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Propagation and Bioecological Peculiarities of Higher Water Plants in Conditions of Karakalpakstan

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ABSTRACT

This study investigates the adaptation strategies, reproductive potential, and bioecological characteristics of four higher aquatic plant species - *Pistia stratiotes*, *Azolla caroliniana*, *Eichhornia crassipes*, and *Nelumbo nucifera* - under the arid and saline environmental conditions of Karakalpakstan. These species were selected for their ecological significance and potential applications in environmental management. Field observations and controlled experiments were conducted to assess their growth dynamics, reproduction rates, and responses to key environmental variables such as water salinity, temperature fluctuations, nutrient concentrations, and light availability. The results revealed that all four species exhibited high levels of ecological plasticity and tolerance to abiotic stress factors characteristic of the region. *Azolla caroliniana* and

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Eichhornia crassipes, in particular, showed rapid vegetative reproduction and significant nitrogen-fixing capacity, which can improve water quality and soil fertility. *Pistia stratiotes* and *Nelumbo nucifera* demonstrated efficient biomass production and potential for phytoremediation. All studied species contributed to ecosystem services such as water purification, nutrient cycling, and habitat creation for aquatic organisms. These attributes suggest their utility in integrated water resource management, wetland restoration, and climate adaptation frameworks in arid zones. The study emphasizes the necessity of including such resilient aquatic macrophytes in regional biodiversity strategies to enhance ecological stability and sustainability. The findings provide a scientific basis for the future use of these species in biotechnological and conservation-oriented projects across Central Asia, where water scarcity and environmental degradation pose ongoing challenges.

Keywords: *Azolla caroliniana*; Nitrogen Fixation; Symbiotic Relationship; *Eichhornia crassipes*; *Nelumbo nucifera*; Biomass Production

1. Introduction

This article explores the adaptation, bioecological features, and reproductive capacity of higher aquatic plants—*Pistia stratiotes* L., *Azolla caroliniana* Willd., *Eichhornia crassipes* Solms, and *Nelumbo nucifera*—under the climatic and environmental conditions of Karakalpakstan, a region characterized by arid landscapes and complex ecological challenges. These species, introduced into specially constructed biological ponds, demonstrated high adaptability to local conditions, including varying levels of salinity, water temperature, and nutrient availability.

The study presents comprehensive data on plant growth dynamics, biomass production, and reproductive strategies under experimental and semi-natural conditions. Physico-chemical parameters such as water temperature, pH, nitrate, phosphate, and other ion concentrations were closely monitored. The findings revealed optimal growth conditions for each species, including temperature thresholds and light requirements. For instance, *Pistia stratiotes* and *Azolla caroliniana* showed rapid biomass accumulation in nutrient-enriched water, while *Eichhornia crassipes* exhibited vigorous vegetative reproduction. *Nelumbo nucifera* showed promising development in freshwater ponds, with a daily growth rate of up to 5 cm under ideal conditions.

The ecological functions of these aquatic plants are also discussed. Their role in maintaining water quality, contributing to nutrient cycling, providing habitats for aquatic fauna, and supporting gas exchange processes is emphasized. Additionally, the research highlights their potential in wastewater treatment, biogas production, and as a sustainable source of

biomass. The results demonstrate that the introduction and controlled cultivation of these aquatic species can enhance biodiversity conservation, ecosystem stability, and resource management in arid regions like Karakalpakstan.

The study supports further research into integrating these plants into ecological restoration programs and sustainable agricultural practices across Central Asia.

In the current era, the implementation of climate adaptation processes and the conservation of biological diversity within natural flora have emerged as some of the most critical and urgent challenges facing scientists, environmentalists, and policymakers alike. Rapid climate change, driven primarily by anthropogenic activities such as industrialization, deforestation, and pollution, along with the relentless depletion of natural resources, have placed ecosystems and global biodiversity under unprecedented threat. These environmental changes disrupt the delicate balance of ecosystems, leading to the loss of species, degradation of habitats, and a decline in ecosystem services vital for human survival and well-being.

Under conditions of rapid climate change and degradation of natural ecosystems, preservation of biological diversity and adaptation of flora to new conditions become one of the priority tasks of modern science and environmental policy. Global warming caused by anthropogenic factors, such as industrialization, deforestation and pollution, has a significant impact on aquatic ecosystems, leading to species loss, disruption of food chains and reduction of water quality.

Climate adaptation processes, which refer to the complex adjustments and transformations of ecosystems in response to evolving natural climatic conditions, play a crucial

role in mitigating these impacts. Such processes support the restoration and maintenance of ecological balance by enabling flora and fauna to survive, reproduce, and sustain their populations despite environmental stresses. Moreover, understanding and facilitating these adaptive responses are essential for promoting ecosystem resilience and long-term sustainability in the face of ongoing and future climatic fluctuations.

Pistia stratiotes, known as waterweed, is widespread in tropical and subtropical regions and is characterized by rapid vegetative reproduction through stolons. Its ability to form dense mats on the water surface helps to reduce evaporation and protect water bodies from overheating, but if overgrown, it can cause oxygen deficiency and depress other species.

Azolla caroliniana, or Carolina azolla, is a floating fern-like plant that has a symbiotic relationship with cyanobacteria of the genus *Anabaena*, which allows it to fix atmospheric nitrogen and enrich water bodies with this important element. Thanks to this characteristic, Azolla is widely used in agriculture as a green fertilizer and in biological wastewater treatment systems.

Eichhornia crassipes, or water hyacinth, is characterized by its high growth rate and ability to establish large populations in a short period of time. Although this plant can have a negative impact on local ecosystems by displacing native species and disrupting hydrological regimes, it also has significant potential for phytoremediation, effectively absorbing heavy metals and other pollutants from water.

Nelumbo nucifera, is widely distributed in India, China, and Southeast Asian countries. It reproduces both by seeds and vegetatively. The leaves are large, up to 60 cm in diameter, and either float on the water surface or rise above it. The flowers are 10–20 cm in diameter, white or pink in color, and fragrant. It grows well at temperatures between 20–30°C. It thrives in water bodies with depths of 30–150 cm and prefers loamy, humus-rich soils. It is a light-loving plant and is intolerant to shade.

The analysis of reproduction and bioecological characteristics of *Pistia stratiotes*, *Azolla caroliniana*, *Eichhornia crassipes* and *Nelumbo nucifera* indicates that all species possess a strong ability for vegetative reproduction and form dense mats on water surfaces, significantly impacting ecosystems by reducing light penetration and oxygen levels^[1–3]. *Pistia stratiotes* reproduces both sexually and asex-

ually, with propagation influenced by water level management and manual seedling removal for control^[4–6]. *Azolla caroliniana* maintains symbiotic relationships with nitrogen-fixing cyanobacteria, allowing it to thrive in nutrient-poor waters. *Eichhornia crassipes* mainly reproduces vegetatively, is highly invasive across multiple continents, and biological control via *Cornops aquaticum* has been proposed as a management strategy^[7,8]. Furthermore, studies in Central Asia highlight the promise of cultivating these aquatic plants for biological purification of polluted waters and sustainable development of regional biodiversity^[9–12].

Studies conducted in various regions, including Central Asia, confirm the effectiveness of using these aquatic plants for biological purification of polluted water bodies and restoration of ecological balance.

In this context, special attention is paid to the study of aquatic plants with a high capacity for adaptation and ecosystem restoration. Species such as *Pistia stratiotes*, *Azolla caroliniana* and *Eichhornia crassipes* demonstrate unique bioecological characteristics that allow them to effectively adapt to changing environmental conditions and fulfill important ecological functions.

Thus, the integrated study of bioecological characteristics and adaptation mechanisms of aquatic plants such as *Pistia stratiotes*, *Azolla caroliniana*, *Eichhornia crassipes* and *Nelumbo nucifera* is an important direction in the development of sustainable management strategies for aquatic ecosystems under global climate change. Understanding their role in maintaining ecological balance, cleaning water bodies and conserving biodiversity will allow for more effective use of these species in conservation practices and adaptation measures.

The novelty of this research lies in its focus on studying the propagation and bioecological characteristics of *Pistia stratiotes* L., *Azolla caroliniana*, *Eichhornia crassipes*, and *Nelumbo nucifera* aquatic plants under the saline and arid climate conditions of Karakalpakstan and Central Asia. Since scientific data on the role of these aquatic plants in the sustainable management of water resources and the preservation of biological diversity in this region, as well as their adaptation mechanisms to the environment, is limited, this study provides important new insights. Additionally, by determining how key factors such as water temperature, pH, and nutrient levels affect the growth and phytoremediation

capacity of these aquatic plants, effective recommendations were developed to ensure ecological stability.

The study focuses on the reproduction and bioecological characteristics of *Pistia stratiotes* L., *Azolla caroliniana*, *Eichhornia crassipes*, and *Nelumbo nucifera*, particularly investigating their adaptation mechanisms and environmental impacts under the saline and arid climatic conditions of Karakalpakstan and Central Asia. Furthermore, there is limited information on the role of these aquatic plants in improving water quality, their responses to temperature, pH, and nutrient levels, as well as their phytoremediation capacity. This research aims to fill these gaps, which is crucial for developing new strategies for effective water resource management and the conservation of biological diversity.

2. Materials and Methods

Studies on adaptation of high level aquatic plants—*Pistia stratiotes*, *Azolla caroliniana*, *Eichhornia crassipes* and *Nelumbo nucifera*—were conducted in conditions of Karakalpakstan. For this purpose, special ponds were organized on the territory of Karakalpak Research Institute of Natural Sciences: depth—120 cm, width—5.20 m, length—6.30 m, total area—0.02 ha (2 hectares), consisting of 6 ponds. Organic fertilizers were applied to 4 of them and aquatic plants were planted in them. The growth, biomass and ecological adaptability of the plants were studied during the experiments.

To determine the productivity of higher aquatic plants, the guidelines developed by Taubaev T.T. were strictly followed, ensuring a standardized and reliable approach^[13]. For detailed phenological observations of the plant species under study, the established recommendations by Beydeman I.N. were applied^[14], allowing for accurate tracking of developmental stages and growth patterns.

Additionally, light intensity, a critical factor influencing photosynthetic activity and overall plant productivity, was measured using a luxmeter, ensuring accurate quantification of illumination levels throughout the experimental period.

The physicochemical composition of the water samples was comprehensively analyzed using well-established methodologies outlined by Lurie and Stroganov^[15,16]. These methods allowed for detailed assessment of water quality parameters, which are crucial for interpreting the aquatic

plants' growth and ecological dynamics.

Organic and mineral fertilizers were applied to the ponds. Organic fertilizer mainly consisted of livestock manure, which helped stimulate the growth of the plants. Mineral fertilizers included compounds of nitrogen, phosphorus, and potassium, and were applied in specific amounts to promote better development of the plants. Fertilization was carried out in accordance with the ecological conditions of the ponds and the needs of the aquatic plants.

In our research, the organic fertilizers used were derived from livestock manure. These were applied in a semi-composted state — that is, although the fermentation process was not fully completed, the manure had been sanitized and rendered safe for use. This type of fertilizer contains essential elements such as nitrogen, phosphorus, and potassium, which are necessary for the growth of aquatic plants.

An amount of 30–50 kg of organic fertilizer was added to each artificial pond. The fertilizer was evenly distributed, mechanically crushed beforehand, and mixed with water before being introduced into the ponds.

The biomass of the cultivated plants is determined by completely harvesting the plants from a designated area. The fresh weight of the plants is measured, which includes the water content. The plants are then dried in a special heating device for at least 48 hours or until the water is completely evaporated. The drying temperature is usually around 60–70°C. After drying, the weight of the plants (dry mass) is measured. This represents the true biomass of the plants, as the water content is excluded. The dry weight is then calculated per the designated area and converted to hectares or other units as needed.

- **Water reservoir** — outlines of the ponds where aquatic plants are growing;
- ***Pistia stratiotes* L** — floating freely or in mats on the surface of the pond;
- ***Azolla caroliniana*** — forming a fine cover on the water surface;
- ***Eichhornia crassipes*** — growing in clusters or small groups on the water surface;
- ***Nelumbo nucifera*** — planted in the soil at the bottom of the pond;
- **Pumps, sensors, and measuring instruments** — installed near the water reservoir to measure temperature, pH, and nutrient levels.

3. Results

Researchers at the Institute of Natural Sciences of Karakalpakstan, taking into account the region's specific climatic conditions, are conducting scientific studies aimed at conserving the biological diversity of flora and fauna, restoring natural resources, and stabilizing ecosystems. Given the fragility of arid zone ecosystems and the growing anthropogenic pressures, these studies are of great importance not only for Karakalpakstan but also for the entire Central Asian region. Studying and preserving local biodiversity is essential for ensuring ecological stability and supporting sustainable development under increasingly adverse environmental conditions.

Research on the conservation and adaptation of plant diversity is being carried out based on the plant collection of one of Uzbekistan's key scientific centers—the Tashkent Botanical Garden named after Academician F.N. Rusanov. Plant materials from the garden were carefully selected and transferred to the Institute of Natural Sciences of the Academy of Sciences of Uzbekistan in Karakalpakstan. This transfer of genetic resources provides a foundation for studying species adaptability and developing conservation strategies suited to the environmental conditions of the region.

The main goal of the experiments was to determine the extent to which these species can adapt to new growing conditions and explore opportunities to enhance their genetic potential. As a result of successful research, several approaches have been developed aimed at preserving plant adaptability and maintaining genetic diversity. This is important not only for the survival of individual plant species but also for their sustainable development in harmony with existing ecosystems. These approaches include the selection of genotypes with high adaptive capacity, nutrient management, and the optimization of cultivation technologies that mimic natural environmental conditions. These processes are especially crucial for the arid regions of Uzbekistan, where native plant communities face severe environmental stress.

Higher aquatic plants such as *Pistia* (*Pistia stratiotes* L.), *Azolla caroliniana* (*Azolla caroliniana* Willd.), *Eichhornia* (*Eichhornia crassipes* Solms), and Lotus (*Nelumbo nucifera*) are mainly native to tropical and subtropical regions and do not naturally occur in the climatic conditions of Cen-

tral Asia. These plants are notable for their aesthetic appeal and ecological value in aquatic environments. Studying their adaptation to new environments—including the influence of abiotic factors such as light intensity, water temperature, and nutrient availability—is essential. It also involves analyzing their bioecological characteristics and assessing their integration potential into local water bodies.

Experiments were conducted in both natural and artificial aquatic environments to determine optimal conditions for the reproduction, growth, and conservation of these species. These studies also aimed to enrich local flora with new species that can serve as raw materials for the pharmaceutical, bioenergy, and water purification industries. A scientific understanding of these processes helps lay the foundation for the sustainable use and management of aquatic plant resources in Central Asia and similar climatic zones.

In addition, studying the adaptation of aquatic plants is vital for enhancing the aesthetic and recreational value of gardens, parks, and urban water bodies, as well as for producing high-quality biomass for industrial and environmental applications. Developing effective adaptation technologies for higher aquatic plants plays a crucial role in ensuring the sustainability and functional integrity of aquatic ecosystems, especially in regions prone to environmental degradation.

Pistia, *Azolla*, *Eichhornia*, and *Nelumbo* are widely used for biomass production, maintaining ecological balance, and treating wastewater. Studying their hydrobiological and hydrochemical properties is essential for understanding their ecological roles and interactions with human activity. **Table 1** below presents the origin, growth rate, and key ecological characteristics of the aquatic plants *Pistia*, *Azolla*, *Eichhornia*, and *Nelumbo*.

Many researchers have studied the responses of aquatic plants to environmental conditions, climate change, and their biogeohydromechanical functions. For example, Akinbile et al. (2011) evaluated the phytoremediation potential of *Eichhornia crassipes* and *Pistia stratiotes* for treating aquaculture wastewater in Malaysia. Over a 30-day experimental period, significant reductions were observed in several water quality parameters, including turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD), nitrate, ammonia, and phosphate. These results demonstrate the effectiveness of these aquatic plants in improving water quality in aquaculture systems^[17].

Olguin et al. (2017) assessed the efficiency of floating treatment wetlands (FTWs) in improving water quality and delivering ecosystem services in a eutrophic urban pond. Their study found that FTW systems significantly improved

water quality by reducing pollutants such as nitrogen, phosphorus, and suspended solids. The study also emphasized the role of FTWs in preserving biodiversity and enhancing the overall ecological condition of urban water bodies^[18].

Table 1. Characteristics of the Aquatic Plants *Pistia stratiotes* L., *Azolla caroliniana* Willd., *Eichhornia crassipes* Solms, and *Nelumbo nucifera*.

Plant Name	Origin	Growth Rate	Main Ecological Functions
<i>Pistia stratiotes</i> L.	Tropical and subtropical regions	Very fast vegetative growth	Covers water surface, reduces heat, filters water
<i>Azolla caroliniana</i>	Americas, some tropical regions	Very fast growth	Fixes atmospheric nitrogen, improves water quality
<i>Eichhornia crassipes</i>	Tropical America	Very rapid vegetative growth	Controls algae, absorbs excess nutrients from water
<i>Nelumbo nucifera</i>	India, China, and Southeast Asia	Moderate growth rate	Provides shade, supports biodiversity, reduces light penetration

Ariffin et al. (2019) investigated the phytoremediation capacity of five aquatic plant species—*Centella asiatica*, *Ipomoea aquatica*, *Salvinia molesta*, *Eichhornia crassipes*, and *Pistia stratiotes*—in treating aquaculture wastewater. The results showed that these plants effectively reduced levels of total suspended solids (TSS), ammonia nitrogen (NH₃-N), and phosphate. Among them, *Eichhornia crassipes* and *Pistia stratiotes* exhibited the highest removal efficiencies, with reductions of up to 96% for TSS, 74% for NH₃-N, and 98% for phosphate. This study highlights the significant potential of aquatic plants in improving water quality and supporting sustainable aquaculture^[19].

Mustafa et al. (2020), Fonseka et al. (2023), Justin et al. (2024) examined the effectiveness of *Pistia stratiotes*, *Salvinia molesta*, and *Eichhornia crassipes* in treating domestic wastewater under different retention times. The findings showed that these plants significantly reduced turbidity, BOD, and COD levels in the treated water. The study recognized these aquatic plants as sustainable and cost-effective solutions for enhancing wastewater treatment processes^[20–22].

J.M. Evans pointed out that while *Azolla caroliniana* can be beneficial under controlled conditions, it may become invasive outside its native range. It tends to form dense mats that outcompete native vegetation and disrupt the natural state of aquatic ecosystems. Although it has been introduced to various countries for agricultural use, ongoing monitoring is necessary to prevent its negative impact on ecological balance^[3].

In Uzbekistan, pioneering studies on aquatic plants and their applications were conducted by Shoyokubov et al. (1988), Tokhirov et al. (2020)^[23,24]. These studies examined the hydrobiological and hydrochemical characteristics

of aquatic plants, offered recommendations for efficient water resource management in arid zones, and emphasized the ecological and economic importance of these species.

Specifically in Karakalpakstan, research has focused on the adaptability of higher aquatic plants such as *Pistia*, *Azolla caroliniana*, *Eichhornia crassipes*, and *Nelumbo nucifera*. To support this research, the Karakalpak Scientific Research Institute of Natural Sciences established six biological ponds, each measuring 120 cm in depth, 5.20 m in width, and 6.30 m in length, with a total area of 0.02 hectares (2 sotok). Organic fertilizers in controlled quantities were applied to four of these ponds, where aquatic plants were cultivated.

Throughout the study, observations and measurements were conducted to evaluate plant growth, biomass production, and ecological adaptability. These experiments helped assess how well aquatic plants can adapt to the arid and saline conditions specific to Karakalpakstan. The results indicated that these species could be effectively integrated into local ecosystems to improve ecological balance and stability.

The climate of the Republic of Karakalpakstan is sharply continental, with moderately cold winters and little snowfall. The only water source is the Amu Darya River, whose water is used for irrigating crops through large canals. Due to its location among sandy deserts, the summer is very hot, with sunny days lasting up to 200–220 days. In June, July, August, and September, cloudy days are almost nonexistent. The summer season is characterized by high daytime air temperatures (43–45°C) and water temperatures ranging from 27–33°C. In autumn, the average air temperature ranges between 5°C and 20°C, with autumn beginning around mid-September.

During the experiment, water temperature was moni-

tored daily using installed sensors. The temperature ranged from 20°C to 28°C, which provided optimal conditions for the growth of aquatic plants *Pistia stratiotes* L., *Azolla caroliniana*, *Eichhornia crassipes*, and *Nelumbo nucifera*. Temperature fluctuations were minimal, ensuring a stable environment for biological activities.

Over the 90-day experimental period, significant growth was observed in all studied species. *Pistia stratiotes* L. showed an average increase in leaf area by 45%, *Azolla caroliniana* exhibited rapid biomass doubling every 15 days, *Eichhornia crassipes* grew by 60% in coverage area, and *Nelumbo nucifera* showed steady root and leaf development.

Biomass measurements were conducted biweekly. *Eichhornia crassipes* produced the highest biomass, averaging 350 g/m² dry weight by the end of the experiment. *Pistia stratiotes* L. and *Azolla caroliniana* produced 280 g/m² and 260 g/m² respectively, while *Nelumbo nucifera*, being rooted, showed a moderate biomass increase of 220 g/m².

Reproductive activity was also recorded. *Azolla caroliniana* showed prolific spore formation throughout the experiment. *Pistia stratiotes* L. produced new daughter plants via vegetative propagation at a rate of 3 new plants per week. *Eichhornia crassipes* developed numerous stolons and flowers during the second month, contributing to its rapid spread. *Nelumbo nucifera* demonstrated flowering by the end of the experiment, indicating readiness for seed production.

4. Discussion

Pistia (*Pistia stratiotes* L.) is a floating aquatic plant belonging to the Araceae family. It was thoroughly studied and

described in the environmental conditions of Uzbekistan by Shoyokubov (1993)^[25]. This species is considered a perennial hydrophyte, thriving on the surface of mineralized water bodies that are rich in organic matter. Due to its unique structure, *Pistia* is capable of forming dense plant mats, which play an essential role in nutrient cycling and habitat creation in aquatic ecosystems.

Pistia stratiotes, due to its ability to absorb waste substances in water, can be used to create natural water purification systems in small to medium-sized water bodies.

In the specific climatic context of Uzbekistan, *Pistia* demonstrates promising adaptability. During the colder months of winter, the plant can be successfully cultivated under controlled conditions in laboratories, including in aquariums, glass vessels, and plastic containers maintained in greenhouses. These environments provide the warmth and light necessary for its survival and growth. With the arrival of spring, *Pistia* can be transplanted into larger outdoor water structures, such as reinforced concrete trays and cement-lined ponds. These installations allow researchers to monitor its development under semi-natural conditions. The successful growth and adaptation of *Pistia* in such systems are visually illustrated in **Figure 1**, which depicts the plant at different stages of development in an artificial aquatic environment.

The experimental findings revealed several key indicators of *Pistia*'s high productivity. Water temperature was consistently maintained within the range of 25–26 °C, which is considered optimal for the plant's physiological processes, including photosynthesis and nutrient uptake. In the presence of sufficient light and warmth, the plant demonstrated robust growth.



Figure 1. *Pistia* (*Pistia stratiotes* L.).

Under these conditions, *Pistia* reached a height of 30–40 cm, with leaf length averaging 11 cm and root systems extending up to 30 cm, reflecting healthy development stages and well-formed vegetative structures. The biomass productivity per square meter was notably high—typically around 3 kg, and in some instances, up to 5 kg of wet biomass. Moreover, over a five-day growth period, biomass accumulation reached up to 1900 g/m², indicating a rapid growth rate and strong vegetative propagation capacity.

These observations underscore *Pistia*'s potential as a fast-growing aquatic plant capable of forming dense mats on the water surface, contributing significantly to nutrient cycling and potential applications in water purification and biomass production.

The Carolina Azolla (*Azolla caroliniana* Willd.) is a species predominantly distributed in tropical regions and is known for its extremely fast vegetative growth, which allows it to cover large water surfaces in a short time. Its ability to fix atmospheric nitrogen through symbiosis with the cyanobacterium *Anabaena azollae* makes it particularly valuable for ecological and agricultural purposes.

Azolla caroliniana is distinguished by its symbiotic relationship that allows it to fix nitrogen from the air, making it especially useful in agriculture, particularly for enriching water reservoirs.

All species of *Azolla* float freely on the water surface, where they form extensive mats that influence light penetration, nutrient cycling, and gas exchange. Their ecological significance lies in their capacity to absorb nitrogen from both air and water, enriching aquatic environments and benefiting nearby plant species.

Azolla also holds immense agricultural potential: its rapid reproduction and high protein content make it a valuable feedstock for poultry and fish farming. In addition, it serves as a green manure, particularly in rice paddies, enhancing soil fertility without the need for synthetic fertilizers.

Azolla requires consistent light exposure and thrives in water temperatures between 16–28 °C. Reproduction occurs mainly via vegetative fragmentation: its lateral branches detach easily and drift with currents, establishing new colonies elsewhere. Observations during our research confirmed that *Azolla* can double its biomass in just 48 hours. For instance, placing 800 grams of biomass per 1 m² of water resulted in growth to 1600 grams within two days.

This extraordinary growth capacity, coupled with its roles in bioremediation, biogas production, and sustainable agriculture, highlights *Azolla*'s value. Moreover, its presence enhances ecological resilience, reinforces food webs, and stabilizes aquatic ecosystems (**Figure 2**).



Figure 2. Carolina azolla (*Azolla caroliniana* Willd.).

Currently, in our country, *Azolla* is widely utilized in poultry and aquaculture sectors as a nutritious and cost-effective feed, owing to its high protein content and rapid biomass production. Additionally, it is increasingly applied in wastewater treatment systems due to its ability to absorb excess nutrients, particularly nitrogen and phosphorus, thereby improving water quality and contributing to sustainable environmental management.

Eichhornia (Eichhornia crassipes), commonly known as water hyacinth, is an aquatic plant native to the tropical and subtropical regions of South America and does not naturally occur in Uzbekistan due to climatic constraints. It was introduced into Uzbekistan in the 1980s, and since then, studies have been conducted on its adaptation to local conditions.

Eichhornia crassipes (water hyacinth) is considered an invasive pest in some countries due to its rapid growth and reproduction. Therefore, careful control and management are necessary when introducing or cultivating it.

Eichhornia is characterized by its broad, glossy leaves

and purple flowers. It thrives in nutrient-rich, well-lit water and can rapidly produce numerous daughter plants in a short period. Research shows that it can increase from 10 to 16–22 daughter plants in one week, and under ideal conditions, this number may reach 30–40. This demonstrates its high vegetative propagation capacity and potential invasiveness. It grows best in water temperatures ranging from + 25 °C to + 30 °C. Observations at the Tashkent Botanical Garden confirmed that *Eichhornia* can successfully grow and reproduce in controlled water bodies under Uzbekistan's climatic conditions.

This plant acts as a natural biofilter by absorbing excess nutrients and heavy metals from the water, thereby improving water quality. Its aesthetic appeal also makes it popular in landscape design for gardens, ponds, and canals (**Figure 3**).

Due to its high biomass production and nutrient content, it is also used as animal feed. *Eichhornia* is considered a multifunctional and beneficial plant in both environmental and agricultural contexts, though effective management is required to prevent its uncontrolled spread.

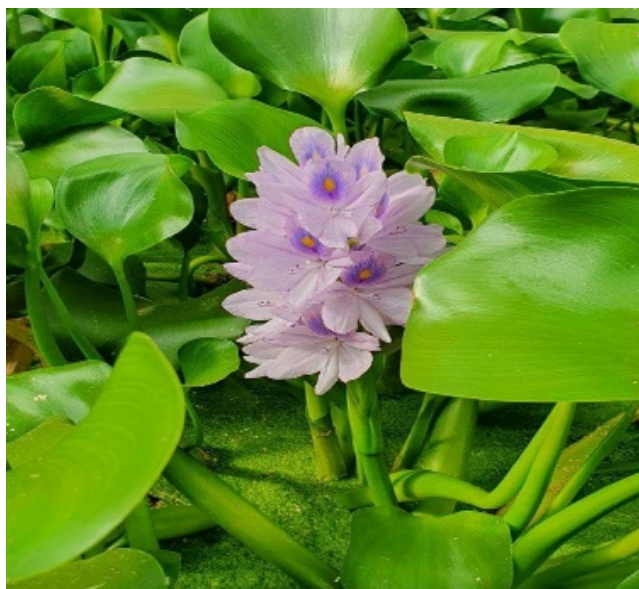


Figure 3. *Eichhornia crassipes* Solms.

Lotus (*Nelumbo nucifera*) is a perennial aquatic plant highly revered and culturally significant in many regions, especially in India and China, where it is associated with religious rituals, traditional medicine, and symbolic meanings of purity and enlightenment. Beyond its aesthetic and symbolic value, the lotus plays a crucial role in aquatic ecosystems. Its large leaves provide shade, reducing water temperature and

inhibiting excessive algal growth, while its root systems stabilize sediments and promote oxygenation. By contributing to water purification and enhancing habitat conditions for aquatic fauna, the lotus actively supports ecological balance and biodiversity conservation (**Figure 4**).

To enrich the plant gene pool and promote its adaptation to the unique climatic conditions of the Republic of

Karakalpakstan, the lotus (*Nelumbo nucifera*) was successfully introduced and cultivated in the pond of the children's health camp "Istiklol". The low salinity of the water body created favorable conditions for the growth and establishment of the plant. Laboratory studies confirmed the viability and rapid development of lotus seeds: when placed in a well-lit environment with clean, warm water (25–30°C), the

seeds swelled within a few days. The initial growth rate was observed to be 4.5–5 cm per day, underscoring the importance of optimizing environmental factors such as light and temperature for successful cultivation.

Nelumbo nucifera, besides its beautiful appearance, is widely used in medicine and food products (such as teas, ground seeds, and leaves).



Figure 4. Lotus (*Nelumbo nucifera*).

Additionally, the research emphasized the significance of monitoring and maintaining key physicochemical parameters of the water. These included temperature, pH, nitrate and nitrite content, and the levels of chlorides, sulfates, and phosphates. The stability of these indicators directly influences

plant health, nutrient availability, and the overall ecological balance of aquatic systems. The data collected were visualized through diagrams (**Figures 5 and 6**), which illustrate the dynamic changes and optimal ranges of these parameters in the study ponds.

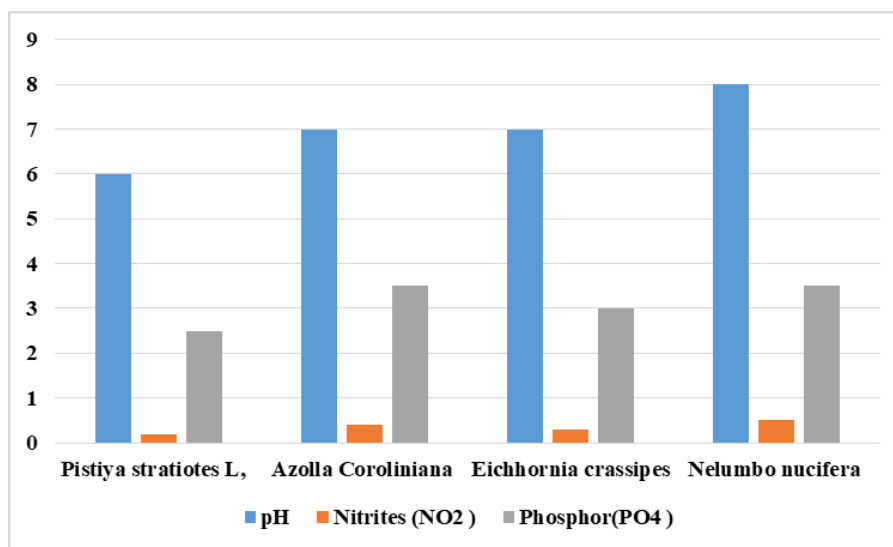


Figure 5. Physicochemical Parameters of Water in Water Bodies.

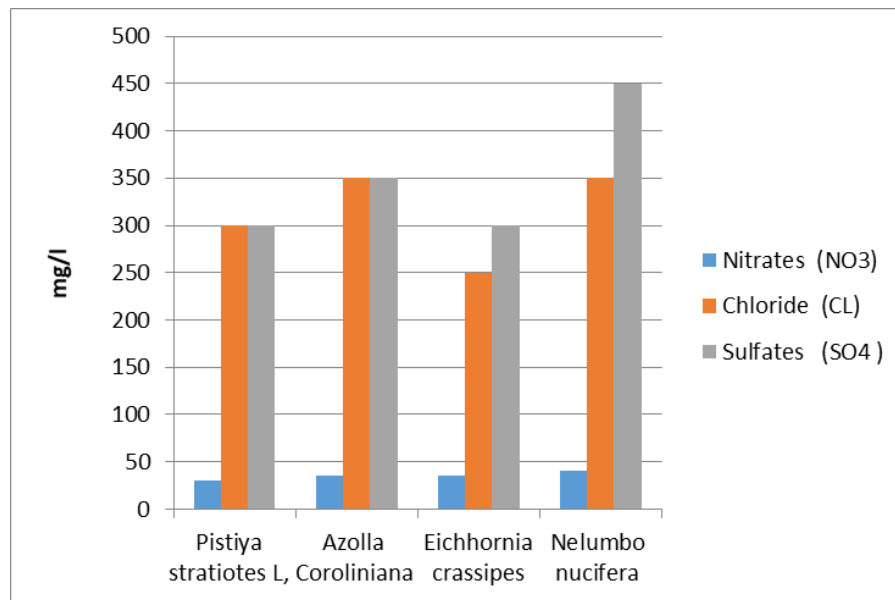


Figure 6. Physicochemical Parameters of Water in Water Bodies.

Water temperature is one of the most critical environmental factors influencing aquatic ecosystems. It directly affects the rate of photosynthesis in plants and the metabolic activity of microorganisms. Even slight changes in temperature can significantly alter the solubility of oxygen in water, which in turn impacts the respiration processes of aquatic flora and fauna. Therefore, maintaining a stable temperature range is essential for the health of the ecosystem.

Equally important is the pH level, which reflects the water's acid-base balance. It affects the solubility and availability of nutrients and directly influences biological processes such as nutrient uptake and microbial decomposition. Fluctuations in pH can hinder plant growth and alter microbial communities, thereby disrupting the ecological equilibrium.

Nitrates and phosphates serve as primary nutrients essential for the growth, development, and reproductive

success of aquatic plants. However, their excess can lead to eutrophication, while deficiency may suppress biodiversity. Thus, achieving and maintaining their optimal concentration is key to ensuring the sustainability of aquatic ecosystems.

Throughout the study, these physicochemical indicators were carefully measured and monitored using standardized methods. The data were recorded regularly, and necessary adjustments were made to maintain water quality. Their consistent control played a pivotal role in ensuring stable ecological conditions and supporting the successful growth of introduced aquatic plant species. **Table 2** below presents the changes in air and water temperature during May and June of 2024. The data in the table is crucial for evaluating the thermodynamic conditions of the environment throughout the experimental period.

Table 2. Changes in Air and Water Temperature During May and June of 2024.

The Date	May							June			
	1	5	10	15	20	25	30	1	5	10	13
Air temperature (C ⁰)	22	34	32	33	33	32	34	36	32	25	36
Water temperature (C ⁰)	19	29	28	27	29	28	29	30	28	21	29

At the beginning of May, the air temperature was 22°C, and from May 5 to May 30, it remained consistently high in the range of 32–34°C.

During this period, the water temperature also rose to 28–29°C, which is considered optimal for the growth of

aquatic plants.

From June 1 to June 13, the air temperature further increased to 36°C. The water temperature remained around 30°C, which activated biological processes in the water.

On June 10, the air temperature dropped sharply to

25°C, which was also reflected in the water temperature, decreasing to 21°C. Such fluctuations can have a short-term impact on plant growth.

In the salty and arid climate of Karakalpakstan, creating special water reservoirs (ponds) is important for cultivating these aquatic plants, as this provides optimal conditions for their growth.

5. Conclusions

High aquatic plants such as *Pistia stratiotes* L., *Azolla caroliniana*, *Eichhornia crassipes* and *Nelumbo nucifera* play an important role in ensuring ecological stability, managing water resources efficiently, and preserving regional biodiversity in the arid and saline ecosystems of Karakalpakstan and Central Asia in general.

These plants are effective in tasks such as water purification, nutrient cycling, biomass production, and phytoremediation of wastewater. Additionally, they stand out due to their ability to adapt to local ecosystems and play a crucial role in restoring ecological balance through the introduction of new species.

During the research, the hydrobiological and hydrochemical properties of these plants were continuously monitored, along with key factors influencing their growth such as temperature, pH, nitrates, phosphates, chlorides, and sulfates. The stability of these factors is critical not only for the healthy growth of the plants but also for the overall ecological condition of the aquatic environment.

Thus, *Pistia*, *Azolla*, *Eichhornia* and *Nelumbo* aquatic plants are biological tools of strategic importance, not only for the efficient management of water resources but also for the conservation and restoration of biological diversity.

5.1. Recommendations

For *Pistia stratiotes* L., *Azolla caroliniana*, *Eichhornia crassipes*, and *Nelumbo nucifera*, water temperature, pH, nitrate, phosphate, chloride, and sulfate levels are very important. To provide optimal conditions for these plants, regular monitoring of water quality is necessary. Additionally, the mineral content and levels of microelements in the water should also be taken into account.

Controlled amounts of special organic fertilizers can

be used to supply nutrients in the water and stimulate growth. However, it is important to consider that excessive use of fertilizers may cause eutrophication in the water.

Author Contributions

Conceptualization, Z.A. (Zhazgul Abdyrakhmanova) and K.K.; methodology, D.B. and S.M.; investigation, G.U.; resources, G.U.; supervision, D.B. and B.K.; writing—original draft preparation, O.K.; writing—review & editing, Z.A. (Ziyuar Allamuratova) and N.N. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All data supporting the reported results are provided within the manuscript. Additional data can be made available upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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