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# THE EFFECT OF WATER HYACINTH ON WATER ECOSYSTEM: CONTROL MECHANISMS AND UTILIZATION FOR DIFFERENT PURPOSES

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**ABSTRACT**

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Water is an essential natural resource for the existence of human beings and other living things. Its quality and quantity can be compromised by many factors, one of which is aquatic invasive weeds such as water hyacinth. Exacerbated by a growing population, global warming, and the leaching of minerals into water bodies, the expansion of water hyacinth has become a global concern. Its aggressive reproduction rate accompanied by structural advantages, severely disturbs aquatic habitats by competing for available nutrients, dominating other communities and impeding a range of human activities relying on water bodies. In contrast, because of its high affinity for various nutrients like nitrogen, phosphorus and heavy metal ions, it is an economical and effective choice for treatment of polluted water. Furthermore, its biomass is ideal for the synthesis of organic fertilizers, handcrafts, and animals' feed. To benefit from water hyacinth and minimize the damages it causes, it is essential to know its interaction with the aquatic ecosystem and regulate its expansion. This thesis reviews the control mechanisms and implementation of circular economy strategies in the efficient utilization of water hyacinth. It concludes by underlining the importance of finding a balance between the control and utilization of water hyacinth and suggests research on its application in the field of medicine.



**Key words**
Aquatic ecosystem, control, eutrophication, phytoremediation, utilization, water hyacinth, water hyacinth mat

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## 1 INTRODUCTION

Water hyacinth, also called *Eichhornia crassipes* with its species name, is an aquatic plant that is found floating on water surfaces. Its ability to reproduce and cover a large area in a short time and withstand different unfavorable environmental conditions has made it to be categorized as invasive weed. By changing its growing mechanism depending on the environment it outcompetes other aquatic communities. When there is enough space to grow, the plant spreads out horizontally, increasing its population to maximize its access to sunlight and nutrients available. In case of limited space, it grows vertically to store nutrients for future growth and reproduction. (Yan & Guo 2017.) In terms of capacity to infest a water body in a short time, it is among world´s top ten weeds. (Shanab, Shalaby, Lightfoot, & El-Shemy 2010). In a year it can reproduce millions of offsprings to produce 28 metric tons of biomass (Lu, Wu, Fu, & Zhu 2007). According to Global Invasive Species Database (2023) it can double its population within just 12 days. Water hyacinth is thought to have first been observed in South America in the early 19th century. Widely used for pond landscaping, the aquatic plant is known for its huge, purple, and violet blossoms. Its presence in more than 50 countries across 5 continents is reported. (GISD 2023.)

Water hyacinth has long feathery roots and typically grows 100–200 mm tall, but can reach 1 m in thick mats. Its glossy dark green leaves stand upright on distinctively enlarged petioles. During flowering season, its flowers are found on 8 to 10 spikes, with a diameter of around 50 mm and an upper petal that has blue patch with a yellow center. (Henderson 2001.) Water conditions that are ideal for water hyacinth growth include water that is rich in nutrients (20 mg/L nitrogen, 3 mg/L phosphorus, and 53 mg/L potassium), with temperatures ranging from 28°C to 30°C, a pH value of 6.5 to 8.5, salinity below 2% (Melesse, Abtew, & Senay 2019).

Because of its ability to hyperaccumulate nutrients and chemical makeup, there has been a lot of interest in studying and utilizing water hyacinth for energy production, animal feed, and biofertilizer.

The peculiar biological nature of water hyacinth, together with climate change and the worsening of surface water eutrophication, are the fundamental reasons for its growing global presence. Research on water hyacinth is underway on a global scale due to the plant's detrimental impacts and rapid growth. Scientists are focusing on ways to control the plant and make use of its abundant biomass, such as using it to clean up pollutants in water. (Yan & Guo 2017.)

This thesis covers the various impacts of water hyacinth on different aquatic communities and socioeconomic impacts on various services from water. It also discusses how water hyacinth can be controlled and utilized as totally eradicating is impossible.

# 1 THE IMPACTS OF WATER HYACINTH ON AQUATIC COMMUNITIES

Living components such as plants, bacteria, and animals, and non-living components coexist in water ecosystems. All aquatic animals are consumers, plants are energy producers, while bacteria decompose substances. Water hyacinth is a large, entangled plant that impacts aquatic ecosystems by producing a dense mat that blocks out sunlight and prevents air from circulating. It grows rapidly in a variety of environments.

Picture 1. Water hyacinth (adopted from Alabama Department of Conservation and Natural Resources 2024)

By hosting various aquatic creatures and absorbing pollutants, it can have positive impact. However, because of the complex interactions in the ecosystem, predicting its overall impact is quite challenging. (Yan & Guo 2017, chapter 3.) Figure 1 shows interactions among different aquatic communities including water hyacinth. This chapter will discuss the interactions between water hyacinth and various aquatic communities.

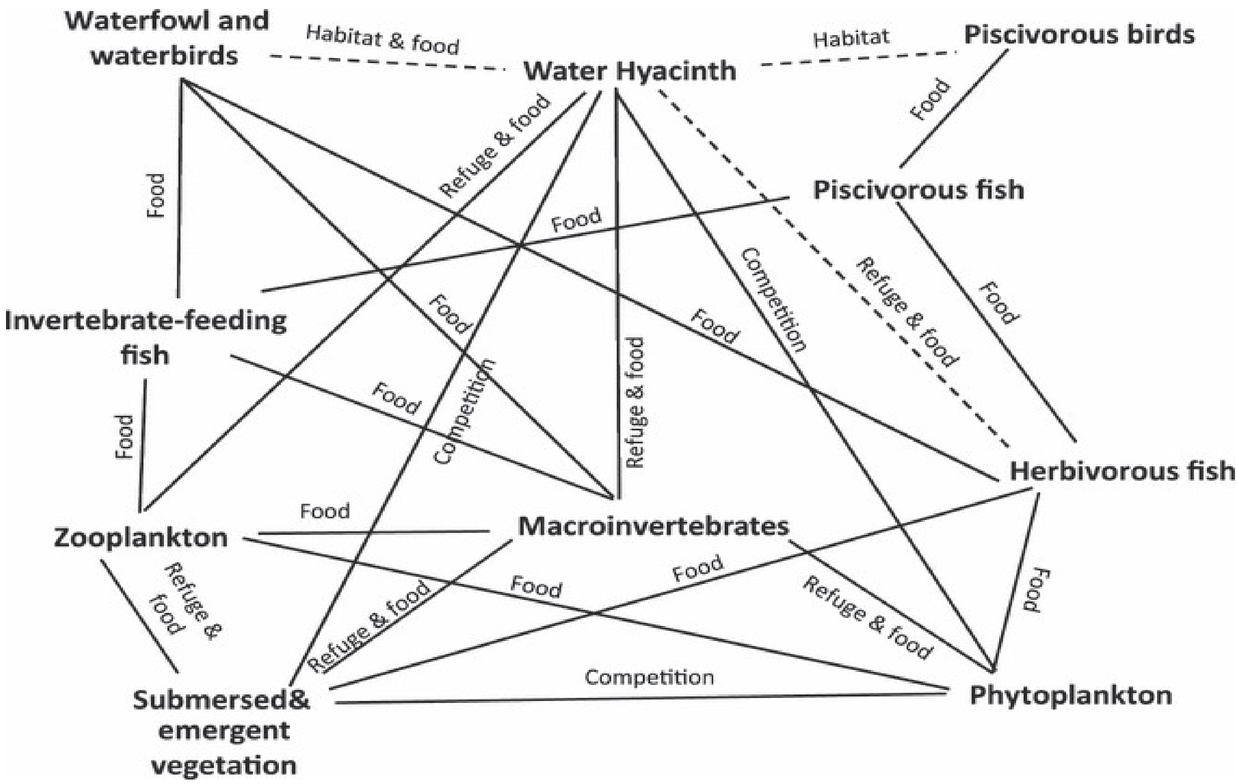


Figure 1. Interactions between water hyacinth and various aquatic communities (adopted from Villamagna & Murphy 2010)

### 2.1 Impacts on phytoplankton

Phytoplankton, also referred to as microalgae, exhibit similarities to terrestrial plants in terms of possessing chlorophyll and necessitating sunshine for their survival and growth (NOAA 2009). Phytoplankton are the most abundant primary producers in water habitats and play crucial roles in energy transmission, cycling of nutrients, and the dissemination of biological information. Different biological and non-biological factors such as light, temperature, nutrients concentration and interactions with the surroundings for dominance all play significant role in the growth, reproduction, and eventual extinction of phytoplankton. (Yan & Guo 2017, chapter 3.)

The presence of water hyacinth has been seen to have a negative impact on the productivity of phytoplankton and submersed vegetation (Villamagna & Murphy 2010). Water hyacinth matt floating on a water surface blocks or minimizes the amount of sunlight reaching phytoplankton communities hindering photosynthesis, thereby creating unfavorable conditions for their growth and reproduction. Its ability to effectively absorb nutrients such as dissolved nitrogen and phosphorus from water causes nutritional deficiency to carry out photosynthesis adequately, leading to a decline in population or even the extinction of phytoplankton communities. By producing allelochemicals it inhibits the growth of phytoplankton and using its extensive root-system it can trap and adsorb them. (Yan & Guo 2017, chapter 3.)

In Lake Naivasha, Kenya, at 10 stations of different depth, concentrations of chlorophyll-a were measured. The surface concentrations of chlorophyll-a at the 5 stations infested with water hyacinth was found to be lower than the other 5 stations free from water hyacinth, demonstrating decreased level of productivity. Levels of mean dissolved oxygen (DO) at the stations covered by water hyacinth mats were lower than at stations free from the invasive seaweed. (Mironga & Momanyi 2006.)

## 2.2 Impacts on aquatic vascular plants

Despite their similarities to terrestrial plants in terms of their stems, leaves, and even flowers, aquatic vascular plants are able to live and reproduce in water. In order to survive, the roots of all vascular plants that live underwater must have access to sunlight and, in most cases, a porous substrate. Turbidity of water caused by eutrophication reduces the habitat of aquatic vascular plants. (MarineFinland 2020.)

Water hyacinth has the same effect on aquatic vascular plants as it does on phytoplankton. As water hyacinth matt float and expand, it blocks some of the light that would otherwise reach submerged macrophytes, making it harder for them to carry out photosynthesis. Water hyacinth development, on the other hand, is capable of decreasing nutrient concentrations, which may increase competition for food with other aquatic plants. (Yan & Guo 2017, chapter 3.)

### 2.3 Impacts on zooplankton

Zooplankton are heterotrophic plankton ranging in size from microscopic to a few millimeters and they may comprise the larval phase of bigger aquatic organisms such as fish and mussels. They inhabit almost all water bodies but rivers and streams. As consumers, zooplankton are situated at the core of aquatic food-web and play vital role on various ecological aspects, including water quality, fish production and alga population and pollutant cycling. They consume bacteria and algae, which serve as the primary producers within the food chain. Consequently, are subject to predation by other zooplankton, fish, and insects. (Paterson 2019.) They act as a link in the food chain, carrying nutrients from primary producers like planktonic algae to consumers like bigger invertebrates and fish (EPA 2023).

Because of their heightened sensitivity to changes in environmental circumstances such as light exposure, pH, temperature, algae and DO, they serve as good bioindicators (Yan & Guo 2017). Through changes in their numbers, community structure and body size distribution, the effects of aquatic ecosystem disruptions are easily observed (EPA 2023).

The presence of water hyacinth in an aquatic ecosystem can lead to changes in both physical and chemical conditions. It can serve as source of food, nutrients, and shelter to other aquatic creatures, disrupt food webs, prey and predator abundance and can cause edge effect due to its fragmented mats. (EPA 2023.)

Chukwuka & Uka (2007) investigated the effect of water hyacinth infestation on zooplankton community in Awba reservoir, located in University of Ibadan, Nigeria. The reservoir covers 6 hectares, with maximum length of 700 m and maximum depth of 5.5 m. It serves as repository of household waste for the campus community. The study on water quality and zooplankton community was conducted during its rainy(wet) season between July and November, 2005 by taking samples every two weeks between 7 a.m. and 11 a.m. In the result, the water hyacinth infested areas showed significant increase in turbidity and total suspended solid, while decrease in DO and pH. From the totally identified 15 species of zooplankton, 6 were absent in the sample taken from the infested areas. The presence of a significant amount of suspended particles in the infected region led to a high degree of turbidity, which negatively impacted the composition and number of zooplankton species. Additionally, the capacity of water hyacinth to absorb and utilize nutrients resulted in the deprivation of nutrients for Phytoplankton. As a consequence, there is a decrease in the number of zooplankton. The diversity of zooplankton was also significantly lower, which can be attributed to dense water hyacinth mats obstructing the mixing of autochthonous materials which promotes the growth of primary producers, favoring zooplankton abundance. Brendonk, Maes, Rommens, Dekeza, Nhiwatiwa, and Barson (2003) also reported that water hyacinth mat covered areas in Lake Chivero, Zimbabwe did not support diversity and abundance of zooplankton.

The influence of coverage size of water hyacinth was investigated using simulations, revealing substantial changes over time. When modest area of the water (15%) was covered, the zooplankton community was affected positively. Increasing the coverage area to 90% had an adverse effect on both diversity and abundance of zooplankton. (Yan & Guo 2017, chapter 3.)

### 2.4 Impacts on macroinvertebrates

Macroinvertebrates may find water hyacinth to be an ideal environment for their existence (Yan & Guo 2017). A total of 96 macroinvertebrate taxa were found in a study focused on Alvarado Lagon System (ALS), Vercaruz, Mexico. The 2-year study focused on the change of macroinvertebrate community associated with the root of Water hyacinth obtained from 12 sample sites. In the result, an increase in diversity, species richness and abundance of macroinvertebrates was observed. (Thi Nguyen, Boets, Lock, Damanik Ambarita, Forio, Sasha, & Goethals 2015.)  Similar positive relationship between invertebrate diversity and root mass of *Enchronia Crassipes* has been reported by Kouame, Dietoa, Edia, Da Costa, Ouattara, & Gourene 2011).

Result from research on Daule-Peripa reservoir, Ecuador, abundance, and composition diversity of both pollutant tolerant and intolerant macroinvertebrates were higher in sampling sites with water hyacinth than without (Thi Nguyen et al. 2015). Kouame et al (2011) investigated Lake Taabo, Ivory Coast which was 26% infested by water hyacinth of its overall 69 $km^2$ size and recorded 43 taxa of invertebrates inhabiting the root of water hyacinth and other macrophyte. Because of sunlight and oxygen circulation blockage by its relatively huge structure, it has advantage over the other macrophytes, hence was the only dominant plant in all the sampling sites. Macroinvertebrates feeding on plants and dead organic matter were specially attracted by the food and nutrients trapped in the root system of it. Too dense water hyacinth coverage may affect macroinvertebrate diversity and water-quality parameters negatively by limiting sunlight penetration, reducing oxygen availability, and increasing competition for limited resource among different water communities (Thi Nguyen et al. 2015).

Different physiochemical variables in combination with water hyacinth presence may affect invertebrate species in a different way, causing changes in species composition as a result. While some species were highly influenced by temperature change, density of species from freshwater were primarily affected by turbidity of water. Other environmental factors such as salinity and dissolved oxygen were also found to be influential in the diversity and density of invertebrates. (Rocha-Ramirez, Ramirez-Rojas, Chaivez-Loipez & Alcocer 2007.) Water hyacinth was observed to reduce wave effects caused by wind and other human factors, thereby creating a less turbid environment and be more prevalent there (Thi Nguyen et al. 2015).

## 2.5 Impacts on fish

Fish is a protein rich source of food for human beings. In addition to being vital at all consumer levels of the food chain, fish are essential to the health of aquatic ecosystem as a whole. Food abundance, threat of predation, physical and chemical water quality variables all play major roles in shaping the fish community structure. Fish populations grow in areas with good water quality, enough food, and no predators, but beyond a certain point, there may not be enough food and the water quality may deteriorate, averting any further growth and possibly causing a decline until a new equilibrium is reached. (Yan & Guo 2017, chapter 3.)

Water hyacinth, upon infesting a water body may alter the community structure and decrease the abundance of phytoplankton, zooplankton, vascular plants, and macroinvertebrates, affecting the fish community by causing resource limitation. However, water hyacinth's impact on the other communities is influenced by factors like cover area, density, and community background, making it difficult to generalize its effect on fish. (Yan & Guo 2017, chapter 3.)

Fish development and survival is influenced by water DO concentration. lowered DO can affect phytoplankton productivity and temperature, altering fish habitat. DO concentration towards the center of large, continuous water hyacinth mat is low. Mats with gaps and patches may affect fish population spatially, especially in the gaps with higher DO because of better light exposure, higher phytoplankton presence and enhanced aeration. (Yan & Guo 2017, chapter3.)

Direct atmospheric diffusion, wind and wave action, and photosynthesis provide oxygen to aquatic environments. Photosynthesis by water plants and phytoplankton is the most essential. Photosynthesis produces oxygen ($O_2$) and glucose ($C_6H_{12}O_6$) by taking in carbon dioxide ($CO_2$) and water ($H_2O$) during the day light hours when aquatic plants are exposed to sunlight.

Reaction equation for photosynthesis:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 \qquad (1)$$

Nighttime respiration by plants and animals, including fish lowers oxygen levels. Fish health is best around 5 mg/L DO. Most fish are agitated when DO drops to 2-4 mg/L, although sensitivity varies by species. Concentrations under 2 mg/L are usually fatal. (Francis-Floyd, 2021.)

### 2.6 Impacts on main decomposers

In nature, microbes like bacteria and fungi aid in decomposition and the cycling of nutrients. When air is obstructed or phytoplankton growth is poor, water hyacinth can compensate by releasing oxygen through its roots. The chemical and organic substances released by the plant also have an effect on the aquatic microbes. The fibrous root structure also supports biofilm growth. (Yan & Guo 2017, chapter 3.)

Allelochemicals from water hyacinth root affect different species of microbials differently. Washed and air dried *Eichhornia crassipes* from El Zomor Canal, Nile River (Egypt) was studied to identify its effect on microbes. Plant tissue extracted with methanol and fractioned by thin layer chromatography (TLC) was tested for antimicrobial and antifungal properties. The extract shown antibacterial effect against *Bacillus subtilis, Streptococcus faecalis*, *Escherichia coli,* and *Staphylococcus aureus*, but no growth inhibition was exhibited on *Aspergillus flavus* and *Aspergillus niger*. (Shanab et al. 2010.)

## 3 SOCIO-ECONOMIC IMPACTS OF WATER HYACINTH

For many reasons, including water supply, rivers, lakes, and reservoirs play an essential role. While water hyacinth can help clean water, it can also harm ecosystem services by causing physical obstruction. Financial losses and high removal costs are two of the many ways in which the invasion of this plant affects economies around the world. While water hyacinth management is not without its difficulties, it does offer some potential advantages, like phytoremediation and biomass utilization. As a result of its invasion numerous socio-economic activities take a financial hit, with estimated yearly costs reaching millions of dollars in various countries. (Yan & Guo 2017, chapter 4.) In this chapter the effects of water hyacinth on different ecosystem services are discussed.

### 3.1 Impacts on tourism and transportation

The stems of water hyacinth can intertwine and grow up to 0.9 m in length to form a dense mat. (USDA 2000). Its root length can grow to reach 0.6 m to 2 m (Rodriguez, Brisson, Rueda, & Rodriguez 2012). In favorable conditions, it has an astonishing reproductive rate: 140 million offspring in a year, which is enough to cover 1.40 $km^2$ and create 28,000 tons of fresh biomass. (Lu, et al. 2007). Its mat can grow large enough to obstruct commercial harbors and waterways that lead to fishing grounds. This makes inland waterway transport more difficult, time consuming, and costly, which has a big impact on the daily lives of people who depend on the waterways for work, communication, and transportation. (Yan & Guo 2017, chapter 4.) The passage of boats can be impacted by thick mats of water hyacinth, which lead to slower speeds, longer engine runs per unit of distance traveled, and higher operating and maintenance expenses. (Enyew, Assefa, Gezie, & Bajwa 2020).

Water hyacinth plagues about 550 kilometers of the Niger River in West Africa. The economic impact of water hyacinth in seven African nations is estimated at US$20-50 million annually. Across the continent, expenditures might reach US$100 million yearly. (UNEP 2006)

Rare plant and animal species, distinctive ecosystem, landscape, and natural processes, diverse habitats, and considerable altitude variations throughout a water body can boost its tourism value and potential (UNEP 2006). Tourism is affected when invasive weeds take over preexisting biotic communities because of changes in visual and cultural aspects of the site. The decline of ecologically significant and attractive tourist destinations is exacerbated when species become extinct, and water hyacinth is a direct threat to the habitats of these species. (Yan & Guo 2017, chapter 4.)

On the other hand, if water hyacinth could be properly managed, it can have an indirect positive effect on tourism. By using its potential to remove excess nutrients like nitrogen, phosphorus and other organic pollutants that promote algal bloom, a better image can be created. The dull scenery of water hyacinth mat may not be as detrimental to tourism as algal outbreaks. (Yan & Guo 2017, chapter 4.)

## 3.2 Impacts on fisheries

According to Food and Agriculture Organization of the United Nations (2020) global aquatic animal production was about 178 million tons in 2020, generating US$ 406 billion. Aquaculture accounted for 88 million metric tons (49%) and capture fisheries for 90 million metric tons (51%). In water bodies where hyacinth is present, it imposes a significant impact on this multi-billion-dollar industry. It has been found it can affect fisheries in three main ways: (1) making it harder to reach fishing grounds and markets, (2) reducing the amount of food available to fish due to a decrease in phytoplankton productivity, and (3) reducing the amount of DO in the water below the mat, which could make it difficult for fish to survive. (Villamagna & Murphy 2010.)

Because the difficult to penetrate water hyacinth mats reduced accessibility to fishing areas, slowed transportation to markets, and raised fishing expenses (in terms of both labor and supplies), fish catch rates dropped in Lake Victoria, the largest lake in Africa and the second largest freshwater lake by surface area. The breeding sites, nurseries, and feeding grounds of commercially significant species, including Nile Perch and Tilapia in the lake can be blocked by mats as well. This situation favors growth in fishery stock as the catchability of the overfished species goes down, it might be beneficial for fisheries and linked human societies in the long term. (Kateregga & Sterner 2009.)

Water hyacinth has varying effects on various fish species. A study on lake Tana, Ethiopia showed the extinction of their breeding grounds and the entanglement by water hyacinth had the greatest impact on the Oreochromis niloticus and Labeobarbus species, while catfish remain uninfluenced by the weed; that could be attributed to the fish's ability to swim through the thick weed mats and the relative accessibility of its food source. However, the reason why no effect on catfish was observed needs further study. (Enyew et al. 2020.) In another study on Lake Cluster of Pokhara Valley in Nepal, comprising 6 major and 3 minor lakes, noted that invasion by water hyacinth resulted in the decline of native species while positively affecting the exotic fish species. (Basaula, Sharma, Paudel, Kunwar & Sapkota 2023).

Many biotic and abiotic variables and their relationship to one another affect fish abundance and population composition in natural habitats. A continuous mat of water hyacinth decreases DO concentration beneath mats by preventing oxygen from the air to the water surface and blocking phytoplankton and submerged vegetation's photosynthesis. All aquatic creatures depend on DO for their existence. Water hyacinth roots emit less oxygen into the water column than phytoplankton and submerged plants. (Yan & Guo 2017, Chapter 4)

Having water hyacinth in open water areas can enhance water quality, particularly in terms of ammonium and oxygen concentrations (Rodríguez et al 2012). Brendonck et al (2003) also found that water hyacinth provided shelter and nursery for small fish, without affecting population abundance or diversity on Lake Chivero, Zimbabwe.

### 3.3 Impacts on hydropower

Globally, about 17% of the total electricity and 60 % of the renewable energy is generated from hydropower (IEA 2021). In addition to generating electricity hydroelectric dams also serve as an infrastructure to deliver potable water to household, businesses, and farms; they also provide recreational opportunities and transportation. During drought and flood times hydroelectric dams can also be used to control water flow and store water (IHA 2022.)

Clearing water hyacinth is a costly and time-consuming task for many big hydropower stations, since it is necessary to keep the weed from getting into the turbine and damaging it or cause power disruptions (Malik 2007). For instance, interfering with power generation through excessive evapotranspiration and damages in turbines causing power outage were reported by Ethiopian Electric Power Authority (EEPA) at its hydroelectric schemes of Koka and Tana Beles, Ethiopia (Gebregiorgis 2017). Related other cases of damages and power interruptions on hydroelectric systems have also been reported in Uganda, Zambia, Suriname, Spain, and China. Although the effects varied by site and management approach, a consistent thread was an increase in operational expenses and a decrease in hydropower operation time, leading to lower electricity output. (Yan & Guo 2017, chapter 4.)

### 3.4 Impacts on human and animal health

There is a lack of scientific evidence regarding direct impact of water hyacinth on human and animals' health. Data collected via questionnaire on 405 households with an average family size of 5 that participated in the manual removal (hand weeding) of water hyacinth from Lake Tana, Ethiopia showed participants having a skin allergy and other health problems from staying long hours in water.

Bloating, diarrhea and increased internal parasites on their livestock after grazing the weed were another health issue (Enyew et al. 2020.) De Groote (2003) also reported cases of itchy skin in southern Benin. Increased rate of malaria and bilharziasis were also mentioned. Providing a suitable habitat for venomous snakes and crocodiles is also another indirect impact of the weed.

Feikin, Tabu, & Gichuki (2010) found a high correlation between cholera cases in Nyanza Province, Kenya, and Lake Victoria water hyacinth coverage in a year. There was a significant difference in Escherichia coli counts between water hyacinth-infested regions versus non-infested areas around Lake Victoria, showing the bacteria like the water hyacinth mats. The weed's spreadability may exacerbate Escherichia coli disease in shoreline areas.

When water hyacinth dies and rotes after harvesting or application of herbicide it may be bad for people’s health because it degrades the quality of water. In such cases, the impact on underdeveloped nations is significantly high since it lowers the quality of water available for drinking and other household needs. (Yan & Guo 2017, Chapter 4.)

### 3.5 Impacts on fresh water sources

Fresh water is essential for human survival, but it also has the potential to inflame tensions and divide communities, nations, and even tribes. Less and less fresh water is accessible from surface sources like rivers, lakes, and reservoirs, and from underground sources. This is a result of several factors, including population increase, ecological stress, socioeconomic development, and climate change. (Yan & Guo 2017, Chapter 4.)

Loss of water through high evapotranspiration has been reported by various studies. Lallana, Sabattini, Del Carmen Lallana (1987) evaluated evapotranspiration of four different floating aquatic plants in a 4-month field trial in Argentina. The mean value of evapotranspiration by water hyacinth was found to be

2.67 centimeters per day ($cm.d^{-1}$), 150% higher than water lettuce, salvinia and water fern. 196,000 liters per hectare per day ($l.ha.d^{-1}$) water loss was recorded. In another study, Penfound and Earle (1948) stated that the mean water loss from water hyacinth covered part was 3.2 times higher than water hyacinth free part.

Most studies examining water hyacinth's impact on water quality concentrated primarily on the adverse effects of the thick mats created when intertwining. Even though the usual focus is on quality and quantity of water hyacinth’s effect on water, there are a lot of complex components in the interactions between freshwater resources, and many variables determining the outcomes. But the rule of thumb in freshwater management involving water hyacinth is: water hyacinth should be harvested, dried out, and moved away from the water; and chemicals to get rid of the plant should only be used in extreme situations. (Yan & Guo 2017, Chapter 4.)

# 4 UTILIZATION OF WATER HYACINTH

Despite its many negative impacts, water hyacinth can be used for various purposes. Treatment of contaminated water, production of energy, biofertilizer, animal feed and crafts are some of them. This chapter will discuss about some of the above-mentioned utilizations of water hyacinth and control methods of the invasive plant.

## 4.1 Nitrogen removal using water hyacinth

Over the past 100 years, nitrogen fertilizers have increased crop yields. On the contrary, nitrogen fertilizer can pollute groundwater and surface water by making nitrogen leach out more easily. Higher crop yields are good for people and society. But as the world's population has grown, it has become harder to treat municipal wastewater and effluent discharge, with nitrogen being the main pollutant. (Yan & Guo 2017, Chapter 5.)

Nitrogen, an essential element for aquatic life, is also one of the primary causes of eutrophication. The overabundance of nutrients causes eutrophication, which in turn causes algal blooms and disrupts environmental equilibrium because the water cannot remove all of the nutrients by itself. The level of nitrogen and phosphorus concentrations to determine water quality and eutrophication varies across nations and regions. For instance in China, water containing above 1 mg/L of nitrogen and 0.2 mg/L phosphorus is classified as eutrophic. In Europe and North America phytoplankton biomass, transparency and other parameters are also considered. In water, nitrogen exists in the form of molecule ($N_2$), ammonium ($NH_4^+$), nitrate ($NO_3^-$), nitrite ($NO_2^-$), organic nitrogen compounds, and biological (in the bodies of aquatic organisms). Diverse aquatic processes recycle and transform nitrogen forms interacting with the adjacent land ecosystem. Microorganisms lead the transformation of different nitrogen forms. (Yan & Guo 2017, Chapter 5.)

Using three different mechanisms nitrogen can be removed from water: 1) by absorption (assimilation) through aquatic plants and animals, and then harvesting them; 2) transformation of nitrogen in water and sediment to gases (e.g., $N_2O$, $N_2$); and 3) by temporarily blocking the cycle and transformation of deposited nitrogen. (Yan & Guo 2017, Chapter 5.)

Water hyacinth's potential of growing anywhere in the water regardless of depth, floating on the water surface regardless of depth (making it easily harvestable), effectively absorbing and assimilating nutrients like nitrogen and phosphorus, and huge biomass accumulating potential makes it ideal for phytoremediation. Has high tolerance for nitrogen, phosphorus, and other contaminants. Its thick mat can inhibit algal growth and trap debris with its fibrous roots forming stable ecosystem. Water hyacinth's robust root system offers structural flexibility and vast surface area for materials adherence and microbial growth. Also stimulates nitrifying and denitrifying bacteria to remove nitrogen from water. Well planned harvest and post-harvest system for biomass are essential for successful nutrient removal and avoid unwanted returning of pollutants to water. (Yan & Guo 2017, Chapter 5.)

Nitrogen is needed nearly for all plant components such as proteins, chlorophyll, enzymes, and amino acids. Water hyacinth demands a large quantity of nitrogen for its fast growth as it immediately incorporates it to protein and amino acids. Many biochemical processes including photosynthesis and respiration require nitrogen. The growth of water hyacinth biomass in water ecosystem is highly dependent on the amount of nitrogen and other nutrients like phosphorus. However, too much nitrogen can also cause water hyperaccumulation in the tissues of water hyacinth. Nitrogen and protein content varies across its parts depending on their functions and other external factors such as nutrient concentration in water. Usually, the leaf contains higher nitrogen amount than the submerged parts. (Yan & Guo 2017, Chapter 5.)

Without the assistance of microorganisms that convert molecular nitrogen into absorbable inorganic form water hyacinth can't assimilate organic nitrogen. In eutrophic water nitrifying bacteria quickly converts ammonium into nitrate in aerobic conditions, raising nitrate concentration. After roots absorb nitrate, before being assimilated in plant metabolism it must be reduced to ammonium in the root and leaves. At high concentrations, this assimilation process is quick to avoid toxicity of ammonium. In many nutrient-rich waters, there is not much absorbable inorganic nitrogen. The water hyacinth efficiently absorbs and store this low available nitrogen using special transporters which has high affinity for nitrogen. These qualities make water hyacinth a good choice for water management strategies. For instance, In Lake Dianchi, China, a project aimed at using water hyacinth for ecological cleanup revealed that the plants stored different amounts of nitrogen in their biomass depending on the location and the nitrogen levels in the water. The more nitrogen in the water, the higher the nitrogen content in the water hyacinth biomass. There is a wide range of nitrogen removal capacities for water hyacinth mats, from 416 mg N $m^2$/d to 2316 mg N $m^2$/d, according to various studies. Efficiency can also be expressed in nitrogen removed per biomass weight per time. (Yan & Guo 2017, Chapter 5.)

Improving water quality is always the end goal of phytoremediation process. In order to accomplish this, a thorough investigation and planning of the following must be carried out prior to the commencement of a eutrophic water purification project: desired water cleanness degree, quantity of inflow of effluents, how much water hyacinth is needed, and harvesting ways (including post-harvest handling). Achieving high water quality and highly polluted water demands more time and more water hyacinth. But longer times or more water hyacinth mean higher costs. So, in practical projects, finding balance between having clean water and doing it efficiently is important. (Yan & Guo 2017, Chapter 5.)

### 4.2 Phosphorus removal using water hyacinth

Phosphorus is essential for all forms of life. It is a vital component of DNA and other plant and animal structures like cell membrane and cell wall. Phosphate ($PO_4^{3-}$) is the most prevalent phosphorus form utilized by living things. Many commercial fertilizers contain phosphorus. (EPA 2023)

In water it exists in form of organic phosphorus, orthophosphate, and polyphosphate. Physically, it can be in particulate or dissolved state. Dissolved orthophosphate is easy to absorb and assimilate by aquatic plants. (Yan & Guo 2017, Chapter 6.)

The balance between external source of phosphorus (exogenic) and from plant biomass (endogenic) is important for a healthy aquatic ecosystem. As a result of natural processes, phosphorus from exogenous sources can accumulate in a sediment form at the water's bottom. Upon decomposition phosphorus retained by plants can be released back into water, feeding bacteria and algae, which in turn pollutes water. By lowering DO, it can contribute to eutrophication (Yan & Guo 2017, Chapter 6.) For instance, in 2002, in the United States of America, the amount of phosphorus in discharge wastewater had to be in the range of 0.008-0.0375 mg/L. (EPA 2007)

Depending on growing environment and growth stages phosphorous in various parts of water hyacinth is different, highlighting its ability to adapt and thrive in various habitats (Yan & Guo 2017, Chapter 6). According to Boyd and Vickers (1971), the average phosphorus content in water hyacinth was 5.4 g $kg^{-1}$ dry matter, although it ranged from 1.4 to 8.0 g $kg^{-1}$ dry matter. The yield of water hyacinth is 65.2 tons (dry matter) $ha^{-1}$ $yr^{-1}$, with phosphorus levels 1.6 to 2.9 g P $kg^{-1}$. (Polomski, Taylor, Bielenberg, Bridges, Klaine, & Whitwell 2009) reported 87% P in above water parts of water hyacinth compared to roots. In addition, phosphorus in water hyacinth also varies due to habitat differences, including nutrient levels, pH, light, and temperature. For instance, higher phosphorus content at the mat center than the edge was observed by Boyd and Vickers (1971).

Water hyacinth efficiently uses phosphorus for growth and competing with other plants by allocating more of the assimilated phosphorus to its above water parts. In water with high phosphorus concentration, early harvested blades can be animal feed; in water with low phosphorus, mature plants are better for methane and fertilizer. Managing water hyacinth in different eutrophic zones is vital for effective phosphorus removal in phytoremediation. (Yan & Guo 2017, Chapter 6.)

Water hyacinth's flexible shape and ability to hyperaccumulate nutrients makes it ideal for phytoremediation. Its adaptable form allows changes in root and petiole length, and as per Rodríguez et al. (2012), it can grow up to 2 meters long roots in low-nutrient conditions to enhance nutrient absorption. Hormones and nitrogen content can affect this morphological flexibility. (Yan & Guo 2017, Chapter 6.)

Water hyacinth's growth in moving waters like rivers is influenced by nutrient concentration and form. In static waters, chemical forms affect nutrient assimilation by plants. Nitrogen to phosphorus (N:P) ratios also impact plant growth and concentration of nutrients. However, water hyacinth effectively removes nitrogen and phosphorus, even when pollutant ratios differ. Managing nutrient loading levels in large water bodies involves controlling external and internal phosphorus sources. Algae-water hyacinth interactions and particulate phosphorus influence phytoremediation outcomes. By converting soluble reactive phosphorus into organic phosphorus algae can influence phosphorus amount in water. with its short life cycle and easily moving with water flow and wind, can release phosphorus in different locations. Hence, static and flowing water bodies need different management considerations for nutrient removal. (Yan & Guo 2017, Chapter 6.)

### 4.3 Heavy metal removal using water hyacinth

Water hyacinth has special capacity to purify contaminated water by absorbing toxic chemicals and heavy metals like mercury, lead, chromium, and cadmium, organic pollutants such as pesticides, pharmaceuticals, dyes and detergents, and metalloids. Because these contaminants are so difficult for conventional sewage treatment systems to remove, water contamination is a major problem. Even low concentrations of heavy metals and other harmful substances can have a major impact on ecosystems and human health. Moreover, these contaminants have the ability to build up in living organisms, making their way up the food chain and eventually posing a threat to human health. (Yan & Guo 2017, Chapter 7.)

The lack of agreement on the interactions between different metals explains why water hyacinth's success rate in removing heavy metals varies so widely (Tekestebrihan, Ancha, Afessa, & Manenti 2022). One theory is that the plant contains lignocellulose, which can bind metal ions (Premalatha, Parameswari, Davamani, Malarvizhi, & Avudainayagam 2019). 65% extraction success of Cu and Cr was mentioned by Lissy (2011). After 8 days of treatment, the amounts of metals relative to their initial concentrations were 8% for Cu, 11% for Pb, 24% for Cd, and 18% for Zn at pH 8 and pH 6, respectively, in another experiment conducted by (Smolyakov 2012). The initial concentrations of Zn, Cu, Pb, and Cd were 500 µg/L, 250 µg/L, 250 µg/L, and 50 µg/L, respectively. In Mosquera, Colombia, a study by Sayago (2019) showed that water hyacinth biomass could be sustainably used to produce bioethanol following phytoremediation for chromium-contaminated water treatment.

### 4.4 Water hyacinth for livestock feed

Among the many potential worldwide applications of water hyacinth biomass is as a feed source for livestock. But because nutrient value and pollutants content vary, the management to utilize water hyacinth biomass have been challenging. Concerns about the safety and quality of freshwater hyacinth biomass, especially because roots can accumulate harmful elements, make it difficult to produce animals feed on a large scale. The high fiber content of water hyacinth is difficult to digest for monogastric animals like pigs and chickens to digest, which sparks ongoing discussions about its suitability as feed. However, literature suggests positive results for fish, pigs, and chickens. (Yan & Guo 2017, Chapter 10.)

For instance, (Adeyemi & Osubor 2016) Extracted leaf protein concentrate from water hyacinth biomass collected from River Ijana, Niger and analyzed the contents. There was protein making up 50% of the total, carbohydrates 33%, and fat, ash, and fiber making up 17%. 17 distinct amino acids were also discovered. As the heavy metal content was also in the safe limit, the study concluded water hyacinth leaf protein extract to be edible and nutritious.

### 4.5 Water hyacinth as biofertilizer

Water hyacinth harvested and dried out on land is great source of organic nutrients, potassium, nitrogen, and phosphorus. When it composts, it adds those nutrients to the soil. By using methods of composting, vermicomposting, mulching, or anaerobic digestion, water hyacinth can be utilized as biofertilizer. Mulching helps to keep soil from drying out, as well as to keep weeds at bay by using water hyacinth as it is. Water hyacinth and animal excretions are mixed in composting, while worms are added in vermicomposting to improve soil condition. In anaerobic digestion different wastes are mixed to make biogas. Then its byproducts can become biofertilizers. Soil nutrient content, crop growth, crop quality, and pest and weed control are all improved by these biofertilizers. While results vary depending on application ways and crop type, water hyacinth biofertilizers have been useful in agriculture. (Harun, Pushiri, Amirul-Aiman, & Zulkeflee, 2021.)

### 4.6 Water hyacinth for crafts production

A wide variety of bags, purses, wallets, and other crafty things can be made from water hyacinth. Its length and flexibility make the stem ideal for use in craft projects. Many countries, including the Philippines, Bangladesh, and Indonesia, make coasters, mats, shoes, and more out of dried petioles.

Because of the rise of e-commerce, many people are starting small-scale businesses by crafting goods like furniture, flipflops, and bags out of water hyacinth. This in turn is helping communities to create job opportunities and manage waste. In Indonesia, for instance, there are programs that teach people, particularly women, how to make things out of water hyacinths, which opens new economic avenues for them. (Harun et al. 2021.)

## 5 CONTROL METHODS OF WATER HYACINTH

The three main ways to manage water hyacinth are mechanical, chemical, and biological. Each of these approaches has its own unique set of advantages and disadvantages. Fish habitats, fishing grounds, inland water traffic and recreational areas are cleared through mechanical harvesting by using human labor or machineries, which also presents logistical, cost and oxygen-related challenges. When harvested water hyacinth rots it releases nutrients, leading to algal bloom and eutrophication. On the other hand, because of free flow of water after mechanical harvesting, DO can increase. Chemical control methods involving herbicides such as Glyphosate (Roundup), Diquat and 2, 4-D amine are less laborious, but they pose risks to aquatic species that are not targeted and water quality. Environmentally friendly but potentially slow-acting, biological control makes use of insects or plant pathogens. However, the consequences of biological control in the long run needs further studies. There are benefits and drawbacks to each approach; picking one will rely on things like one method cannot work for all situations because different factors like application site conditions, economic cost, water hyacinth coverage size and purpose of water body usage. (Villamagna & Murphy 2010.)

## 6 CURRENT STATUS OF WATER HYACINTH INFESTATION AND RECOMMENDED APPROACHES

A study that analyzed more than 30 years (1984-2018) of archived satellite images to examine randomly selected 20 reservoirs in tropical and subtropical regions reported worsening of floating plants invasion, including water hyacinth despite expensive and extensive control efforts. The selected reservoirs were water hyacinth infested reservoirs from Africa, Asia, and Europe. According to the study, urbanization at the water source areas highly contributed to the coverage growth of invasive plants by increasing nutrient inflow. Poor wastewater treatment was mentioned as one major source of nutrients. (Kleinschroth, Winton, Calamita, Niggemann, Botter, Wehrli & Ghazoul 2021.)

The control of aquatic weed invasions has received significant financial support and has been the subject of extensive research. On a global scale, several initiatives have been launched, including the use of herbicide spraying, biological control programs, and heavy machinery. But, because of global warming it is even expanding to regions with cooler temperature (higher latitudes) continuing to pose challenges. (Kleinschroth et al. 2021.)

Studying the spatial and temporal distribution of floating vegetation, as well as any connections between their presence and factors like human-caused pollution, helps to understand the trend of this phenomenon. If the pollution causing the expansion of water hyacinth persists, the control efforts will not stop or minimize the growth in the most affected warm regions of the world. It is important to figure out ways to control and utilize water hyacinth as part of the ecosystem rather than totally focusing on trying to completely eradicate it. Taking this route, it would be possible to benefit from these floating plants, while reducing reliance on costly control measures. (Kleinschroth et al. 2021.)

For example, in one of the investigated reservoirs Lake Koka, Ethiopia and Lake Batujai, Indonesia, the potential of using nutrients carried by the floating plants from the water as a natural fertilizer on nearby farmland was observed during seasonal flooding in 2018. A large portion of floating aquatic plant that ended up on the shore was used to fertilize farms. Water pollution and eutrophication can be reduced, and farmers can save money by using water hyacinth as a natural fertilizer, which also provides a natural alternative to commercial fertilizers. (Kleinschroth et al. 2021.)

Energy production is another benefit that can be gained from water hyacinth. Successful projects implemented in Niger and Kenya demonstrated water hyacinth can provide an alternative means of energy. According to BiogasWorld (2023), from 1$m^3$ of biogas 2 kwh of useable electricity can be produced and can power a 100 W light bulb for 20 hours. From the total water hyacinth biomass of about 220,000 $m^3$ from the 20 reservoirs, 130 million kwh can be produced. (Kleinschroth et al. 2021.)

Harun et al. (2021) presented how a circular approach can provide socio-economic and environmental advantage while addressing water hyacinth problems. Besides providing electricity, harvesting, and digesting machines can also be operated with low operational costs by using the energy produced. Produced crafts, compressed solid biofuel, and fresh plant biomass can generate income. Biproducts can be used as natural fertilizer and water from the processes can be reused. In addition, industries can use water hyacinth for cost efficient wastewater treatment and sell the extracted heavy metals to metallurgical industries. Applying these procedures which are in line with the principles of circular economy it is possible to transform the problem of water hyacinth invasion into a chance to create a sustainable environment.

Recommendations for continuous surveying, keeping an eye out for early infestations, creating awareness and use of integrated approach considering the various aspects of the water hyacinth infested water was forwarded by Dechassa & Abate (2021). The importance of government policies that encourage the sustainable utilization of water hyacinth, commitment of all involved parties to mitigate the impacts of water hyacinth, strong monitoring and corrective measures on effluent discharge by industries, and incentivizing them to use water hyacinth for waste treatment was presented by Tekestebrihan et al. (2022). In case of border-crossing waters, collaboration among governments for pollution control and water hyacinth utilization projects such as biorefinery was also advised.

# 7 CONCLUSIONS

Water hyacinth is a complex environmental hazard because it disrupts the balance of aquatic life. Macroinvertebrates, zooplankton, phytoplankton, fish, and vascular plants are all negatively impacted by the lack of sunlight and airflow caused by its dense mats. It also competes for food and nutrient and invade water aided by its morphological flexibility. However, being a source of habitat and food can positively affect the aquatic community. As the complexity of its interaction within the aquatic system is high and not fully understood yet, thorough studies under various conditions are essential for an efficient management.

Water hyacinth is valuable in phytoremediation because of its capacity to absorb contaminants, leading to an improvement in water quality when applied in a cautious manner considering its invasive nature. On the other hand, its rapid growth is a concern for an economy, resulting significant losses on a global scale. Because it blocks waterways several socioeconomic activities such as transportation, tourism, power production, and fisheries are affected. Human and animals' health is also affected by the suitable environment it creates for disease causing organisms, wild animal attacks, and water quality and quantity degradation.

Water hyacinth may be an invasive plant, yet it has several other potentials for environmental and economical friendly uses, such as in craft production, bioenergy, animal feed and organic fertilizer. Because of its intrusive tendencies, comprehensive methods of control, including mechanical, chemical, and biological approaches, are required.

Incorporating water hyacinth into a circular economy model and using it for energy generation, crafts, and fertilizer is a promising and sustainable method (Harun et al. 2021). Educating people, continuous monitoring, and early-stage detection are essential for successful control of the plant (Dechassa & Abate 2021). The sustainable utilization of water hyacinth and the encouragement of its utilization for waste treatment should be supported by government legislation (Tekestebrihan et al. 2022). It can be concluded that it is essential to find a balance between utilization of the plant and preventing its uncontrolled expansion.

Considering the current gaps in the available research, further studies to investigate the possible application of water hyacinth allelochemicals in the advancement of medications can be suggested.

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