Invasive Water Hyacinth

Subjects: Plant Sciences

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Water hyacinth, or *Eichhornia crassipes (Mart.) Solms*, from the family *Pontederiaceae*, is a free-floating aquatic plant that commonly grows in inland freshwater bodies such as lakes, rivers, streams, ponds and wetlands. The plant has broad, wide canopy-like waxy leaves and purple clustered flowers that grow in spikes. The petioles of the plant appear bulbous with air-sacs that help make it buoyant. The plant varies in height from a few centimetres to nearly a metre, while the leaves may be around 15–20 cm in length and width. The plant can sometimes become rooted when it lodges in muddy, shallow waters and the flowers may be blue or white. With the ability to reproduce both sexually through seed propagation and asexually through stolon vegetative reproduction, water hyacinth exhibits the reproductive characteristics suited to invasive success.

Keywords: Eichhornia crassipes ; circular economy ; community empowerment ; community resilience ; green nudge ; invasion control ; pro-environmental behaviour ; waste management

1. Overview

Water hyacinth (WH) is notorious for causing severe environmental degradation and being an economic burden to manage. However, it offers substantial prospects if exploited, especially by rural communities. High temperatures, eutrophic conditions and other environmental factors promote the proliferation of the plant in regions where it has been introduced. Regarded as among the world's worst invasive weeds, WH is nearly impossible to control and eradicate without an integrated approach and community participation. The effectiveness of control methods varies, yet sustained community involvement determines the long-term success of these methods. Reproducing rapidly, WH has the resource capacity to support a unique microeconomic ecosystem, incentivising WH control by generating sustainable income. The WH ecology, the socioeconomic impacts of its invasion and its various applications are reviewed, and revenue generation and cost-saving options are highlighted. A circular microeconomic model is proposed by integrating WH valorisation into the general limitations of a rural community. Empowering locals with opportunities and enticing them with potential economic gains can be a nudge towards a pro-environment behavioural change in managing WH. This would aid in upgrading local livelihoods and could foster resilience within the community in tackling both environmental problems and economic setbacks through the management of WH invasions.

2. Water Hyacinth

Invasive in nature, water hyacinth has been extensively addressed in reviews due to its destructive environmental and economic impact [1][2]. Originating from the Amazon, this notorious macrophyte has spread to many other tropical and sub-tropical regions [2][3], invading freshwater waterways, displacing native species, reducing biodiversity [4][5] and deteriorating water quality [6]. In terms of its direct impact on mankind, it disrupts human activities [7][8], acts as a breeding ground for disease vectors [6][9] and continues being a pest in the aquatic environment. Further environmental problems related to water hyacinth are evident. Managing water hyacinth through physical, mechanical, chemical, and biological means causes additional complications [10]. Herbicides used in the chemical cleansing of water hyacinth will pollute water bodies and may bioconcentrate, bioaccumulate and biomagnify in the aquatic food web, potentially eliminating non-target organisms [2]. Introducing a predator, the weevil beetle, for the weed to gain biological control might lead to a secondary catastrophic impact, besides the long duration required to achieve significant success [10]. While they remain the most practical means, physical and mechanical interventions are both costly and labour-intensive [11]. Moreover, once harvested, water hyacinth biomass can create waste issues if not properly managed.

Conversely, a remarkable number of studies have emerged for the potential use and conversion of water hyacinth into value-added products, suggesting a positive aspect of the weed [12][13][14][15][16]. Transforming management issues into opportunities and harvesting water hyacinth through physical and mechanical means by collecting its biomass can be manageable, feasible, and profitable.

Current and recent reviews addressing the valorisation of water hyacinth have focused on several aspects, including water hyacinth biomass-to-energy [15], biochar production potential [12], phytoremediation capacities [17], cost-benefit analyses and the economic feasibility of its utilisation [12][13][18] and various other products [16]. Though frequently mentioned in previous works of literature, the direct and indirect prospects for the utilisation of water hyacinth in affected, and especially rural areas, for the benefit of the people within those areas, has not yet been thoroughly discussed. Most of the literature has focused on the socio-economic impacts that water hyacinth infestations have on the community, rather than on the ways the community can gain immediate benefits from it [7][9][19][20].

Listed among the top 100 in the Global Invasive Species Database by the Invasive Species Specialist Group (ISSG), water hyacinth has been described by many experts as nearly impossible to eradicate. However, the key to its successful control, it has been reported, is the active participation of relevant stakeholders, including the affected locals [21]. However, a lack of enthusiastic involvement in many instances has led to failures and the re-establishment of the aquatic weed invasion [7][22]. Furthermore, the involvement of locals in water hyacinth management has remained limited to roles at the ground level, for example, monitoring the effect of control strategies implemented by relevant authorities or becoming directly involved in the manual clean-up of water hyacinth [21]. Community empowerment to instil knowledge regarding the weed and the prospects of managing it remains deficient.

Promoting pro-environmental behaviours among community members can be vital in addressing environmental problems [23]. One strategy to achieve this is through the introduction of green nudges. Green nudges, or environmental nudges, are informal suggestions aimed at creating a behavioural change, leading to more pro-environmental actions [23][24]. As such, the eradication of water hyacinth and the proper management of its harvested biomass waste could be made economically attractive to rural people through green nudges. This would subtly encourage community members to become actively involved and opt for a more ecological form of water hyacinth management. Some regard nudges as unethical, as they serve to benefit others but overlook the normative cost of the well-being of those being nudged [24]. However, it is often agreed that optimal environmental nudges serve the common good and collective welfare, for both the present and future generations [25]. Therefore, empowering rural communities with the prospects of water hyacinth would not only benefit the environment by making it cleaner, but also the well-being of the locals by potentially allowing income generation. Hence, the normative cost associated with the alleged unethical aspects of green nudging would simultaneously be addressed.

3. Water Hyacinth Invasion

Water hyacinth is native to the Amazon in South America and especially to Brazil and Argentina. Initially intended to be given as gifts, it was introduced worldwide and has spread both accidentally and deliberately into the natural environment. Invasions have been reported in Africa, Asia, Europe, Central America, North America and the Caribbean [26]. Successful weed invasions are due to the optimum conditions provided by the invaded areas, especially in terms of temperature and nutrient levels, among other relevant factors. According to Wilson et al. [27], at a constant temperature and nutrient level, the projected growth of water hyacinth is a rate of 0.1 kg/m^2, while under nutrient-rich or eutrophic conditions the rate will increase to 10 kg/m^2. Supplemented with an average optimum temperature of 30 °C, it takes around 50 days for the plant to reach the 10 kg/m^2 rate. For these reasons, water hyacinth invasions have been observed to predominantly affect equatorial regions that have warm average temperatures and eutrophic lakes, with rivers and wetlands affected more commonly and severely.

3.1. Ecology of Water Hyacinth

Water hyacinth, or *Eichhornia crassipes (Mart.) Solms*, from the family *Pontederiaceae*, is a free-floating aquatic plant that commonly grows in inland freshwater bodies such as lakes, rivers, streams, ponds and wetlands. The plant has broad, wide canopy-like waxy leaves and purple clustered flowers that grow in spikes. The petioles of the plant appear bulbous with air-sacs that help make it buoyant. The plant varies in height from a few centimetres to nearly a metre, while the leaves may be around 15–20 cm in length and width [14]. The plant can sometimes become rooted when it lodges in muddy, shallow waters and the flowers may be blue or white [14]. With the ability to reproduce both sexually through seed propagation and asexually through stolon vegetative reproduction, water hyacinth exhibits the reproductive characteristics suited to invasive success. According to Zhang et al. [26], the invasive spread of water hyacinth is characterised by its genetic uniformity due to its prolific clonal reproduction, dominated through vegetative propagations. In the absence of interspecific competition, water hyacinth outcompetes other aquatic plants, even outside its native range; thus, its growth is rapid and unchecked. Its seeds can remain viable for up to 20 years and may germinate in moist soil or warm, shallow waters [28]. Additionally, the high dispersal of its buoyant propagules and well-developed phenotypic plasticity and its ability to change in response to different stimuli are among the factors that enhance the plant's adaptive capacity to any

local environmental changes in its native range. Meanwhile, these factors facilitate its ability to colonise its introduced ranges [26].

A study by Wu and Ding [5] discussed the abiotic factors in terms of environmental parameters and the biotic, species-specific factors influencing water hyacinth invasion. Interesting highlights from the abiotic study include the influence that the dissolved oxygen level has on reducing the plant growth, while high levels of conductivity, indicating nutrient availability, promotes the plant's propagation. Water hyacinth has also been proven to reduce the biodiversity of the invaded area, according to four biodiversity indices. Water hyacinth invasion was observed to reduce the overall biodiversity in terms of species richness and evenness. Various other factors may either promote and accelerate or limit and slow a water hyacinth infestation. These include temperature, nutrients, salinity, light, wind, water currents, carbon dioxide levels, waves, turbidity and changes in water levels [27][29]. In general, higher temperatures and greater nitrogen and phosphorus content are important factors promoting water hyacinth growth [27][29]. Higher salinity levels inhibit water hyacinth proliferation by inducing growth reduction and an increase in its mortality rate [30], which hamper invasions in coastal areas. In cases where both salinity and nutrients vary, nutrients will have a greater influence on the leaf count while total biomass remains limited [30]. A higher flow velocity reduces the probability that water hyacinth can become established. Consequently, a higher level of dissolved oxygen derived from the turbulence similarly limits the plant's growth. Water hyacinth has also been reported to reduce phytoplankton productivities due to the fall in dissolved oxygen and chlorophyll-a levels in water bodies covered by the plant. These have major ecological impacts on the infested water as the aquatic food web becomes disrupted, leading to a drop in aquatic species composition and biodiversity [31].

Despite the extensive knowledge of the inhibiting factors of the plant, the water hyacinth invasion rate can be uncontrollable, especially when aided by continuous inputs of nutrient pollution from agricultural activities. The mechanical harvesting of water hyacinth requires a weed harvester, an excavator and other heavy machinery. Physical harvesting may refer to the same process or involve manual harvesting. Both the mechanical and physical methods lead to an abundance of harvested biomass that must be managed. In contrast, chemical and biological methods aim to eradicate the weed. Chemical cleansing using herbicides kills the plant but may also affect non-target species [2]. Biological control involves the use of biocides or, more commonly, an insect predator of the plant, namely the weevil beetle. Biocides are not commonly used as they are less commercially available compared to their chemical counterparts [32]. Biological control using the weevil relies on its herbivorous nature to shorten the plant petioles and reduce the above- and below-surface biomass [33]. Although successful in reducing the size and increasing the mortality of the plant, weevil biocontrol fails in reducing the plant cover, one of the most important factors in deterring the invasion [33]. With such different approaches and varying levels of success, controlling water hyacinth invasions clearly requires an integrated approach using all available means to ensure long-term success and to avoid the re-establishment of an aquatic weed invasion.

3.2. Impacts on Rural Communities

The invasion of water hyacinth has a major impact on the rural people affected, especially those who depend on water bodies for their livelihoods, such as fishing and riparian communities [7][8][9][20][34]. As discussed by Dersseh et al. [1], a water hyacinth invasion has negative impacts on the hydrology and environment, resulting in subsequent socio-economic impacts, as it disrupts human daily activities and health. The increase in evapotranspiration compared to surface evaporation disrupts the hydrological water balance in the infected areas, which could disrupt local rainfall events. Reduced water flows in rivers due to water hyacinth blockages will promote sedimentation, deoxygenation and water quality deterioration. Weed canopies on lakes reduce sunlight penetration. This increases the water turbidity and reduces variability in temperatures, as well as other similar water quality concerns [35]. Consequently, all these events lead to a reduction in fish and other aquatic organism populations as their habitat becomes less habitable. Instead, the proliferation of disease vectors such as mosquitoes and snails will occur, as the plant hosts a variety of these species [9].

Dense weed mats mean limited access to waterways, leading to conflicts among the affected communities to gain access to watercourses. As water hyacinth is buoyant and not anchored, it moves with the wind. This is especially disruptive to fishermen, making boat navigation harder, delaying fishing preparation and resulting in fishing net entanglements and damage to other equipment [20]. In places with hydroelectric dams, the invasion has led to damaged generators and coolers and threats to the electricity supply [28][36]. Hence, locals' livelihoods are disrupted as many lose their source of income, incur costs due to damage and are further inconvenienced in many ways.

Coping strategies for water hyacinth invasion can be described as reactive- or recovery-based [34]. Reactive behaviour is a short-term coping mechanism for handling an immediate current situation. Affected communities tend to be reactive, for instance, by joining clean-up activities to remove the weed or simply halting their daily routine during the invasion peak. On the other hand, some communities have been reported to adopt alternative sources of income when interrupted by

water hyacinth. Such actions are considered recovery-based, as locals recover their livelihoods through other means, such as switching to agriculture.

From the rural perspective, water hyacinth has only negative impacts on communities, according to a survey conducted on communities affected by an invasion of Lake Tana, Ethiopia [7]. Livelihood security concerns may hinder the prospects for water hyacinth to be explored by a rural community, especially without support from relevant authorities, which can provide information and technical and financial aid [37]. Thus, a community tends to adopt alternatives to overcome its hardship. Consequently, the water hyacinth problem remains unresolved.

Therefore, a community must be empowered so that it becomes resilient in coping with a water hyacinth invasion. The problem tends to recur because fully eradicating the plant appears to be impossible as it rapidly expands its territory. The key to successful community involvement is the dissemination of information coupled with empowerment programmes. These approaches would enlighten locals, offering not only the knowledge but also the skills needed to manage water hyacinth for their benefit. One example of a successful empowering project was reported in Indonesia. The Bangkit Bersama Cooperation, a community empowerment institution, developed a water hyacinth waste scavenger programme in the Saguling Reservoir area that created job opportunities through the utilisation of the weed [38][39][40]. The success of such programmes highlights the importance of integrating the concept of the weed into the community and local livelihoods in order to ensure that its management is sustainable [37].

References

1. Dersseh, M.G.; Melesse, A.M.; Tilahun, S.A.; Abate, M.; Dagnew, D.C. Water hyacinth: Review of its impacts on hydrology and ecosystem services—Lessons for management of Lake Tana. In Extreme Hydrology and Climate Variability; Melesse, A.M., Abtew, W., Senay, G., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 237–251.
2. Villamagna, A.M.; Murphy, B.R. Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): A review. Freshw. Biol. 2010, 55, 282–298.
3. Eid, E.M.; Shaltout, K.H. Growth dynamics of water hyacinth (Eichhornia crassipes): A modeling approach. Rend. Lincei 2017, 28, 169–181.
4. Lolis, L.A.; Alves, D.C.; Fan, S.; Lv, T.; Yang, L.; Li, Y.; Liu, C.; Yu, D.; Thomaz, S.M. Negative correlations between native macrophyte diversity and water hyacinth abundance are stronger in its introduced than in its native range. Divers. Distrib. 2020, 26, 242–253.
5. Wu, H.; Ding, J. Abiotic and biotic determinants of plant diversity in aquatic communities invaded by water hyacinth [Eichhornia crassipes (Mart.) Solms]. Front. Plant Sci. 2020, 11.
6. Gezie, A.; Assefa, W.W.; Getnet, B.; Anteneh, W.; Dejen, E.; Mereta, S.T. Potential impacts of water hyacinth invasion and management on water quality and human health in Lake Tana watershed, Northwest Ethiopia. Biol. Invasions 2018, 20, 2517–2534.
7. Enyew, B.G.; Assefa, W.W.; Gezie, A. Socioeconomic effects of water hyacinth (Eichhornia crassipes) in Lake Tana, North Western Ethiopia. PLoS ONE 2020, 15, e0237668.
8. Honlah, E.; Segbefia, A.Y.; Appiah, D.O.; Mensah, M. The Effects of Water Hyacinth Invasion on Smallholder Farming along River Tano and Tano Lagoon, Ghana. Cogent Food Agric. 2019, 5, 1567042.
9. Honlah, E.; Yao Segbefia, A.; Odame Appiah, D.; Mensah, M.; Atakora, P.O. Effects of water hyacinth invasion on the health of the communities, and the education of children along River Tano and Abby-Tano Lagoon in Ghana. Cogent Soc. Sci. 2019, 5, 1619652.
10. Cerveira Junior, W.R.; Carvalho, L.B.d. Control of water hyacinth: A short review. Commun. Plant Sci. 2019, 9, 129–132.
11. Su, W.; Sun, Q.; Xia, M.; Wen, Z.; Yao, Z. The resource utilization of water hyacinth (Eichhornia crassipes [Mart.] Solms) and its challenges. Resources 2018, 7, 46.
12. Gaurav, G.K.; Mehmood, T.; Cheng, L.; Klemeš, J.J.; Shrivastava, D.K. Water hyacinth as a biomass: A review. J. Clean. Prod. 2020, 277, 122214.
13. Ilo, O.P.; Simatele, M.D.; Nkomo, S.P.L.; Mkhize, N.M.; Prabhu, N.G. The Benefits of Water Hyacinth (Eichhornia crassipes) for Southern Africa: A Review. Sustainability 2020, 12, 9222.
14. Jafari, N. Ecological and socio-economic utilization of water hyacinth (Eichhornia crassipes Mart Solms). J. Appl. Sci. Environ. Manag. 2010, 14, 43–49.

15. Li, F.; He, X.; Srishti, A.; Song, S.; Tan, H.T.W.; Sweeney, D.J.; Ghosh, S.; Wang, C.-H. Water hyacinth for energy and environmental applications: A review. Bioresour. Technol. 2021, 327, 124809.
16. Sindhu, R.; Binod, P.; Pandey, A.; Madhavan, A.; Alphonsa, J.A.; Vivek, N.; Gnansounou, E.; Castro, E.; Faraco, V. Water hyacinth a potential source for value addition: An overview. Bioresour. Technol. 2017, 230, 152–162.
17. Ali, S.; Abbas, Z.; Rizwan, M.; Zaheer, I.E.; Yavaş, İ.; Ünay, A.; Abdel-Daim, M.M.; Bin-Jumah, M.; Hasanuzzaman, M.; Kalderis, D. Application of Floating Aquatic Plants in Phytoremediation of Heavy Metals Polluted Water: A Review. Sustainability 2020, 12, 1927.
18. Buller, L.S.; Bergier, I.; Ortega, E.; Salis, S.M. Dynamic emergy valuation of water hyacinth biomass in wetlands: An ecological approach. J. Clean. Prod. 2013, 54, 177–187.
19. De Groote, H.; Ajuonu, O.; Attignon, S.; Djessou, R.; Neuenschwander, P. Economic impact of biological control of water hyacinth in Southern Benin. Ecol. Econ. 2003, 45, 105–117.
20. Segbefia, A.Y.; Honlah, E.; Appiah, D.O. Effects of water hyacinth invasion on sustainability of fishing livelihoods along the River Tano and Abby-Tano Lagoon, Ghana. Cogent Food Agric. 2019, 5, 1654649.
21. Jones, R.W. Integrated control of water hyacinth on the Nseleni/Mposa Rivers and Lake Nsezi, Kwa Zulu-Natal, South Africa. In Biological and Integrated Control of Water Hyacinth: Eichhornia crassipes, Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, Beijing, China, 9–12 October 2000; Australian Centre for International Agricultural Research (ACIAR): Canberra, Australia, 2000; pp. 123–129.
22. Yitbarek, M.; Belay, M.; Bazezew, A. Determinants of manual control of water hyacinth expansion over the Lake Tana, Ethiopia. Int. J. Sci. Technol. 2019, 8, 1–14.
23. Fanghella, V.; d'Adda, G.; Tavoni, M. On the use of nudges to affect spillovers in environmental behaviors. Front. Psychol. 2019, 10, 1–18.
24. Schubert, C. Green nudges: Do they work? Are they ethical? Ecol. Econ. 2017, 132, 329–342.
25. Hilton, D.; Treich, N.; Lazzara, G.; Tendil, P. Designing effective nudges that satisfy ethical constraints: The case of environmentally responsible behaviour. Mind Soc. 2018, 17, 27–38.
26. Zhang, Y.Y.; Zhang, D.Y.; Barrett, S.C.H. Genetic uniformity characterizes the invasive spread of water hyacinth (Eichhornia crassipes), a clonal aquatic plant. Mol. Ecol. 2010, 19, 1774–1786.
27. Wilson, J.R.; Holst, N.; Rees, M. Determinants and patterns of population growth in water hyacinth. Aquat. Bot. 2005, 81, 51–67.
28. Lu, J.; Wu, J.; Fu, Z.; Zhu, L. Water hyacinth in China: A sustainability science-based management framework. Environ. Manag. 2007, 40, 823.
29. Zarkami, R.; Esfandi, J.; Sadeghi, R. Modelling Occurrence of Invasive Water Hyacinth (Eichhornia crassipes) in Wetlands. Wetlands 2021, 41, 8.
30. Bick, E.; de Lange, E.S.; Kron, C.R.; da Silva Soler, L.; Liu, J.; Nguyen, H.D. Effects of salinity and nutrients on water hyacinth and its biological control agent, Neochetina bruchi. Hydrobiologia 2020, 847, 3213–3224.
31. Mironga, J.M.; Mathooko, J.M.; Onywere, S.M. Effect of water hyacinth infestation on the physicochemical characteristics of Lake Naivasha. Int. J. Humanit. Soc. Sci. 2012, 2, 103–113.
32. Dagno, K.; Lahlali, R.; Diourté, M.; Jijakli, H. Present status of the development of mycoherbicides against water hyacinth: Successes and challenges. A review. Biotechnol. Agron. Société Environ. 2012, 16, 360–368.
33. Jones, R.W.; Hill, J.M.; Coetzee, J.A.; Hill, M.P. The contributions of biological control to reduced plant size and biomass of water hyacinth populations. Hydrobiologia 2018, 807, 377–388.
34. Honlah, E.; Appiah, D.O.; Segbefia, A.Y. Coping strategies to water hyacinth invasion among riparian communities in Ghana. Am. J. Environ. Sustain. Dev. 2019, 4, 12–25.
35. Tobias, V.D.; Conrad, J.L.; Mahardja, B.; Khanna, S. Impacts of water hyacinth treatment on water quality in a tidal estuarine environment. Biol. Invasions 2019, 21, 3479–3490.
36. Tewabe, D. Preliminary survey of water hyacinth in Lake Tana, Ethiopia. Glob. J. Allergy 2015, 1, 013–018.
37. Rakotoarisoa, T.F.; Waeber, P.O.; Richter, T.; Mantilla-Contreras, J. Water hyacinth (Eichhornia crassipes), any opportunities for the Alaotra wetlands and livelihoods? Madag. Conserv. Dev. 2015, 10, 128–136.
38. Akhyadi, A.S.; Sadikin, I.S. The construct of community empowerment through social compass strategy: Case study of empowerment in processing waste and water hyacinth. Int. J. Educ. Stud. 2020, 13, 27–48.

39. Ramadani, R.F.; Heryanto, N.; Komar, O.; Hasanah, V.R. Community empowerment through social compass strategy: Case study of empowerment in processing waste and water hyacinth. J. Nonform. Educ. 2020, 6, 9.
40. Ramadani, R.F.; Akhyadi, A.S.; Heryanto, N. Community Empowerment Strategy in Bangkit Bersama Cooperation (Case Study of the Waste Management and Water Hyacinth Craftsmen Empowerment Program). Int. Conf. Elem. Educ. 2020, 2, 1567–1573.