Journal of Fish Health
Volume 5, Issue 3, August 2025
https://doi.org/10.29303/jfh.v5i3.7942

Bioremediation in Aquatic Systems: A Literature Review on Fish as Natural Agents for Water Quality Management in Aquaculture

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Received:
August 1st, 2025
Accepted:
August 19th, 2025
Published:
August 22th, 2025

Keywords:
Aquatic Animals, Bioremediation, Water Quality

ABSTRACT

Aquatic animals play a significant role in bioremediation processes in aquatic environments through their natural activities, such as filtering particles, aerating water, and nutrient cycling. This study aims to review the use of aquatic animals as natural biofilters in aquaculture systems, highlighting their efficiency and the supporting role of microbial technology. The method used is a literature review from 24 relevant articles published between 2015 and 2024. Results show that species such as goldfish, catfish, and eels can reduce organic waste, regulate plankton composition, and enhance oxygen levels. Moreover, the integration of probiotics and biotechnologies such as microbial fuel cells, bioaugmentation, and biostimulation improves pollutant degradation and water quality. The implications of these findings suggest that aquatic animal-based bioremediation is a promising and environmentally friendly approach to sustainable aquaculture, reducing reliance on antibiotics and chemical disinfectants while supporting ecological balance and animal health.

INTRODUCTION

Bioremediation is an environmentally friendly approach that utilizes living organisms to reduce or eliminate pollutants from the environment. Etymologically, this term comes from a combination of the words “bio,” meaning living organisms, and “remediation,” which refers to the process of restoring or improving degraded environmental conditions (Vidali, 2001). In aquaculture, bioremediation is utilized to improve water quality, regulate the buildup of harmful substances like ammonia, nitrite, and heavy metals, and promote the well-being of farmed aquatic organisms (Maqsood *et al*., 2024; Umar *et al*., 2024). This approach may involve microorganisms, aquatic plants, or aquatic animals that act as natural biofilter agents.

Bioremediation plays an important role in addressing environmental pollution, particularly in aquatic ecosystems. Water pollution can be caused by the presence of heavy metals from various sources, such as industry, mining, domestic waste, and agriculture. Heavy metals discharged into water bodies have the potential to accumulate within aquatic ecosystems and affect living organisms, including fish, aquatic plants, and invertebrates. Therefore, the application of bioremediation becomes highly important. The use of living organisms such as bacteria and microorganisms can address heavy metal pollution and other water pollutants. These organisms can modify the chemical properties of heavy metals through mechanisms like bioaccumulation, biosorption, and biomineralization, which transform them into less harmful forms or attach them to more stable biological compounds (Rahayu & Mangkoedihardjo, 2022).

The success of bioremediation is influenced by factors such as oxygen concentration, nutrient availability, temperature, pH, and other abiotic parameters. The selection of bioremediation techniques must also consider the nature of the pollutant, depth and level of pollution, cost, and environmental conditions (Smith *et al*., 2015). Bioremediation methodologies are conventionally classified into two principal categories, *in situ* which is implemented directly at the contaminated site and *ex situ* which involves the transfer of contaminated material to a controlled environment for treatment. In situ techniques are performed directly at the contaminated site, with success highly influenced by environmental conditions such as humidity, nutrient availability, pH, and temperature. This technique is effective for reducing pollutants such as dyes, heavy metals, and chlorinated hydrocarbons (Kuppusamy *et al*., 2016). In contrast, ex situ techniques involve moving contaminated material to another location for remediation, allowing for the modification of biological, chemical, or physicochemical conditions to enhance the effectiveness of the process (Melati, 2020).

The rapid growth of plastic manufacturing, which has increased 200 times since the 1950s and amounted to around 381 million tons in 2015, has generated considerable environmental consequences. Although plastic has advantages such as low cost, versatility, and high durability, the presence of microplastics has become a serious issue due to their persistent nature and the presence of toxic and carcinogenic chemicals (Faujiah & Wahyuni, 2022). The complexity of aquaculture issues has also increased due to poor management practices, including the use of antibiotics and chemicals that can disrupt the balance of pond ecosystems, particularly in terms of microorganism diversity and quantity (Qodriyah *et al*., 2025). Pollution from aquaculture waste can harm public health, cause unpleasant odors, and serve as a source of dangerous pathogens. One technique proposed to address these issues is bioremediation, which offers an environmentally friendly, effective, and economical solution (Darmayati & Afianti, 2017). However, the effectiveness and safety of bioremediation remain controversial, particularly regarding the management of long-term pollution involving microplastics and hazardous chemicals, as well as the potential negative impacts on local ecosystems if its application is not carried out carefully.

The increasing rate of urbanization and industrialization has also exacerbated environmental pollution due to the release of toxic chemicals from various sectors, including manufacturing, agriculture, mining, and construction. These pollutants not only affect the health of plants, animals, and humans but can also reduce microbial populations in both aquatic and terrestrial environments (Philp *et al*., 2005). Pollution from household and industrial activities entering water bodies, such as rivers, has the potential to degrade water quality and disrupt bacterial communities (Lusiana *et al*., 2020). Although industrialization and fishing activities have positive economic impacts, the fish processing industry, which has not implemented adequate environmental management, actually increases pollution in water bodies (Desey *et al*., 2022).

Bioremediation has emerged as a potential solution to address this pollution. However, the challenges faced are quite complex, including effectiveness that is influenced by the type and concentration of pollutants, environmental conditions, and the presence of microorganisms capable of decomposing pollutants. A deeper understanding of the complex interactions between microorganisms and their environment is essential to optimize the application of bioremediation.

This article aims to thoroughly examine the role of aquatic animals as bioremediation agents in managing water quality. The study involves exploring technological innovations that can strengthen bioremediation performance, determining aquatic animal species most suitable as natural biofilters, and evaluating their capacity to reduce contaminants in aquatic environments. In general, this article is expected to provide a more comprehensive understanding of aquatic animal-based bioremediation strategies so that it can serve as a reference in the application of sustainable aquatic environmental management technologies.

METHODS

This study uses a literature review which is a research methodology that systematically collects, evaluates, and synthesizes existing knowledge from academic sources to provide a comprehensive understanding of a particular topic, highlight research gaps, and establish a foundation for further studies (Snyder, 2019). This method by adopting and analyzing various scientific articles, journals, and relevant documents discussing aquatic animal-based bioremediation techniques. The research was conducted at the Department of Aquaculture, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman, Banyumas, Central Java, Indonesia, during the period of January to May 2025. The literature review process was carried out in two main stages.

1. Literature Screening

Literature was obtained through online searches on several reputable research databases related to bioremediation techniques, aquatic animals, biofilters, and aquaculture. The sources used included articles and journals published between 2015 and 2024, focusing on the topic of bioremediation using aquatic animals as natural biofilter agents in aquaculture systems. The search process was conducted through Google Scholar and several other scientific websites, yielding a total of 24 relevant references. These consisted of 18 journal articles, 3 conference proceedings, 2 theses, and 1 book. The selection was carried out by reviewing the titles, abstracts, and full texts to ensure their relevance to the objectives of this study. The selection process was then conducted by examining the titles, abstracts, and main content to verify their alignment with the research objectives.

2. Content Analysis

The selected articles were analyzed using a qualitative content analysis approach, considering the relationship between the content of the study and the research context (Vourvachis & Woodward, 2015). This analysis was aimed at evaluating the potential of bioremediation techniques as a solution in utilizing aquatic animals as natural biofilter agents in aquaculture ecosystems.

RESULTS AND DISCUSSION

This study is based on articles that examine research activities on aquatic animal-based bioremediation techniques as natural biofilter agents in aquaculture. Fish function as biofilters in aquatic ecosystems through various significant mechanisms for improving water quality. First, certain fish, particularly plankton-eating species such as herring and sardines, can filter small particles from the water column (Tom *et al*., 2021). This process reduces the number of suspended particles, thereby improving water clarity and allowing better light penetration into the water column (Lindholm, 2023). In addition, fish help control the diversity and abundance of plankton species through their feeding habits, thereby supporting the stability of aquatic ecosystems. Fish activity is not limited to filtration but also involves the production of feces, which serve as a nutrient source for microorganisms at the bottom of the water. Fish feces aid in the biogeochemical cycle and contribute to the accumulation of organic matter in sediments, which in turn supports water purification (Gao *et al*., 2021). Additionally, fish movement in the water enhances aeration, improving oxygen quality in the water, which is crucial for the survival of other organisms. Thus, fish, as biofilters, play a vital role in maintaining aquatic ecosystem health and improving water quality.

The use of aquatic animals as bioremediation agents has become an important focus in water quality management in sustainable aquaculture systems. The movement of fish in water creates significant turbulence that directly contributes to enhancing natural aeration processes within the water column. This turbulence accelerates gas exchange between water and the atmosphere, thereby increasing dissolved oxygen (DO) levels—a critical factor for the metabolism and survival of aquaculture organisms such as fish and shrimp (Nian *et al*., 2019). Sufficient dissolved oxygen not only supports the growth of aquatic organisms but also accelerates the decomposition of organic matter by microorganisms, thereby reducing the accumulation of toxic ammonia and nitrite. High stocking densities in intensive aquaculture and the accumulation of uneaten feed and feces make the role of fish as natural bioremediation agents critically important. This approach is environmentally friendly as it utilizes the natural behavior of aquatic animals without the need for external chemical additives. By reducing dependence on antibiotics and disinfectant compounds, the risk of antimicrobial resistance and negative environmental impacts can be minimized. Additionally, using fish as living biofilters enables more efficient and cost-effective farming systems, particularly in integrated aquaculture systems such as polyculture and aquaponics.

Bioremediation technology can be carried out by utilizing the potential of indigenous microbes or bacteria grown in a controlled environment exposed to microplastics (Rahim, 2024). One application of technology in bioremediation is microbial fuel cell technology. Microbial fuel cell technology is a technology that can convert chemical reactions into electrical energy through bacterial metabolism. This technology can also assist in the bioremediation process. MFC technology utilizes the metabolic activity of microorganisms such as bacteria to oxidize organic materials or pollutants. Microbial Fuel Cell (MFC) technology can reduce ammonia concentrations depending on the initial ammonia concentration, where the higher the initial ammonia concentration, the greater the reduction caused by MFC. Additionally, Microbial Fuel Cell (MFC) technology can generate power density from hotel waste, depending on the ammonia concentration and the number of bacterial isolate colonies used (Rahmanto *et al*., 2016).

In addition, there are several technologies that can be applied in bioremediation, including bioaugmentation, biostimulation, and bioavailability. Bioaugmentation refers to the introduction of specific degrading microorganisms to enhance the native microbial community, while biostimulation involves promoting the growth of indigenous hydrocarbon-degrading microbes through nutrient addition and/or habitat modification. Bioavailability is achieved by increasing microbial access to the hydrocarbon substrate. Bioaugmentation technology is often used to add probiotic bacteria that can degrade organic waste and reduce ammonia concentrations and other harmful compounds in water. Biostimulation technology can be implemented by adding nutrients required by microorganisms to support the process of cleaning water from organic waste. Bioavailability technology can enhance the bioavailability of nutrients for microorganisms, thereby accelerating the degradation of pollutants (Handrianto, 2018). Research findings indicate that fish have significant potential as natural biofilter agents in aquaculture bioremediation systems. Certain fish species, such as carp, catfish, and eels, have proven effective in reducing organic waste levels, particularly feed residues and excrement, through metabolic processes that convert toxic organic compounds into less toxic forms (Fidyandini *et al*., 2016).

Research conducted by Saniswan & Lestari (2019) shows that the use of a bioremediation system combining fish and probiotics can significantly improve water quality and the growth of carp fry. The movement and feeding behavior of fish also help stir the pond bottom, accelerate the decomposition of organic matter, and prevent the formation of harmful anaerobic sludge layers. Earthworms or mud worms can also be used for sediment bioturbation, making it easier for microorganisms to break down pollutants (Saputra *et al*., 2022). Microorganisms such as bacteria have a specific mechanism for degrading pollutants. The mechanism used by degraders is in line with the metabolic processes of bacteria and the pollutant substrates that contaminate the environment. Probiotic or beneficial bacteria offer an environmentally friendly alternative to physical and chemical methods for managing the accumulation of organic and inorganic pollutants in the environment. Microorganisms are abundant across the biosphere, and their metabolic ability to utilize pollutants as energy sources under diverse environmental conditions makes them valuable agents in remediation processes (Khastini *et al*., 2022).

Bioremediation represents an environmentally responsible strategy for improving polluted ecosystems, where microorganisms, plants, and animals act to break down and eliminate harmful contaminants. Microorganisms such as Pseudomonas bacteria have the ability to utilize various carbon sources, enabling them to grow and thrive in environments rich in organic compounds. This makes Pseudomonas bacteria highly effective in the bioremediation process (Safitri *et al*., 2025).

Bioremediation using aquatic animals is an effective approach to reducing pollution in aquatic environments. The addition of probiotics can increase the population of beneficial bacteria that play a role in bioremediation, thereby preventing the growth of harmful bacteria. In this experiment, the administration of probiotics at a dose of 50 mL yielded the best performance, as evidenced by increased absolute weight gain, body length, and higher survival rates compared to lower doses. The results indicate that probiotics not only improve water quality but also support fish growth by enhancing feed digestion and nutrient absorption. Overall, the use of probiotics in carp aquaculture can be considered an effective strategy for improving fish health and aquatic environmental quality (Samsia *et al*., 2024). The incorporation of mangrove leaf extract into carp diets leads to elevated erythrocyte, leukocyte, and hematocrit counts, signifying improved physiological condition and resilience. A 1% dose of the extract was found to be most effective, with significant improvements in the measured blood parameters. These results suggest that mangrove leaf extract can function as a natural immunostimulant with the potential to enhance fish resistance to pathogenic infections and provide an environmentally friendly alternative to antibiotic use. This study highlights the importance of using natural materials in aquaculture to improve fish health and aquatic system quality (Maknun *et al*., 2024).

CONCLUSION

Based on the results of the literature review, it can be concluded that bioremediation based on aquatic animals, particularly fish, is an effective and environmentally friendly approach to water quality management in aquaculture systems. Fish such as carp, catfish, and eels have the ability to act as natural biofilter agents through particle filtration mechanisms, increased oxygen levels, and the breakdown of organic waste through feeding and metabolic activities. Additionally, integrating fish with bioremediation technologies such as probiotics, microbial fuel cells, bioaugmentation, biostimulation, and bioavailability can enhance pollutant degradation efficiency and support aquatic ecosystem health. The use of aquatic animals as part of a bioremediation strategy also reduces reliance on chemicals and antibiotics and promotes the development of more sustainable aquaculture systems. These findings indicate that aquatic animal-based bioremediation approaches have significant potential for widespread application in modern aquaculture practices.

ACKNOWLEDGEMENT

Author would like to thank all parties who have helped so that this research article can be completed properly. Our appreciation also extends to our colleagues and mentors for their insightful guidance and constructive feedback throughout the research. Lastly, we thank our families and friends for their unwavering encouragement and support during this research process.

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