

Review Article

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Role of Native Aquatic Plants in Improving Water Quality and Plankton Diversity in Small-Scale Fish Culture Systems

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ABSTRACT

Native aquatic plants have long been recognized as critical ecological components in freshwater systems. In the context of small-scale fish culture, their role extends beyond mere aesthetic value to encompass vital functions such as nutrient uptake, dissolved oxygen regulation, physical habitat structuring, and support for diverse planktonic communities. This review comprehensively examines the multifaceted contributions of native macrophytes including emergent, submerged, and floating-leaved species to water quality improvement and plankton diversity enhancement in small-scale aquaculture ponds and reservoirs. Evidence from global literature consistently demonstrates that the strategic integration of native aquatic vegetation significantly reduces concentrations of Total Nitrogen (TN), Total Phosphorus (TP), ammonia and Biochemical Oxygen Demand (BOD), while simultaneously promoting the proliferation of phytoplankton and zooplankton communities that serve as natural fish food. The review further discusses the mechanisms underlying these interactions, management strategies for macrophyte integration, and the challenges associated with maintaining appropriate plant densities. Future research directions emphasizing indigenous plant species selection, integrated farming models, and ecosystem-based aquaculture approaches are also highlighted. This article aims to provide a scientific foundation for sustainable, low-input aquaculture systems where native flora plays an instrumental role in maintaining ecological balance and productivity.

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Received: August 26, 2026; Accepted: September 02, 2026; Published: September 09, 2026

Keywords: Native Aquatic Macrophytes, Water Quality, Plankton Diversity, Small-Scale Aquaculture, Phytoplankton, Zooplankton, Nutrient Removal, Integrated Fish Farming

Introduction

Freshwater aquaculture, particularly small-scale fish culture in ponds and minor reservoirs, has emerged as a vital component of global food security strategies, particularly in developing nations across Asia, Africa, and Latin America. These systems are often characterized by limited water exchange, high stocking densities, and elevated nutrient inputs from artificial feeds and organic fertilizers, which collectively contribute to deteriorating water quality a primary constraint to fish health and productivity.

The eutrophication of aquaculture waterbodies, driven by excess nitrogen and phosphorus, leads to algal blooms, oxygen depletion, and the collapse of natural food webs. Conventional remediation approaches, including mechanical aeration, water exchange, and chemical treatments, are often cost-prohibitive for small-scale farmers and carry environmental risks.

In contrast, the strategic use of native aquatic macrophytes offers a biologically sound, cost-effective, and ecologically compatible alternative. Macrophytes the vascular plants and large algae that grow in or near water perform a suite of ecological services including nutrient assimilation, sediment stabilization, provision of shelter and substrate, and the modulation of light and temperature regimes. Critically, they form the structural basis for complex food

webs by supporting phytoplankton and zooplankton communities that represent the primary natural food for many cultured fish species.

Despite growing recognition of these benefits, the systematic integration of native aquatic plants into small-scale aquaculture remains underexplored relative to their exotic or commercially cultivated counterparts. This review aims to synthesize available scientific evidence on the roles of native macrophytes in water quality improvement and plankton diversity enhancement within small-scale fish culture systems, thereby providing a knowledge base for ecologically informed aquaculture management.

Native Aquatic Macrophytes: Classification and Ecological Significance

Classification of Aquatic Macrophytes

Aquatic macrophytes are broadly classified into four functional groups based on their growth form and relationship to the water surface:

- Emergent macrophytes (e.g., *Phragmites australis*, *Typha* spp., *Eleocharis* spp.): rooted in sediment with aerial vegetative parts.
- Submerged macrophytes (e.g., *Hydrilla verticillata*, *Vallisneria spiralis*, *Ceratophyllum demersum*): fully submerged, rooted or free-floating.
- Floating-leaved macrophytes (e.g., *Nymphaea* spp., *Nelumbo* spp., *Trapa natans*): rooted with leaves floating at the water surface.

- Free-floating macrophytes (e.g., *Eichhornia crassipes*, *Lemna* spp., *Pistia stratiotes*): not rooted, floating on the water surface.

Native species within each of these categories have co-evolved with local fish fauna, microbial communities, and plankton assemblages, conferring distinct adaptive advantages over introduced species in terms of ecological fit, disease resistance, and long-term sustainability.

Ecological Roles in Aquatic Ecosystems

Native macrophytes contribute to ecosystem functioning through multiple pathways. They oxygenate the water column via photosynthesis, stabilize sediments through root networks, attenuate water turbulence, and create microhabitats for invertebrates and juvenile fish. Their root zones (rhizospheres) host complex microbial communities that mediate biogeochemical transformations, including nitrification, denitrification, and phosphorus immobilization. These functions collectively underpin the capacity of macrophyte-rich systems to self-regulate water quality and support diverse biological communities.

Role Of Native Aquatic Plants in Water Quality Improvement Nitrogen and Phosphorus Removal

Excess nitrogen (N) and phosphorus (P) are the principal drivers of eutrophication in fish ponds. Native macrophytes contribute to their removal through direct uptake into plant biomass, stimulation of microbial denitrification in the rhizosphere, and the physical entrapment of particulate matter. Studies on *Hydrilla verticillata* and *Vallisneria spiralis* in Asian fish ponds have demonstrated nitrogen removal efficiencies ranging from 40–75%, with phosphorus removal of 30–60% under moderate stocking conditions [1,2]. Emergent species such as *Typha* spp. and *Phragmites australis* in constructed wetland-pond systems have further shown effective TN and TP reduction, making them valuable components of integrated water treatment in small-scale aquaculture [3].

Ammonia and BOD Regulation

Elevated ammonia concentrations, resulting from fish excretion and uneaten feed decomposition, are among the most acute toxicological threats in intensive pond culture. Native floating macrophytes such as *Lemna* spp. and *Pistia stratiotes* absorb ammonia directly from the water column, while their root surfaces facilitate the growth of nitrifying bacteria that convert ammonia (NH₃-N) to less toxic nitrate forms [4]. Concurrently, the shading effect of floating plants moderates phytoplankton productivity and organic matter decomposition, reducing Biochemical Oxygen Demand (BOD) and improving overall water transparency.

Dissolved Oxygen Dynamics

The role of submerged native macrophytes in oxygenating shallow water bodies is well-documented. Species such as *Ceratophyllum demersum* and *Myriophyllum spicatum* release oxygen during daylight photosynthesis, contributing to Dissolved Oxygen (DO) concentrations that support fish metabolic requirements. However, their nocturnal respiration can cause DO fluctuations, particularly in dense monocultures. The balance between macrophyte biomass and oxygen dynamics necessitates careful management of plant density in fish culture systems, typically advocating for coverage not exceeding 30–40% of water surface area [5].

Sediment Stabilization and Turbidity Reduction

Turbidity, caused by suspended sediment and algal biomass, impairs fish feeding behavior, gill function, and light penetration necessary for photosynthesis. The physical structure of aquatic

macrophytes particularly their root mats and leaf canopies dampen water turbulence and facilitates the sedimentation of suspended particles. Native emergent species along pond margins effectively reduce wave action and resuspension of bottom sediments, improving water clarity and reducing the oxygen demand exerted by decomposing organic matter.

Influence On Plankton Diversity and Abundance

Phytoplankton Communities

Plankton communities in fish ponds are profoundly shaped by the presence and composition of aquatic macrophytes. Native macrophytes influence phytoplankton through multiple mechanisms: resource competition (for light, CO₂, and inorganic nutrients), allelopathy (release of plant secondary metabolites that inhibit algal growth), and physical light attenuation. Studies have consistently shown that ponds with native macrophyte coverage exhibit lower cyanobacterial bloom frequencies and greater taxonomic diversity of phytoplankton, including higher proportions of Chlorophyceae and Bacillariophyceae, which are more nutritionally valuable as fish food compared to bloom-forming Cyanobacteria [6,7].

Zooplankton Communities

Zooplankton represent a critical link in the pond food web, converting microbial and algal biomass into a form accessible to fish larvae and juvenile fishes. Native macrophytes provide structural refuge for zooplankton particularly cladocerans (e.g., *Daphnia* spp., *Moina* spp.) and copepods (e.g., *Cyclops* spp., *Diaptomus* spp.) from predation by planktivorous fish. This refuge effect has been demonstrated to sustain higher zooplankton densities and diversity indices in vegetated versus unvegetated ponds [8]. Enhanced zooplankton biomass in macrophyte-rich ponds correlates positively with improved growth rates of herbivorous and omnivorous fish species in integrated culture systems.

Microbial Plankton and Bacterial Diversity

The rhizospheres of native aquatic plants harbor diverse bacterial communities that participate in nutrient cycling, including nitrifying bacteria (*Nitrosomonas*, *Nitrobacter* spp.), denitrifiers, and phosphate-solubilizing bacteria. Macrophyte-associated biofilms also support periphyton communities (attached microalgae and bacteria), which function as supplementary food sources for detritivorous and benthic invertebrates in fish ponds. The presence of native macrophytes thus supports a richer and more functionally diverse microbial plankton community compared to open-water systems lacking vegetative structure [9].

Macro-invertebrate and Periphyton Interactions

Macrophyte surfaces provide substrates for the colonization of periphytic algae and epiphytic invertebrates, which contribute significantly to the nutritional ecology of omnivorous fish. In small-scale pond systems stocked with species such as common carp (*Cyprinus carpio*), tilapia (*Oreochromis* spp.), and catla (*Catla catla*), periphytic communities associated with native macrophytes supplement formulated diets and reduce dependence on external feed inputs, thereby lowering production costs and environmental nutrient loads [10].

Commonly Used Native Aquatic Plants in Fish Culture Systems

Table 1 summarizes key native aquatic plant species widely used or recognized for their potential in small-scale fish culture systems, their ecological function, and associated fish culture benefits.

Table 1: Native Aquatic Plants Beneficial in Small-Scale Fish Culture Systems

Species	Type	Key Function	Fish Culture Benefit
Hydrilla verticillata	Submerged	O ₂ production, nutrient uptake	Natural fish feed, water clarity
Vallisneria natans	Submerged	Nutrient removal, shelter	Fish refuge, zooplankton habitat
Ceratophyllum demersum	Submerged	Allelopathy, O ₂ release	Cyanobacteria control
Lemna spp.	Free-floating	Ammonia uptake, shading	Reduces ammonia toxicity
Nymphaea spp.	Floating-leaved	Temperature moderation	Fish shelter, diversity boost
Nelumbo nucifera	Floating-leaved	Nutrient cycling, shading	Reduces algal blooms
Typha spp.	Emergent	P removal, sediment trapping	Turbidity reduction
Phragmites australis	Emergent	N removal, bank stabilization	Pond margin protection
Trapa natans	Floating-leaved	BOD reduction, shading	Algal bloom suppression

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Management Considerations for Macrophyte Integration
Optimal Coverage and Density

The integration of native macrophytes into fish culture systems requires careful attention to coverage levels to avoid negative consequences such as nocturnal hypoxia, excessive shading of the water column, or physical impediment of fish movements and harvest operations. The general recommendation in the literature is to maintain macrophyte coverage at 20–40% of total water surface, with species selection guided by the specific management goals of the culture system [11,5].

Species Selection Criteria

Selection of appropriate native species should consider: (1) local ecological adaptability and competitive performance, (2) compatibility with the target fish species and their feeding habits, (3) palatability avoiding species that may be toxic or unpalatable to fish, (4) growth rate and harvestability to prevent overgrowth, and (5) absence of allelopathic compounds harmful to planktonic communities at high concentrations. Indigenous knowledge of traditional fish-plant associations can provide valuable guidance for species selection, particularly in tropical and subtropical regions.

Harvesting and Biomass Management

Periodic harvesting of macrophyte biomass is essential to prevent overgrowth and maintain optimal plant densities. Harvested biomass, rich in nitrogen and phosphorus, can be composted and returned to the pond as organic fertilizer or used as animal feed, creating circular nutrient cycles within the farm. Mechanical or manual harvesting at intervals of 4–6 weeks during peak growing seasons is generally sufficient to maintain desired densities without disrupting ecological functions [3].

Case Studies and Empirical Evidence
Asian Integrated Pond Farming Systems

Traditional integrated rice-fish and vegetable-fish systems in China, Bangladesh, and India have long incorporated native aquatic plants as integral components of the culture environment. Studies in Chinese shallow lakes and fish ponds with Vallisneria natans and Hydrilla verticillata reported significant reductions in total nitrogen (35–65%) and phosphorus (25–55%), alongside markedly higher zooplankton diversity indices (Shannon-Wiener H' = 2.1–3.4) compared to unvegetated control ponds [2-7]. Enhanced cladoceran densities in vegetated ponds were strongly correlated with improved growth rates of silver carp (Hypophthalmichthys molitrix) and bighead carp (H. nobilis).

African Small-Scale Aquaculture

In sub-Saharan Africa, pilot projects integrating native macrophytes particularly Typha australis and Phragmites mauritanus into small earthen fish ponds stocked with Nile tilapia (Oreochromis niloticus) demonstrated water quality improvements comparable to partial water exchange treatments. Turbidity was reduced by 40–55%, and phytoplankton diversity increased significantly, with an observed shift from Cyanobacteria to Chlorophyceae dominance, indicating improved trophic conditions and reduced algal toxin risk [12].

South Asian Periphyton-Based Aquaculture

Research from Bangladesh and Sri Lanka on periphyton-based aquaculture systems utilizing native bamboo substrates and aquatic plants demonstrated that substrate-associated periphytic communities could supply 30–50% of the dietary protein requirements for rohu (Labeo rohita) and common carp, substantially reducing feed input costs. The integration of native floating macrophytes further enhanced periphyton production and zooplankton diversity, contributing to improved feed conversion ratios and lower nitrogen excretion rates [10].

Challenges And Limitations

Despite their considerable benefits, the integration of native aquatic plants in fish culture systems presents several practical and ecological challenges:

- **Overgrowth and Management Burden:** Fast-growing native species may rapidly exceed optimal densities, requiring frequent manual harvesting that adds to labor costs.
- **Dissolved Oxygen Fluctuations:** Dense macrophyte beds can cause diurnal DO swings, with hypoxic conditions at night posing risk to fish health.
- **Competition with Fish:** Herbivorous fish species may consume macrophyte biomass at rates that prevent the establishment of stable plant communities.
- **Shading Effects:** Excessive floating plant coverage reduces light penetration, limiting the productivity of submerged phytoplankton and beneficial submerged macrophytes.
- **Lack of Species-Specific Research:** Many native macrophyte species lack comprehensive studies on their effects in aquaculture settings, hindering evidence-based management

recommendations.

- **Invasiveness Risk:** Even native species can become ecologically dominant if management is insufficient, potentially disrupting local biodiversity outside the pond system.

Future Research Directions

Future research should prioritize several key areas to advance the evidence base for native macrophyte integration in aquaculture:

- Region-specific screening of native macrophyte species for water treatment efficiency and compatibility with indigenous fish species.
- Long-term monitoring studies assessing plankton community succession and stability in macrophyte-integrated pond systems.
- Quantification of economic benefits, including reduced feed and input costs, associated with macrophyte integration.
- Molecular and metagenomic approaches to characterize rhizosphere microbial diversity and its functional contributions to nutrient cycling.
- Development of farmer-accessible guidelines and decision-support tools for macrophyte species selection and management.
- Climate change vulnerability assessments for macrophyte-based water quality management in changing thermal and hydrological regimes.

Conclusions

The evidence reviewed in this article strongly supports the proposition that native aquatic macrophytes are powerful, multifunctional agents of ecological management in small-scale fish culture systems. Through mechanisms encompassing nutrient assimilation, oxygen dynamics regulation, microhabitat provision, and trophic support for planktonic communities, native plants contribute significantly to the biological, chemical, and ecological quality of aquaculture waterbodies.

Their integration into pond management represents an alignment with ecosystem-based principles that favor sustainability, biodiversity conservation, and low-input productivity. The promotion of zooplankton and phytoplankton diversity through native macrophyte communities not only improves water quality indices but also enhances natural food availability for fish, with direct implications for growth performance and economic returns for small-scale farmers.

Achieving these benefits requires context-sensitive management encompassing appropriate species selection, density control, and biomass recycling informed by robust local research and participatory approaches with farming communities. As global aquaculture continues to expand to meet rising food demands, the ecological wisdom embedded in native aquatic plant integration offers a viable pathway toward productive, resilient, and environmentally responsible small-scale fish culture systems.

References

1. Reddy KR, DeLaune RD (2008) Biogeochemistry of Wetlands: Science and Applications. CRC Press 732.
2. Xie Y, Zhang X, Xiao J, Hu Z, Liu Y, et al. (2013) Biomanipulation of aquatic macrophytes in Chinese shallow lakes: Restoration and management. *Hydrobiologia* 713: 83-91.
3. Vymazal J (2011) Constructed wetlands for wastewater treatment: Five decades of experience. *Environmental Science & Technology* 45: 61-69.
4. Caicedo JR, van der Steen NP, Arce O, Gijzen HJ (2000) Effect of total ammonia nitrogen concentration and pH on growth rates of duckweed (*Spirodela polyrrhiza*). *Water Research* 34: 3829-3835.
5. Scheffer M (1998) Ecology of Shallow Lakes. Chapman & Hall, London <https://research.wur.nl/en/publications/ecology-of-shallow-lakes/>.
6. Hilt S, Gross EM (2008) Can allelopathically active submerged macrophytes stabilize clear-water states in shallow lakes? *Basic and Applied Ecology* 9: 422-432.
7. Zhang X, Zhu X, Jiang L, Li K, Liu Z (2014) Allelopathy and the possible importance of phytoplankton and zooplankton in lake restoration. *Science of the Total Environment* 73: 5141-5151.
8. Diehl S, Kornijów R (1998) Influence of submerged macrophytes on trophic interactions among fish and macroinvertebrates. In: *The Structuring Role of Submerged Macrophytes in Lakes*. Springer 24-46.
9. Wetzel RG (2001) *Limnology: Lake and River Ecosystems* (3rd ed.). Academic Press, San Diego.
10. Azim ME, Verdegem MCJ, van Dam AA, Beveridge MCM (2005) *Periphyton: Ecology, exploitation and management*. CABI Publishing 1-13.
11. Boyd, CE (1990) Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama 482.
12. Mchau GJ, Makule E, Machunda R, Gong YY, Kimanya M (2019) Harmful algal bloom and associated risk factors among under-five children: Evidence from Ukerewe Island, Tanzania. *Journal of Water and Health* 17: 826-836.