

# BIOREMEDIATION IN Wastewater Aquaculture

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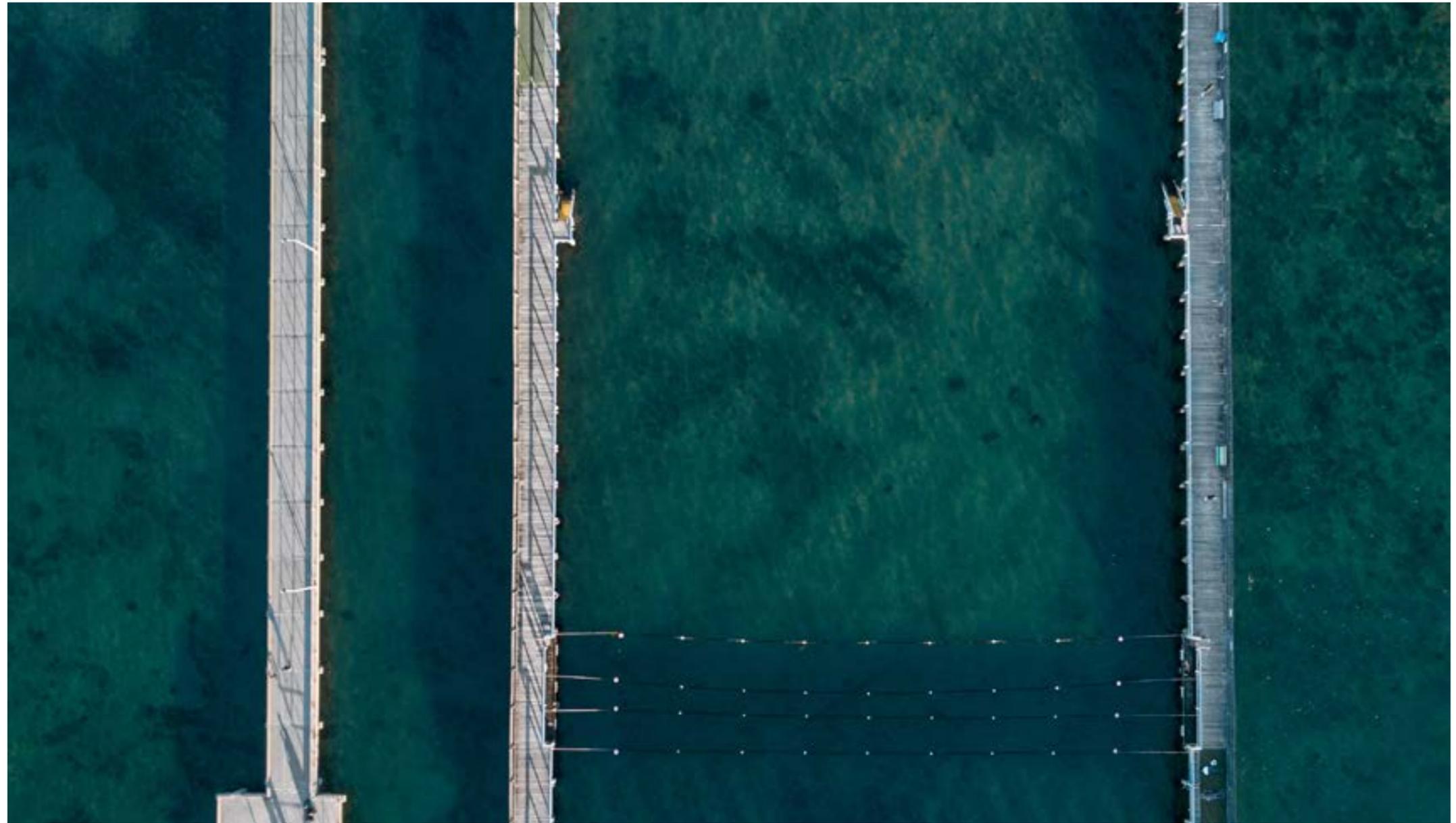
**EDITION: VOLUME 02, ISSUE 02 , - FEBRUARY 2026**

**ISSN 3107-9903**

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## Abstract

Aquaculture intensification has generated large volumes of nutrient-rich wastewater containing organic matter, nitrogenous compounds, suspended solids, and other pollutants, posing serious environmental challenges. Bioremediation offers an eco-friendly, cost-effective approach to treating aquaculture wastewater by harnessing natural biological agents, including microorganisms, microalgae, aquatic plants, fungi, and filter-feeding organisms. This article discusses the principles, processes, and types of bioremediation techniques applied in wastewater aquaculture, including in-pond treatment, pre-discharge remediation, and water reuse systems. The role of bacteria in nitrogen transformation, microbial mats in integrated treatment systems, microalgae in nutrient removal and biomass production, and aquatic macrophytes and seaweeds in constructed wetlands is highlighted. Several case studies demonstrate the effectiveness of integrated bioremediation systems involving algae, bivalves, fungi, and plants in improving water quality and reducing pollution load. Economic analysis indicates favorable cost-benefit ratios, emphasizing the financial viability of such systems. Sewage-fed aquaculture and duckweed-based treatment models further illustrate the potential for sustainable resource recovery and a circular economy. Overall, bioremediation emerges as a sustainable, scalable, and environmentally sound solution for wastewater management in aquaculture, particularly in water-limited regions.

**Keywords:** Waste water, sewage, aquaculture, bioremediation

## Introduction

Bioremediation is a biological treatment process that utilizes living organisms, primarily microorganisms, plants, and algae, to degrade, transform, or detoxify pollutants present in contaminated environments. George M. Robinson introduced the concept of bioremediation during the 1960s. It is the biological degradation of organic waste under controlled conditions, converting harmful substances into harmless end products. In aquaculture, bioremediation has gained importance as a cost-effective, environmentally friendly solution for

managing wastewater and improving water quality. Naturally occurring bacteria, fungi, microalgae, and aquatic plants play a key role in removing nutrients and toxic compounds, ensuring sustainable aquaculture practices.

## Process of Bioremediation

The bioremediation process begins when microorganisms release specific enzymes into the environment. These enzymes break down complex organic contaminants into simpler, digestible molecules. The degraded substances are then taken up by microbial cells and utilized as

energy and nutrient sources. Through this process, organic pollutants are mineralized into non-toxic end products such as carbon dioxide, water, and inorganic nutrients.

## Types of Bioremediation Techniques

Bioremediation techniques are broadly classified into in situ and ex situ methods. In situ bioremediation involves treatment of contaminated soil or water at the site with minimal disturbance. This approach is highly dependent on site-specific conditions such as soil characteristics and environmental factors. Common in situ techniques include biosparging, bioventing, and bioaugmentation. Ex situ bioremediation involves removing contaminated material

from the site for treatment. This method is primarily used for soil contamination and is less commonly used for wastewater remediation. Techniques include landfarming, composting, and biopiles. Both approaches require isolating and characterizing microorganisms, culturing them, studying their catabolic activity, and continuously monitoring remediation progress.

### Bioremediation Organisms and Their Roles

Different biological agents are involved in bioremediation. Phytoremediation utilizes plants, macroalgae, and microalgae to absorb nutrients and contaminants. Species such as *Chlorella* and *Gracilaria* are widely used. Bioremediation employs beneficial bacteria to convert nitrogenous compounds and degrade organic waste; examples include *Bacillus subtilis* and ammonia-oxidizing bacteria. Mycoremediation involves fungi such as *Trichoderma* and white-rot fungi that degrade toxic compounds. Zooremediation uses bivalves and other filter feeders, such as mussels, oysters, and clams, to remove suspended solids, algae, and organic matter from water.

### In-Pond Bioremediation and Waste Generation

Aquaculture systems generate various types of waste, including uneaten feed, fecal matter, metabolic by-products, residues of biocides and fertilizers, molting waste in shrimp farming, and collapsing algal blooms. In-pond bioremediation focuses on the decomposition of internal waste using beneficial microorganisms and algae to maintain water quality. Biotechnological solutions involving microbes, microalgae, and bioprocessing methods support sustainable aquaculture development.



### Bioremediation of Nitrogenous Compounds

Nitrogenous wastes, particularly ammonia, originate mainly from fish excretion and sediment mineralization. Ammonia-oxidizing bacteria, such as *Nitrosomonas*, *Nitrosococcus*, and *Nitrospira*, convert ammonia into nitrite, which is further oxidized to nitrate by nitrite-oxidizing bacteria, such as *Nitrobacter*. Denitrifying filters create anaerobic conditions that allow bacteria to convert nitrate into nitrogen gas, thereby reducing nitrogen load in aquaculture systems.

### Bioremediation of Hydrogen Sulphide

Hydrogen sulphide is a toxic compound produced by sulphate-reducing bacteria under anaerobic conditions. In the presence of oxygen, sulphur-oxidizing bacteria convert sulphide into non-toxic sulphate. Photosynthetic benthic bacteria and purple non-sulphur bacteria play an essential role in decomposing hydrogen sulphide, nitrite, and organic wastes at the pond bottom, thereby maintaining a favorable aquaculture environment.

### Bioremediation Before Discharge

Before releasing aquaculture wastewater into natural water bodies or reusing it, bioremediation is applied to reduce nutrient and organic load. Microalgae such as *Chlorella vulgaris*, *Nannochloropsis oculata*, and *Tetraselmis chuii* are effective in removing nitrogen and phosphorus while producing valuable biomass. However, wastewater must be free from heavy metals to prevent accumulation in algal cells.

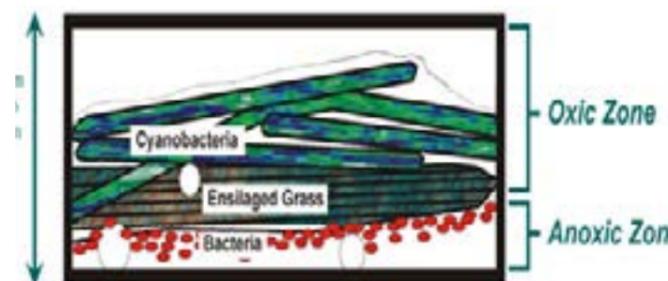


Figure 1. Layers of Microbial Mat

### Aquatic Plants and Seaweeds in Nutrient Removal

Aquatic plants and seaweeds such as *Gracilaria*, *Caulerpa*, and *Sargassum* absorb nitrogen and phosphorus from aquaculture effluents. Constructed wetlands using macrophytes effectively remove organic matter and suspended solids, enabling safe discharge or reuse of treated water

### Microbial Mats and Integrated Systems

Microbial mats consist of layered microbial communities that simultaneously manage nitrogen and carbon. The surface layer of cyanobacteria produces oxygen, supporting nitrification. The middle layer contains nitrifying bacteria that reduce ammonia toxicity, while the lower layer consists of denitrifying microbes that remove nitrate. Integrated microbial mat bioreactor-constructed wetland systems enhance wastewater treatment efficiency.

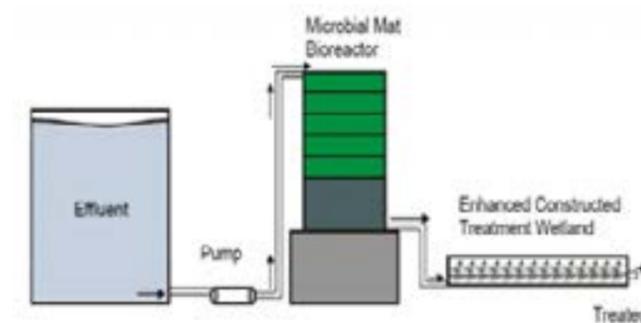


Figure 2. Integrated Microbial Mat Bioreactor



## Case Studies and Integrated Bioremediation

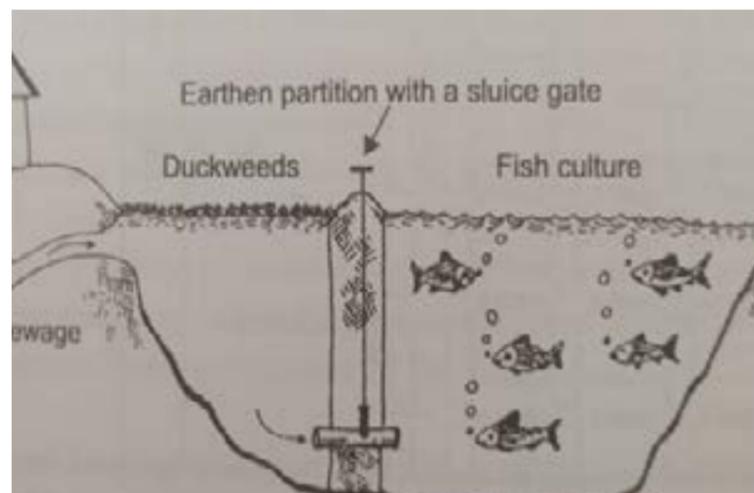
Several case studies demonstrate the effectiveness of integrated bioremediation systems. Papyrus–bivalve systems showed maximum removal of nutrients and total dissolved solids. Macroalgae combined with *Artemia* improved nitrogen removal, while mussel–microalgae–bacteria systems efficiently removed nutrients and organic pollutants. Fungal bioremediation using *Aspergillus* species significantly reduced phosphorus, nitrogen, and chemical oxygen demand

## Economics and Water Reuse

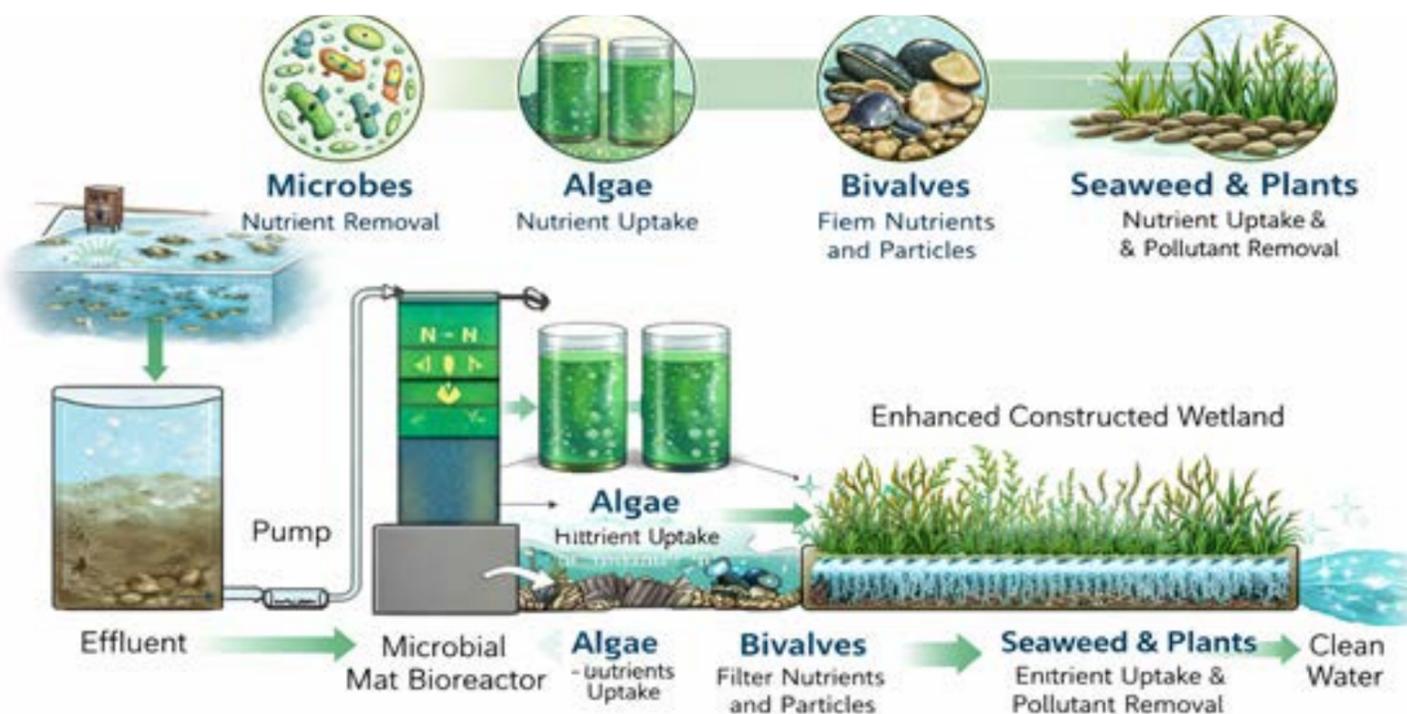
Integrated bioremediation systems provide favorable economic returns through reduced water exchange, lower chemical use, improved fish growth, and the sale of biomass. Cost–benefit analysis indicates a ratio of 1.69:1, demonstrating economic and environmental sustainability. Treated wastewater can be reused for fish culture, addressing freshwater scarcity in India.

## Sewage-Fed Aquaculture and Duckweed Systems

Sewage-fed aquaculture systems, particularly in Kolkata, utilize natural purification processes involving wetlands, macrophytes, sunlight, and microbial activity. Duckweed-based systems effectively remove nutrients, convert sewage into fish protein, and generate revenue, though they require large land areas and are best suited for domestic wastewater.



**Figure 4.** Duckweed-based sewage treatment for fish pond (Source: *Handbook of Fisheries and Aquaculture*)



**Figure 3.** Integrated bioremediation of aquaculture wastewater using microbes, algae, bivalves, and plants (Self-designed conceptual diagram of bioremediation in aquaculture)



## Conclusion

Bioremediation in wastewater aquaculture offers low-cost, eco-friendly treatment with effective nutrient removal and biomass production. However, it depends on climatic conditions and requires large land areas. With rising demand for sustainable wastewater solutions and government support, bioremediation holds strong potential. Overall, bioremediation supports circular economy principles and provides a sustainable solution.

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