What do research evidence tell us about:
Water hyacinth control methods?
Rapid Evidence Review

[05 Mar 2021]

Key Message

Biological control method is regarded as the most preferred form of control and can provide a long-term solution. Physical and chemical controls are effective for short-term result.

Question

- What are the control methods of water hyacinth?

Why is the issue important?

- Water hyacinth is a treat to the water bodies in Ethiopia. Particularly to the Lake Tana and the central Rift Valley lakes where it has spread and affected the livelihood of the riparian community and biodiversity in water bodies.

What we found?

- The control methods of water hyacinth include physical, biological, chemical, and integrated control approach.
- Biological control is the most preferred (efficient, cost effective and safe to the environment) form of control, either on its own or in combination with other techniques. This method is especially effective for long-term results.
- Physical and chemical controls are effective for short-term results.
- Chemicals have rarely been used with complete success, owing to the need for repeated treatment over a long period. Besides, use of chemical controls may have an impact on organisms living in water bodies.
- In addition, the pros and cons of control methods, countries experiences, success/unsuccessful stories are mentioned in this document.

What is Rapid Evidence Review?

Rapid evidence review addresses the needs of policymakers and managers for research evidence that has been contextualized to a specific context in a matter of hours or days. This rapid evidence review goes beyond research evidence and integrates multiple types and levels of evidence

Where did this Rapid Evidence Review come from?

This document was prepared in response to a specific question from the Traditional and Modern Medicine Research Directorate of Ethiopian Public Health Institute (EPHI). It was prepared by Knowledge Translation Directorate, Ethiopian Public Health Institute, Addis Ababa, Ethiopia

✚ Included:

- Key findings from research and countries experiences

✖ Not included:

- Recommendations
- Detailed descriptions

Rapid and Responsive Evidence Partnership (RREP)

Background

Water hyacinth (Eichhornia crassipes) is a perennial, mat-forming, aquatic plant, free-floating or anchored in shallow water, usually 10-20 cm high but up to 1m when growing in dense mats. The mature plant consists of long-fibrous roots which may be up to three meters in length, rhizomes, buoyant petioles, stolons, leaves, inflorescences and fruit clusters. It is originated from South America's tropical regions, and spread to every continent except Antarctica. This plant increases biomass rapidly and forms dense mats that replicate from stolons (i.e., vegetative runners) (Stohlgren, 2013).

Water hyacinth can cover lakes and wetlands entirely, outcompeting native aquatic species, reducing fish oxygen and creatinine levels (Stohlgren, 2013). The most visible impacts include: restricting proper water flow, water loss through excessive evapo-transpiration, interference with fishing, grazing and crop production activities (accessibility to land water hindered). It has also an effect on power generation, increase siltation, flooding, increase the cost of production, affect tourism, lowers the dissolved oxygen in water bodies, and effect on native plants (Gebregiorgis, 2017; Jianqing et al., 2001; Bhattacharya et al., 2015).

In Ethiopia, water hyacinth has spread aggressively infesting Lake Tana of Ethiopia (Melese & Samuel, 2018). The Lake Tana survey findings show that about 43.4 percent (2 sq.km) of crop fields were covered by water hyacinth during the peak season. Of these, 43.7% of the infested area was seriously affected, a quarter of the infested area was moderately affected and the infestation rate (30.4%) of the remaining cultivated area was minimal (Enyew et al., 2020).

According to studies, a number of fungal pathogens exist on water hyacinths to cause death of plants. Both abiotic (non-living physical and chemical elements) and biotic (living or once-living organisms in the ecosystem) factors in the upper Amazon basin rivers and lakes (Evans & Reeder 2001) are reported to affect the growth of water hyacinth. Thus, there are different approaches in control of water hyacinth. Before implementing each method, the pros and cons, the unique constraints and conditions including the degree of infestation, and the characteristics of the infested sites have to be known (Ministry of Water Irrigation & Electricity, 2019). Research reports indicate that, different factors affect the degree of water hyacinth infestations. Salinity, temperature, nutrients, destruction by natural enemies, and competition from other aquatic plants are among the major factors (Wilson et al., 2001; Jianqing et al., 2001).

This rapid evidence review, therefore, provides available evidence on the control methods of water hyacinth that may support decision-making.

Methods

How this Rapid Evidence Review was prepared?

The methods used to prepare in this rapid evidence review were adapted from the SURE Rapid Response Service: www.evipnet.org/sure/rr/methods

In this review, we have searched for relevant studies about the control methods of water hyacinth. We identified the Population, Concept and Context (PCC) with respect to the objective of the review to facilitate searching of relevant articles.

Population: Water hyacinth
Concept: Control methods of water hyacinth.
Context: Global studies were considered without restriction to any geographical context.

Data sources: We searched data from different data source including TEEAL, PubAG, JSTOR, AGRIS, D SPACE, and grey literature. The searching was made in English language and no date restriction. The last search was made on December 05, 2020.

The review findings are thematized and presented in brief statement with details in a table. Similarly, the document incorporates the pros and cons of control method of water hyacinth. In addition, country experience, successful/unsuccessful stories, and details of the research findings are annexed.

Review findings

In this review we identified 42 relevant documents by searching five databases and supplementing it with grey literatures. Accordingly, we found several relevant studies including peer reviewed journal articles, literature reviews, forum and proceedings that provide evidence about the effectiveness of water hyacinth control methods. The methodological quality of the included studies was not assessed since we included all types of studies.

Different water hyacinth control methods are found and discussed in this review. Accordingly, the summary of the findings from the documents are thematized to four categories: physical, biological, chemical and integrated control. Physical control method includes manual removal, and mechanical harvesting (Ministry of Water Irrigation & Electricity, 2019). Biological controlling strategy use natural enemies to reduce infestation of the weed (Guideline Document for Water Hyacinth Control, 2017). The chemical control of water hyacinth includes herbicides such as 2, 4-d, Diquat and Glysophate to control water hyacinths (Labrada et al., 1996). The integrated weed management (IWM) technique comprises biological control, manual and mechanical removal, legislation for quarantine, and control nutrient enrichment through erosion control (Mallya et al., 2001; Jones, 2001).

The key findings on control methods and their pros and cons are presented below. Whereas, the summary of findings (from peer reviewed journal articles, literature reviews, forum and proceedings), countries experience, and successful/unsuccessful stories of water hyacinth control methods are annexed at the end of this document.

1. Key findings of physical control methods

We identified journal articles, literature reviews, proceedings and papers from forums. According to a study by Sokoyo and Goldman, water hyacinth was effectively reduced by mechanical and manual control methods without any variations from their intended effects (Sikoyo & Goldman, 2007). As an emergency measure, these play an important role, particularly in the decongestion of harbours and hydroelectric reservoirs (Woomer, 1997). However, water hyacinth plants that were cut by machine at the end of the growing season produced new leaves faster than plants that had not been cut at all (Spencer, 2006). Consequently, mechanical harvesting is unlikely to provide a long-term solution to most infestations due to reinvasion and regrowth by the plant (Julien, et.al., 1996).

Hand removal for water hyacinth weeds can be done in sparsely infested regions (Lancar & Krake, 2002). In a few cases, manual control is performed on a large scale, such as where labour is inexpensive, water value is high, infestations are smaller than a hectare, or where regrowth can be quickly cleared after chemical control (Julien, et.al., 1996). In the case of Ethiopia in Lake Tana physical methods (e.g., manual hand picking) were used by mass mobilization of hundreds of thousands of people. This strategy has played an important role in removing the large biomass of the weed and limit the weed's expansion and decomposition (Ministry of Water Irrigation and Electricity, 2019).

2. Key findings of biological control methods

As evident in various parts of the world, biological regulation of water hyacinth using weevils is the most favoured technique compared to others. Although it may take several years for biological control to produce results, these methods are by far said to be the best, in terms of environmental protection, safety and cost (Ministry of Water Irrigation and Electricity, 2019; Julien et.al., 1996). Six arthropod biological control agents have been released around the world. Five are insects (two weevils, two moths and a sucking bug), and one is a mite. The two weevils, N. bruchi and N, eichhorniae, and one of the moths, Niphograpta albiguttalis, have been released widely since 1971 in 30, 32 and 13 countries, respectively, while the others, the mite Orthogalumna terebrantis, the moth Xubida infusellus and the bug Eccritotarsus catarinensis, have been released in fewer countries: 2, 3 and 6, respectively. The mite was first released in 1971 while the other two were first released in 1996 (Julien, 2001).

In recent years, the emphasis has turned to natural water hyacinth enemies, particularly to the two South American weevil beetles (Neochetina eichhorniae and Neochetina bruchi), which in many countries have successful long-term control of water hyacinths (Julien et al, ed., 2001; Hill & Coetzee, 2008; Wilson et al., 2007; Phiri et al., 2001). Three pairs of herbivory load of N. Bruchi as well as two pairs of N. eichhorniae was shown the highest degree of leaf damage, defoliated petioles and decreased water hyacinth coverage (Gebregiorgis, 2017; Aguilar et al., 2003).

Neochetina eichhorniae was launched and released and then the area and height of water hyacinths were significantly reduced from 1996 to 1999 (Xujian et al., 2001). Post-release of curculionid weevils (Neochetina spp.) showed a decrease in leaf length, laminar area, and fresh water hyacinth weight within 2-3 years of the initial releases under Lake Victoria conditions (Ochiel et al (Ed)., 2001; Lancar & Krake, 2002). The two weevils, N. eichhorniae and N. bruchi, were introduced into Ethiopia from Uganda in 2008 because of their successful experience on biological control. Following the introduction, climatic suitability studies were made including their life cycle, adaptability, damage potential, and their host specificity. Thereafter, and mass rearing and release was made in lake Koka. A study by Gebregiorgis (2017) indicate that two weevils of Neochetina and the fungus A. alternate were identified to greatly reduce the vegetative growth and fresh weight of plants (Gebregiorgis, 2017). Similarly, water hyacinth sequentially infested with Neochetina weevils and inoculated with C. Piaropi shows lower live leaf counts and lower plant densities (Moran, 2005). As well, two weevil and moth N. albiguttalis have been effective in weed control (Julien, 2001).

Together with generalist herbivores such as grass carp, biocontrol agents such as alligator weed flea beetles, salvinia weevils (Cyrtobagous salviniae), and water hyacinth weevils (Neochetina eichhorniae and N. bruchi) can be useful for aquatic weed control but may not fully eliminate invasive weeds (Gettys, 2014). On the other study, the grasshopper Cornops aquaticum (adults and nymphs) were found extremely mobile and very harmful to water hyacinths (Oberholzer & Hill 2000). Furthermore, in Lake Tana, majority of wetland habitat is free of water hyacinths by enabling native plant species (Cyperus spp, Echionochloa spp and other species of Graminae.) only in one growing season with the use of creative cultural methods (fencing and canalization).

Mycoherbicide could replace the use of broad-spectrum herbicides, which are widely used but have raised concerns about fish pollution and water quality degradation (Bateman, 2001). Although there are potential mycoherbicide (Sclerotinia sclerotiorum in Hyakill™ and Cercospora rodmanii, named ABG-5003) have been identified, none have been commercially available for market (Dagno et al., 2012).

A study by Bahir Dar University that piloted the indigenous papyrus vegetation on the damaged shores of Lake Tana showed that papyrus out competed water hyacinth as papyrus produces canopy (shed) over water hyacinth and prevents growth. Papyrus also provides lake and river buffer stabilization and serves as a sink for the input of catchment nutrients, which in turn contributes to the regulation of water hyacinths. This is regarded as one of the most sustainable long-term measures (Ministry of Water Irrigation and Electricity, 2019).

3. Key findings of chemical control methods

In particular circumstances where rapid removal in small areas is necessary and other approaches are not practical, the treatment of water hyacinths with herbicides may be very useful (Julien et.al., 1996). In larger areas, however, more mats of water hyacinths are likely to survive the herbicides and can fragment to further propagate a large area of water hyacinth mats. The use of chemical is more cost-effective and less laborious than mechanical control. Yet, it can lead to environmental effects as it can penetrate into the ground water system and can affect not only the hydrological cycle within an ecosystem but also negatively affect the local water system and human health. It is also notable that the use of herbicides is not strictly selective of water hyacinths; keystone species and vital organisms such as microalgae can perish from the toxins and can disrupt fragile food webs (Villamagna et al, 2009). Herbicides such as 2, 4-d, Glysophate, Diquat, paraquat and Amitrole are used to manage water hyacinth (Calvert, 1997; Lancar & Krake, 2002).

4. Key findings of integrated control methods

Integrated weed management (IWM) techniques could include biological control, manual and mechanical removal, legislation for quarantine, and nutrient enrichment management (Mallya et al., 2001; Jones, 2001). Mechanical harvester and the herbicide together help to minimize the amount of water hyacinth (Guideline Document for Water Hyacinth Control, 2017). Integrated weed management with chemical and physical controls can be used when biological control is being instigated to minimize the weed in sensitive regions. Studies show that biological control should be the preferred form of control, either on its own or in combination with other techniques (Julien, et.al., 1996).

The combination of biological and herbicidal methods can only be done if herbicides are non-toxic to the biocontrol agent. For instance, *Alternaria alternata* with two widely used herbicides (glyphosate and 2,4-dichlorophenoxy acetic acid) at three prescribed doses, slowed the feeding activity of insect biocontrol agent (water hyacinth weevil, N. *bruchi* and phytopathogen). Though neither of the two herbicides killed the fungus, both prevented its growth (Sushilkumara, and Pandeyb, 2008). Similarly, integrated approaches of chemical (herbicide 2,4-D) and biological method reduce the biomass more than one method of control, and these control measures were consistent as active leave and petiole damage were compatible. Herbivory significantly improved the overall efficacy of the herbicide by biological control agents (Tipping, 2017; Woomer, 1997).

The pros and cons of water hyacinth control methods

Water hyacinth is extremely difficult to eradicate once established; therefore, the goal of most management efforts is to minimize economic costs and ecological damage. Mechanical, chemical and biological control methods are used to control water hyacinth, but no one method is suitable for all situations (Villamagna & Murphy 2010). Table 1 below indicates the pros and cons of water hyacinth control methods.

Table 1. Pros and cons of different methods used for water hyacinth control

Control method	Pros	Cons
Manual and mechanical control	Do not require much technical expertise (Villamagna & Murphy 2010)	Have physical limitations and are labor intensive which could involve health risks (Smith et al. 1994)
	There are no water- use restrictions associated with mechanical control (Villamagna & Murphy 2010)	Might be expensive and energy intensive (Harley et al. 1997)
	Immediately opens physical space for fish, boat traffic, fishing and recreation (Villamagna & Murphy 2010)	In situ cutting, where plants are left to die and decompose in the water, can decrease dissolved oxygen and alter trophic structure as result of changes in nutrient and carbon balances (Greenfield et al. 2007).
	Is effective for short-term results	Eutrophication can lead to a subsequent increase in water hyacinth or algae blooms (Bicudo et al. 2007).
		Disposal of water hyacinth from polluted water bodies also becomes an important health and ecological consideration due to its capacity to absorb contaminants and, in some cases, the cost of an offsite disposal area can be more expensive than the removal process itself (Thayer & Ramey 1986).
		Mechanical control may not be cost effective for large areas when expensive cutting or dredging equipment is required (Villamagna & Murphy 2010).

Control method	**Pros**	**Cons**
Biological control	Avoids the introduction of toxic chemicals into the environment, is not labor or equipment intensive and has the potential to be self- sustaining (Seagrave 1988).	It takes longer period to obtain successful result
	Most efficient and environmental safety method for water hyacinth management, especially for long-term results.	
Chemical control	Chemical control is less labor intensive and expensive than mechanical control, especially at large scales (Guitierrez- Lopez 1993).	The use of chemical control might be effective but it had negative side effects on the environment (Julien et al. 1996). Herbicides can become expensive if management requires repeated applications. The cost of chemical control will depend heavily on the equipment used to apply the herbicide (Villamagna & Murphy 2010).
	Is effective for short-term results,	Herbicides are less selective than mechanical or manual approaches. They can kill non- target algae, a critical foundation of aquatic food webs (Wetzel 1983) and macrophytes (Seagrave 1988) resulting in far reaching ecological impacts and dangerous deoxygenation of water (Lugo et al. 1998).
		The water use restrictions that may be required by law following herbicide spraying due to chemical control can have significant socio-economic impacts if beneficial or designated uses of the water body are affected (Villamagna & Murphy 2010).

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Annexes

The following tables provide detailed information from primary studies and literature reviews identified in the rapid evidence review

Annex 1. Summary of findings in water hyacinth control methods based on source of information

Water Hyacinth control methods	Key findings
Physical control methods	**Key findings from journal article** - Water hyacinth plants that were cut by machine at the end of the growing season, either once or twice, produced new leaves more quickly than plants that had not been cut at all (Spencer, 2006). **Key findings from Literature Review** - Water hyacinth can be removed by hand in areas where the infestation is sparse(Lancar & Krake, 2002). - The water hyacinth was effectively reduced by mechanical and manual control methods without any variations from their intended effects (Sikoyo & Goldman, 2007). - The strategy of using mass mobilization in the infested areas (e.g. manual hand picking) has played an important role in removing the large biomass and limits its expansion and decomposition (Ministry of Water Irrigation and Electricity, 2019). **Key findings from Proceeding** - In a few cases, manual control is performed on a large scale, such as where labor is inexpensive, water value is high, infestations are smaller than a hectare, or where regrowth can be quickly cleared after chemical control. Due to reinvasion and regrowth of the plants, mechanical harvesting is unlikely to provide a long-term solution to most infestations (Julien et.al., 1996). **Key findings from Forum** - As an emergency measure, mechanical and manual clearance play an important role, particularly in the decongestion of harbors and hydroelectric reservoirs (Woomer, 1997).

Biological control methods	**Key findings from journal articles**
	- The coverage of water hyacinth was decreased by water hyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*) (Aguilar et al., 2003). - Three pairs of herbivory load of *N. Bruchi* as well as two pairs of *N. eichhorniae* has shown the highest degree of leaf damage and defoliated petioles. Integrated use of *Neochetina* weevils and an indigenous plant pathogen (two species of *Neochetina* and the fungus *A. alternate)* were found to greatly reduce the vegetative growth and fresh weight of water hyacinth plants. Thus, joint use of use of fungal species and the two weevils is advised to combat water hyacinths (Gebregiorgis, 2017) - Water hyacinth plants sequentially infested with *Neochetina* weevils and inoculated with *C. Piaropi,* showed greater damage in the early stages of a positive interaction between laminar scarring and fungal necrosis growth. Plots supplemented with these agents had 20 percent lower live leaf counts per plant and 38 percent lower plant densities than control plots at the end of the experiment (24 days after *Neochetina* infestation, 17 days after *C. piaropi* inoculation). The mutual involvement of *Neochetina* spp. weevils and *C. piaropi* increases the effectiveness of biological control (Moran, 2005). - About 200,000 Neochetina have been raised and released, mostly in the Shire River. Water hyacinth infestation decline and testing at one site in the Lower Shire has ceased due to so little water hyacinth presence(Phiri et al., 2001). - In South Africa, the grasshopper *Cornops aquaticum* (adults and nymphs) is actually considered a natural enemy of water hyacinths. The insects are extremely mobile and very harmful to water hyacinths. Similarly, there were 28 sites and 30 sites surveyed in Argentina and Peru respectively. *C. aquaticum* was found to be the most harmful to water hyacinths at all the sites of all the insect species assessed (Oberholzer & Hill, 2000). - Post-release of curculionid weevils (*Neochetina* spp.) showed a decrease in leaf length, laminar area and fresh water hyacinth weight, and a substantial increase in the number of weevil and adult weevil feeding scars per square meter. Thus, the critical threshold was reached within 2-3 years of the initial releases under Lake Victoria conditions (Ochiel, Njoka, Mailu, & Gitonga (Ed), 2001) - *Neochetina eichhorniae* was launched and released in 1996 at four locations (Wutian, Liushi, Yaoxi and Kunyang). The area and height of water hyacinths at Wutian and Liushi were significantly reduced from 1996 to 1999 (Xujian et al., 2001).

	Key findings from Literature Review - In 1984, the use of N. *bruchi* for water hyacinth control was investigated in Karnataka (India). A total of seven releases consisting of 1700 beetles were made into a 20-hectare tank fully infested with water hyacinths. Approximately 90% of water hyacinth had been achieved by September 1987 (Lancar & Krake, 2002). - Classical biological control has successfully suppressed many troublesome aquatic plants over the last three years with the exception of water hyacinths (Coetzee et al., 2011). - In the absence of the weevils, the massive reduction of water hyacinth population on Lake Victoria may not have occurred, but the impact could have been exacerbated by the stormy weather associated with the El Nin˜o event (Wilson et al., 2007). - As evident in various parts of the world, biological regulation of water hyacinth using weevils is the most favored technique compared to others. In several African nations, it is environmentally friendly and has effectively minimized infestations. Although it may take several years for biological control to produce results, these methods are by far said to be the best, both in terms of environmental protection and cost. - In recent years, emphasis has turned to natural water hyacinth enemies, including the two South American weevil beetles (*N. eichhorniae and N. bruchi*), which in many countries have successful long-term control of water hyacinths (Ministry of Water Irrigation and Electricity, 2019; Hill & Coetzee, 2008; Julien, 2001). - The result of a pilot study done on indigenous papyrus vegetation restoration showed that papyrus out competed water hyacinth. It also provides stabilization of the lake and river buffer and acts as a sink for catchment nutrient input, which in turn contributes to the control of water hyacinth. This approach is considered one of the most sustainable steps for long-term management (Ministry of Water Irrigation and Electricity, 2019). However, as it was seem from different country experience, pyrus is also a weed that has various impacts including social, economic and biodiversity. These impacts are starting in Ethiopia especially in the Rift valley lakes and wetands

	- In 2016, a pilot project on water hyacinth regulation was conducted at Lake Tana. This was achieved by enabling native plant species (Cyperus spp, *Echionochloa* spp and other Grass species) to germinate and grow earlier by preventing free grazing, as germination/growth of these native species is prevented by over grazing. Over 300 ha of wetland habitat is free of water hyacinths from the pilot project only in one growing season with the use of creative cultural methods (fencing and canalization). If this were scaled up and accompanied by more integrated approaches, the unchecked growth of the weed could be controlled (Ministry of Water Irrigation and Electricity, 2019). - Two weevil and moth, *N. albiguttalis* have been released since the 1970s in various infestations and have led in many places to effective weed control (Julien, 2001). - In many places biological control can be used as a control method (Jianqing et al., 2001). - A long-term solution is provided through biological control and excellent results have been obtained in a variety of large tropical freshwater bodies, most notably Lake Victoria (Hill & Coetzee, 2008). **Key findings from fact sheet** - Together with generalist herbivores such as grass carp, biocontrol agents such as alligator weed flea beetles, salvinia weevils (*Cyrtobagous salviniae*), and water hyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*) can be useful for aquatic weed control but may not fully eliminate invasive weeds(Gettys, 2014). **Key findings from Proceeding** - Neochetina eichhorniae *or N. Bruchi,* or both of them shown to be effective in biological control of water hyacinth (Julien et al., ed., 2001) - The only way that provides safe, environmentally sound, long-term control at a reasonable cost is biological control. At present, two species of weevil and a moth are commonly used as biological control agents (Julien et.al., 1996).
Chemical control methods	**Key findings from Experimental studies** - Mycoherbicide could replace the use of broad-spectrum herbicides, which are currently widely used but have raised concerns about fish pollution and water quality degradation (Bateman, 2001).

	Key findings from Literature Review - Diquat and paraquat can control water hyacinths efficiently. Similarly, Amitrole, used in particular to suppress perennial weeds and effective on water hyacinth (Lancar & Krake, 2002). - Herbicides such as 2, 4-d, Diquat and Glysophate to manage water hyacinth are suitable for small areas of infestation. It can be harmful, especially if the water sources used for drinking and washing (Calvert, 1997). - In diseased water hyacinth plants, many fungal pathogens with mycoherbicide potential (Sclerotinia sclerotiorum in Hyakill™ and Cercospora rodmanii, named ABG-5003) have been detected, but none have been commercially available on the market (Dagno et al., 2012). **Key findings from Proceeding** - In particular circumstances where rapid removal in small areas is necessary and other approaches are not practicable, the treatment of water hyacinths with herbicides may be very useful (Julien et.al., 1996).
Integrated control methods	**Key findings from Experimental studies** - The combination of biological and herbicidal methods can only be done if herbicides are non-toxic to the biocontrol agent. Therefore, laboratory experiments were performed to establish the toxic effect of herbicides. Alternaria alternata with two widely used herbicides, glyphosate and 2,4-dichlorophenoxy acetic acid at three prescribed doses, on insect biocontrol agent, waterhyacinth weevil, Neochetina bruchi Hustache, and phytopathogen. The result shows that, there was also a decline in the feeding of the leaves treated with herbicides. When the weevils were able to move freely between the treated herbicide and untreated plants, the untreated waterhyacinth was found to have a higher orientation of the weevils than the treated ones. Neither of the two herbicides killed the fungus, but both prevented its growth (Sushilkumara & Pandeyb, 2008). - Three rates of herbicide 2,4-D were applied: (1) control (no herbicide), (2) decreased (2.1 kg ai ha-1), and (3) operational (4.3 kg ai ha-1). By biological control alone, the biomass of the waterhyacinth populations was reduced by 16.9%, 10.5% by the reduced herbicide rate alone, 44.6% by the operational rate, and 97.3% and 99.9% by the combination of biological control and herbicide reduction and operational rates, respectively. Overall, for both studies, the findings were strong; herbivory significantly improved the overall efficacy of the herbicide by biological control agents (Tipping, 2017).

	- The population of water hyacinths can be decreased by 90 percent by water level control and mechanical destruction. To sustain these levels, integrated approaches are used, but the input of urban and industrial pollutants for long-term recovery must be monitored (Gutiérrez et al., 2001). - In Tanzania, integrated weed management (IWM) techniques have a major effect on the regulation of water hyacinths. This includes biological control, manual removal, legislation for quarantine, and nutrient enrichment management. Sixty landing beaches in Lake Victoria have been kept clear of water hyacinths by manual removal. Two weevils, Neochetina eichhorniae and N. Bruchi, has established up to 30 per plant with adult. There was a significant decrease in the population density of water hyacinth plants, from 45 to 7 plants per 0.5 m2, and a significant decrease in covered surface area and biomass. Within a period of 3 years, water hyacinth was reduced by over 70 percent (Mallya et al., 2001). - Between 1995 and 2000, a total of 18.9 km of river was cleared of water hyacinths by using the integrated control method. Local rural communities that rely on fish as a food source suggested that their catches have increased, it is a strong indication that the system's management of water hyacinth has a positive ecological effect (Jones, 2001). - Mycoherbicide may be more consistent with the use of biological control agents for insects (Bateman, 2001) **Key findings from Literature Review** - An integrated approach, including herbicide application and augmentive biological control, is required against water hyacinth in eutrophic water bodies at high elevations that experience cold winters (Coetzee et al., 2011). - Together with a mechanical harvester, the herbicide was used and joint efforts helped minimize the amount of water hyacinth in the dam (Guideline Document for Water Hyacinth Control, 2017). **Key findings from Proceeding** - Integrated weed management (chemical and physical controls) can be used when biological control is being instigated to minimize the weed in sensitive regions. Once the population of the weed has been decreased by biological regulation, additional controls should not be needed in most areas. Biological control should be the preferred form of control, either on its own or in combination with other techniques (Julien, et.al., 1996). **Key findings from Forum** - Biological and chemical control measures were consistent as active leave and petiole damage were compatible (Woomer, 1997).

Annex 2. Country Experiences in controlling water hyacinth

Title	Document type	Country	Experience
Water Hyacinth in China: Its Distribution, Problems and Control Status (Jianqing, Ren, Weidong, and Guoliang, 2001).	Review	China	Manual removal has been employed in most areas in China. It was estimated that more than 100 million RMB yuan (US$12m) was spent on artificial control of water hyacinth each year but the practice was neither economic nor effective.
Biological Control Initiatives against Water Hyacinth in South Africa: Constraining Factors, Success and New Courses of Action (Hill, & Olckers, 2001).	Review	South Africa	In South Africa, the control of water hyacinth relies heavily on the application of herbicides, and this policy has been antagonistic to biological control for two reasons. Firstly, certain herbicide formulations used on the weed in South Africa, especially those with high surfactant content, cause high mortality in the natural enemies. Although N. eichhorniae was resistant to most herbicide applications, those that contained diquat as an active ingredient were toxic to the weevil. Secondly, herbicidal destruction of water hyacinth populations, especially in impounded systems, causes extensive mortality of the sessile immature stages and dispersal of the adult stages, when the weed mats start to sink. Re-infestation of these treated sites occurs via seed germination and isolated plants that were left unsprayed and the water hyacinth populations proliferate in the absence of natural enemies. Solutions to these problems, under investigation, include: (i) using herbicide formulations that are less toxic to the natural enemies; (ii) re-inoculating plants that are overlooked during herbicidal applications; and (iii) accepting the concept of leaving untreated ‘reserves’ to act as refugia for the agents. This allowing sufficient time for biocontrol to take affect and limiting the use of herbicides. Although the biocontrol program in South Africa has been less successful than those implemented in other tropical areas of the world, it has, nevertheless, lessened the overall impact of water hyacinth.

Title	Document type	Country	Experience
Biological Control Initiatives against Water Hyacinth in South Africa: Constraining Factors, Success and New Courses of Action (Hill, & Olckers, 2001).	Review	South Africa	It is believed that biocontrol is more successful in larger water bodies where wind and wave action increase the mortality of agent-stressed plants. These considerations have prompted several courses of action in South Africa, notably: (i) mass-rearing and re-releases of agents that failed to establish at specific sites; (ii) evaluation of the impact of the combinations of agents already established; (iii) development of management strategies in which biocontrol can be appropriately integrated with existing control operations; and (iv) search for additional agents that are effective under more temperate conditions. The success of these initiatives will ultimately rely on the extent to which water authorities and policy-makers become educated about, and come to accept, the principles of biological control.
Progress with Biological Control of Water Hyacinth in Malawi (Phiri, et al., 2001)	Experimental	Malawi	Approximately 200,000 Neochetina, primarily in the Shire River, but recently at other sites outside the Shire, have been reared and released. The beetles in the Shire are well known, although the establishment and subsequent population build-up in the Lower Shire has been faster than in the Upper and Middle Shire. There is now less water hyacinth infestation in the Shire River than it was two years ago.

Annex 7. Successful/ Unsuccessful Stories in controlling water hyacinth

	Successful Story	Unsuccessful Story
Physical Control/Mechanical or Human Removal	There has been success using mechanical control in Mexico at Trigomil Dam, when it was used in combination with herbicide application of 2,4 – dichlorophenoxy acetic acid (or more commonly known as 2,4-D).	In Zimbabwe, mechanical control was initiated around Port Bell and Owen Falls Dam on Lake Victoria, as well as at Lake Chivero. All with very limited success due to the rapid regeneration of the weed.
Manual removal	Demands a high labor force but, if systematically implemented it may be of great value to reduce a moderate stand of the weed. In Malaysia, in various sites water hyacinth has been successfully controlled through the combination of manual removal with biological control. Manual removal of the weed is invariably the first control option practiced in most countries.	The team removed 500 tonnes of Water Hyacinth, but the rapid regeneration of the weed made the effort slow and expensive with no obvious impact.
Biological control	In many African countries it was successful	Slower reduction of water hyacinth was observed on Lake Mariout, due to water pollution in Egypt
Chemical Control	It has been found that there is a good success rate when dealing with small infestations but less success with larger areas.	Resulting in a fish kill incident. Associated impact of low dissolved oxygen concentrations.

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Conflict of interest

There is no conflict of interest

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