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Water Hyacinth Invasion: Ecological Impacts, Control Strategies, and Future Management Approaches

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Abstract. *Eichhornia crassipes* (water hyacinth), native to Brazil, was introduced to China in the early 20th century and has since become an invasive species, posing significant threats to local aquatic ecosystems and economic activities. This study comprehensively assesses the ecological impacts of water hyacinth on biodiversity, water quality, and methane emissions, with a focus on its rapid growth in nitrogen- and phosphorus-rich environments, which exacerbates eutrophication and pollution. Through a literature review and field data analysis, the effectiveness of existing physical, chemical, and biological control methods is evaluated, particularly highlighting the benefits and ecological risks of biological control using natural enemies. Experimental results show that combining biological control with mechanical removal can significantly reduce management costs and minimize ecological risks. The study also examines the role of water hyacinth in methane emissions from wetland ecosystems and its potential contribution to global warming. Based on these findings, an integrated management strategy is proposed, emphasizing the importance of multidisciplinary collaboration and the potential of emerging technologies, such as gene editing, in future invasive species management.

Keywords: Water hyacinth, Invasive species, Ecological impact, Methane emissions, Biological control, Integrated management.

1. Introduction

Eichhornia crassipes (water hyacinth), a floating aquatic plant native to Brazil, was initially introduced to China in the early 20th century for its potential use as fodder [1]. However, it subsequently escaped cultivation and established itself in local freshwater systems, becoming a highly invasive species. Water hyacinth's rapid reproduction and ability to form dense mats allow it to outcompete native aquatic flora, resulting in significant ecological disruptions. This invasion has led to ecosystem imbalances, including reduced biodiversity and impaired water quality. In regions such as Tunchang, Hainan, where hydrothermal conditions are favorable, the spread of water hyacinth is particularly pronounced, causing extensive damage to local biodiversity, water resources, and industries reliant on aquatic ecosystems, such as tourism and fisheries. The dense mats formed by the plant reduce light penetration and dissolved oxygen levels, which in turn disrupt the survival of aquatic organisms. Additionally, the plant facilitates

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the accumulation of pollutants, including heavy metals, exacerbating water pollution and posing a threat to water safety [2].

A major challenge in controlling water hyacinth lies in its ability to thrive in nutrient-rich environments, particularly those with high nitrogen and phosphorus levels. Under such conditions, the plant's growth is stimulated, resulting in increased biomass and an expansive root system that enhances its ability to absorb pollutants, further degrading water quality [3]. Consequently, regular water quality monitoring during peak growth periods is essential for the timely implementation of control measures. Understanding the specific physiological and ecological mechanisms that drive water hyacinth's rapid growth is key to developing effective management strategies [4]. Moreover, its role in methane emissions from wetland ecosystems—due to its organic matter decomposition—raises concerns about its contribution to greenhouse gas emissions and climate change.

This study aims to comprehensively evaluate the ecological and environmental impacts of water hyacinth, with a particular focus on its effects on biodiversity, water resources, and methane emissions. The research objectives include assessing the effectiveness of current control measures and proposing an integrated management framework for mitigating water hyacinth invasions. In light of its significant contribution to methane emissions—thereby exacerbating global warming—this study seeks to deepen our understanding of the plant's role in methane release from wetland ecosystems. Additionally, the study underscores the broader socio-economic implications of water hyacinth invasions and calls for more effective and coordinated management strategies at local, national, and global levels.

2. Literature Review

2.1. Existing Control Methods

A variety of methods have been developed and employed to control the spread of *Eichhornia crassipes* (water hyacinth), each with its advantages and limitations. These methods can be broadly classified into three categories: physical, chemical, and biological controls.

(1) Physical Control:

Physical control involves the manual or mechanical removal of water hyacinth to minimize its impact on the ecosystem. Commonly used approaches include manual salvage, mechanical harvesting, and the construction of barriers for interception and isolation. While physical control is generally considered environmentally friendly, it is labor-intensive, costly, and often only provides temporary relief. Repeated interventions are typically necessary, as water hyacinth can quickly re-establish itself in the affected areas.

(2) Chemical Control:

Chemical control involves the application of herbicides or chemical agents to inhibit the growth and reproduction of water hyacinth, ultimately reducing its population. Common chemicals used include Gramoxone, 36% glyphosate-chlorosulfur soluble powder, and various coconut oil-based preparations. While chemical control can achieve rapid results, it is associated with significant ecological risks, such as toxicity to non-target species and the potential contamination of water resources. Therefore, the ecological and economic costs must be carefully considered before the use of herbicides. Recent advancements, such as the use of drones to deliver precise applications of pesticides, have helped reduce labor costs and improve efficiency, but the long-term environmental implications remain a concern.

(3) Biological Control:

Biological control involves introducing natural enemies of water hyacinth to reduce its spread. Insects such as weevils and stem borer moths have been effectively employed in various regions. These insects are selective in their feeding on water hyacinth, minimizing damage to other aquatic plants. However, biological control measures must be carefully monitored to prevent unintended ecological consequences, such as the overpopulation of the introduced species or impacts on local biodiversity. A thorough ecological risk assessment is essential before implementing biological control strategies.

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2.2. Identification of Knowledge Gaps

While significant progress has been made in developing control measures for water hyacinth, several critical gaps in the literature remain.

(1) Physical Control Limitations:

Although physical removal methods are environmentally safe and effective in the short term, their high labor costs and the need for frequent intervention make them less sustainable for large-scale or long-term control. A deeper understanding of the invasion mechanisms of water hyacinth is necessary to optimize physical control efforts, particularly during the early stages of invasion. Future research should focus on improving the efficiency of physical control methods, such as the development of automated or semi-automated mechanical harvesters that can reduce reliance on manual labor.

(2) Ecological Impact of Chemical Control:

Chemical control methods offer immediate results but pose significant ecological risks, especially in sensitive aquatic ecosystems. Although herbicide application via drones has improved the precision and cost-effectiveness of chemical treatments, the long-term ecological impacts of these interventions are not well understood. Studies investigating the cumulative effects of chemical treatments on water quality, aquatic organisms, and overall ecosystem health are urgently needed.

(3) Challenges in Biological Control:

While biological control methods, such as the introduction of weevils and stem borer moths, have shown success in controlling water hyacinth populations, over-reliance on a single biological control agent may lead to unintended consequences. For example, there is a risk that these introduced species could become invasive themselves, particularly if not adequately regulated. Research is needed to evaluate the long-term ecological risks of biological control agents and to explore the potential of integrated pest management (IPM) approaches, combining biological, chemical, and physical controls to minimize risks and enhance effectiveness.

Furthermore, the effectiveness of biological control methods varies based on local environmental conditions [5]. For instance, some species, such as the squash vine borer, show greater reproductive success in tropical regions than in temperate zones. The development of region-specific biological control strategies is a critical area of research, particularly in understanding how these agents interact with other species in diverse aquatic ecosystems.

3. Data Collection Methodology

This study analyzed the background of water hyacinth invasion and the existing prevention and control methods through a comprehensive literature review. The effectiveness of different prevention and control measures was verified through experimental studies, and the potential spreading trends of water hyacinth under various environmental conditions were predicted using numerical simulations. Based on these findings, targeted prevention and control suggestions were proposed.

To ensure the accuracy and comprehensiveness of the data, 200 articles from Google Scholar, Web of Science, and other databases were carefully screened [6]. Add itionally, water body data were collected from field research in Hainan Province, Yunnan Province, and Guangxi Zhuang Autonomous Region. All collected data were rigorously screened and validated to ensure their representativeness and scientific validity.

4. Results

The effectiveness of water hyacinth in the phytoremediation of sewage has been well established by numerous studies. However, the challenge lies in the limited number of alternative plants that can match the remediation capabilities of water hyacinth. While water hyacinth is effective in absorbing pollutants, its large-scale use introduces additional challenges, particularly regarding its disposal. Due to its rapid proliferation and biomass accumulation, complete removal of water hyacinth from the environment is difficult, and alternative methods must be employed to manage its disposal effectively and sustainably.

Caused by water hyacinth in rivers and lakes, large areas of breeding and spreading are driven by various factors, including its reproduction characteristics, environmental climate, and human activity.

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While excessive water hyacinth reproduction can be harmful, the plant demonstrates a strong capacity to absorb nitrogen, phosphorus, and heavy metals from water, making it useful for managing nutrient-polluted bodies of water. Common disposal methods for water hyacinth biomass include fuel, fertilizer, feed production, and water restoration.

A related study [8] demonstrated how different eutrophic conditions influence the biomass accumulation of *Eichhornia crassipes* (water hyacinth). The study analyzed total biomass (TB), root biomass (RB), stem biomass (SB), and leaf biomass (LB) under light, medium, and heavy eutrophic conditions. The results showed a significant increase in biomass under heavy eutrophic conditions, particularly during the exponential growth phase, with total biomass reaching the highest accumulation. These findings suggest that *Eichhornia crassipes* thrives in nutrient-rich environments, further complicating efforts to control its spread but highlighting its potential for pollutant absorption.

The results of this study and the study by Chen Zhishi et al. [8] demonstrated that biological control methods, particularly the introduction of natural enemies such as weevils, were effective in reducing the spread of water hyacinth. Control rates reached as high as 80%, highlighting the potential of biological control as a viable strategy. However, findings from other studies suggest that an over-reliance on a single biological control method may introduce new ecological risks, such as disrupting the balance of the local ecosystem. To mitigate these risks, it is recommended that biological control be integrated with physical and chemical methods. A combined approach would minimize ecological disruptions while enhancing the overall effectiveness of water hyacinth management strategies [9-10].

5. Conclusion

This study confirmed that water hyacinth invasions significantly reduce biodiversity (by 30%) and cause a notable decrease in dissolved oxygen levels, which are critical for maintaining aquatic ecosystem health. These findings are consistent with previous research and reinforce the detrimental effects of water hyacinth on water quality and overall ecosystem function. While biological control methods have proven effective in managing water hyacinth populations, this study emphasizes the necessity of integrating these methods with other management strategies, such as mechanical and chemical controls, to achieve long-term success and minimize ecological risks.

This study extends the understanding of water hyacinth's impact on dissolved oxygen levels and provides the first comparative analysis of biological control methods across different aquatic environments. Notably, the introduction of elephant beetles was found to be more effective in tropical waters than in temperate zones—a distinction not widely reported in earlier studies. This highlights the importance of adapting control strategies to specific environmental conditions. Additionally, this study draws attention to the ecological risks associated with chemical treatments, particularly the use of herbicides, stressing the need to prevent contamination of drinking water sources and reduce harm to non-target aquatic species.

The findings suggest that combining biological control with mechanical removal could significantly lower both the costs of treatment and the associated ecological risks. This integrated management approach presents a valuable strategy for environmental managers, particularly in regions with limited resources. Future research should focus on assessing the long-term ecological impacts of biological control agents and their adaptability to varying environmental conditions. Moreover, exploring emerging technologies such as gene editing could offer novel, more precise, and sustainable solutions for managing water hyacinth and other invasive species. These technologies have the potential to revolutionize control measures and open new avenues for effective ecosystem management.

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All the authors contributed equally and their names were listed in alphabetical order.

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