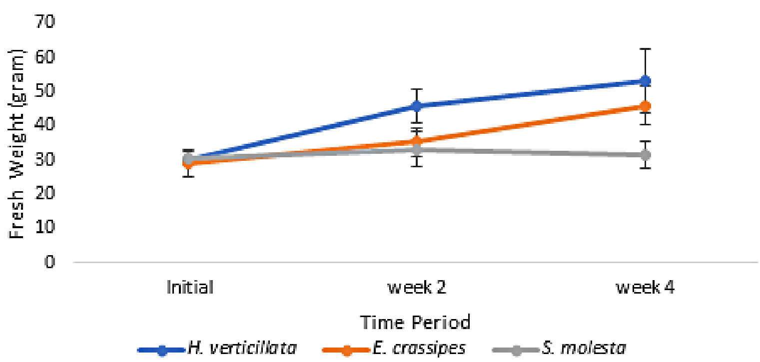

Figure 2. Species specific growth rate: curves of three species of aquatic macrophytes. *H. verticillata* performs a higher growth rate compared to the other two species. There is a significant difference in final fresh weight between *H. verticillata* and *S. molesta* ($p<0.05$)

Using macrophytes to remove excess nutrients is an effective way to rehabilitate the eutrophic lake (Yu et al., 2019).

The macrophyte growth rate is one of the important parameters, as it can be used to predict the effectiveness of freshwater ecosystem rehabilitation. The higher the growth rate, the more profitable and the higher the potential to be used as a forcing function in ecological engineering principal. A key factor including aquatic plants' specific growth rate is useful for environmental management planning (Bianchini Jr et al., 2015). The approach through macrophyte growth modeling can be used to calculate the effectiveness of environmental management strategies. Thus, the rehabilitation of Lake Rawapening, which is currently experiencing environmental damage and is threatening to become land (Prasetyo et al., 2022), can be handled with the application of ecological engineering using the basis for calculating the growth rate of macrophytes.

Macrophyte salt tolerance

The results from this study revealed that *H. verticillata* is the most tolerant to salinity change, followed by *S. molesta. E. crassipes* is the least tolerant. Under normal conditions, *H. verticillata* can increase their biomass to more than 100%. When salinity was increased, the growth of *H. verticillata* started to be inhibited. With an increase of salinity to 2 ppt and 3 ppt, *H. verticillata* started to reduce its growth rate and only a slight increase in their fresh biomass. The growth continued until the 3rd week and began to decline after 4 weeks. With 4 ppt salinity changes, their growth started to decline right away after 2 weeks. The growth of *H. verticillata,* when exposed to salt stress, is shown in Figure 3.

E. crassipes is the least tolerant to salinity changes, compared to the other two macrophytes (Figure 4). If salinity was increased this emerged macrophyte can only survive up to a week, without any biomass gained. This indicated that *E. crassipes* has low adaptability to salinity changes. A study by Bick et al. 2020 found that water hyacinth mortality occurred at more than 1.5 ppt. *E. crassipes* cannot survive at a salinity of the environment greater than or equal to 9 g/L (Guezo et al., 2017). Growth and salinity tolerance in *S. molesta* was relatively low when compared to *H. verticillata*, but higher than *E. crassipes*. Without changes in salinity, the growth of *S. molesta* is also quite high. By the 5th week, the growth of *S. molesta* can reach 75% more biomass. Meanwhile, with changes in salinity, *S. molesta* growth has decreased. Changes in salinity up to 2 ppt, resulted in more decrease in *S. molesta* growth (Figure 5).

One of the major abiotic stresses is salinity (Munns and Tester, 2008). The results from this

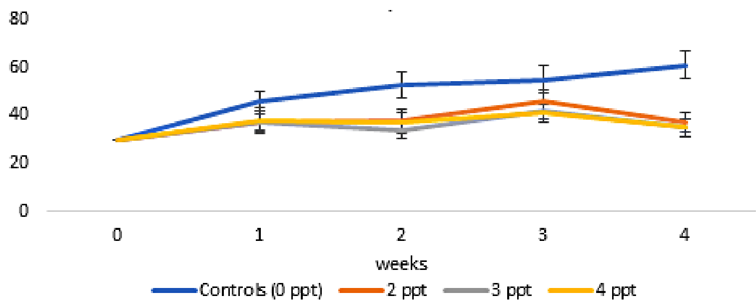

Figure 3. Growth and salinity tolerance in *H. verticillata*

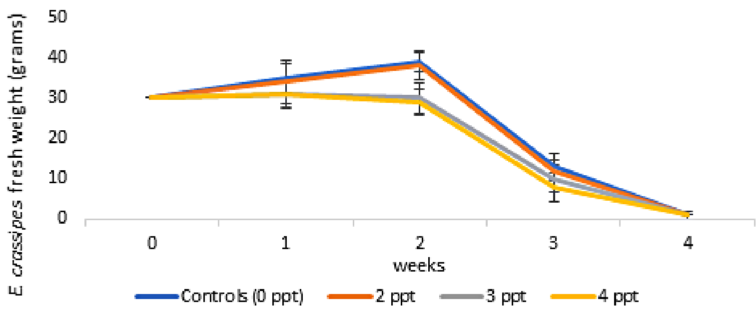

Figure 4. Growth and salinity tolerance in *E. crassipes*

study indicated that *H. verticillata* is more tolerant to salinity changes compared to the other two tested macrophytes. Nevertheless, the study by Rout, and Shaw (2001) concluded that *Hydrilla* is considered a salt-sensitive aquatic plant. The relatively low salinity tolerance of this species is an obstacle to being applied in waters with rather high salinity. However, compared to *E. crassipes* and *S. molesta*, *Hydrilla* as a submersed macrophyte is more tolerant to salinity. According to Al-Abbawy et al. (2020), submerged aquatic macrophytes play an important role in freshwater ecosystems, as it considered the key to healthy water bodies. However, an increase in salinity due to a lower freshwater supply has negative effects on the diversity of submerged macrophytes (Herbert et al. 2015; Tootoonchi and Gettys, 2019). With a relatively higher tolerance to salinity, *H. verticillata* is predicted to be able to survive in a wider salinity range of water environments. This character would be very helpful to be used even in a water ecosystem with a slight increase in salinity. This submerged macrophyte can be used as a candidate for rehabilitation agent for a broader area of salinity range.

Dissolved oxygen profiles

The data on oxygen profile indicated that *H. verticillata* produce oxygen more than consume it. Meanwhile, *E. crassipes* and *S. molesta* consumed more oxygen than produce it (Figure 6).

As a submerged macrophyte, oxygen production during photosynthesis is discharged into the water body. This may explain the high oxygen content in the water where *H. verticillata* is present. According to Rehman et al. (2017), submerged macrophytes are determinants of healthy water bodies and a key role in providing dissolved oxygen. The submerged macrophyte is an important determinant to predict dissolved oxygen concentration in the water body (Swe et al., 2021). The results from this study revealed that *E. crassipes* and *S. molesta* consumed more oxygen than their production. As emerged macrophyte, oxygen production during photosynthesis will be released into the air, this may explain the low oxygen content in the water. According to Selvaraj and Velvizhi (2021), emerging and floating macrophytes reduced oxygen through the respiration of their root system. This will result in lower oxygen, as they consume more than their production. A study by Akwuma et al. (2021), shows that *E. crassipes* were negatively associated with dissolved oxygen. Water hyacinth mats can reduce oxygen concentration by restricting oxygen diffusion from the air into the water (Yongo et al., 2021). Oxygen depletion will have an impact on decreasing water quality, leading to reduced

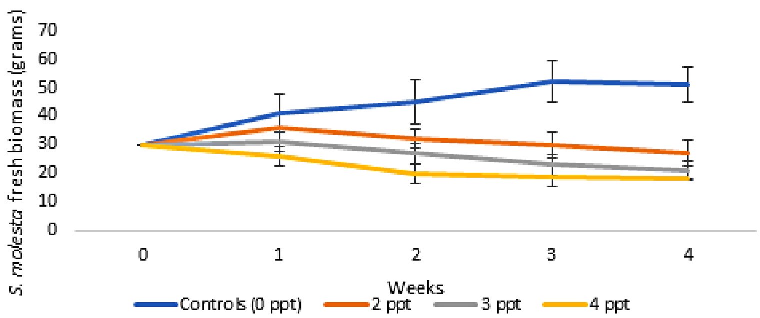

Figure 5. Growth and salinity tolerance in *S. molesta*

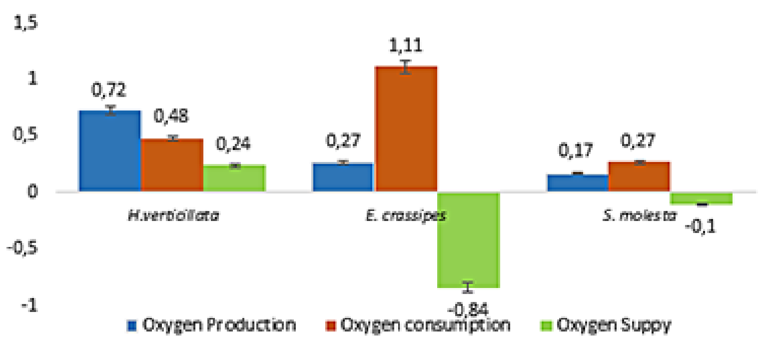

Figure 6. The dissolved oxygen profile performed by three macrophyte species

biodiversity, increasing the rate of evapotranspiration, and providing breeding grounds for insect vectors which resulted in a negative impact on public health (Kamau et al., 2015; Goshu and Aynalem., 2017; Gupta and Yadav, 2020). The water hyacinth bloom is often associated with a fish population decrease as some of the water surfaces are covered by *E. crassipes* (Mironga et al., 2012; Güereña et al., 2015).

Similar to *E. crassipes*, the floating macrophyte *S. molesta* also resulted in low oxygen concentration, even though its amount of oxygen consumption is lower than that of *E. crassipes*. Another study by Munfarida, (2020) shows a positive role of *S. molesta* in enhancing oxygen levels in the water column and has potential as a phytoremediator for water pollution. However, excessive growth of *S. molesta* may degrade the aquatic ecosystem quality and lead to the lack of dissolved oxygen, low pH and increase nutrients loading into the sediment (Wahl et al., 2020). *S. molesta* has a rapid growth rate and can form dense mats that can severely reduce the oxygen level by limiting gas exchange between the atmosphere and the water. According to Caraco et al. (2006) in some ecosystems where submersed vegetation, has been replaced by floating-leaved plants, oxygen concentrations have been substantially reduced. Without removal, plant masses will die and decompose. As a consequence, the oxygen concentration will be reduced to the level that may result in mass mortality of fish. From this result of characterization, it can be concluded that the presence of floating and emerging macrophytes is not suitable for oxygen suppliers to support animal culture. From the character of oxygen production and consumption, it is recommended to use submerged macrophyte *H. verticillata*. This type of aquatic plant could provide the appropriate dissolved oxygen concentration, and it is supposed will result in a more diverse ecosystem because the availability of oxygen for respiration will be sufficient. It will support the rehabilitation of the ecosystem, if it is desired for animal cultivation. One principle in ecological engineering is to use an agent to change the ecosystem into environmental and economical function as desired (Dale et al., 2021). Thus, the selection of *H. verticillata* is very appropriate to rehabilitate the quality of the waters of Lake Rawapening which has now reached a hypereutrophic condition (Prasetyo et al., 2021a).

Macrophyte nutritive value

The characterization of nutritive value from these three macrophytes showed that the highest protein content was found in *H. verticillata* (17.28 %), followed by *S. molesta* (13.58%), and *E. crassipess* (5.49%). The highest lipid content was also found in *H. vertillata* (3.95%), followed by *E. crassipes* (2.67%) and then *S. molesta* (1.57%), The crude fiber content analysis indicated that *E. crassipes* has the lowest content (7.08%). The highest content of fiber results in *S. molesta* (32.81%), and *H. verticillata* has a medium crude fiber content (14.29%). The characterization of the nutritional value of the three macrophytes studied is presented in detail in Figure 7.

From this nutritional value analysis, it was shown that the best candidate as a feed source was represented by *H. verticillata*. This is based on the consideration that *H. verticillata* has the highest protein and fat content, while its fiber content is the lowest. This nutritive value will support other organisms in the ecosystem as a source of nutrients. According to Shearer et al. (2008), *H. verticillata* is one of the excellent sources of protein. The high protein content in *H. verticillata* is usually present in shoot tissues. The use of *H. verticillata* as food resulted in a significant increase in Tilapia's growth rate (Dhamayanti et al. 2016). Submerged species like *H. verticillata* are suitable plants as food for fishes, due to their high protein, water content and low values of heavy metals, and higher survival rate compared to E, crassipess (Haroon, 2008; Kumar et al., 2008; Shrivastava and Shrivastava, 2021). The potential uses of *H. verticillata* indicate that this aquatic plant will stimulate the growth and production of cultured animals. Therefore, this macrophyte species is recommended for the freshwater ecosystem that is intended for fish culturing and production. It will add economic value to the surrounding society. The benefit of economical value is one of the principles of ecological engineering (Brüll et al., 2011).

Among these three selected macrophytes, *E. crassipes* shows the lowest protein content. Its lipid content is moderate, while its fiber content is the lowest. According to Moses et al. (2020), the most abundant fatty acids in the *E. crassipes* were palmitic, Linoleic, and Linolenic acids. A study by Hossain et al. (2015), also shows that *E. crassipes* contained moderate amounts of crude protein. However, this aquatic plant has successfully been processed

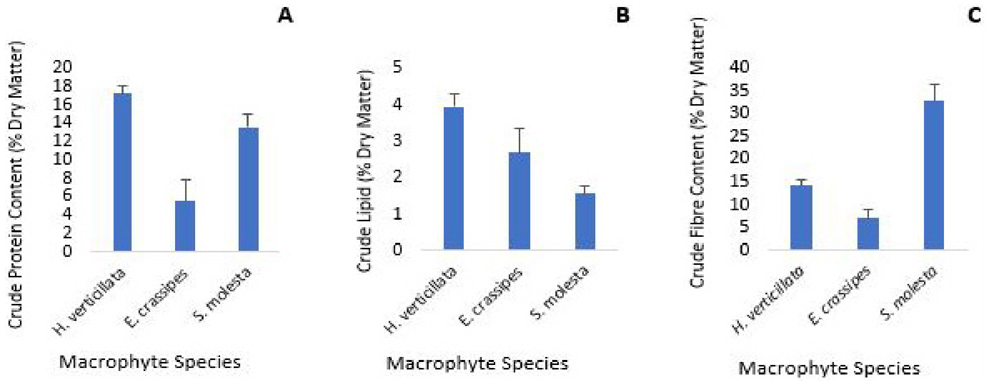

Figure 7. Characterization of the nutritional value of the three macrophytes studied; (a) crude protein; (b) crude lipid; (c) crude fiber

into concentrate protein and resulted in 50% of protein content (Adeyemi and Osubur 2016). *E. crassipes* is an excellent source of leaf protein concentrate. The water hyacinth concentrate meal has increased a crude protein by 248% (Hontiveros and Serrano, 2015). According to Adeyem et al., (2016), water hyacinth leaf protein concentrate contained 17 out of 20 common amino acids. It was suggested that the protein concentrate is suitable as raw material for the food and food additive industry (Adeyem et al. 2016). The nutrition values of *E. crassipes* favored it as the most suitable species, as animal food after the removal of its roots (Haroon, 2008). In addition, the *E. crassipes* flour can also be used as a mixture for fish feed, as has been done by Prasetyo et al. (2021b). The use of *E. crassipes* as a protein source has also been reported by Saha and Ray (2011), which resulted in a better growth rate when fish fed a diet containing 30% leaf meal was mixed with a higher concentration of *E. crassipess*. The use of *E. crassipes* as a source of protein has been reported by Saha and Ray (2011), which resulted in a better growth rate if fish-fed diets containing 30% leaf meal mixed with a higher concentration of E. crassipess.

The results from this study indicated that *E. crassipes* can be chosen as raw material to produce protein concentrate. It is recommended to be harvested, remove their roots and select only for the leaves to make a highly concentrated protein as a source plant-based rich protein feed.

The results also showed that *E. molesta* has the lowest protein, medium lipid, and highest crude fiber content. Thus, *S. molesta* is the least recommended if this plant will be used as feed resources. This is also supported by Leterme et al. (2010) who reported *S. molesta* shows a high content of lignin. According to Yáñez et al. (2018), *S. molesta*, had no value as fodder, especially because it concentrated lignin, which reduces the digestibility and voluntary consumption. However, some studies indicated another result that *S. molesta* has been successfully used as substitution feed for soybean in increasing the growth rate of chicken (Gena et al., 2014). Up to 18% of *S. molesta* leave resulted in the best economic performance for kampong chicken (Setiadi et al., 2020). Moreover, the high content of crude fiber can be used as a choice as an alternative to ruminant animal feed. (Kamaruddin et al., 2019).

The nutritive value analysis indicates that *H. verticillata* and *E. crassipes* can be an option as candidates for rehabilitation of Rawapening lake, as the high nutritional value can act as a food chain that will support the growth of farmed animals. The use of aquatic plants as a source of food and feed is very is also prospective. This can be seen from the high protein content in several types of aquatic plants. With the discovery of aquatic plant species that contain high enough protein, it is hoped that it can be used for several purposes. According to Slembrouck et al. (2018), the nutritive value of some aquatic macrophytes is important for natural food resources for animal culture. In this case, removal of this macrophyte from the freshwater environment is necessary. Loading of excess nutrients from the catchment area can be slowly reduced.

Macrophyte preferred by herbivorous fish

Macrophyte, as the preferred food of herbivore fish, is shown in Figure 8. It is indicated that among these three species, *H. verticillata* is the most preferred food compared to the other two species. This submerged macrophyte has proven to be consumed as much as more than 35% of total

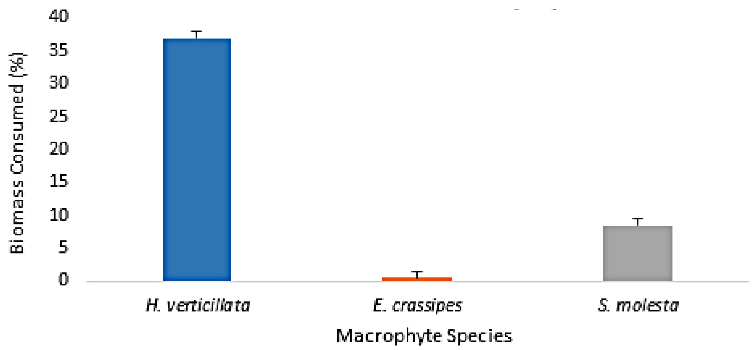

Figure 8. Preferred food macrophyte by herbivores

biomass. *S. molesta* has only 8% consumed, while *E. crassipes* are the least consumed. The edibility character of the macrophyte is an important determinant in supporting the water ecosystem. Macrophytes with a high level of edibility will support the assurance of natural food chains. Thus, the growth of herbivores fish, or shrimp will also be more secure. It will support the production of fish if the lake is to be used for the fishery industry. As the most preferred macrophyte consumed by herbivore fish, *H. verticilata* has the greatest potential as a key macrophyte to be used to force greater fish production in the ecosystem. This result is supported by Cruz et al. (2015) that *H. verticillata* is the most consumed by the Pomacea canaliculata snail, compared to other submerged macrophytes, *Egeria najas*, and *Egeria densa*.

Food preferences are an important indicator as they can be used to control aquatic macrophytes when they start to form a dense settlement and cause negative impacts on the multiple uses of water bodies. As a consequence, oxygen availability will be reduced, and fish-catching electricity generation also be hindered (Borges to Neto and Pitelli, 2004; Mustafá et al., 2010; Souza, 2011). The use of *H. verticillata* to alter the freshwater environmental change will be favored to produce a freshwater ecosystem that will have a high fish production and is easy to be controlled from overpopulation.

The least consumption of *E. crassipes* is in line with the study by Lach et al. (2000), where *E. crassipes* was not preferred in the food choice of the snail. Similar results shown by Effendi, et al. (2017), indicated that reducing the biomass of *E. crassipes* required a large grass carp population. The choice of *S. molesta* as food for fish is indicated that this species is actually can be used as another choice for a key change in freshwater ecosystem function. Studies by Koutika, and Rainey (2015) indicated that weevil (*Cyrtobagous salvinae*) consumed a large portion of S. molesta. This is the indication of potential uses of this species for increasing the production of herbivore fish and easily to be controlled their population when it starts to overgrow.

According to Cronin et al. (2002), plant structure influences feeding preference; however, nonstructural traits are important feeding determinants. Plant chemical content, such as nitrogen, protein, phenolics, lignin, cellulose, or ash were not significantly correlated with feeding preferences. The metabolites contained in Macrophyte can deter some herbivores. Large generalist herbivores and omnivores crayfish made feeding decisions based on structure, nutrition, and chemical defenses. Macrophyte-herbivore interactions are important for predicting herbivores in modifying macrophytes' role in aquatic ecosystems.

CONCLUSIONS

Characterization of three macrophyte species from Rawapening Lake resulted that *H. verticillata* has the highest growth rate, is the most tolerant to salinity change, produces the highest dissolved oxygen, has high nutritive value, and is preferred as food by herbivore fish. These characteristics will facilitate will be and be more efficient in the process of rehabilitation. This submerged macrophyte is the best candidate for Rawapening lake rehabilitation. The presence of *E. crassipes* and *S. molesta* in the lake must be controlled by regular removal. The removed biomass has the potential to be used as animal feed. This management may result in economic and environmental sustainability for residents.

Acknowledgements

The authors are grateful to the Research Institute of Diponegoro University for the funding of this research. We thank Prof Endah Dwi Hastuti who has provided the laboratory facility.

REFERENCES

1. Akwuma, O.D., Ezra, A.G., Nayaya, A.J. 2021. Assessment of Emergent and Floating Macrophytes in Relation to Some Physicochemical Parameters of Waya Pond, Bauchi, Nigeria. Open Journal of Bioscience Research, 2(2), 66–73.
2. Al-Abbawy, D.A., Al-Sweid, Z., Al-Saady, S.A.2020. Effects of salinity stress on biochemical and anatomical characteristics of Ceratophyllum demersum L. EurAsian Journal of BioSciences, 14, 5219–5225.
3. Bergen, S.D., Bolton, S.M., Fridley, J.L. 2001. Design principles for ecological engineering. Ecological Engineering, 18(2), 201–210.
4. Bianchini Jr, I., Cunha-Santino, M.B., Milan, J. A., Rodrigues, C. J., Dias, J.H. 2015. Model parameterization for the growth of three submerged aquatic macrophytes. J. Aquat. Plant Manage, 53, 64–73.
5. Brüll, A., Van Bohemen, H., Costanza, R., Mitsch, W.J., van den Boomen, R., Chaudhuri, N., Schönborn, A. (2011). Benefits of ecological engineering practices. Procedia Environmental Sciences, 9, 16–20.
6. Caraco, N., Cole, J., Findlay, S., Wigand, C. 2006. Vascular plants as engineers of oxygen in aquatic systems. BioScience, 56(3), 219–225.
7. Cronin, G., Lodge, D.M., Hay, M.E., Miller, M., Hill, A.M., Horvath, T., Wahl, M. 2002. Crayfish feeding preferences for freshwater macrophytes: the influence of plant structure and chemistry. Journal of Crustacean Biology, 22(4), 708–718.
8. Dale, G., Dotro, G., Srivastava, P., Austin, D., Hutchinson, S., Head, P. Schönborn, A. 2021. Education in ecological engineering – A need whose time has come. Circular Economy and Sustainability, 1(1), 333–373.
9. Dey, C.J., Rego, A.I., Bradford, M.J., Clarke, K.D., McKercher, K., Mochnacz, N.J., Koops, M.A. 2021. Research priorities for the management of freshwater fish habitat in Canada. Canadian Journal of Fisheries and Aquatic Sciences, 78(11), 1744–1754.
10. Dhamayanti, R.R., Nursyam, H., Hariati A.M. 2016. Utilization of *hydrilla verticillata* fermented meal as alternative sources of protein in feed formulation for Tilapia (Oreochromis Sp.) Growth. International Journal of Scientific & Technology Research, 5(3), 34–35.
11. Effendi, H., Utomo, A.A., Darmawangsa, G.M. 2017. Utilization of grass carp (*Ctenopharyngodon idella*) for inhibition of hyacinth (*Eichhornia crassipes*) population blooming. World Applied Sciences Journal, 35(2), 270–274.
12. Freitas, A.D., Thomaz, S.M. 2011. Inorganic carbon shortage may limit the development of submerged macrophytes in habitats of the Paraná River basin. Acta Limnologica Brasiliensia, 23(1), 57–62.
13. Goshu, G., Aynalem, S. 2017. Problem overview of the Lake Tana Basin. Social and Ecological System Dynamics. Springer, 9–23.
14. Guezo, N.C., Fiogbe, E.D., Tobias, M.A.H.U.N.A.N. 2016. Evaluation of sodium chloride (NaCl) effects on water hyacinth *Eichhornia crassipes* development: Preliminary results. EWASH & TI Journal, 1, 34–40.
15. Güereña, D. et al. 2015. Water hyacinth control in Lake Victoria: Transforming an ecological catastrophe into economic, social, and environmental benefits. Sustainable Production and Consumption, 3(March), 59–69.
16. Gupta A.K., Yadav D. 2020. Biological Control Of Water Hyacinth. Environmental Contaminants Reviews, 3(1), 37–39.
17. Haroon A.M. 2008. Nutrition value and factors affecting the energy and biochemical composition of some macrophytes from Lake Manzalah (Egypt). Egypt J. Aquat. Res, 34(4), 143–157.
18. Herbert, E.R., Boon, P., Burgin, A.J., Neubauer, S.C., Franklin, R.B., Ardón, M., Gell, P. 2015. A global perspective on wetland salinization: ecological consequences of a growing threat to freshwater wetlands. Ecosphere, 6(10), 1–43.
19. Henry-Silva, G.G., Camargo, A.F., Pezzato, M.M. 2008. Growth of free-floating aquatic macrophytes in different concentrations of nutrients. Hydrobiologia, 610(1), 153–160.
20. Kamau, A.N., Njogu, P., Kinyua, R., Sessay, M., 2015. Sustainability challenges and opportunities of generating biogas from water hyacinth in Ndunga Village, Kenya. Responsible natural resource economy program issue paper 005/2015. Retrieved from https://www.africaportal.org/documents/14234/Issue_paper_0052015.pdf
21. Kordi, K.M.G.H. 2010. Budidaya papaya. Andi. Yogyakarta. Magomya, A.M., Kubmarawa, D., Ndahi, J.A., Yebpella, G.G. 2014. Determination of plant proteins via the Kjeldahl method and amino acid analysis: a comparative study. International Journal of Science & Technology Research, 3(4), 68–72.
22. Koutika, L.S., Rainey, H.J. 2015. A review of the invasive, biological, and beneficial characteristics of aquatic species Eichhornia Crassipes and Salvinia molesta. Applied ecology and environmental research, 13(1), 85–97.
23. Kumar, J.N., Soni, H., Kumar, R.N., Bhatt, I. 2008. Macrophytes in phytoremediation of heavy metal contaminated water and sediments in Pariyej Community Reserve, Gujarat, India. Turkish Journal of Fisheries and Aquatic Sciences, 8(2).
24. Lach, L., Britton, D.K., Rundell, R.J., Cowie, R.H. 2000. Food preference and reproductive plasticity in an invasive freshwater snail. Biological invasions, 2(4), 279–288.
25. Li, Q., Han, Y., Chen, K., Huang, X., Li, K., He, H. 2021. Effects of Water Depth on the Growth of the Submerged Macrophytes Vallisneria natans and Hydrilla verticillata: Implications for Water Level Management. Water, 13(18), 2590.

26. Madsen, T.V., Cedergreen, N. 2002. Sources of nutrients to rooted submerged macrophytes growing in a nutrient-rich stream. Freshwater Biology, 47(2), 283–291.
27. Matthews, N. 2016. People and fresh water ecosystems: pressures, responses, and resilience. Aquatic Procedia, 6, 99–105.
28. Mironga, J.M., Mathooko, J.M., Onywere, S.M. 2012. Effect of water hyacinth infestation on the physicochemical characteristics of Lake Naivasha. International Journal of Humanities and Social Science, 2(7), 103–113.
29. Mitsch, W.J. 2012. What is ecological engineering? Ecological Engineering, 45, 5–12.
30. Mohd Izam, N.A., Azman, S.N., Jonit, E., Sallehoddin, S.M.H., Khairul, D.C., Zainul Abidin, M.K., Farinordin, F.A. 2021. Freshwater ecosystem: A short review of threats and mitigations in Malaysia. Gading Journal of Science and Technology, 4(1), 109–117.
31. Munfarida, I., Auvaria, S.W., Suprayogi, D., Munir, M. 2020. Application of Salvinia molesta for water pollution treatment using phytoremediation batch system. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 493(1), 012002.
32. Munns, R., Tester, M. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol., 59, 651–681.
33. National Medium-Term Development Plan (RPJMN). 2020. Government of the Republic of Indonesia
34. Piranti, A., Waluyo, G., Rahayu, D.R. 2019. The possibility of using Lake Rawa Pening as a source of drinking water. Journal of Water and Land Development, 41(4–6), 111–119.
35. Prasetyo, S., Anggoro, S., Soeprobowati, T.R. 2021. The Growth Rate of Water Hyacinth (Eichhornia crassipes (Mart.) Solms) in Rawapening Lake, Central Java. Journal of Ecological Engineering, 22(6).
36. Prasetyo, S., Anggoro, S., Soeprobowati, T.R. 2021. Potential of water hyacinth (Eichhornia crassipes (Mart.) Solms) in Rawapening lake as raw material for fish feed. Journal of Physics: Conference Series, 1943(2021), 012072. DOI: 10.1088/1742-6596/1943/1/012072
37. Prasetyo, S., Anggoro, S., Soeprobowati, T.R. 2022. Water hyacinth Eichhornia crassipes (Mart) Solms management in Rawapening Lake, Central Java. AACL Bioflux, 15(1). http://www.bioflux.com.ro/aacl
38. Rehman, F., Pervez, A., Khattak, B.N., Ahmad, R. 2017. Constructed wetlands: perspectives of the oxygen released in the rhizosphere of macrophytes. CLEAN–Soil, Air, Water, 45(1).
39. Rout, N.P., Shaw, B.P. 2001. Salt tolerance in aquatic macrophytes: possible involvement of the antioxidative enzymes. Plant Science, 160(3), 415–423.
40. Schönborn, A., Junge, R. 2021. Redefining ecological engineering in the context of circular economy and sustainable development. Circular Economy and Sustainability, 1(1), 375–394.
41. Selvaraj, D., Velvizhi, G. 2021. Sustainable ecological engineering systems for the treatment of domestic wastewater using emerging, floating, and submerged macrophytes. Journal of Environmental Management, 286, 112253.
42. Shearer, J.F., Grodowitz, M.J., Freedman, J.E. 2008. Nutritional characteristics of Hydrilla verticillata and its effect on two biological control agents. In: Proceedings of the XII International Symposium on Biological Control of Weeds. Wallingford: CAB International, 44–51.
43. Soeprobowati, T.R. 2017. Lake Management: Lesson learns from rawapening lake. Advanced Science Letters, 23(7), 6495–6497.
44. Soloviy, K., Malovanyy, M. 2019. Freshwater ecosystem macrophytes and microphytes: development, environmental problems, usage as raw material. Review. Environmental Problems, 3(4), 3, 115–124.
45. Swe, T., Lombardo, P., Ballot, A., Thrane, J.E., Sample, J., Eriksen, T.E., Mjelde, M. 2021. The importance of aquatic macrophytes in a eutrophic tropical shallow lake. Limnologica, 90, 125910.
46. Tootoonchi, M., Gettys, L.A. 2019. Testing salt stress on aquatic plants: effect of salt source and substrate. Aquatic Ecology, 53(3), 325–334.
47. Vári, A., Podschun, S.A., Erős, T., Hein, T., Pataki, B., Iojă, I.C., Báldi, A. 2022. Freshwater systems and ecosystem services: challenges and chances for cross-fertilization of disciplines. Ambio, 51(1), 135–151.
48. Wahl, C.F., Diaz, R., Ortiz-Zayas, J. 2020. Assessing Salvinia molesta impact on environmental conditions in an urban lake: a case study of Lago Las Curias, Puerto Rico. Aquatic Invasions, 15(4).
49. Wang, H., Ji, F., Qin, J., Zhou, Y. 2014. Submerged macrophyte restoration differentiation for a waterfront body. Journal of Clean Energy Technologies, 2(1).
50. Wuryanta, A., Murtiono, U.H. 2018. Eutrophication and solving effort in lake rawapening, semarang district Central Java (A Spasial Approach). Jurnal Geografi: Media Informasi Pengembangan dan Profesi Kegeografian, 15(1).
51. Yongo, E., Cishahayo, L., Mutethya, E., Alkamoi, B.M.A., Costa, K., Bosco, N.J. 2021. A review of the populations of tilapiine species in lakes Victoria and Naivasha, East Africa. African Journal of Aquatic Science, 46(3), 293–303.
52. Yu, S., Miao, C., Song, H., Huang, Y., Chen, W., He, X. 2019. The efficiency of nitrogen and phosphorus removal by six macrophytes from eutrophic water. International journal of phytoremediation, 21(7), 643–651.
53. Zhu, B., Wang, Z., Wang, T., Dong, Z. 2012. Non-point-source nitrogen and phosphorus loadings from a small watershed in the Three Gorges Reservoir area. Journal of Mountain Science, 9(1), 10–15.