Water hyacinth *Eichhornia crassipes* (Mart) Solms management in Rawapening Lake, Central Java

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Abstract. The invasion of water hyacinth (*Eichhornia crassipes* (Mart) Solms has been highlighted as an important environmental problem for Indonesian lakes. Water hyacinth grows rapidly. It triggers a significant loss of water in lakes compared to local weeds through evapotranspiration. The water hyacinth invasion has caused various problems in lakes, such as decreased water quality, depletion of oxygen levels, decreased fish production, destruction of the natural scenery and public health problems. Therefore, this study was conducted to determine an appropriate water hyacinth control formulation. The research was conducted in November–December 2019 at three stations, namely: site I in the floating net cage area (FNCA), Rowoboni Village, Banyubiru District, site II in the natural area of Bejalen Village, Ambarawa District (afar from the location of a fish farm) and site III in Tuntang river upstream, Asinan Village, Bawen District. Water hyacinth biomass, the presence of biological agents, and mechanical cleaning of water hyacinths were observed directly. A literature review related to water hyacinth control methods is used as research supporting data. The water hyacinth problem can be managed physically, chemically, and biologically. Each method used has its own advantages and disadvantages. The application of physical methods does not require specific technical expertise in removing water hyacinths from water bodies. However, cutting and drowning plants will affect dissolved oxygen and tropic structures, which will accelerate eutrophication, further triggering the hyacinth boom itself. The use of chemical methods can save energy and costs compared to the physical method. However, the use of herbicides can destroy non-target plants and may induce broad ecological problems. Biological methods need a long period to produce results compared to mechanical and chemical methods, facing reluctance in application. The application of biological methods is relatively safe.
Key Words: biological control, chemical, physical, Rawapening Lake.

Introduction. Water hyacinth *Eichhornia crassipes* (Mart) Solms is an aquatic weed belonging to the Pontederiaceae family (Gaikwad & Gawande 2017; Roopnarain et al 2019). Water hyacinths float in deep water and take root at the bottom when the water is shallow. Water hyacinth in Indonesia was originally introduced by the Bogor Botanical Gardens in 1894. It is an aquatic plant discovered accidentally by Karl Von Mortius in 1824, on an expedition in the Brazilian Amazon River (Setyanto 2011). Water hyacinth is considered the most dangerous and invasive aquatic weed in the world because it can reproduce very rapidly with ecological adaptability (Ruan et al 2016). This freshwater weed has a detrimental effect on the environment, human health, and the economy (Patel 2012; Sharma et al 2016; Moorthy et al 2017). Due to its ecological and socio-economic impacts, water hyacinth is included in the 100 most dangerous invasive species in the world (Guezo et al 2017). The existence of large amounts of water hyacinth threatens biodiversity (Plaza et al 2010), and are vectors of diseases and pests (Ndimele et al 2011; Waithaka 2013; Gupta & Yadav 2020), including malaria and filariasis (McBeath et al 2014).

This invasive species from South America has now spread throughout the world, except for the Antarctic continent (Jiménez & Balandra 2007; Gaikwad & Gawande 2017). The growth rate of water hyacinth is fast, because the plant has a relatively short life

(Aloo et al 2013; Gaikwad & Gawande 2017). Its threats are very serious to aquatic systems and hinder human use of surface water (Chander et al 2018). A higher nutrient content, especially nitrogen and phosphorous helps the growth of water hyacinth (Verma & Sivappa 2017), spreading out of control and often causing problems such as clogging waterways and flooding (Kriticos & Brunel 2016). Water hyacinth covering the surface of waters depletes dissolved oxygen (Hasiubuan et al 2020), decreasing water quality and biodiversity (Güereña et al 2015).

Water hyacinth also increases the rate of evapotranspiration (Kamau et al 2015; Goshu & Aynalem 2017; Honlah et al 2019). Water hyacinth takes one to two weeks to multiply (Dickinson & Royer 2014). A study conducted in India showed that one water hyacinth plant can multiply within 14 days, and cover an area of 1 m^2 in 52 days (Guitierrez et al 2001). Siahaan et al (2016) found that the relative growth rate of water hyacinth in Lake Toba was 4.21%. Soeprobowati (2017) found that one water hyacinth plant from Rawapening Lake was able to cover 1 m^2 within 22 days. The rapid growth of water hyacinth is a result of the proliferation of nutrients in freshwater. This study aims to determine the best method for controlling water hyacinth in the studied region.

Material and Method

Description of the study sites. Rawapening is a semi-natural lake that is administratively located in Semarang Regency, Central Java Province, Indonesia. Rawapening Lake is located 45 km south of Semarang City and 9 km northwest of Salatiga City. It includes 4 subdistricts, namely Banyubiru subdistrict, Ambarawa subdistrict, Bawen subdistrict, and Tuntang subdistrict (Figure 1). Rawapening is one of the National Priorities Lakes II that are threatened by the water hyacinth problem (Directorate of Land Water Damage Control 2019).

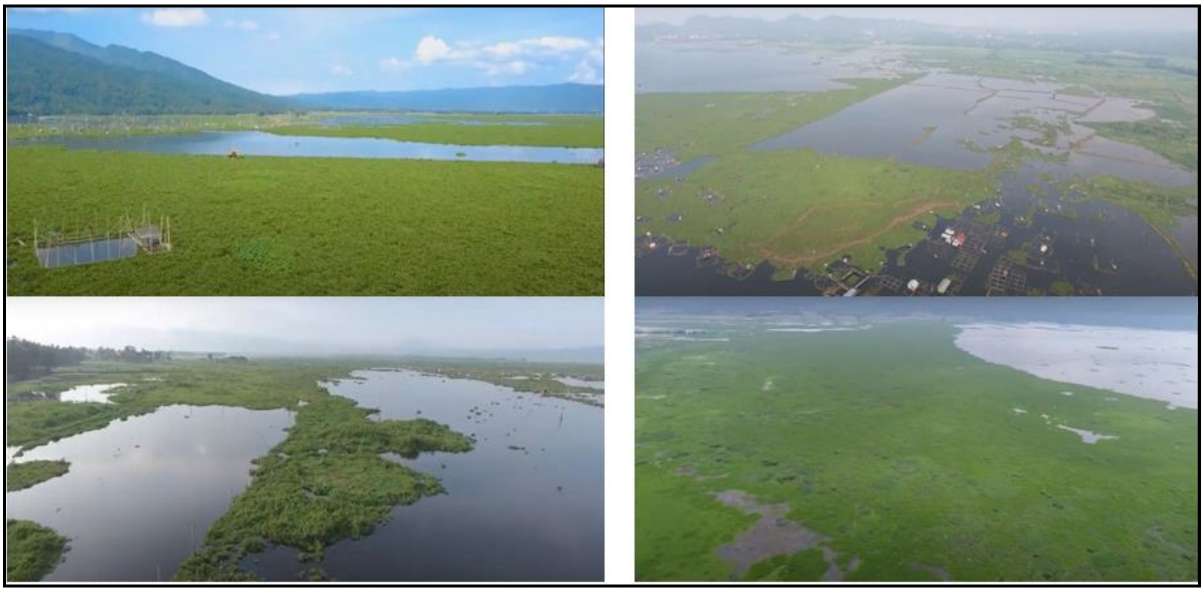

Figure 1. Rawapening Lake in 2020.

Rawapening Lake is the center of agricultural activities, fisheries, tourism, and a source of electrical energy, located at the coordinates of 7°04'-7°30 SL and 110°24'46'-110°49'06' EL, at an altitude of 460 m above sea level. Rawapening Lake has an inundation area of 2667 ha in the rainy season and shrinks to 1650 ha in the dry season (Sudjarwo et al 2014). Rawapening Lake has shallow water, so organic matter is easily absorbed and triggers eutrophication, which causes water hyacinth boom (Figure 1). Water hyacinth biomass measurements were carried out at three research stations, namely site I in the natural area of Bejalen Village, far from the aquaculture site, site II in the upper reaches of the Tuntang river, Asinan Village, and site III in the floating net cage area (FNCA), Rowoboni Village.

Sample collection. This research was conducted from December 2019 to May 2020. Data collection included measuring the density of water hyacinth *in situ* at the predetermined research stations. Data collection of biological agents that play a role in water hyacinth control focused on grass carp and rodent beetles using secondary data from scientific literature. Observation of water hyacinth physical removal actions, both in traditional systems by the community that utilizes the weeds and in modern systems using heavy equipment.

Data analysis. Primary data collected directly through measurement, observation, and interviews were analyzed and discussed. Secondary data were obtained by reviewing published research results, especially those related to water hyacinth control methods.

Results and Discussion. The average wet weight of water hyacinth in Rawapening Lake was 25.9 kg m^{-2} or 259 tons ha^{-1} (Table 1 and Figure 2). The lowest wet weight was 12.5 kg m^{-2} or 125 tons ha^{-1} at site I, and the highest was at site II, namely 34 kg m^{-2} or 340 tons ha^{-1}. At site III, the wet weight of water hyacinth reaches 31.2 kg m^{-2} or 312 tons ha^{-1}.

Table 1

Weight of water hyacinth in Rawapening Lake

Site	*Site I Bejalen Village*	*Site II Asinan Village*	*Site III Rowoboni Village*	*Average weight of water hyacinth in Rawapening Lake*
Kg m^{-2}	12.5	34	31.2	25.9
Tons ha^{-1}	125	340	312	259

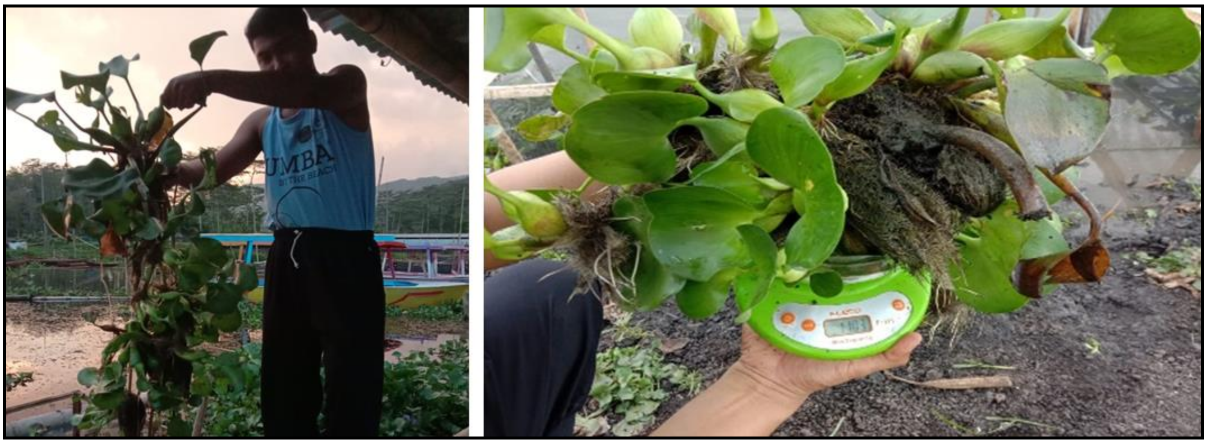

Figure 2. Measurement of water hyacinth biomass.

The growth rate of water hyacinth in Lake Rawapening is very fast, namely one water hyacinth can cover 1 m^2 of water in 22 days (Soeprobowati 2017). The difference in the wet weight of water hyacinth at each research site could be influenced by differences in the nutrient content that triggers growth rate. N and P are important nutrients that affect the growth rate of water hyacinth in Rawapening Lake (Prasetyo et al 2021). N and P that enter Rawapening lake water bodies come from aquaculture, household waste, and agriculture. This condition is similar to the situation from the Batujai reservoir (Rahim & Soeprobowati 2019). Site I, Bejalen Village, is a natural area far from settlements and there is no agricultural or aquaculture activity. Thus, that the content of N and P that enter the water is low. Site II, at Asinan Village, is a river flow that crosses agricultural areas, settlements, and tourist attractions, so the organic material that enters is higher than in the other sites. The wet weight of water hyacinth in this site is also the higher than in the other sites. At site III, Rowoboni Village, the wet weight of water hyacinth is in the second rank of the three research sites. The organic material from the floating net cages for aquaculture plays a role in the growth rate of water hyacinth.

The wet weight of water hyacinth in Rawapening Lake is also close to the findings of Prasetyo et al (2021), who determined a biomass production of water hyacinth in Rawapening Lake between 20 to 30.5 kg m^{-2} or 200-300 tons ha^{-1}. Rawapening lake water hyacinth biomass is also close to that reported by the National Academy of Science (1977) in Bangladesh, where the biomass of water hyacinth can reach 300 tons ha^{-1} per year.

In 1994, it was reported that Rawapening Lake was covered in a proportion of 18.45% by water hyacinth (Goltenboth & Timotius 1994). The growth of water hyacinth increased rapidly, reaching a coverage of 60-70% in 2004 (Soeprobowati et al 2005). Water hyacinth control was attempted by the government at that time, so that the coverage fell to 42% of the total area in 2015 (Gennisa et al 2018). The growth rate of water hyacinth is high, so that in 2017 it was covering 47.6% of Rawapening Lake (Indrayati & Hikmah 2018). A simulation based on a Geographic Information System was carried out by Indrayati & Hikmah (2018) to see the impact of effective handling in controlling water hyacinth. Simulation results using the Geographic Information System showed a decrease in weed cover of only 1.6%. The prediction from the simulation is in 2020 and Lake Rawapening is still covered with water hyacinth with a proportion of 46%. It turns out that factual measurements made by Rahardjo et al (2019) showed that Lake Rawapening was still covered by water hyacinth on 70% of the lake's surface, 1866.9 ha, with a biomass of 483527.1 tons.

The uncontrolled boom of water hyacinths occurring in Rawapening Lake indicates that there has been eutrophication due to nutrient enrichment in the lake (Grasset et al 2016; Chander et al 2018; Sutadian et al 2018). This is in line with the results of Piranti et al (2018) noted that the status of Rawapening Lake water quality is in the heavily polluted category and is only suitable for agriculture and irrigating landscapes.

Cleaning up 483527.1 tons of water hyacinth biomass covering an area of 1866.9 ha would require a very large amount of energy and costs. Such a large cost is used to clean water hyacinth without considering the growth rate of weeds covering the waters. During the process of cleaning the water hyacinth from the lake, the weeds continue to grow and form new colonies, so that the financing for cleaning them will continue to increase. Research related to proper water hyacinth control has been carried out, among others, by Julien (2001), Ray & Hill (2013), Pratiwi et al (2018), and Thamaga & Dude (2018). The most common methods used for water hyacinth control are physical, chemical, and biological control (Williams et al 2005; Su et al 2018). Each method has advantages and disadvantages.

Physical control. The physical method applied in Rawapening Lake includes handling weed invasion. Some of the techniques employed included removing plants from the water by hand, cutting them with sickles, and installing bamboo barriers. Every year, the people collectively extract water hyacinths to the mainland to reduce their numbers in water bodies. Rawapening IV (OP IV) Operation Control Unit has been established by the Pemali Juwana Watershed Agency (BBWSPJ) for water hyacinth control. Various sophisticated equipment (Figure 3) is used for water hyacinth cleaning, namely Harvester Berky (11 units), Amphibian Weed Harvester (3 units), Excavator (3 units), and Dump Trucks (5 units) to transport water hyacinths (Figure 3). The efforts made have significantly reduced the area of water hyacinth in Rawapening Lake with 200 ha each year (Rizaldi 2020). However, mechanized harvesting of water hyacinth is expensive (Villamagna & Murphy 2010). Three years after the OP IV Rawapening unit was in function, conditions were continuing to deteriorate with the growth of water hyacinths increasing. This happened because the equipment used only reduced the coverage by 200 ha, but the total plant growth was greater than 200 ha every year. Mechanical handling of water hyacinth in Lake Rawapening is considered a failure because it does not consider the fundamental factor in its handling, namely the growth rate of water hyacinth.

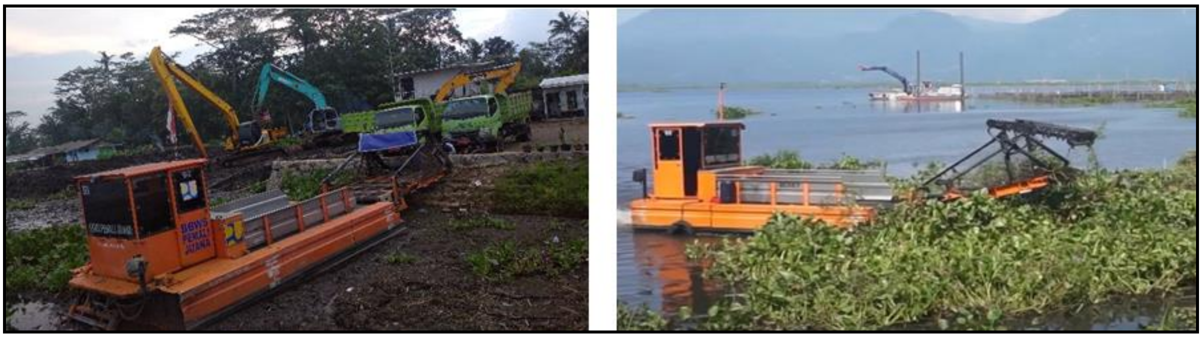

Figure 3. Harvester for physical treatment for water hyacinth equipment in Rawa Pening lake.

Eutrophication, which is very important to understand and control, is not considered in the physical method in Rawapening. According to Piranti et al (2018), the water condition is eutrophic due to the high total P from the catchment area that enters the water body. A total of 10.32 mg per second of P enters and 64.9% settles in the sediment. Eutrophication has fostered the growth of water hyacinth. The equipment and technology cannot keep up with the reproductive capacity and growth of water hyacinths, being difficult to control the weeds. Mechanical control of water hyacinth can work effectively in small areas, but large lakes like Rawapening require more time, money, and energy (Hidayati et al 2018).

Chemical control. Spraying chemical herbicides such as Glyphosate, Bispyribac, Imazapyr, Penoxsulam, Triclopyr, 2,4-D, Florpyrauxifen benzyl, Imazamox, and Diquad is more effective in reducing water hyacinth (Murugesan 2014; Cerveira & Carvalho 2019; Garlich et al 2019). Glyphosate can provide very good water hyacinth control efficiency and does not significantly change water quality parameters, including pH and dissolved oxygen (Souza et al 2020). Spraying Glyphosate at a dose of 450 g ha^{-1} can provide 92.13% control of water hyacinth (Wagga & Gburi 2018). Herbicides work systemically to be absorbed by the green parts of the plant and move into the cells, thus inhibiting the photosynthesis process. Chemical control of water hyacinth using herbicides is very limited because of the high risk of polluting the environment (El-Ghafar El-Shahawy 2015). Hazardous chemical elements pose a risk to human health if water is used drinking and washing (Chander et al 2018). The use of herbicides is also less selective against the target when compared to mechanical means. Chemical methods are more harmful to non-target microorganisms and plants that provide habitats for other organisms. In addition, it also affects fish productions (Gupta & Yadav 2020).

Chemical control of water hyacinth is cheaper than using mechanical means. However, it still depends on the equipment used to apply the herbicide (Villamagna & Murphy 2010). Although this method has proven successful for smaller areas, it is not suitable for large areas such as Rawapening Lake. In addition, Rawapening Lake has complex uses: drinking water, agricultural activities, aquaculture, tourism, and others. Therefore, the chemical control of water hyacinth has never been applied in Rawapening Lake because herbicides are heavy and non-essential toxins that harm animals and humans (Koutika & Rainey 2015).

Biological control. Biological control of water hyacinth has been carried out in Rawapening Lake using grass carp (*Ctenopharyngodon idella*) (Figure 4). Grass carp is not a specific agent for controlling water hyacinth (Silva et al 2014), but is one of the most important aquaculture species in the world effective in removing aquatic vegetation (Singla 2016; Effendi et al 2017). It was used for this purpose in the Nile in Egypt (Sharma & Chauhan 2017), in Lake Kerinci, Indonesia (Samuel et al 2015) and in many other places.

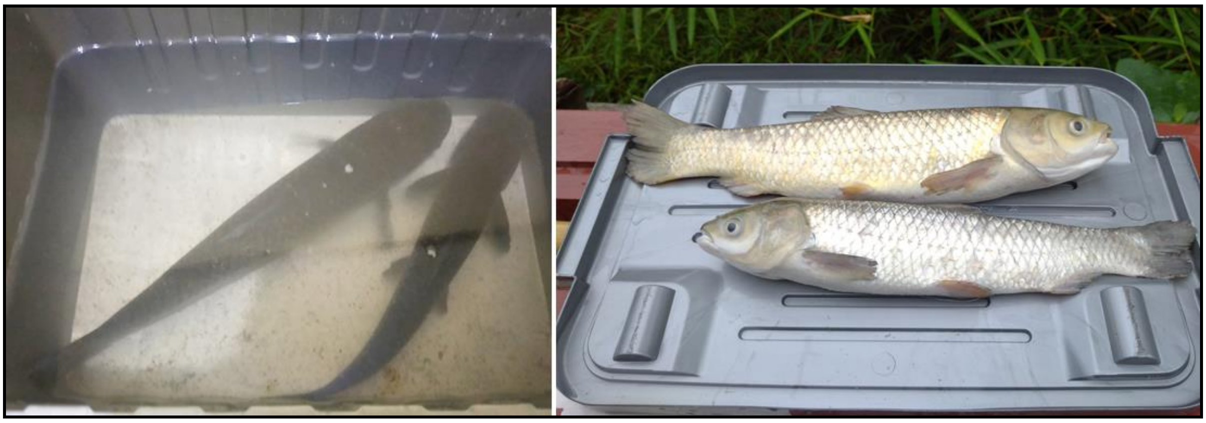

Figure 4. Grass carp (*Ctenopharyngodon idella*) regularly released in Rawapening Lake.

The government, through the Marine and Fisheries Service (DKP) of Central Java Province, has also attempted to reduce water hyacinth by using grass carp. Five million fish should eat the water hyacinth covering 70% of the lake surface (Raharjo et al 2019). The grass carp stocking program has been realized by releasing 100000 fish in 2012 and 2013, 105000 in 2014, and 148300 in 2015. In 2016 and onwards the release of grass carp fish was no longer carried out due to the enactment of Law 23/2014 of the Regional Government (Hidayati et al 2018).

Grass carps can consume water hyacinths 1.5 times their body weight (Soeprobowati 2012), and have great potential for water hyacinth control. However, the effort to reduce water hyacinth using grass carp fish in small quantities in Rawapening was ineffective and inefficient, being considered a failure. The problem that arises after the release of grass carp in Rawapening Lake is its capture by fishermen freely. Cleaning Lake Kerinci in Jambi, Sumatra, of water hyacinth using only 2000 grass carps in 10 years was effective (Samuel et al 2015). However, this action apparently could not be implemented in Rawapening Lake, because the program stopped before reaching the target of releasing five million fish. However, controlling water hyacinth using grass carp is one of the safest ways ecologically, although it requires time and maintenance of the grass carp population. To accelerate the performance of biological agents in controlling water hyacinth in Rawapening Lake, several species can be combined at the same time.

Utilizing special insect herbivores whose diet is limited to one host species (Littlefield & Buckingham 2004; Center & Dry 2010) is an appropriate measure for water hyacinth control in Rawapening Lake. Biological agents commonly used for water hyacinth control include moths, insects, and fungal parasites (Sharma & Chauhan 2017). *Neochetina bruchi* and *N. eichhorniae* are natural predators of water hyacinth (Gichuki et al 2012; Onyango & Ondeng 2015) (Figure 5). This beetle is a specific biological agent that has been successfully used in water hyacinth control (Firehun et al 2015). The hyacinth-eating beetle was introduced to the states of Louisiana, Texas, and Florida, which are filled with thousands of ha of water hyacinth beds. In 1980, the results showed that 33% of water hyacinth had decreased (Benedict et al 2014).

N. bruchi and *N. eichhorniae* have a short cycle of 90 days, so they were selected as biological agents (Benedict et al 2014). Both species of beetles eat water hyacinth plant parts in different locations, so that they can live together without having to compete. In the research of Pratiwi et al (2018), *N. eichhorniae* was found in Rawapening Lake, while *N. bruchi* was not found. This finding is in line with a research which found that *N. eichhorniae* is widespread in several freshwater areas in West Java, Indonesia, but *N. bruchi* was not found (Sapdi et al 2006). *N. eichhorniae* attacks water hyacinth leaves with a damage rate of 0.43% per leaf (Pratiwi et al 2018).

The beetles used for water hyacinth control can limit the growth of weeds. In addition, they also interferes with vegetative propagation, seed production and carry pathogenic microorganisms for water hyacinths. Beetles attack water hyacinths by eating tissue, destabilizing the plant’s buoyancy and drowning it (Jiménez 2003). Biological control using borer beetles against water hyacinth has been carried out in various parts of the world (Koutika & Rainey 2015; Sivaraman & Murugesan 2016). Even the biological controls implemented in Lake Victoria have shown remarkable success (Wilson et al 2007). In 1979, Sudan had reported that the use of *N. bruchi* and *N. eichhorniae* in a mixture was successful in increasing the rate of water hyacinth control by 136.6%, reducing the growth of water hyacinth by 22.5% (Gupta & Yadav 2020).

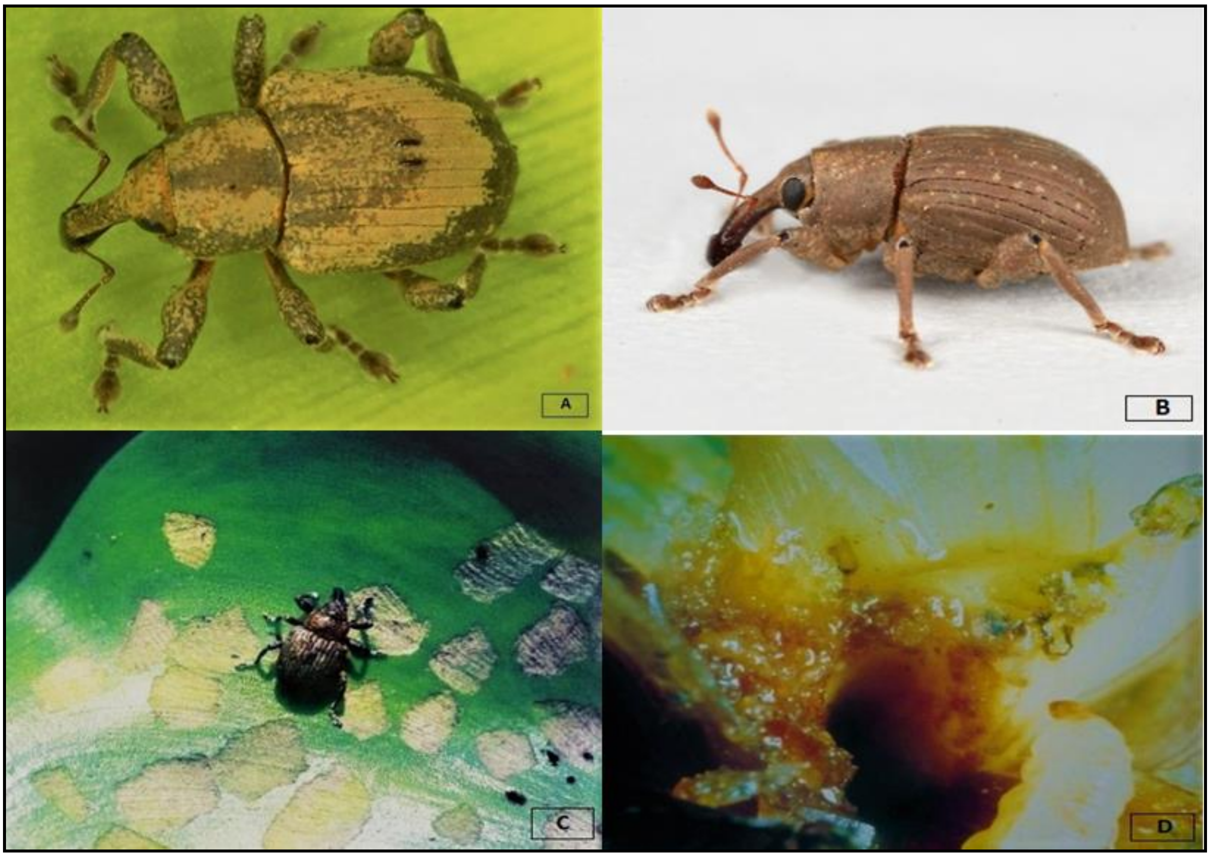

Figure 5. Biological control agents; A - *Neochetina bruchi*; B - *Neochetina eichhorniae* (Dechassa 2020); C - leaf surface damaged by adult weevil infestation: D - damage by weevil larva to the plant (Oberholzer 2001).

The application of several biological agents to control the growth rate of water hyacinth will greatly assist the process of physically cleaning the weeds in Rawapening Lake. Grass carp, *N. bruchi* and *N. eichhorniae* can be a good combination, because they have been proven to be more efficient and environmentally friendly (Ayyaru et al 2011). The existence of these biological agents in Rawapening Lake needs to be improved with precise calculations and control. The grass carp and beetle released should be sterilized to minimize the negative impact on the environment.

Conclusions. Water hyacinth control in Rawapening Lake can be done physically, chemically, and biologically. Biological control, especially with grass carp, is the most efficient and safe method for the environment for long-term results. Effective physical control for short-term results has proven efficient in smaller lakes, and this method is applied together with biological methods in Rawapening Lake.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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