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Assessing the Role of Native Aquatic Plants in Maintaining Water Quality in Integrated Fish Farming Systems: A Quantitative Evidence Synthesis

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Abstract: The intensive pond farming system loses most of the feed's nitrogen and phosphorus content as dissolved and particulate nutrients, causing eutrophication that can be dangerous to the farm itself and the receiving water body. Using native aquatic plants has been suggested as an economic natural method to help mitigate the problem, but information is scattered over different species, sizes and systems. The current study summarises the nine-research works conducted between 2020 and 2025 on the effectiveness of the use of floating, submerged and emergent macrophytes, and rice floating beds in lab tanks, ponds and commercial scale wetlands. Removal efficiency was 50–98%, 64–98% and 73–98% in 14 days for phosphate, ammonia-nitrogen and suspended solids, respectively. The commercial scale wetland was able to remove 25–44% and 62–72% of total nitrogen and total phosphorus, respectively. Submerged macrophytes retained 75% less total phosphorus than control sites after 90 days in pond studies, and avoided cyanobacteria blooms, while rice-fish farming reduced phosphorus mobilization from sediments by 82%. It varied according to the species used, the season, dissolved oxygen levels, retention time and biomass harvesting. There were several successful species that were invasive in non-native regions, and only occasionally is their nativeness noted. The provided block diagram for plant-based treatment trains, a decision matrix for species selection, and research needs for incorporating native plants into fish farms.

Keywords: Native Macrophytes; Phytoremediation; Integrated Aquaculture; Water Quality; Nutrient Removal; Eutrophication.

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I. Introduction

Aquaculture provides as much feedstock of aquatic animals as does capture fisheries. It has generated 130.9 million metric tons in total in 2022 and, for the first time, has accounted for 51% of production of aquatic animals, with the inland aquaculture generating 62.6% of farmed aquatic animals (Wu et al., 2023). Such growth has been achieved primarily due to intensification practices involving high stocking rates, formulation of feeds, and minimal water renewal. Integrated systems ranging from traditional mulberry-paddy-fish pond to more recent IMTA work on the contrary principles of integrating species in order for the wastes of one to be a resource for the other (Li et al., 2022).

The environmental impact of intensification lies in the excessive loading of nutrients. Fish are able to absorb just 20-30% of the nitrogen and 25-35% of the phosphorus from their diet, while the rest goes to the water environment (Kamilya et al., 2022). According to the latest research conducted in intensive ponds and referencing previous studies, only 2.4-48.4% of phosphorus consumed by fish is accumulated in the body of fish itself, and more than 60% of the unused phosphorus is deposited in the sediment (Blandford et al., 2024). The unused feed and the fish excrements contribute to the process of eutrophication of stagnant and shallow ponds (Nabi et al., 2025). The effluent leads to contamination of the adjacent waters (Ma et al., 2018).

The purification of this effluent is expensive. Biofilters and physical filters require high capital costs, while the constructed wetlands are preferred because they are low-cost and environmentally friendly (Ma et al., 2018). In regions with scarce water resources, biological ecotechnologies involving aquatic plants are regarded as an affordable method in contrast to chemical and physical purification that is costly to install and maintain (Sharma et al., 2021). The contamination removal process is performed by macrophytes using

rhizofiltration, phytoextraction, phytostabilisation, phytovolatilisation, and phytotransformation; the removal of nitrogen and phosphorus in non-sterile phytoremediation systems varies from 35% to 98% and 45% to 99%, respectively (Kamilya et al., 2022).

One of the main problems is that the plants used for the test are not native to the area where the farms are located. Eichhornia crassipes, which is one of the most common plants used in phytoremediation, is known as the world's most damaging aquatic weed and creates such thick layers on the surface of water that sunlight does not reach the water underneath (de Vasconcelos et al., 2021). However, native plants can be a solution, as they allow using all the advantages of the plant without worrying about its weediness, but the effectiveness of native plants in fish farming has not been studied.

This literature review poses three such questions, all falling into the category of topics related to sustainable aquaculture, water quality assessment and control of eutrophication, and ecological restoration, namely: (i) What nutrient, organic and solid load does the plant-based unit remove from water used for raising fish; (ii) Which kinds of plants and systems ensure the highest stability of the water quality; and (iii) What do we know, and what remains unknown about the importance of native species. We address them by critically reviewing quantitative data from recent literature and conclude with a decision-making tool.

II. Background and Conceptual Framework

Plant Functional Groups in Fish-Farm Water

FTWs cultivate macrophytes on floating rafts whereby the roots are immersed in the water column increasing the nutrient uptake. The roots trap suspended solids while hosting biofilm that degrades pollutants (Zheng et al., 2024). FTWs do not require additional land use and move up and down with changing water levels hence suitable for fish ponds (Zheng et al., 2024). Different floating and semi-aquatic plant species like water spinach, water lettuce, and ferns have been tested simultaneously in the aquaculture wastewater treatment, where ammonia, phosphate, and solids removed by these different plant species during 14 days are highly variable (Xu et al., 2024). Seasonality provides an additional factor to consider whereby decreased water temperature decreases nutrient removal and biomass production; therefore, the most efficient species is seasonal (Truong et al., 2024; Oktaviyani et al., 2024; Wang et al., 2023). Rooted plants are different from the above ones as they compete with phytoplankton and stabilise sediment within the pond (Nabi et al., 2025). Crops grown on floating beds provide another example whereby growing rice in the pond covered by floating beds of 30% reduced nitrogen, phosphorus and alkalinity than non-planted ponds (Zhao et al., 2024; Zhao et al., 2023).

Native Versus Introduced Species

Native plants are those that occur in a region without being introduced by man, meaning nativeness is a feature of the plant-place combination and not of the individual plant alone. This point is relevant since performance and invasiveness are two distinct concepts, and some of the most productive plants can be considered the most invasive ones as well (de Vasconcelos et al., 2021). Thus, nativeness is regarded as a feature that needs to be indicated in the studies.

Conceptual Framework

The treatment chain presented in figure 1 is the one employed to structure the evidence. Feeding occurs in the fish pond; the water containing dissolved nitrogen, phosphorus, and solids leaves the pond through a settling chamber and then enters the macrophyte modules for nutrient removal through uptake, filtration, and biofilm support. The effluent is either recycled or discharged, and the plants are harvested to export the nutrients while being used for compost or feed supplement when possible (Kamilya et al., 2022). The three locations identified in the literature are in-pond modules (submerged macrophytes Nabi et al., (2025) and floating rice bed (Zhao et al., 2024)), side-stream floating modules Zheng et al., (2024), and downstream

emergent wetlands (Ma et al., 2018). The monitoring layer is used to monitor dissolved oxygen, nitrogen species, phosphorus, and solids.

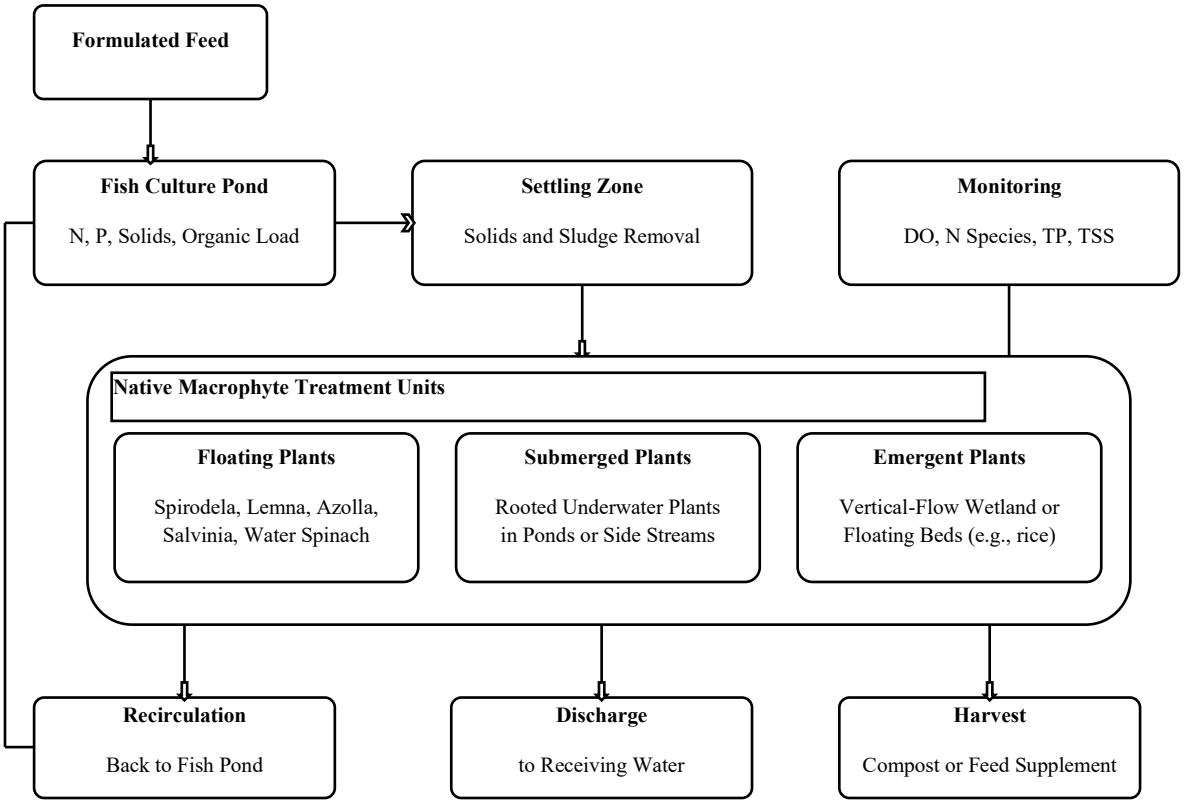


Figure 1: Conceptual Block Diagram of a Plant-Based Treatment Train in an Integrated Fish Farm

III. Materials and Methods

Study Design and Search

This is a non-systematic review of quantitative evidence synthesis and not a systematic review according to PRISMA principles. The search strings involved native or aquatic macrophytes, phytoremediation, aquaculture effluent, floating treatment wetland, constructed wetlands, and rice-fish co-cultures or integrated multi-trophic aquaculture. The search was not exhaustive and the following results are thus a mapping of recent literature.

The inclusion criteria were that the paper (i) was peer-reviewed; (ii) worked on or manipulated fish-pond water or effluent; (iii) employed a plant-based unit or crop; and (iv) measured nutrient, organic-load or solids quantitatively. Nine primary studies, all between 2020 and 2025, met these criteria (Table 1). There were three additional sources on global statistics of aquaculture, integrated multi-trophic aquaculture and water hyacinth management which provided background for the introduction section.

Data Extraction and Calculation

The system type and scale, plant species and growth form, duration or retention time, and the outcome values were noted for each study. The percentage removal is the same as that reported. In cases where a paper reported only the average concentration for a control and a treatment (Figures 3), Thus calculated the difference as in equation (1):

$$Difference\ (\%) = \frac{C_0 - C_1}{C_0} \times 100 \quad (1)$$

Where C_0 is the control or input concentration and C1 is the treatment or output concentration. No value was derived from a graph. Due to differences in designs, measurements and time periods, no meta-analysis was conducted.

Classification

Plant type was classified according to growth type (floating, submerged, or emergent/bedgrown). Scale of systems was categorized as laboratory/mesocosm, pond, or commercial. Nativity was indicated if stated ; if no nativity was stated, then "not reported" was entered. In table 3, the weight of evidence for the plants under each category was evaluated according to two criteria: if the experiment was done using pond/commercial systems and if a comparison was provided.

Evidence Comparability and Interpretation

These nine qualifying primary studies have distinct intervention types and outcomes defined. A decrease in concentration compared to the untreated control group does not equate to influent-removed ratio to effluent and vice versa, neither which necessarily proves the quantity of nutrients absorbed in the biomass. Results were thus categorized based on experimental design, response variable and period of observations prior to analysis. No pooled average was derived since sample sizes, variance between replicates and common control groups were not provided by the synthesis. The numerical values presented below consist of those reported explicitly in the source manuscript only. The reported ranges are kept as such rather than being converted into individual species' responses to avoid considering the maximum value of one experimental setup as the representative value for all native macrophytes. This is especially relevant since native status is geographical in nature; what is native in one basin can be an introduction or invasive in another.

IV. Results and Discussion

Cross-Study Evidence Summary

It is clear from the evidence reviewed that aquatic vegetation affects nutrient concentrations through plant uptake, sediment interactions, particulate interception, and microbiology. However, treatment efficacy varies by plant type, duration of exposure, and scale of the experiment. Screening experiments at short durations have utility in identifying potential candidates while larger-scale systems such as ponds and commercial-scale have more relevance to practical applications. The evidence reviewed supports the utility of macrophyte-based treatment but does not establish rankings of native species.

Table 1: Quantitative Outcomes Explicitly Reported in the Source Evidence Synthesis

Evidence setting	Response variable	Reported outcome	Interpretive constraint
14-day five-species floating-plant trial	Phosphate removal	50–98%	Range across tested conditions/species
14-day five-species floating-plant trial	Ammonia-N removal	64–98%	Not a native-species-specific estimate
14-day five-species floating-plant trial	Suspended-solids removal	73–98%	Particulate endpoint, not nutrient recovery
Commercial-scale wetland	Total nitrogen removal	25–44%	Different scale and nitrogen definition
Commercial-scale wetland	Total phosphorus removal	62–72%	Different scale and phosphorus definition
90-day submerged-plant pond trial	Total phosphorus versus control	Approximately 75% lower	Control contrast, not inlet/outlet removal
Rice–fish co-culture	Sediment phosphorus release	82% reduction	Sediment-flux endpoint

Table 1 shows how cross-study synthesis should protect the original measure of the endpoint. For instance, a 75% decrease in total phosphorus in the pond compared with a control is not equivalent to a 72% removal of total phosphorus between influent and effluent in a commercial wetland. The former represents an ecological comparison within the pond, while the latter represents a treatment effect across a system boundary. Likewise, reducing phosphorus mineralization from sediments might contribute to long-term improvement in water quality without exporting phosphorus from the farm.

However, the largest reduction reported in response to the screening of floating plants was 14 days, with maximum levels of 98% for phosphate, ammonia nitrogen, and suspended solids. However, these are maximums across all of the plants and conditions screened and not typical performance levels expected from a random native plant. The commercial wetland had lesser total nitrogen removal but significant total phosphorus reduction. Its importance is that it shows performance at the operational level.

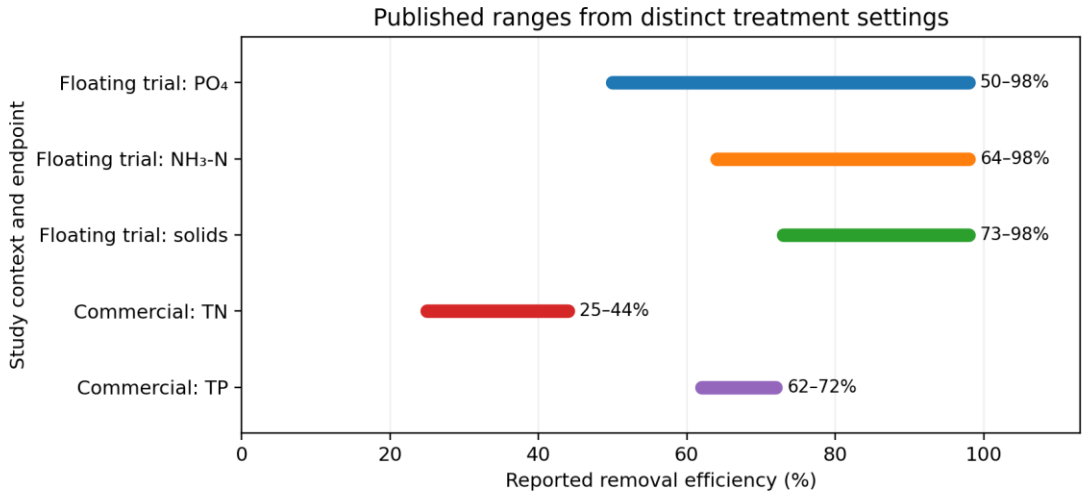


Figure 2: Reported Removal-Efficiency Intervals Reproduced from The Manuscript Synthesis. Values Describe Different Experiments and Pollutant Endpoints; Interval Lengths Do Not Represent Confidence Intervals (Ma et al., 2018; Xu et al., 2024)

Figure 2 highlights the similarity between multiple ranges that have been found; however, it should not be considered a statistical analysis. Since each observation varies in scale and definitions, it should be understood as a descriptive map showing data points rather than as a meta-analytical effect size.

Functional Mechanisms and Ecological Trade-Offs

The properties of floating plants and floating treatment beds of nutrient interception in the water column and large surface areas for microbial biofilm formation are beneficial in side-stream polishing tanks, where plant biomass can be harvested without interfering with the fishes. The major issues that arise from their application are related to overgrowth on the surface area, low penetration of sunlight, limited gas exchange and potential contamination of the environment with propagules. Native and contained status needs to be verified prior to use of the species on farms.

Submerged macrophytes act in the pond environment and may impact nutrient cycling through sediment stabilization, competition with phytoplankton and altering local oxygen levels. Submerged vegetation, according to source synthesis, was linked to lower concentrations of total phosphorus in ponds by approximately 75% compared to the control ponds after 90 days, along with preventing cyanobacterial blooms. This is certainly encouraging ecological data, although the results need to be evaluated in the context of their particular pond experiment; it does not mean that every native submerged plant will perform the same way.

Emergent macrophytes in artificial wetlands provide the service of filtration, microbial activities in the rhizosphere, and nutrient storage in plant tissues. The efficiency of emergent plants in artificial wetlands will depend upon hydraulic loading, media used, plant installation and maintenance. The role of plant uptake may not explain all the removal since phosphorus may get stored in sediments or substrate. Nutrients can be exported from the wetland through harvest of plant biomass, but measurement of nutrient storage in the biomass is needed.

Table 2: Plant-Group Selection Matrix for Integrated Fish-Farming Systems

Plant group	Preferred placement	Potential advantage	Priority safeguard
Floating macrophytes	Contained side-stream cell	Rapid uptake and accessible harvest	Prevent escape and excessive shading
Submerged macrophytes	Pond refuge or shallow cell	Sediment stabilization; algal competition	Maintain oxygen and fish movement
Emergent macrophytes	Constructed wetland bed	Root-zone filtration and biofilm habitat	Prevent clogging; manage hydraulic loading
Bed-grown crops	Floating beds in pond	Harvestable biomass and nutrient uptake	Assess food/feed safety and surface coverage

The decisions made based on functional group analysis are shown in table 2. For a small fish farm that lacks adequate land, it would be important to consider a containment wetland, while for a farm that has its own drainage area, an emergent wetland would be considered. Plants in submerged form can work well in ponds in terms of ecological management, so long as fish production is favorable and there is enough oxygen.

Nutrient Pathways and the Meaning of Recovery

Improvement of water quality is possible via several mechanisms: the nutrients may get into biomass of plants, phosphorus may attach to sediments/media, nitrogen is biologically converted, and sedimentation occurs with the suspended particles. This affects differently on possibilities of nutrient recovery. Concentration reduction is a good indicator of treatment process; however, recovery implies presence of certain nutrient-containing material and its separation and recycling.

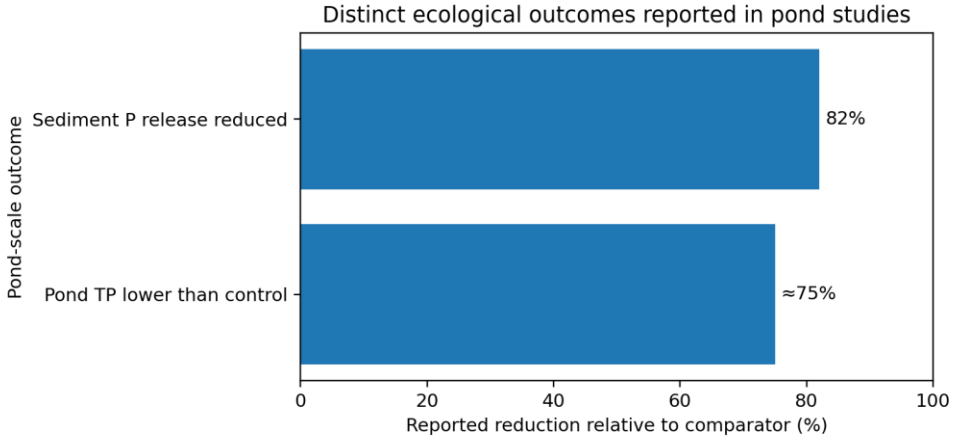


Figure 3: Two Separately Reported Pond-System Effects: Approximately 75% Lower Total Phosphorus Relative to Control After 90 Days and 82% Lower Sediment Phosphorus Release in Rice–Fish Co-Culture Nabi et al., (2025); Zhao et al., (2024). These are Different Endpoints, Not Paired Treatments

Both these approaches to improve water quality, which are mentioned in figure 3, involve reducing the concentration of nutrients in the water of the pond or reducing the amount of nutrients that are released from the sediment. While the percentage decreases are equal, these results do not have any grounds for comparison.

Native-Species Evidence and Uncertainty

One limitation associated with the evidence base is that it fails to report on nativeness consistently. The provided an accurate definition of nativeness, which involves the relationship of a plant with a particular geographical area. While a certain species might be native around one fish farm, the same might not be introduced at other areas. Published data on the performance of phytoremediation needs to be taken in conjunction with floristic data of regions, advice for conservation and containment considerations before its implementation. The performance advantage of native plants over introduced species cannot be quantified through evidence synthesis. Invasive species can provide excellent performance in terms of biomass production and nutrient removal. However, there will be a significant cost to the environment when the species escape. A sustainable solution should not result in the transfer of pollution control responsibilities from the farm to adjacent wetlands, canals or rivers (de Vasconcelos et al., 2021).

V. Implementation Framework for Small-Scale Fish Farms

Staged Treatment and Monitoring

Figure 1 shows the conceptual treatment train for practical implementation where input feed produces pond waste; a settling area acts as a barrier for coarse waste; macrophyte areas act as biological polishers; and treated water is recycled or discharged depending on the quality of water. Separation of solids prior to the planting area may be helpful in order to minimize the accumulation of excess sediment around roots and media. The bypass or overflow may be considered in case of heavy rains, while the containment screens may be used in order to avoid the escape of plants. Monitoring should include dissolved oxygen, temperature, pH, nitrogen compounds, phosphorous total, suspended solids, water flow rate, and plant condition. It should be conducted in both inflow and outflow areas at the same time. It would be more convenient to conduct monitoring sessions at the beginning of implementation in order to check whether plants grow and whether the process is steady.

Table 3: Proposed Monitoring and Evidence-Reporting Checklist

Indicator	Measurement or record	Reason for inclusion
Nitrogen species	TAN, nitrite, nitrate at paired locations	Distinguishes nitrogen transformations
Phosphorus	Total P and soluble reactive P	Separates particulate and dissolved fractions
Solids	TSS or turbidity with settling observations	Tracks particulate interception
Oxygen and pH	DO, pH, temperature	Supports fish health and process interpretation
Hydraulic conditions	Inflow, outflow, retention time	Enables mass-based comparison
Plant condition	Coverage, growth, harvest mass	Detects maintenance needs
Ecological safeguards	Nativeness, escape checks, receiving-water observations	Addresses invasive-species risk
Nutrient recovery	Biomass dry mass and tissue N/P	Tests whether captured nutrients are reusable

Table 3 gives a reproducible reporting template for future field trials. Concentration alone may give a misleading picture of the treatment under rainfall, evaporation, or recycling of water. The recording of hydraulic volumes would enable the loadings to be determined, while biomass determinations after harvest would allow determination of whether the nutrients are being exported from the system. This is especially true if the plant has good growth capacity and an unknown status in that locality.

Practical Design Choices and Seasonal Management

These factors (plant density, plant coverage, residence time, and harvesting interval) will need to be optimized through site-specific experimentation. An excessive amount of plant coverage can affect aeration and fish management; while too little may not achieve sufficient treatment. Variations during the seasons can affect growth and nutrient uptake, such that the plant suitable for warm seasons requires winter treatment complementarily. In summary, from the literature analyzed above, several functional types of plants could have provided complementary services, but the combined effect was not confirmed in a systematic controlled test (Zheng et al., 2024; Truong et al., 2024).

The stages of conducting an experiment can start with a small contained unit cell and matched sampling at the inlet and outlet along with a defined baseline period. The expansion stage comes when the water quality benefits, lack of health effects on fish, and manageable maintenance requirements are assured. Whenever the harvested biomass is intended for use in composting or feed, there should be testing for contaminants to conform to safety regulations.

VI. Conclusions and Research Priorities

From the studies reviewed, it can be seen that macrophyte-based treatments are able to significantly enhance water quality parameters in integrated fish farms. Ranges of removal rates for a 14-day floating plant experiment include 50-98% phosphate, 64-98% ammonia-nitrogen, and 73-98% suspended solids. Removal rates in a commercially sized wetland were at 25-44% for total nitrogen and 62-72% for total phosphorus. Additionally, pond experiments showed about 75% less total phosphorus compared to controls as well as 82% reduction in sediments phosphorus release. However, due to different endpoints, these findings cannot be used for efficiency pooling. This conclusion is also methodological and ecological: nutrient removal, stabilization of nutrients in the plant, and export of recoverable nutrients need to be accounted for separately. The data is not enough to conclude about the superiority of native plants over exotic plants because geographic origin of the plants is not established and direct comparisons are scarce. The future research needs to establish the origin of the plants regionally, provide control groups for comparison, describe hydraulic flows, time of treatment and nutrient contents of the harvested biomass. Such controlled trials, conducted at least through multiple seasons, would allow evaluating the reliability, cost-effectiveness and environmental safety of the treatment.

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