diversity

MDPI

Review

A Comprehensive Review of the Biology, Ecological Impacts, and Control Strategies of *Eichhornia crassipes*

Matlhatse Daisy Khotsa, Nqobile Monate Mkolo, Mmei Cheryl Motshudi, Mukhethwa Micheal Mphephu, Mmamudi Anna Makhafola and Clarissa Marcelle Naidoo *

Department of Biology and Environmental Sciences, School of Science and Technology, Sefako Makgatho Health Science University, Pretoria 0204, South Africa; mdkhotsa.daisy@gmail.com (M.D.K.); nqobile.mkolo@smu.ac.za (N.M.M.); cheryl.motshudi@smu.ac.za (M.C.M.); 201429242@swave.smu.ac.za (M.M.M.); annammamudimakhafola@gmail.com (M.A.M.)
* Correspondence: clarissa.naidoo@smu.ac.za

Abstract

Eichhornia crassipes, also known as water hyacinth, is a harmful aquatic weed that has spread globally, causing significant ecological and economic damage. Originating in the Amazon basin, it has spread to tropical and subtropical regions, obstructing water movement, limiting sunlight, and reducing oxygen levels. Control measures for *E. crassipes* include chemical, mechanical, and biological methods. Chemical controls are cost-effective but present environmental hazards, whereas mechanical removal is effective but expensive and labor-intensive. Lastly, biological control uses natural predators to reduce weeds. Despite its significant costs, *E. crassipes* has potential applications in bioenergy, biofertilizer production, and wastewater treatment. This review includes an overview of *E. crassipes*' biology, reproductive strategies, socioeconomic impact, and management approaches, as well as an exploration of its potential benefits in Africa's sub-Saharan region, especially South Africa.

Keywords: *Eichhornia crassipes*; water hyacinth; management strategies; ecological impact; potential benefits

check for updates

Academic Editor: Mario A. Pagnotta

Received: 11 June 2025
Revised: 8 August 2025
Accepted: 9 August 2025
Published: 12 August 2025

Citation: Khotsa, M.D.; Mkolo, N.M.; Motshudi, M.C.; Mphephu, M.M.; Makhafola, M.A.; Naidoo, C.M. A Comprehensive Review of the Biology, Ecological Impacts, and Control Strategies of *Eichhornia crassipes*. *Diversity* **2025**, *17*, 564. https://doi.org/10.3390/d17080564

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Eichhornia crassipes (Mart.) Solms, commonly known as water hyacinth, is an invasive plant that belongs to the family Pontederiaceae [1,2]. Recent phylogenetic research suggests that *E. crassipes* should be reclassified as *Pontederia crassipes* [3]. However, for consistency with current ecological research and invasive species management in South Africa, where the traditional name is still commonly used [4,5], this review continues to refer to the species as *E. crassipes*.

The species was first described as *Pontederia crassipes* by the German naturalist Carl Friedrich Philipp von Martius in 1823. It was later reclassified and renamed *Eichhornia crassipes* by Paul Friedrich August Ascherson and Ludwig Ascherson von Solms-Laubach in 1883 [6]. The weed was introduced as an ornamental species to enhance water bodies in many places due to its beautiful blue or purple flowers and oblong to oval, glossy leaves with bulbous or spongy petioles [7].

Eichhornia crassipes produces dense floating mats on the water surface, which tend to impede sunlight penetration and the exchange of gases between the water surface and the atmosphere [8]. It has spread from the Amazon basin to tropical and subtropical countries

in Latin America, the Caribbean, Africa, Southeast Asia, and the Pacific [9]. *E. crassipes* mats can affect irrigation systems, obstruct water flow, and reduce oxygen levels in the water, potentially killing fish as well as adversely affecting aquatic plants, amphibians, waterbirds, and invertebrates that rely on open water and oxygen-rich habitats [10,11]. Due to its quick spread throughout waterways, *E. crassipes* is one of the world's worst invasive, perennial, herbaceous, free-floating aquatic weeds [6]. Furthermore, it also creates a breeding environment for mosquitoes, increasing the risk of waterborne infections, such as malaria, dengue fever, and Zika virus [10].

In the treatment of water and the reduction of *E. crassipes*, three main strategies are commonly used: chemical, mechanical, and biological control [12]. Chemical control, while cost-effective, is not ideal for long-term solutions due to its negative environmental impacts, including the contamination of soil and water with pesticides and herbicides, posing risks to ecosystems and humans [13]. On the other hand, mechanical control involves advanced technology and has demonstrated its ability to recover significant biomass [14]. However, the high costs associated with acquiring and maintaining mechanical equipment and personnel limit its potential effectiveness [10,15]. In contrast, biological management holds promise as a sustainable approach for *E. crassipes* reduction, as it can mitigate invasive species' advantages over native plants, offering a long-term solution [16]. Biological control uses natural predators to control weeds, such as weevils (*Neochetina eichhorniae* and *Neochetina bruchi*), planthoppers (*Megamelus scutellaris*), and fungal species, such as *Fusarium* spp. and *Aspergillus* spp., which have been widely used in South Africa to control *E. crassipes* [17].

Eichhornia crassipes was introduced to South Africa as an ornamental plant in 1900 and quickly spread among gardeners, aquarium owners, and boating enthusiasts [18]. The literature has reported that it has spread throughout the country, but it is especially prevalent in Natal's coastal districts, the Vaal, and both Crocodile rivers in Transvaal [17]. The cost of controlling these invasive species is significant, and southern African countries are inadequately suited for this task, as the process must be undertaken constantly [1]. Estimates suggest that invasive alien plants cost South Africa approximately ZAR 6.5 billion per year (about 0.3% of the national GDP), and, if left unmanaged, these costs could exceed 5% of the GDP [1]. However, there are potential benefits of *E. crassipes* that can be useful to create economic and environmental returns [12,19,20]. The objective of this review is to provide a comprehensive analysis of *E. crassipes*, focusing on its biological characteristics, reproductive strategies, and ecological impacts and the effectiveness of various control methods, while also exploring its potential applications in bioenergy, biofertilizer production, and wastewater treatment. While there are several reviews on *E. crassipes* around the world, there is an evident gap in region-specific syntheses that focus on the species' unique ecological, economic, and management difficulties in sub-Saharan Africa, including, notably, South Africa. This review aims to fill the gap by offering a thorough and geographically contextualized analysis of *E. crassipes*, including its range, ecological effects, and control techniques, as found in Southern African environments. This research aims to inform both local management methods and worldwide discussions about invasive aquatic plant control, evaluate the ecological effects of *E. crassipes* invasion, synthesize current management strategies, and emphasize its potential benefits, particularly in a South African context. To effectively support these aims, a comprehensive literature evaluation was conducted, as outlined in the following section. Furthermore, the review will investigate the ecological significance of *E. crassipes* and include recently published management measures pertinent to its control.

2. Methodology

To ensure thorough and relevant literature coverage, we performed a structured search of databases, such as PubMed, Scopus, and Google Scholar. Keywords included "*Eichhornia crassipes*", "water hyacinth", "biological control", "mechanical control", "chemical control", "invasive aquatic plants", "management strategies", "socioeconomic", and "utilization".

The literature produced between 2000 and 2024 was reviewed systematically. While priority was given to research published after 2020 due to its modern relevance, older studies were also considered if they provided fundamental information, historical contexts, or were extensively cited with reference to the ecology, distribution, and management strategies of *Eichhornia crassipes*. We included peer-reviewed journal papers, government and non-governmental organization reports, and regional case studies relevant to South Africa, sub-Saharan Africa, and the global context.

Articles were chosen based on their relevance to the following topics: ecological impact, reproduction and distribution, control and management strategies (biological, mechanical, chemical, integrated), and socioeconomic usage. Review papers served as a backdrop, while primary research and case studies provided evidence. Duplicates and papers not relevant to aquatic invasive species were eliminated (Figure 1). The qualitative synthesis comprised 57 papers that were relevant to the ecological implications, control techniques, and potential uses of *E. crassipes*, with a specific focus on sub-Saharan Africa.

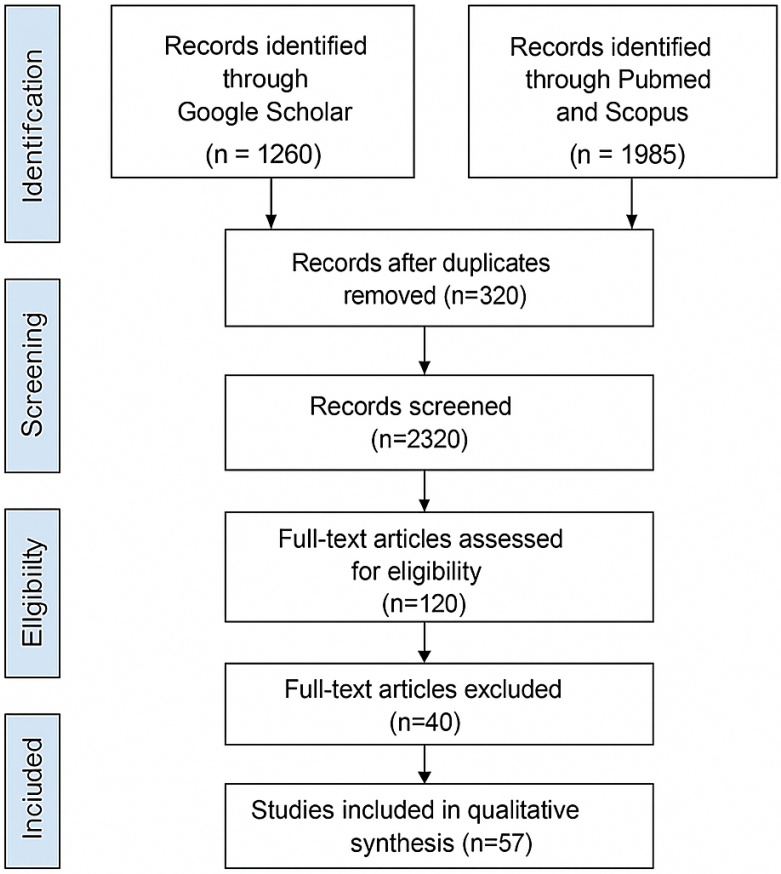


Figure 1. Flowchart illustrating the identification, screening, eligibility, and inclusion of papers assessed using a PRISMA-inspired technique.

These studies are fully cited in the reference list and identified as relevant to key review sections (Sections 6–10). A PRISMA-style flowchart (Figure 1) depicts the inclusion process.

3. Taxonomic and Biological Overview

Eichhornia is a genus with seven species [21]: *E. natans*, *E. heterosperma*, *E. crassipes*, *E. azurea*, *E. diversifolia*, *E. paniculata*, and *E. paradoxa*. Only two of the seven species, *E. natans* and *E. crassipes*, are numerous in Africa, with the latter being particularly common in Nigeria [21]. *Eichhornia azura*, which was first discovered in Jamaica, has extensively spread, with a range that almost totally overlaps that of *E. crassipes* [22]. *Eichhornia crassipes* is abundantly dispersed throughout South America. *Eichhornia diversifolia* is mostly found in Brazil but also in Surinam, Cuba, Haiti, Puerto Rico, and Santo Domingo [21], whereas *E. paniculata* is found primarily in northern Argentina and Brazil [23]. *Eichhornia* has two endemic species: *E. natans* (Beauv.) Solms, which are found in Senegal, Sudan, Nigeria, and Mali, and *E. paradoxa* Solms, which are found in Brazil and probably Caracas, Venezuela [22]. According to the literature, *E. crassipes* are the most prevalent of the seven species of crassipes [2]. *Eichhornia crassipes* are from the family Pontederiaceae and distinguished from other similar water plants by their shiny leaves, the partial lump of their petioles, and the distinctive purple blooms [2].

4. Morphological Characteristics of *E. crassipes*

4.1. Leaf Structure

Eichhornia crassipes leaves float on the water's surface because of their thick, glossy, and buoyant nature [1], as seen in Figure 2. The presence of air-filled sacs in the leaves and stems allows them to float on the surface of the water [23]. Radially arranged leaves surround the primary stem to form a dense canopy that blocks light from the underlying water and competes with natural aquatic vegetation [24]. The plant's broad, glossy leaves with air-filled tissues not only allow it to float but also promote the production of dense mats that block sunlight from reaching submerged aquatic plants, outcompeting native flora and affecting ecosystem dynamics [7,25]. Additionally, the floating leaves help prevent water from evaporating from the surface and provide a habitat for a variety of aquatic creatures [2]. The plump green leaves allow for photosynthesis, and the plant can reach a height of up to 1 m, with an average of 40–60 cm [2]. The plant's capacity to float allows it to grow in adverse environments, such as damp sediments, for a lengthy period.

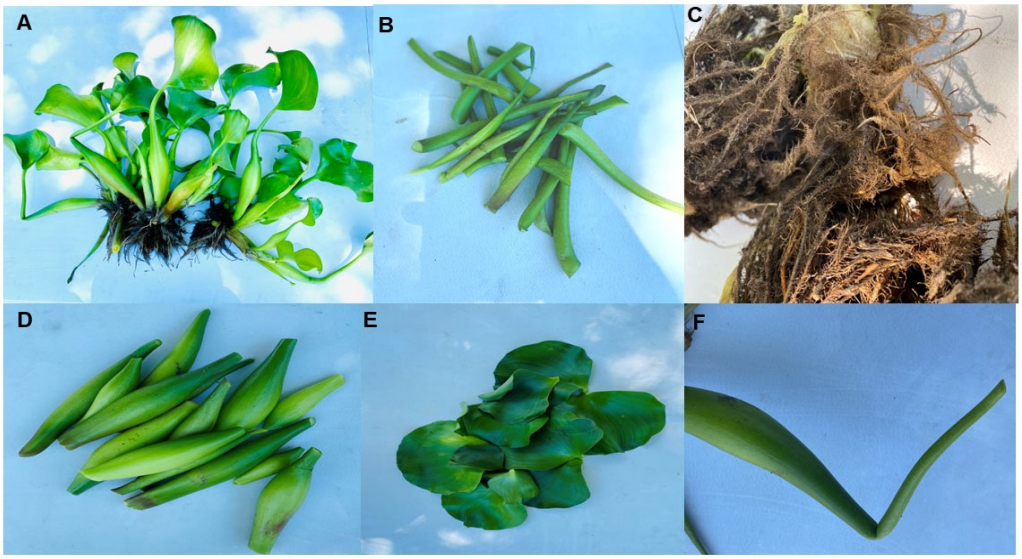


Figure 2. *Eichhornia crassipes* plant (images captured by Khotsa M.D). (**A**) *Eichhornia crassipes* (Mart.) whole plant; (**B**) stolon; (**C**) roots; (**D**) spongy petiole; (**E**) leaves; (**F**) petiole.

4.2. Flower and Inflorescence

Eichhornia crassipes has stunning lavender–blue flowers that are carried above the water's surface on upright stalks [13]. The inflorescence is composed of multiple individual flowers grouped into a raceme that resembles a spike [6]. Every flower has six petals, with the bottom petals displaying a noticeable yellow patch that directs pollinators toward the nectar. *Eichhornia crassipes* has a beautiful appearance, but its prodigious flowering adds to its ability to proliferate and spread [2]. The plant's inflorescence may produce 6–10 flowers, comparable to lilies, each measuring 4–7 cm in diameter [21]. *Eichhornia crassipes* in South Africa shows maximum vegetative growth during the warmer seasons, with best proliferation at water temperatures of 24 to 30 °C. Growth slows significantly during the colder months, but plants may continue to grow well in sheltered areas or thermally stable water bodies [17]. Local temperature fluctuations and fertilizer levels in eutrophic waters influence these phenological patterns.

4.3. Petiole and Spongy Petiole

Eichhornia crassipes can float on water because of its spongy, bulbous, and buoyant petiole, as observed in Figure 2 [26]. It has aerenchyma tissue, which improves gas exchange and buoyancy by having air gaps [10]. The petiole's suppleness allows it to tolerate currents; its length and thickness fluctuate depending on the surrounding conditions [2]. Furthermore, the bulbous petiole, which includes spongy aerenchyma tissue, gives *E. crassipes* buoyancy and flexibility, allowing it to float and spread horizontally across water surfaces [24,25]. This structural adaptability is critical for the plant's rapid vegetative reproduction and ability to colonize extensive aquatic habitats [27]. In addition, it is vital to the plant's ability to stay afloat and spread quickly in aquatic habitats, and its size and form vary according to the surroundings [1].

4.4. Root System

Eichhornia crassipes has long, loosely hanging, feathery roots that dangle freely in the water column as part of its root system, indicated in Figure 2 [1]. The roots are black and purple, and they stabilize the plant by anchoring it to the substrate and preventing it from floating with the flow of water to absorb nutrients [2,27]. In addition to providing microhabitats for aquatic creatures, the large root system aids in the cycling of nutrients and stabilizes silt [10]. The long, fibrous roots also improve nutrient absorption, especially in eutrophic environments, and form microhabitats that disrupt natural species. Furthermore, the root system supports the floating mats, which contribute to the plant's persistence and invasiveness [10,28]. Its growth is easily stimulated in the presence of nutrients, particularly due to excess nitrate and phosphate concentrations, its high rate of vegetative development and reproduction, and its production of seeds with the ability to remain viable for very long periods (up to 15 years) and four daughter plants (from each mother plant) that possess the ability to reproduce after two weeks [23]. Huang et al. [28] found that eutrophic conditions had significant impacts on the root morphological and topological features of *E. crassipes*, increasing its ability to absorb nutrients and maintain high growth rates. This adaptability in root architecture enables the species to thrive in nutrient-rich waters, contributing to its aggressive invasiveness and dominance in aquatic habitats [28].

5. Reproduction and Growth

As mentioned, *E. crassipes* is a highly invasive plant that spreads quickly through aquatic environments all over the world, mainly due to its rapid reproduction and growth [6]. To manage and control *E. crassipes* populations, one must comprehend the mechanisms underlying growth and reproduction [2]. This section examines the growth

patterns, reproductive tactics, and other elements that affect *E. crassipes*' proliferation rate [29–37]. Ref. [17] has shown that *E. crassipes* is mostly stoloniferous as a means of vegetative reproduction. These stolons, or horizontal stems, spread across the water's surface and give rise to daughter plants at nodes along their length [12]. After developing a rosette of leaves and roots, each daughter plant finally separates from the parent to become an individual [2]. *Eichhornia crassipes* populations can quickly colonize and spread due to this vegetative growth method [25].

Although the main method of proliferation for *E. crassipes* is vegetative reproduction, it can also reproduce sexually by producing flowers and seeds [6]. For instance, *E. crassipes* seeds are predominantly spread by water currents, which transport them across aquatic ecosystems, allowing for colonization of new places. Furthermore, birds and human activities may contribute to the unintended spread of seeds across extended distances. The plant bears striking lavender–blue flowers that are held above the water's surface on upright stalks [2]. Because every flower has both male and female reproductive parts, self-pollination is made easier [10]. The blossoms become tiny, buoyant fruits with several seeds after fertilization. However, compared to vegetative reproduction, sexual reproduction is less prevalent in *E. crassipes*, particularly in populations that are not native [1]. Under ideal environmental circumstances, *E. crassipes* grows quickly; a single plant can double its biomass in a few short days [25]. Water depth, light intensity, temperature, and nutrient availability are a few examples of the variables that affect growth rates [30,31]. In South Africa, *E. crassipes* has demonstrated aggressive vegetative growth in nutrient-rich and slow-flowing water bodies, such as the Vaal River and Hartbeespoort Dam. Under these conditions, the plant can double its biomass within 5–15 days, forming dense mats that obstruct water flow, reduce oxygen levels, and outcompete native aquatic vegetation [17]. Studies from Gauteng and KwaZulu-Natal provinces confirm that eutrophication and elevated summer temperatures (20–30 °C) significantly accelerate reproduction and spread [11,13,17].

Plants thrive in well-lit environments with little shade because photosynthesis and biomass formation depend on adequate sunlight [32]. Growth is largely dependent on the availability of nutrients, especially nitrogen and phosphorus, with nutrient-rich waters favoring fast multiplication [33]. *Eichhornia crassipes* populations' development and dispersion are also influenced by water velocity, temperature, pH, and depth [34]. The management and control efforts of *E. crassipes* are confronted with substantial obstacles due to their swift development and abundant reproduction [35]. *Eichhornia crassipes* populations are often suppressed by mechanical removal, chemical herbicides, biological control agents, and integrated management techniques [10]. Effective management tactics, however, necessitate considering the reproductive and developmental features of the plant in addition to the underlying environmental conditions that propel its expansion [36].

6. Global Distribution

Understanding the biological traits of *E. crassipes* provides insight into its global distribution, particularly across tropical and subtropical regions. Native to the Amazon Basin, especially Brazil, the species has adapted to warm climates and aquatic environments [6,29,37]. Over time, *E. crassipes* has spread extensively to parts of North, Central, and South America, Europe, Asia, and Africa, with reports from the United States, the Virgin Islands, Argentina, Venezuela, El Salvador, India, Indonesia, and numerous other countries [2,37,38]. In sub-Saharan Africa, the species is well established in countries like Nigeria, Ethiopia, Kenya, Uganda, Tanzania, and South Africa, where it thrives in nutrient-rich, slow-moving waters, particularly in river systems and human-made reservoirs [29,37]. One of the most severe infestations has occurred in Lake Victoria, shared

by Kenya, Uganda, and Tanzania, where the weed has significantly affected biodiversity, fisheries, and local economies [29]. Similarly, in East Asia, particularly China, *E. crassipes* has disrupted freshwater ecosystems, with dense mats reducing native epiphytic algal populations [39].

In South Africa, *E. crassipes* was introduced around 1900, largely via the ornamental plant trade and unregulated aquatic plant movement [40]. It is now well established in provinces like KwaZulu-Natal, North West, and Gauteng, with major infestations reported in the Vaal River, Crocodile River, Hartbeespoort Dam, and Roodeplaat Dam [4,11]. These ecosystems are especially vulnerable due to heavy nutrient loading from wastewater effluent and agricultural runoff. Eutrophic conditions, coupled with low water flow and elevated summer temperatures, create optimal conditions for rapid proliferation. As shown in Figure 3, the species is widely distributed across the country, with infestations linked primarily to anthropogenic dispersal [40].

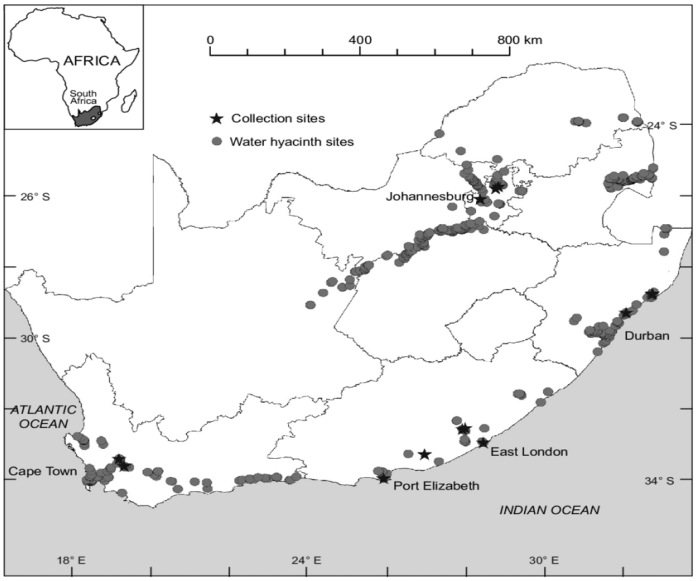


Figure 3. Areas of South Africa infested by *Eichhornia crassipes* and the collection locations of diseased plant parts from which phytopathogens were isolated [40].

7. Habitat Requirements and Invasion Ecology

The biological and ecological flexibility of this invasive species has enabled it to spread aggressively across similar climatic regions worldwide, including much of sub-Saharan Africa. In South Africa, the species thrives in nutrient-rich freshwater impoundments that are prone to eutrophication, especially those receiving continuous inflow of municipal wastewater and agricultural runoff. Water bodies like the Hartbeespoort Dam, Roodeplaat Dam, and parts of the Vaal and Crocodile Rivers provide ideal conditions for invasion, with high concentrations of nitrates and phosphates accelerating biomass production [4,11,17].

E. crassipes commonly inhabits ponds, lakes, rivers, seasonal wetlands, and floodplains with slow or stagnant water flow [30]. It prefers shallow water bodies (0.5–2 m depth) with soft sediments, where its fibrous roots can occasionally anchor and stabilize floating mats [10,30]. These mats flourish in calm conditions, often occupying backwaters, inlets, and shoreline margin areas where water velocity is minimal and disturbance is low [24,25]. In sub-Saharan Africa, this pattern is evident in reservoirs and artificial irrigation canals, where slow flow and sediment-rich water promote extensive spread [41,42].

The species favors warm, humid environments with high sunlight availability and a water temperature range between 20 °C and 30 °C [1,41,42]. These conditions are commonly met in African lowland regions throughout the year. Under such thermal regimes, *E.*

crassipes displays rapid growth and reproduction, facilitated by its stoloniferous growth habit and ability to form large, dense, floating rosettes. In South Africa's summer months, the combination of high solar radiation, calm water, and nutrient influx creates peak conditions for photosynthesis and vegetative propagation [35,43].

While native to tropical regions, *E. crassipes* shows remarkable ecological plasticity. It can colonize floodplains and ephemeral wetlands during seasonal inundation, rapidly exploiting newly flooded environments [42]. Its ability to persist under fluctuating hydrological regimes is due to its floating morphology and tolerance of variable water depths [43]. Though sensitive to freezing temperatures, the species is increasingly adapting to warmer winters in parts of southern Africa, raising concern over its potential range expansion under future climate change scenarios. For example, Huang et al. [44] reported that increasing water temperatures and fluctuating depths significantly influence the overwintering success and growth dynamics of *E. crassipes*.

The invasion success of *E. crassipes* in African contexts is further exacerbated by anthropogenic disturbances, such as land use changes, urbanization, and agricultural intensification. Polluted waters from human settlements and nutrient-rich discharges from aquaculture and farmlands create favorable eutrophic conditions that promote establishment and persistence [35,41,43]. High nutrient loads, especially elevated phosphorus and nitrogen levels, stimulate excessive growth, enabling the species to rapidly outcompete native flora and dominate aquatic ecosystems [42,45].

Although *E. crassipes* can tolerate a range of hydrological conditions, it thrives in clear, unshaded environments where maximum light penetration facilitates efficient photosynthesis [35,41]. The species is often excluded from heavily canopied streams but dominates open reservoirs and lakes where solar radiation is unobstructed. Its capacity to form expansive mats alters light availability, reduces dissolved oxygen, and disrupts the aquatic habitat structure [35].

8. Ecological and Socioeconomic Impacts

Eichhornia crassipes, a well-known, rapidly spreading invasive plant, is considered a global threat to ecosystems [11]. The thick mats that *E. crassipes* create on the water's surface shade out native aquatic plants and change the structure of the environment [10]. *Eichhornia crassipes* can harbor disease vectors, such as mosquitoes, increasing the risk of vector-borne diseases, such as malaria and dengue fever, in areas where it proliferates [1]. Additionally, the decomposition of *E. crassipes* biomass can release noxious odors and potentially harmful gases, such as methane and hydrogen sulfide, impacting air quality and human health in nearby communities [11]. The dense plant mats of *E. crassipes* can impede outdoor pursuits like swimming, boating, and fishing, devaluing water bodies visually and hurting local tourism [46]. Additionally, the existence of *E. crassipes* may discourage locals and tourists from enjoying and using water resources [11]. Because *E. crassipes* creates thick mats on the water's surface that obstruct sunlight and lower the amount of oxygen in the water, it is likely to cause an alteration in the habitat [11]. This modifies the aquatic environment, which reduces biodiversity and upsets the ecosystems' natural equilibrium [25]. Additionally, the mats block water flow, which interferes with sedimentation and nutrient cycling processes [10]. Native aquatic plant species may become less diverse because of *E. crassipes*' invasion, as they may be outcompeted and displaced. This decline in biodiversity may affect fish populations, invertebrates, and other organisms that depend on a variety of habitats, potentially having a domino effect on the ecosystem [29]. Aside from ecological disruption, *E. crassipes* has far-reaching socioeconomic impacts, especially in sub-Saharan Africa, where most communities are directly dependent on infested water bodies for drinking water, fishing, irrigation, and transportation. In South Africa, infestations in

major dams like Hartbeespoort have caused additional expenditure for water treatment, decreased agricultural production, and loss of recreational and tourism revenues [11]. In Hartbeespoort Dam, thick mats of *E. crassipes* have been shown to reduce dissolved oxygen and promote eutrophication, negatively affecting fish populations and water usability [11]. Furthermore, water quality is impacted because of nutrient enrichment and decreased oxygen levels beneath the dense mats. *E. crassipes* can cause water quality to deteriorate. Senescent biomass breaks down and releases nutrients into the water, which exacerbates eutrophication and encourages algal blooms [24]. In Lake Victoria, *E. crassipes* mats led to a 50% reduction in native macrophyte cover and significantly altered fish community structures [29]. The invasion of *E. crassipes* has significant negative effects on the economy, especially in areas where it clogs waterways, makes navigation difficult, and hinders the production of hydroelectric power and irrigation [10]. For impacted communities and the government, managing and controlling *E. crassipes* infestations come at a high cost [1]. Despite its significant ecological and socioeconomic impacts (Figure 4), such as a large loss of water resources, *E. crassipes* has potential industrial uses. These include the production of bioenergy, biofertilizer, wastewater treatment (heavy metal absorption), and animal feed [47].

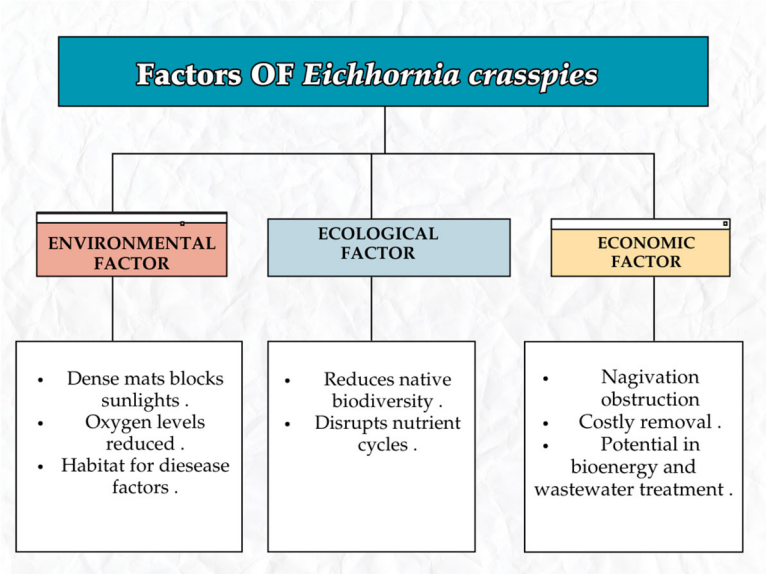


Figure 4. Environmental, ecological, and economic impacts of *Eichhornia crassipes* [1,10,11,29,47].

9. Control and Management Strategies

Each of the control strategies has unique strengths and limitations. Mechanical removal produces rapid benefits, but it is labor-intensive and frequently unsustainable in the long run [48]. Chemical control is fast, but it can harm nontarget species and water quality. Biological control, which employs agents like *Neochetina* spp. and *Megamelus scutellaris*, is environmentally friendly but often yields slower results. Therefore, coordinated management, combining biological control with targeted mechanical or chemical approaches, is recommended for effective and long-term control *of E. crassipes* invasions [13,49], as shown in Table 1.

9.1. Mechanical Control

This involves using machines and other approved pieces of equipment to remove weeds from water [48]. Some of the machinery employed includes mechanical mowers, destroyer boats, mechanized dredgers, weed harvester tractors, and crusher boats [7]. The weed is removed and placed on the equipment's bed [50]. However, it is crucial to

ensure that the process of eradicating the weeds does not damage nontarget species [2]. Mechanical removal can be used as a preliminary step toward chemical control, which involves spraying pesticides into the water after the weeds have been removed [50]. Given the nature of the technology used, this control method may be prohibitively expensive [10]. Manual removal does not require any technical expertise, especially when plants are removed from the water body by hand, but it is only successful in small bodies of water and thus ineffective in large lakes or water bodies [45]. It also has the disadvantage of being time consuming [10]. This control mechanism can also cause changes in the dissolved oxygen concentration of water and the trophic structure, hence speeding up the pace of eutrophication [2].

Salvinia molesta and *Pistia stratiotes* are both examples of other invasive plants. They both create dense floating mats in the freshwater setting, and they have also been effectively harvested mechanically, similar to techniques for *E. crassipes*. In several regions, such as Australia and parts of Africa, mechanical removal, such as weed cutting boats, conveyor systems, or floating booms, has greatly reduced infestation [17]. In South Africa, mechanical control of *Eichhornia crassipes* has been applied in heavily infested systems like Hartbeespoort and Roodeplaat Dams [4]. This method comprises physical removal with weed harvesters, dredgers, and crusher boats and provides quick short-term relief. However, it is costly and labor-intensive and frequently requires repetition due to quick regrowth. Furthermore, mechanical disturbance can modify water quality by changing dissolved oxygen levels and increasing the eutrophication processes [4,10,19].

9.2. Chemical Control

This method involves the use of herbicides to eliminate weeds. Paraquat and glyphosate are two herbicides commonly used for this purpose, particularly in Africa [23]. This kind of control is quick, efficient, and cost-effective when compared to mechanical and manual control systems, but it requires a specific skill to be efficient [40]. Even if environmental stakeholders advise caution when considering chemical control due to the potential effects on nontarget creatures, these concerns are not always realized [23]. Other nonherbicidal herbicides are being utilized to control *E. crassipes*. A recent study described the use of acetic acid to kill *E. crassipes* [51]. The acid was said to be as effective as glyphosate, implying that it might be used as an alternative because it is more environmentally benign [40,51]. Other acids, such as citric acid, formic acid, and propionic acid, have been tested for the management of *E. crassipes* with varying degrees of success [52].

Another example of a chemical control strategy is the use of herbicides like glyphosate and diquat, which are frequently used against *Salvinia molesta* and *Pistia stratiotes*. These herbicides are administered directly to foliage or water surfaces, which can cause rapid plant biomass death. For example, research in Brazilian reservoirs has shown that glyphosate and diquat can effectively manage *P. stratiotes* and *S. molesta* with low environmental residue when used properly. However, chemical management must be treated with caution due to the potential of water contamination, injury to nontarget species, and transient results that do not address underlying nutrient enrichment [53]. While glyphosate and paraquat are permitted for aquatic weed control in South Africa, their use is heavily regulated due to environmental concerns. Thus, herbicide application is often limited to specific, high-priority regions, and it is frequently combined with mechanical removal [40]. Chemical treatment of *E. crassipes* in South Africa typically includes the use of herbicides, such as glyphosate and paraquat, which are allowed for aquatic usage but strictly regulated [19,23]. These herbicides are excellent at rapidly reducing biomass, particularly when paired with mechanical removal. However, environmental considerations, particularly the risk to nontarget species and water contamination, have prevented their widespread use [23,40]. Trials

employing alternative compounds, such as acetic acid, have shown encouraging results as more environmentally friendly solutions in South Africa [17,19,23].

9.3. Biological Control

Biological control approaches include exploiting a host as a separate natural opponent of *E. crassipes* to reduce the weed population size [18]. Some of the natural enemies that have been recorded include moths *(Bellura* spp., *Xubida* spp., *Niphograpta* spp.), flies (*Thrypticus* spp., *Megamelus scutellaris*), mites (*Orthogalumna terebrantis*), weevils (*Neochetina* spp.), and grasshoppers (*Cornops aquaticum*) [10]. Furthermore, fungal species, *Trichothecium* spp., *Aspergillus* spp., *Trichoderma* spp., *Fusarium* spp., and *Rhizoctonia* spp., were introduced into *E. crassipes*-infested waters in Lake Tana, and they were very promising as a weed biocontrol agent [24]. *Megamelus scutellaris* (Hemiptera) has also been used with varying degrees of success [34]. It is claimed that combining this insect with mycoherbicide can improve the biological control of the weed [54]. Biological and chemical controls could be combined. Tipping et al. [54] found that combining chemical and biological treatment increased the effectiveness of using herbicides alone to control *E. crassipes*. Biological control is an ecologically safe strategy, albeit complex and slow to implement [2]. In comparison, the use of the weevils *Neochetina eichhorniae* and *N. bruchi* has demonstrated up to a 70–90% drop in biomass in specific South African reservoirs during multi-year programs [30]. However, fluctuation in climate and infection scale affects success.

An example of another biological control is the introduction of the weevil *Cyrotbagous salviniae*, which has had a positive impact on *Salvinia molesta* in a number of countries, including Australia, Botswana, and South Africa. The *C. salviniae* larvae and adults feed on the plant's leaf buds and tissues, resulting in significant biomass reduction and mat disintegration. In South Africa, biological control has been the most extensively practiced long-term *E. crassipes* management strategy. As reported by Coetzee et al. [30,49], introductions of weevils (*Neochetina eichhorniae and N. bruchi*) since the 1980s have resulted in significant biomass reductions of up to 90% in controlled reservoirs like Hartbeespoort Dam. Recent achievements have also been noted with *Megamelus scutellaris*, particularly in high-altitude areas where weevils had limited efficacy [49]. These programs have been cost-effective and sustainable, but their success depends on climate, water chemistry, and infestation size. Current research continues to investigate the synergies between fungal biocontrol (e.g., *Fusarium* spp.) and insect agents for improved control. Furthermore, *C. salviniae* has demonstrated resilience in a variety of climatic circumstances, making it appropriate for both tropical and subtropical regions [54]. Biological control is the most extensively used long-term management technique for *E. crassipes* in South Africa. More recently, the planthopper *Megamelus scutellaris* has been employed successfully, particularly in cooler, high-altitude areas where weevils are less efficient [30]. These agents are environmentally safe, cost-effective, and self-sustaining, but their success depends on climatic and ecological conditions [17,30,49].

9.4. Integrated Approaches

Integrated management combines different control mechanisms (e.g., biological, mechanical, and chemical) (Tables 1 and 2) to maximize effectiveness with minimal harmful environmental effects. Tipping et al. [54], for instance, determined that herbicide application combined with biological agents, such as *Megamelus scutellaris,* enhanced control success with reduced herbicide use. Likewise, Coetzee et al. [36] noted that integrated methods are more sustainable and versatile in applications across African environments with diverse resource levels and ecological conditions. These approaches are site-specific, requiring site assessment, stakeholder participation, and continuous monitoring [13,16].

These comparative references to invasive aquatic species, such as *Pistia stratiotes* and *Salvinia molesta*, are highlighted to contextualize control experiences in sub-Saharan Africa, as these species coexist with *E. crassipes* in many regions and are managed using similar biological and chemical strategies. Similarly, lessons from Brazil and India are given where applicable to inform regional modifications.

Table 1. Management strategies for *E. crassipes*.

Method	Description	Example	References
Mechanical control	Involves physically removing weeds from bodies of water using machinery and equipment.	Machines used: weed harvester tractors, dredgers, crusher boats, destroyer boats, and mechanical mowers. For instance, tarping, digging.	[10,50]
Chemical control	Uses pesticides to get rid of weeds fast and efficiently.	Herbicides: triclopyr, glyphosate, and paraquat. For instance, herbicides are used to eliminate *E. crassipes* and *Salvinia molesta*.	[23,40,52]
Biological control	Involves using weeds' natural enemies, like fungi and insects, to control their population.	Natural enemies: fungi (such as *Aspergillus* and *Trichothecium species*), beetles, flies, moths, and weevils. For instance, weevils are utilized against *E. crassipes* and *Salvinia molesta*, also known as Giant Salvinia.	[10,19,34,55]

Table 2. Comparative cost, effectiveness, and regional applicability of different control methods.

Method	Description	Effectiveness	Limitation	Regional Examples
Mechanical	Machine and manual removal	High in small areas	Costly, labor-intensive	South Africa, India
Chemical	Herbicide application	Fast, effective	Environmental risks	South Africa, Nigeria, Brazil
Biological	Insects, fungi	Sustainable long-term	Slow implementation	South Africa, Ethiopia, USA
Integrated	Combined approach	Most effective overall	Requires coordination	South Africa, Kenya, China

10. Utilization Potential

Aside from its invasive nature, *E. crassipes* holds considerable promise as a renewable and sustainable biomass resource, particularly in developing countries where waste management and resource accessibility are ongoing challenges. Its rapid growth and high biomass production, along with its significant nitrogen and phosphorus uptake capabilities, make it suitable for various environmentally beneficial applications [1]. Composted *E. crassipes* was discovered to contain 1.8% nitrogen, 0.9% phosphorus, and 1.6% potassium, making it suitable as an organic fertilizer [1,47]. In the energy sector, *E. crassipes* can be converted into biogas, bioethanol, or briquettes, offering communities alternative and cost-effective fuel sources. Studies have shown that it produces methane yields comparable to other aquatic plants when subjected to anaerobic digestion, and its high cellulose content further supports its use in bioethanol production [29,37,56]. In a constructed wetland system in India, *E. crassipes* removed up to 90% of lead and 65% of nitrogenous waste from municipal effluent [55,56]. Given the ongoing invasions in South African water bodies, utilizing *E. crassipes* for biogas, compost, and wastewater treatment could offer sustainable economic returns [47]. In agriculture, composted *E. crassipes* serves as an organic biofertilizer that enhances soil fertility and reduces dependence on synthetic inputs [1,47]. Additionally, due to its protein and fiber content, the plant can be used in animal feed if its antinutritional factors are properly treated [12]. The species also plays a promising role in environmental remediation. Its extensive root system offers a large surface area for the

absorption of heavy metals and excess nutrients, making it effective in phytoremediation and wastewater treatment applications [55,56].

In South Africa, local municipalities and NGOs in Gauteng have tested composting and mulching programs based on harvested *E. crassipes*, but scalability has been limited due to a lack of consistent biomass supply and public–private collaboration [47]. The plant's phytoremediation capacity has also been evaluated in urban water bodies, such as Roodeplaat Dam, where it reduced heavy metal concentrations in polluted runoff, indicating that there is still room for improvement in decentralized wastewater management [30]. These novel applications align with circular economic principles and reflect a paradigm shift from viewing *E. crassipes* solely as a problematic invader to recognizing it as a valuable resource. Nevertheless, leveraging its benefits requires careful management, investment, and regulatory oversight to avoid unintentional promotion of its spread.

11. Discussion

Eichhornia crassipes continues to be a significant invasive species of ecological and socioeconomic importance in sub-Saharan Africa, specifically South Africa, where its effects are well-recorded in dams like Hartbeespoort and Roodeplaat. Although a number of management options exist, sustainable and long-term control is difficult because of the plant's adaptability and highly reproductive modes and conducive environmental conditions in the country.

Biological control in South Africa has achieved some success, particularly with the release of *Neochetina* spp. and *Megamelus scutellaris*. This has resulted in substantial biomass decrease in some water bodies. Nevertheless, the effectiveness of biological control is region-specific and, in many cases, determined by environmental factors, including temperature, water chemistry, and infestation density. Integrated management using a combination of biological, chemical, and mechanical techniques provides a more holistic approach, but its implementation demands sufficient funding, inter-agency coordination, and long-term community participation.

This review also brings to the fore the prospects of *E. crassipes* as an asset. Its high biomass yield, nutrient assimilation efficiency, and cellulose content are promising for its use in bioenergy, organic fertilizer, and phytoremediation. Pilot projects on composting and biomass valorization are ongoing in South Africa, yet upscaling the solutions is hampered by limited infrastructure, unreliable biomass supply, and regulatory lacunae.

Notably, ongoing research and management tend to be piecemeal. Coordinated long-term monitoring of control effects, especially regarding ecosystem recovery following invasion, is lacking. In addition, cost–benefit analysis of various control methods is rarely performed at the regional scale, thus making it hard for decision makers to rank interventions. Looking ahead, region-specific research is key to realizing the complete ecological impacts of *E. crassipes* and developing context-specific control measures. Community education and stakeholder engagement must be at the forefront of any management strategy, especially where local livelihoods are inextricably linked with infested water systems. In addition, policy coordination and funding streams enabling integrated weed management and sustainable use need to be urgently developed to balance ecological restoration with economic opportunity.

12. Recommendations

Despite advances in understanding the biology and ecology of *E. crassipes*, significant challenges to effective management persist. Biological control has shown promise but remains region-specific in its success, while chemical interventions continue to raise serious environmental and sustainability concerns. Long-term, effective management requires

localized research, supportive policy frameworks, and active public engagement. Climate change further complicates control efforts by altering rainfall patterns and temperature regimes, potentially enhancing the plant's spread and persistence.

Future research should prioritize predictive ecological modeling, the development of cost-effective biocontrol agents, and resource-based utilization strategies. Governments and environmental agencies must support policies that facilitate integrated management approaches, combining biological, mechanical, and socio-ecological methods. In parallel, community education and involvement are vital to improving awareness of the ecological and socioeconomic impacts of *E. crassipes* and fostering participation in control efforts. Establishing robust monitoring and evaluation systems is essential for tracking the efficacy of interventions and understanding their broader ecological consequences.

In line with emerging technological developments, integrating artificial intelligence (AI) with remote sensing offers substantial potential for improving *E. crassipes* surveillance and control. AI-powered image analysis, coupled with satellite data, enables continuous habitat monitoring, automated species identification, and real-time assessments of ecosystem health and land cover changes [57]. This integration supports precise population tracking, facilitates predictive modeling, and enables timely responses to new infestations. Additionally, AI-driven analytics can optimize resource allocation, ensuring that management efforts are both cost-effective and sustainable. These "smart" technologies could be particularly transformative in regions with limited capacity for manual monitoring, enhancing early detection, control, and long-term planning.

Despite ongoing efforts, critical research gaps remain. There is a lack of longitudinal monitoring of the environmental outcomes of control strategies, particularly biological interventions, in African aquatic systems. Moreover, most cost–benefit analyses of management approaches are based on case studies from outside of the continent and do not adequately reflect the socioeconomic realities of southern Africa. Addressing these gaps will require long-term studies on ecosystem resilience post-management, as well as context-specific assessments of the socioeconomic impacts of integrated control strategies. Further investigation of the economic potential of *E. crassipes*, including its use in bioenergy production and wastewater treatment, in African contexts also represents a promising but underexplored research avenue.

13. Conclusions

Eichhornia crassipes poses serious ecological and economic challenges due to its invasive behavior, rapid proliferation, and ability to form dense mats that disrupt aquatic ecosystems, reduce biodiversity, and hinder water flow. While chemical, mechanical, and biological control methods are commonly employed, each approach presents limitations ranging from environmental concerns to region-specific effectiveness. Despite these challenges, *E. crassipes* also presents promising opportunities for sustainable use, including bioenergy production, phytoremediation, organic fertilizer, and animal feed. Leveraging these benefits aligns with circular economic principles and offers a potential pathway for transforming a harmful invader into a valuable resource. Effective long-term management of *E. crassipes* requires an integrated, region-specific strategy that combines diverse control measures with the exploration of its socioeconomic benefits. Continued research is critical, particularly in developing predictive models, improving cost-effective and ecologically safe biocontrol methods, and promoting resource-based utilization. Policy integration, public awareness, and adaptive management frameworks, especially under changing climate conditions, are essential to mitigate its negative impacts while maximizing its potential contributions.

Author Contributions: Conceptualization, M.D.K. and C.M.N.; methodology, M.D.K. and C.M.N.; investigation, M.D.K. and C.M.N.; writing—review and editing, M.D.K., C.M.N., N.M.M., M.C.M., M.M.M. and M.A.M.; visualization, M.D.K., C.M.N., N.M.M., M.C.M., M.M.M. and M.A.M.; supervision, C.M.N.; project administration, C.M.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to extend our sincere appreciation to the Department of Biology and Environmental Sciences, School of Science and Technology, at Sefako Makgatho Health Sciences University.

Conflicts of Interest: No conflicts of interest.

References

1. 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. [CrossRef]
2. Ayanda, O.I.; Ajayi, T.; Asuwaju, F.P. *Eichhornia crassipes* (Mart.) Solms: Uses, Challenges, Threats, and Prospects. *Sci. World J.* **2020**, *2020*, 3452172. [CrossRef]
3. Pellegrini, M.O.O.; Horn, C.N.; Almeida, R.F. Total evidence phylogeny of pontederiaceae (commelinales) sheds light on the necessity of its recircumscription and synopsis of *Pontederia* L. *PhytoKeys* **2018**, *108*, 25–83. [CrossRef] [PubMed]
4. Mqingwana, P.; Shoko, C.; Gxokwe, S.; Dube, T. Monitoring and assessing the effectiveness of the biological control implemented to address the invasion of water hyacinth (*Eichhornia crassipes*) in Hartbeespoort Dam, South Africa. *Remote Sens. Appl. Soc. Environ.* **2024**, *36*, 101295. [CrossRef]
5. de Gouveia, C.C.; Bührmann, J.H. Prediction of water hyacinth coverage on the hartbeespoort dam. *S. Afri. J. Ind Eng.* **2024**, *35*, 179–194. [CrossRef]
6. Dechassa, N.; Abate, B. Current Status of Water Hyacinth (*Eichhornia crassipes*) in Ethiopia: Achievements, Challenges, and Prospects: A Review. *J. Environ. Earth Sci.* **2020**, *10*, 1–13.
7. Téllez, T.R.; López, E.M.D.R.; Granado, G.L.; Pérez, E.A.; López, R.M.; Guzmán, J.M.S. The Water Hyacinth, *Eichhornia crassipes*: An Invasive Plant in the Guadiana River Basin (Spain). *Aquat. Invasions* **2008**, *3*, 42–53. [CrossRef]
8. Ceschin, S.; Abati, S.; Traversetti, L.; Spani, F.; Del Grosso, F.; Scalici, M. Effects of the Invasive Duckweed *Lemna minuta* on Aquatic Animals: Evidence from an Indoor Experiment. *Plant Biosyst.* **2019**, *153*, 749–755. [CrossRef]
9. Julien, M.H. Biological Control of Water Hyacinth with Arthropods: A Review to 2000. In *Aciar Proceedings*; ACIAR: Canberra, Australia, 1998; pp. 8–20.
10. 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. [CrossRef]
11. Coetzee, J.A.; Jones, R.W.; Hill, M.P. Water Hyacinth, *Eichhornia crassipes* (Pontederiaceae), Reduces Benthic Macroinvertebrate Diversity in a Protected Subtropical Lake in South Africa. *Biodivers. Conserv.* **2014**, *23*, 1319–1330. [CrossRef]
12. 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. [CrossRef]
13. Hill, M.P.; Coetzee, J.A. Control of Water Hyacinth (*Eichhornia crassipes* [Mart.] Solms) in South Africa: Historical Perspectives and Current Challenges. *S. Afr. J. Bot.* **2019**, *124*, 309–319. [CrossRef]
14. Kurniadie, D.; Rezkia, N.N.; Widayat, D.; Widiawan, A.; Duy, L.; Prabowo, D.P. Control of aquatic weed *Eichhornia crassipes* using florpyrauxifen-benzyl herbicide—Case study in Cangkuang lake (Indonesia). *Water.* **2023**, *15*, 1859. [CrossRef]
15. Lorenzo, P.; Morais, M.C. Strategies for the Management of Aggressive Invasive Plant Species. *Plants* **2023**, *12*, 2482. [CrossRef] [PubMed]
16. Karouach, F.; Ben Bakrim, W.; Ezzariai, A.; Sobeh, M.; Kibret, M.; Yasri, A.; Hafidi, M.; Kouisni, L. A Comprehensive Evaluation of the Existing Approaches for Controlling and Managing the Proliferation of Water Hyacinth (*Eichhornia crassipes*). *Front. Environ. Sci.* **2022**, *9*, 767871. [CrossRef]
17. Coetzee, J.A.; Hill, M.P. The role of eutrophication in the biological control of water hyacinth, *Eichhornia crassipes*, in South Africa. *BioControl* **2012**, *57*, 247–261. [CrossRef]
18. Hauptfleisch, K.A. A Model for Water Hyacinth Biological Control. Ph.D. Thesis, University of the Witwatersrand, Faculty of Science, School of Animal, Plant and Environmental Sciences, Johannesburg, South Africa, 2015.
19. Van Wilgen, B.W.; De Lange, W.J. The Costs and Benefits of Biological Control of Invasive Alien Plants in South Africa. *Afr. Entomol.* **2011**, *19*, 504–514. [CrossRef]

20. Yan, S.H.; Song, W.; Guo, J.Y. Advances in Management and Utilization of Invasive Water Hyacinth (*Eichhornia crassipes*) in Aquatic Ecosystems–A Review. *Crit. Rev. Biotechnol.* **2017**, *37*, 218–228. [CrossRef] [PubMed]
21. Elenwo, E.I.; Akankali, J.A. The Estimation of Potential Yield of Water Hyacinth: A Tool for Environmental Management and an Economic Resource for the Niger Delta Region. *J. Sustain. Dev. Stud.* **2016**, *9*, 115–137.
22. Jones, R.W. The Impact on Biodiversity, and Integrated Control, of Water Hyacinth (*Eichhornia crassipes* [Mart.] Solms-Laubach) on the Lake Nsezi-Nseleni River System. Ph.D. Thesis, Rhodes University, Makhanda, South Africa, 2009.
23. Mujere, N. Water Hyacinth: Characteristics, Problems, Control Options, and Beneficial Uses. In *Impact of Water Pollution on Human Health and Environmental Sustainability*; IGI Global: New York, NY, USA, 2016; pp. 343–361.
24. Degaga, A.H. Water Hyacinth (*Eichhornia crassipes*) Biology and Its Impacts on the Ecosystem, Biodiversity, Economy, and Human Well-Being. *J. Life Sci. Biomed.* **2018**, *8*, 94–100.
25. Patel, S. Threats, Management and Envisaged Utilizations of Aquatic Weed *Eichhornia crassipes:* An Overview. *Rev. Environ. Sci. Bio/Technol.* **2012**, *11*, 249–259. [CrossRef]
26. Omofunmi, O.E.; Olaniyan, A.M.; Ebietomiye, O.T. Utilisation of Water Hyacinth (*Eichhornia crassipes*) as Fish Aggregating Device by Riverine Fisher Folks in a South West Nigeria Community. *Livest. Res. Rural Dev.* **2018**, *30*, 9.
27. Ndimele, P.E. A Review on the Phytoremediation of Petroleum Hydrocarbon. *Pak. J. Biol. Sci.* **2010**, *13*, 715–722. [CrossRef] [PubMed]
28. Huang, X.; Xu, X.; Liu, S.; Song, S.; Chang, S.; Liu, C.; Yu, D. Impact of eutrophication on root morphological and topological performance in free-floating invasive and native plant species. *Hydrobiologia* **2019**, *836*, 123–139. [CrossRef]
29. Gichuki, J.; Omondi, R.; Boera, P.; Okorut, T.; Matano, A.S.; Jembe, T.; Ofulla, A. Water Hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach Dynamics and Succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications for Water Quality and Biodiversity Conservation. *Sci. World J.* **2012**, *2012*, 106429. [CrossRef]
30. Coetzee, J.A.; Hill, M.P.; Byrne, M.J.; Bownes, A. A Review of the Biological Control Programmes on *Eichhornia crassipes* (C. Mart.) Solms (Pontederiaceae), *Salvinia molesta* DS Mitch. (Salviniaceae), *Pistia stratiotes* L. (Araceae), *Myriophyllum aquaticum* (Vell.) *Verdc*. (Haloragaceae), and *Azolla filiculoides Lam*. (Azollaceae) in South Africa. *Afr. Entomol.* **2011**, *19*, 451–468.
31. Hussner, A.; Stiers, I.; Verhofstad, M.J.J.M.; Bakker, E.S.; Grutters, B.M.C.; Haury, J.; Van Valkenburg, J.L.C.H.; Brundu, G.; Newman, J.; Clayton, J.S.; et al. Management and Control Methods of Invasive Alien Freshwater Aquatic Plants: A Review. *Aquat. Bot.* **2017**, *136*, 112–137. [CrossRef]
32. Mwaura, A.; Kamau, J.; Ombori, O. An Ethnobotanical Study of Medicinal Plants Commonly Traded in Kajiado, Narok, and Nairobi Counties, Kenya: Medicinal Plant Species Traded in Kenya. *East Afr. J. Sci. Technol. Innov.* **2020**, *1*, 1–19. [CrossRef]
33. Kaur, C.D.; Saraf, S. In Vitro Sun Protection Factor Determination of Herbal Oils Used in Cosmetics. *Pharmacogn. Res.* **2010**, *2*, 22–25. [CrossRef]
34. Shin, J.W.; Kwon, S.H.; Choi, J.Y.; Na, J.I.; Huh, C.H.; Choi, H.R.; Park, K.C. Molecular Mechanisms of Dermal Aging and Antiaging Approaches. *Int. J. Mol. Sci.* **2019**, *20*, 2126. [CrossRef]
35. Setshego, M.V.; Aremu, A.O.; Mooki, O.; Otang-Mbeng, W. Natural Resources Used as Folk Cosmeceuticals Among Rural Communities in Vhembe District Municipality, Limpopo Province, South Africa. BMC Complement. *Med. Ther.* **2020**, *20*, 81.
36. Coetzee, J.A.; Hill, M.P.; Julien, M.H.; Center, T.D.; Cordo, H.A. *Eichhornia crassipes* (Mart.) Solms-Laub. (Pontederiaceae). In *Biological Control of Tropical Weeds Using Arthropods*; Cambridge University Press: New York, NY, USA, 2009; pp. 183–210.
37. Guna, V.; Ilangovan, M.; Anantha Prasad, M.G.; Reddy, N. Water hyacinth: A unique source for sustainable materials and products. *ACS Sustain. Chem. Eng.* **2017**, *5*, 4478–4490. [CrossRef]
38. 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*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 237–251. [CrossRef]
39. Lv, T.; Fan, S.; Wang, H.; Li, D.; Wang, Q.; Lei, X.; Liu, C.; Yu, D. Invasion of water hyacinth and water lettuce inhibits the abundance of epiphytic algae. *Divers. Distrib.* **2022**, *28*, 1650–1662. [CrossRef]
40. Ray, P.; Hill, M.P. Fungi Associated with *Eichhornia crassipes* in South Africa and Their Pathogenicity Under Controlled Conditions. *Afr. J. Aquat. Sci.* **2012**, *37*, 323–331. [CrossRef]
41. Quinty, V.; Colas, C.; Nasreddine, R.; Nehmé, R.; Piot, C.; Draye, M.; Destandau, E.; Da Silva, D.; Chatel, G. Screening and Evaluation of Dermo-Cosmetic Activities of the Invasive Plant Species *Polygonum cuspidatum*. *Plants* **2022**, *12*, 83. [CrossRef]
42. Ndhlovu, P.T.; Mooki, O.; Mbeng, W.O.; Aremu, A.O. Plant Species Used for Cosmetic and Cosmeceutical Purposes by the Vhavenda Women in Vhembe District Municipality, Limpopo, South Africa. *S. Afr. J. Bot.* **2019**, *122*, 422–431. [CrossRef]
43. Gebashe, F.C.; Naidoo, D.; Amoo, S.O.; Masondo, N.A. Cosmeceuticals: A Newly Expanding Industry in South Africa. *Cosmetics* **2022**, *9*, 77. [CrossRef]
44. Huang, X.; Ke, F.; Li, Q.; Zhao, Y.; Guan, B.; Li, K. Functional traits underlying performance variations in the overwintering of the cosmopolitan invasive plant water hyacinth (*Eichhornia crassipes*) under climate warming and water drawdown. *Ecol. Evol.* **2022**, *12*, e9181. [CrossRef]

45. Mavundza, E.J.; Street, R.; Baijnath, H. A Review of the Ethnomedicinal, Pharmacology, Cytotoxicity, and Phytochemistry of the Genus Euphorbia in Southern Africa. *S. Afr. J. Bot.* **2022**, *144*, 403–418. [CrossRef]
46. Liu, J.; Chen, X.; Wang, Y.; Li, X.; Yu, D.; Liu, C. Response Differences of *Eichhornia crassipes* to Shallow Submergence and Drawdown with an Experimental Warming in Winter. *Aquat. Ecol.* **2016**, *50*, 307–314. [CrossRef]
47. Ben Bakrim, W.; Ezzariai, A.; Karouach, F.; Sobeh, M.; Kibret, M.; Hafidi, M.; Kouisni, L.; Yasri, A. *Eichhornia crassipes* (Mart.) Solms: A Comprehensive Review of Its Chemical Composition, Traditional Use, and Value-Added Products. *Front. Pharmacol.* **2022**, *13*, 842511. [CrossRef] [PubMed]
48. Hill, M.P.; Coetzee, J.A. Integrated Control of Water Hyacinth in Africa 1. *EPPO Bull.* **2008**, *38*, 452–457. [CrossRef]
49. Coetzee, J.A.; Miller, B.E.; Kinsler, D.; Sebola, K.; Hill, M.P. It's a numbers game: Inundative biological control of water hyacinth (*Pontederia crassipes*), using *Megamelus scutellaris* (Hemiptera: Delphacidae) yields success at a high elevation, hypertrophic reservoir in South Africa. *Biocontrol Sci. Technol.* **2022**, *2*, 1302–1311. [CrossRef]
50. Cerveira Junior, W.R.; de Carvalho, L.B. Control of Water Hyacinth: A Short Review. *Environments* **2019**, *6*, 95.
51. Agidie, A.; Sahle, S.; Admas, A.; Alebachew, M. Controlling Water Hyacinth, *Eichhornia crassipes* (Mart.) Solms Using Some Selected Eco-Friendly Chemicals. *J. Aquac. Res. Dev.* **2018**, *9*, 521.
52. El-Shahawy, T.G. Chemicals with a Natural Reference for Controlling Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms). *J. Plant Prot. Res.* **2015**, *55*, 294–300. [CrossRef]
53. Kodituwakku, K.A.R.K.; Yatawara, M. Phytoremediation of industrial sewage sludge with *Eichhornia crassipes*, Salvinia molesta and Pistia stratiotes in batch fed free water flow constructed wetlands. *Bull. Environ. Contamin. Toxicol.* **2020**, *104*, 627–633. [CrossRef]
54. Tipping, P.W.; Gettys, L.A.; Minteer, C.R.; Foley, J.R.; Sardes, S.N. Herbivory by Biological Control Agents Improves Herbicidal Control of Water Hyacinth (*Eichhornia crassipes*). *Invas. Plant Sci. Manag.* **2017**, *10*, 271–276. [CrossRef]
55. Mustafa, H.M.; Hayder, G. Recent Studies on Applications of Aquatic Weed Plants in Phytoremediation of Wastewater: A Review Article. *Ain Shams Eng. J.* **2021**, *12*, 355–365. [CrossRef]
56. Rezania, S.; Ponraj, M.; Din, M.F.M.; Songip, A.R.; Sairan, F.M.; Chelliapan, S. The Diverse Applications of Water Hyacinth with Main Focus on Sustainable Energy and Production for New Era: An Overview. *Renew. Sustain. Energy Rev.* **2015**, *41*, 943–954. [CrossRef]
57. Singh, G.; Reynolds, C.; Byrne, M.; Rosman, B. A remote sensing method to monitor water, aquatic vegetation, and invasive water hyacinth at national extents. *Remote Sens.* **2020**, *12*, 4021. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.