Aquatic Plants: The Unsung Heroes of Water Quality Management

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Abstract

Aquatic plants are vital for improving water quality and promoting sustainable aquatic ecosystem management through natural phytoremediation. The present article summarizes the roles of emergent, floating, and submerged macrophytes in removing excess nutrients, trapping suspended solids, enhancing dissolved oxygen, supporting beneficial microorganisms, and sequestering heavy metals. Species such as *Eichhornia crassipes*, *Pistia stratiotes*, *Ipomoea aquatica*, *Lemna* spp., and *Azolla* spp. effectively reduce pollutants from aquaculture effluents and wastewater. Their integration into aquaculture systems improves water quality, lowers disease risks and operational costs, and produces valuable biomass for feed, fertilizer, and bioenergy. The article also highlights their application in Recirculating Aquaculture Systems (RAS) and Integrated Multi-Trophic Aquaculture (IMTA), emphasizing careful species management to maximize environmental sustainability and support the blue economy.

Keywords: Aquatic plants, Integrated Multi-Trophic Aquaculture, Phytoremediation, Sustainable aquaculture, Water quality management

1. Introduction

Beneath the surface of every healthy pond, river, and mangrove lies a silent cleaning crew. Aquatic plants - *hydrophytes* - aren't just scenery. They are nature's most understated engineers, evolved to do what chemicals and machinery often cannot: keep water alive. For years, we have leaned on fertilizers, industrial discharge controls, and high-tech interventions to manage nitrates and phosphates in our waterways. Yet contamination keeps climbing - from aquaculture effluent, agricultural runoff, and urban waste. The result is collapsing fish stocks, vanishing biodiversity, and growing risks to human health. Clean water is no longer a local concern; it is a global emergency. Long before treatment plants existed, waterways already knew how to clean themselves. Aquatic plants act as living biofilters, sucking up the same excess nitrogen and phosphorus that fuel toxic algal blooms. Their roots host thriving colonies of beneficial bacteria that break down organic waste and neutralize harmful compounds - no power grid required. And the numbers are striking. In controlled aquarium trials, for instance, tanks with *Najas guadalupensis* held nitrate levels at just 8.75–11.50 mg/L by week four, compared to 33.75–35.00 mg/L in untreated tanks - a roughly 70% reduction (Csontos et al., 2024). Phosphate levels tell a similar story, dropping from around 2.4 mg/L to barely above 1 mg/L (Csontos et al., 2024). In fishponds planted with water spinach (*Ipomoea aquatica*), researchers documented 30.6% removal of total nitrogen and 18.2% removal of total phosphorus after just 120 days (Li & Li, 2009).

Beyond nutrients, certain species pull heavy metals - lead, copper, chromium, cadmium - directly out of the water column through their roots and tissues, effectively detoxifying industrial and municipal wastewater without a single chemical input (Kumar, 2009). During daylight, these plants photosynthesize, releasing oxygen into the water and absorbing carbon dioxide. That simple act stabilizes pH and raises dissolved oxygen levels - two of the most important indicators of water health. Their stems and leaves also trap suspended sediments, clearing turbidity and letting sunlight reach deeper waters. The side effects of clean water, it turns out, are themselves more clean water.

The world is searching for sustainable, low-cost ways to manage pollution, and aquatic plants offer something rare: a solution that is effective, regenerative, and self-replicating. They clean the water, shelter aquatic life, and ask for nothing more than the right conditions to thrive. The next time you spot water hyacinths bobbing on a pond or reeds fringing a riverbank, look closer. They aren't decoration. They are working - quietly, endlessly, and without a single invoice - to keep the ecosystem alive.

2. The Triple-Action Cleaners: How Aquatic Plants Purify Water

Aquatic plants aren't passive decoration on the water's surface. They are extraordinarily efficient natural biofilters, quietly running three integrated processes at once: soaking up nutrients, pumping out oxygen, and trapping pollutants - all while hosting thriving microbial communities on their roots.

2.1 The Nutrient Sponge

Scientists call it *phytoremediation* - from the Greek *phyto* (plant) and the Latin *remedium* (to restore) - and it is, in many ways, the original water treatment. Aquaculture ponds, for instance, are notorious for accumulating nitrogen and phosphate from uneaten feed, fish waste, and decomposing organic matter. Aquatic plants absorb that surplus before it can fuel the algal blooms that smother ponds and kill fish.

The numbers are hard to argue with. A controlled Malaysian study using five common aquatic plants to clean aquaculture wastewater recorded phosphate removal rates as high as 98% with water hyacinth (*Eichhornia crassipes*) and total suspended solids down by up to 98% with water lettuce (*Pistia stratiotes*) (Nizam et al., 2020).

2.2 Keeping Water Clear and Balanced

Those same plants do far more than suck up chemicals. Their dense root systems act like nets, capturing suspended particles and sediments and leaving the water visibly clearer. Beneath the surface, those roots create a perfect habitat for beneficial bacteria that break down organic waste and convert toxic compounds into less harmful forms (Fig.1).

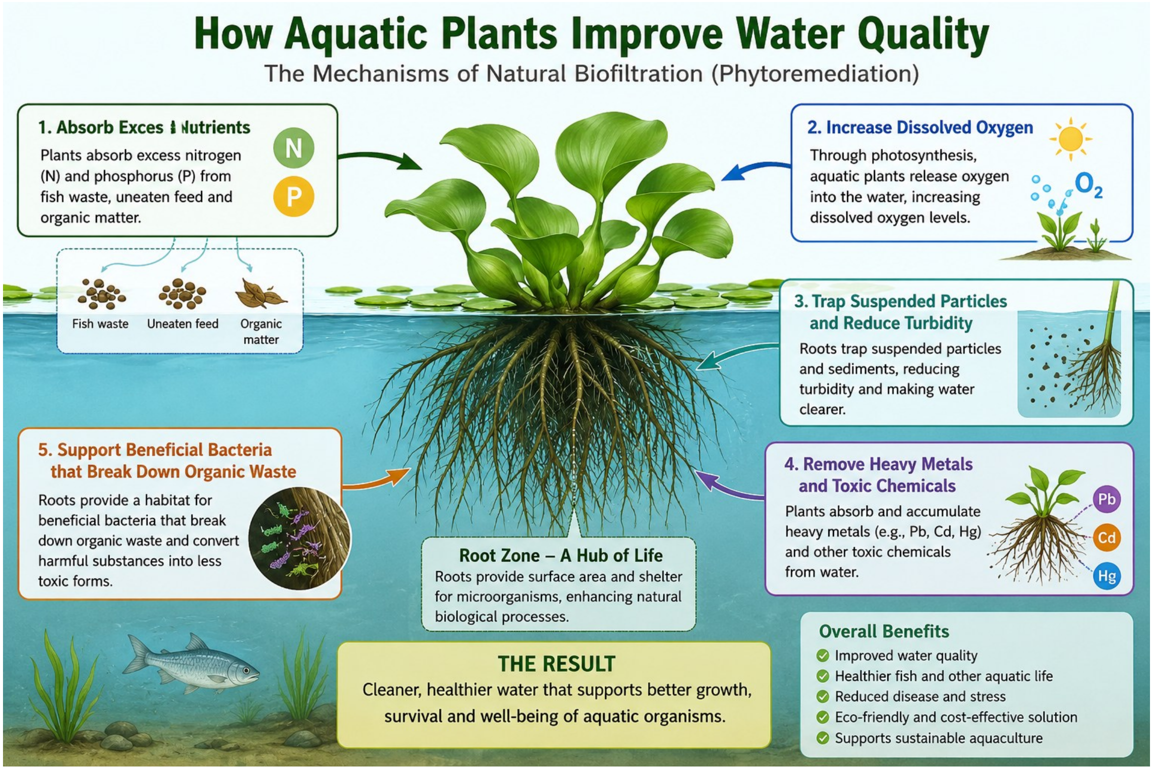

Fig. 1 Use of aquatic plants to improve water quality

During daylight, the plants photosynthesize - releasing oxygen into the water and pulling carbon dioxide out - which stabilizes pH and lifts dissolved oxygen levels. A review of the field confirmed that *Salvinia molesta* and *Pistia stratiotes* are particularly effective at this kind of biological water treatment, owing to their fast growth, resilience in toxic conditions, and high bioaccumulation potential (Mustafa & Hayder, 2020).

2.3 Heavy-Metal Stabilizers

Aquatic plants are also quietly tackling one of the most stubborn pollution problems on Earth: heavy metals. Species like duckweed, water hyacinth, and water lettuce can absorb - and store - toxic elements such as lead, cadmium, mercury, and arsenic in their tissues, drawing them out of the water column. A controlled Vietnamese study found that water hyacinth removed between 59% and 92% of cadmium, arsenic, lead, zinc, and copper from industrial wastewater within just 30 days, bringing concentrations back within safe discharge limits (Huynh et al., 2021). Another study using the same species showed removal rates above 80% for lead, copper, cadmium, and arsenic at concentrations as high as 8 mg/L (Peng et al., 2020). The bonus? The harvested plant biomass can sometimes be put to further use - turned into biogas, compost, or other products - turning a remediation project into a circular one.

3. The Three Eco-Zones of a Healthy Shoreline

Step to the edge of any healthy lake, pond, or estuary, and you'll find three distinct plant communities doing three very different jobs - a shoreline guard, a surface shader, and a deep-water workhorse. Together they form one of nature's most elegant partnerships.

3.1 The Shoreline Guard

These are the sentinels. Rooted in shallow water but rising proudly above the surface, emergent plants like cattails (*Typha spp*.) and reeds (*Phragmites australis*) act as living fences. They slow down incoming runoff, filter out silt, trash, and fertilizer before any of it reaches open water, and their dense stems blunt the force of waves and erosion. They are the first line of defense - ecologically and literally.

3.2 The Surface Shaders

Free-floating species drift at the water's skin, unanchored to the bottom. They range from barely-there specks like duckweed (*Lemna spp*.) and azolla (*Azolla spp*.) to showy mats of water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*), whose rosettes can stretch a foot across. Their leaves shade the water below, cooling it and suppressing the sunlight that fuels unwanted algal growth. And for all their beauty, some - like water hyacinth - are also remarkably efficient at pulling nutrients and even heavy metals from the water column, with documented removal rates exceeding 80–90% for several common contaminants (Huynh et al., 2021; Nizam et al., 2020).

3.3 The Deep-Water Workhorses

Fully underwater and often out of sight, submerged species like hydrilla (*Hydrilla verticillata*), hornwort (*Ceratophyllum demersum*), and eelgrass (*Zostera marina*) are the oxygen factories of the system. They release dissolved oxygen into the water all day, anchor sediments with their roots, and create the tangled cover where juvenile fish can hide from predators. Without them, the deeper layers of any waterbody can quickly become lifeless.

Table 1 Different types of aquatic weeds

Floating	Submerged	Emergent
Water hyacinth (*Eichhornia crassipes*)	Hydrilla (*Hydrilla verticillata*)	Reeds (*Phragmites australis*)
Duckweed (*Lemna spp.*)	Hornwort (*Ceratophyllum demersum*)	Cattails (*Typha spp.*)
Azolla (*Azolla spp.*)	Eelgrass (*Zostera marina*)	Water lettuce (*Pistia stratiotes*)

The point isn't simply to know these categories - it's to appreciate that removing any one of them breaks the system. A shoreline without emergent leaks sediment. A surface without floaters overheats and blooms. A water column without submerged plants suffocates. Healthy water isn't an accident. It's a stack of three living layers, breathing together.

4. Benefits of Aquatic Plants in Aquaculture

For most of the modern aquaculture era, clean water has meant costly infrastructure - aeration systems, mechanical filters, chemical treatments, frequent water exchanges. There's a quieter revolution underway. Instead of fighting nature with machinery, smart farmers are starting to work with it. Aquatic plants in and around grow-out ponds are now recognized as some of the most cost-effective tools available for keeping fish healthy and ponds productive. They pull surplus nutrients from the water, trap sediment, oxygenate during daylight, and create refuge for the microbes that finish the breakdown of organic waste. The difference shows up quickly in growth, survival, and feed-conversion performance.

4.1 Cleaner Water, Healthier Fish

In a Chinese carp-pond trial, simply floating vegetables like water spinach on one-sixth of the pond surface removed 30.6% of total nitrogen and 18.2% of total phosphorus from the system over four months - while unplanted control ponds saw those same nutrients accumulate (Li & Li, 2009). Cleaner water means lower stress on the fish, fewer disease outbreaks, and ultimately, better yields.

4.2 Tiny Biochemical Shields

Several aquatic species also produce alkaloids, tannins, and terpenoids - secondary metabolites that damage the cell membranes of pathogenic bacteria and fungi. Cattails and water hyacinths have shown the ability to physically filter waterborne pathogens like *E. coli* and release antimicrobial exudates into the surrounding water, turning the farm itself into a kind of biological sanitizer. The antioxidant power of some of these compounds exceeds that of vitamin C - the suppression isn't marginal, it's significant.

4.3 Lower Farming Costs

Once established, aquatic plants keep working without electricity or operator input. Mechanical aerators, routine chemical treatments, and the constant chore of water exchange can be reduced or eliminated in well-planted systems - an obvious win for smallholders operating on thin margins.

4.4 An Extra Harvest from the Same Pond

Some plants pay back twice. Azolla and duckweed are protein powerhouses - duckweed carries 20–35% crude protein, Azolla 15–40%, with doubling times as fast as 16–48 hours for some duckweed species. At modest inclusion rates (around 2.5–5% of the diet), both have shown measurable improvements in growth rate, protein efficiency, and feed conversion in carp and other omnivorous fish (Kamil & Taha, 2022; Minich & Michael, 2024). Surplus biomass can be composted, fed to poultry, or used as organic fertilizer - turning a remediation by-product into a second income stream.

5. The Other Side of the Coin: When the Helpers Take Over

Not every aquatic plant stays where you put it. Water hyacinth is the cautionary tale of green technology gone wrong. Under the right conditions, its doubling time can be measured in days, and dense mats can choke entire waterways (Mustafa & Hayder, 2020). The plant suffocates native species, blocks navigation and irrigation canals, raises water acidity, drops oxygen levels, and even creates breeding habitat for mosquitoes and snails carrying bilharzia. The same biological vigor that makes water hyacinth an exceptional purifier in a controlled pond makes it an ecological disaster in open water. The lesson is simple: choice of species, containment, and active management matter as much as the principle itself.

6. What's Next: Plant-Based Aquaculture at Industrial Scale

Two ideas are converging in modern aquaculture - and aquatic plants sit at the center of both. Recirculating Aquaculture Systems already recycle 90–99% of their water, but they depend on energy-hungry biofilters and constant monitoring (Fredricks, 2015). Adding a floating-plant module - duckweed, water lettuce - cuts nutrient loads before they hit the biofilter, raises dissolved oxygen, and lightens the system's energy footprint. In a Chinese floating-bed recirculating system, the plant ponds alone contributed to total nitrogen and total phosphorus removal rates of 69.6% and 77.9% respectively.

Integrated Multi-Trophic Aquaculture is the bolder innovation. Fish excrete ammonia and phosphate; aquatic plants absorb them and grow. A pilot duckweed-based IMTA system has demonstrated removal of 0.78 tonnes of total nitrogen and 0.38 tonnes of total phosphorus per year, while producing biomass with over 21% protein content (Paolacci et al., 2022). Theoretical models suggest marine IMTA systems can theoretically retain up to 79–94% of feed-derived nitrogen, phosphorus, and carbon if the species are carefully matched (Nederlof et al., 2021); realistic on-farm efficiencies still hover at 45–75%.

The future of aquaculture won't be decided only by bigger tanks or better feed (Fig.2). It will be decided by how cleverly farmers close the loop between fish, plants, and the water they share. Aquatic plants may be the cheapest, most versatile, and most underused tool we have to do exactly that.

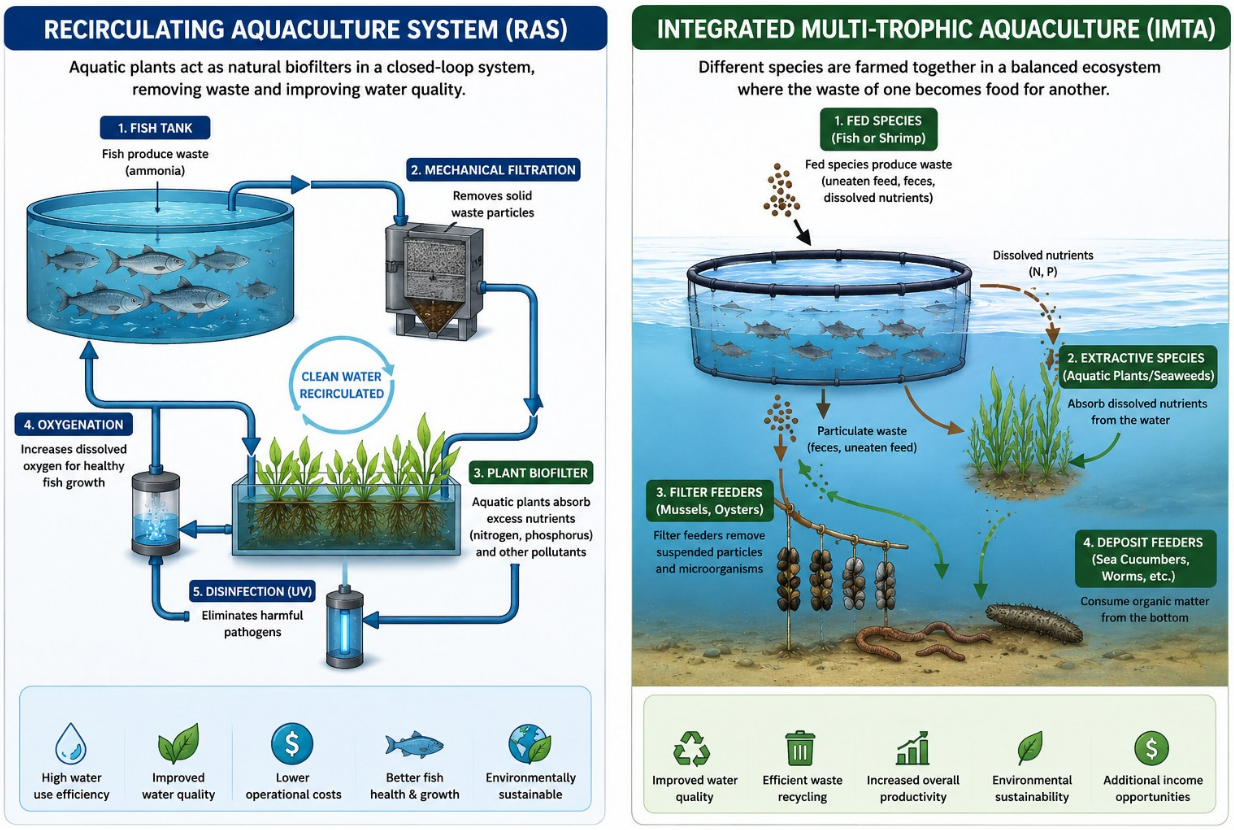

Fig. 2 Use of aquatic plants in RAS and IMTA system

7. Conclusion

Aquatic plants are among the most effective and sustainable natural tools for maintaining and restoring water quality in aquatic ecosystems. Through nutrient uptake, oxygen production, sediment trapping, and heavy metal sequestration, they function as living biofilters that improve water quality while supporting biodiversity and ecosystem stability. Their integration into aquaculture systems offers multiple benefits, including enhanced water quality, reduced disease risk, lower operational costs, and the generation of valuable biomass that can be utilized as feed, fertilizer, or bioenergy resources. Emergent, floating, and submerged aquatic plants each contribute unique ecological functions, collectively creating a balanced and resilient aquatic environment. However, successful application requires careful species selection and management to prevent ecological issues associated with invasive plants. As aquaculture moves toward resource-efficient and environmentally responsible production systems, the incorporation of aquatic plants into Recirculating Aquaculture Systems (RAS), Integrated Multi-Trophic Aquaculture (IMTA), and wastewater treatment frameworks presents a promising pathway toward circular and sustainable blue economy practices. By harnessing the natural purification capacity of aquatic plants, future aquaculture and water management strategies can reduce environmental impacts, improve resource utilization, and contribute significantly to long-term ecosystem health and food security.

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