

RESEARCH ARTICLE

A REVIEW OF FRESHWATER MONO AND POLY AQUACULTURE: COMPARISON STUDY TOWARDS SUSTAINABLE WATER QUALITY MANAGEMENT

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ABSTRACT

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Aquaculture plays a critical role in global food security, although sustainable water quality management remains a key concern. Farmers that solely raise prawns or tilapia underutilize ponds. Prawns reside along the substrate and effectively use the benthic production, whereas fish mostly inhabit the water column and hardly ever explore the bottom. Consequently, both species' pond-based monoculture systems leave a substantial portion of the installations unutilized. Significant waste accumulation on the bottom from monocultured tilapia may be discharged into the environment. This review paper analyses the effectiveness of monoculture and polyculture systems in maintaining optimal water quality in numbers of earthen freshwater ponds. It specifically focuses on using freshwater prawns (*Macrobrachium rosenbergii*) and Nile tilapia (*Oreochromis niloticus*) together as a way to improve water sustainability. This review examines the management of important water quality metrics under monoculture and polyculture systems, including dissolved oxygen, ammonia levels, pH balance, and organic matter accumulation. According to various research results, the polyculture method greatly enhances water quality by stabilizing oxygen levels, encouraging nutrient cycling, and lowering ammonia build-up. Prawns benefit in sediment bioturbation, which lowers the build-up of organic waste, while tilapia helps regulate algae growth. The efficacy of this system in enhancing aquaculture sustainability and optimizing pond ecology is supported by both practical and international studies. This review article emphasizes the benefits of using polyculture as opposed to monoculture systems for improving water quality and raising overall productivity in various culture systems. The adoption of polyculture systems, ongoing water quality monitoring, and the creation of sustainable feeding practices are among the main suggestions. Impending studies should, however, concentrate on the combined culture practices towards long-term ecological and economic feasibility in order to support and adapt sustainable aquaculture development and meet pertinent Sustainable Development Goals (SDGs).

KEYWORDS

Sustainable aquaculture; Water quality management; Monoculture and polyculture; Nile tilapia, Freshwater prawn, Pond Nutrient cycling

1. INTRODUCTION

As the global population approaches 9.7 billion by 2050, the compelling challenge of maintaining adequate food security and nutrition for all becomes more apparent. Agricultural land and freshwater resources are under tremendous pressure, necessitating novel solutions to supplement traditional food systems. Aquaculture, or the production of aquatic organisms such as fish, shellfish, and aquatic plants, has grown as an important sector. Aquaculture, one of the fastest-growing food production systems, has considerable potential to boost global food security, especially in locations where fisheries are overexploited, or terrestrial agriculture is constrained (Van et al., 2021; FAO, 2024).

The concept of sustainability has become crucial to tackling global concerns such as environmental deterioration, resource depletion, and socioeconomic inequality. Sustainable water quality attempts to strike a balance between production expansion and environmental stewardship, maintaining long-term sustainability while contributing to food security. This approach is closely aligned with the United Nations Sustainable

Development Goals (SDGs), particularly SDGs 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-Being), and 14 (Life Below Water), all of which advocate for the preservation of freshwater and marine aquatic ecosystems (Owen, 2020; United Nations, 2015).

Aquaculture has emerged as a critical component of global food production, providing a sustainable source of protein for an increasing population. Aquaculture involves cultivating aquatic creatures like fish, molluscs, and crustaceans to replace traditional fishing methods and reduce strain on natural populations. Aquaculture is expected to contribute 52% of fishery products for human consumption by 2025, representing the highest average yearly growth in the past decade. Every year, this sector generates around 171 million tons worth 36,000 million US dollars. Aquaculture accounts for 47% of the total, with Asia accounting for the majority (89%). (De Silva and Devy, 2010; Ahmed et. al., 2007). The aquaculture industry creates jobs and food items. The rapid growth of aquaculture has been accompanied by significant challenges, particularly in water quality management, which plays a crucial role in ensuring the health and productivity of cultured species. Freshwater aquaculture, especially pond-based systems, requires effective strategies to optimize

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water quality, reduce environmental impacts, and enhance productivity. One approach that has gained attention is the use of monoculture and polyculture systems, particularly involving Nile tilapia (*Oreochromis niloticus*) and freshwater prawns (*Macrobrachium rosenbergii*) (Anderson et al., 2017; Boyd et al., 2020, 2022).

1.1 Importance of Sustainable Water Quality Management in Aquaculture

The history of pond aquaculture is distinguished by ongoing cultural intensification. Early farmers learned that fertilizing ponds to encourage plant growth the foundation of the food chain could boost fish productivity. Fertilizers were frequently locally available waste products, combining pond aquaculture with other human activities (Boyd, 2012).

Fish were consumed in the home or traded locally, and for millennia, the purpose of intensification was simply to increase the number of fish. Wild seafood harvests began to decline in the last part of the twentieth century when ocean fisheries achieved (or exceeded) their maximum sustainable yield. Goals and motivations to increase output changed almost concurrently as new profit opportunities developed. Production methods and management procedures were designed to increase profits and produce higher-value products, frequently for export. The new practices, particularly the use of pelleted feed to assist intensification, consumed more resources and had a greater (or different) environmental impact than extensive, fertilized, or lightly fed pond aquaculture (Edwards, 2015). All these changes occurred during a period of increased environmental awareness and advocacy. The seemingly unbridled desire to create profits was gradually tempered by the realization that aquaculture systems must be designed with increased resource efficiency and lower environmental impact. Nonetheless, economics remains the primary motivator of technological innovation and adoption because farms must be successful to continue operations (Subasinghe et al., 2012). However, recent experience demonstrates that it is possible to reconcile what are frequently regarded as opposing aims of profit and decent environmental performance. This is because better resource efficiency - a major indication of sustainability can result in cheaper per-kg production costs and higher profitability. Recent advances in pond aquaculture technology are good

examples of this positive link, indicating that productive and lucrative systems with significantly superior environmental performance are conceivable (Engle and D'Abramo, 2018).

Aquaculture is a rapidly expanding food production sector that is crucial for food security, ecological health, natural resource usage, biodiversity conservation, and socioeconomic resilience. Aquaculture is now the primary source of aquatic food and protein, contributing to global food security due to dwindling catch fishery supplies and rising demand (Boyd et al., 2022; Troell et al., 2023). Concerns have been raised concerning aquaculture's environmental and natural resource consequences, including habitat degradation, exploitation of wild fish supplies, fishmeal/fish oil requirements, and waste disposal (Bull et al., 2021; Klootwijk et al., 2021).

Aquaculture systems, including extended, semi-intensive, and intensive, as well as closed, semi-open, and open systems, mono-poly cultured species, and stocking numbers, can all have varying environmental implications. Environmental consequences can come through three processes: consumption of natural resources, culture, and technique. To avoid negative repercussions, it is important to work within the system's carrying capacity. The transition from traditional to enhanced cultural practices creates waste that must be properly treated to prevent contamination and negative environmental repercussions (da Silva et al., 2022). Several studies have shown that the water quality directly affects the growth, health, and survival of aquatic organisms. In fact, the poorer water quality can lead to disease outbreaks, reduced growth rates, high mortality, and increased production costs. Key water quality parameters, including dissolved oxygen (DO), ammonia (NH₃), nitrite (NO₂), nitrate (NO₃-), pH, and organic matter, must be effectively managed to maintain an optimal pond environment (Jana and Sarkar, 2005; Yusoff et al., 2004; Boyd and Craig, 2012). Key water quality parameters according research findings are stated in Table 1.

Table 1: Key Water Quality Parameters and their Importance.

| Parameters | Optimal Range | Importance in Aquaculture | Impact of Poor Management |
|-----------------------------|---------------|------------------------------------|--|
| Dissolved Oxygen (DO) | 5-8 mg/L | Essential for fish respiration | Low levels cause fish stress and mortality |
| Ammonia (NH ₃) | < 0.05 mg/L | Toxic byproduct of fish metabolism | High levels cause toxicity and stress |
| Nitrite (NO ₂ -) | < 0.1 mg/L | Affects oxygen transport in blood | Leads to nitrite poisoning |
| pH | 6.5-8.5 | Regulates enzymatic functions | Extreme pH levels affect metabolism |
| Organic Matter | Low | Influences bacterial activity | High levels lead to oxygen depletion |

1.2 Monoculture vs. Polyculture: A Comparative Approach to Water Quality Management

Monoculture is the practice of cultivating a single species within a controlled pond system. It is commonly used in commercial aquaculture operations due to its simplified management, controlled feeding, and predictable harvest cycles. The benefits of monoculture include simplified management and stocking procedures, regular growth and harvest cycles, and decreased competition for space and food. However, monoculture systems frequently result in nutrient accumulation, increased organic waste, and susceptibility to diseases, necessitating extra interventions such as artificial aeration and water exchange to maintain water quality (Wang and Maixin, 2016; Chiquito-Contreras et al., 2022). Table 2 presents a comparison of water quality in monoculture systems.

Table 2: Comparison of Water Quality in Monoculture Systems

| Factors | Impact in Monoculture Systems |
|-----------------------|-------------------------------------|
| Ammonia Accumulation | High due to uniform waste output |
| Dissolved Oxygen (DO) | Moderate to low, requiring aeration |
| Disease Risk | High due to lack of biodiversity |
| Organic Waste Load | High, leading to water degradation |

Polyculture, on the other hand, is the co-cultivation of numerous species, many of which have complementary eating habits that aid in the regulation

of nutrient levels in aquatic ecosystems. In Nile tilapia-freshwater prawn polyculture, each species fulfils a distinct ecological function, minimizing organic matter accumulation and enhancing overall water quality. Some of the benefits of polyculture include improved nutrient cycling, which reduces ammonia accumulation; increased oxygen levels through diverse biological activity; and lower disease prevalence due to a balanced ecosystem. Nonetheless, polyculture has demonstrated more sophisticated management and feeding methods, including careful species selection and stocking density modifications as well (Wang and Maixin, 2016; Tidwell et al., 2010). Table 3. has shown the comparison of water quality in polyculture system.

Table 3: Comparison of Water Quality in Polyculture Systems

| Factors | Impact in Polyculture Systems |
|-----------------------|--|
| Ammonia Accumulation | Reduced due to enhanced nutrient cycling |
| Dissolved Oxygen (DO) | Optimal due to diversified activity |
| Disease Risk | Lower due to ecological balance |
| Organic Waste Load | Reduced due to species interactions |

1.3 Pragmatic Studies on Monoculture vs. Polyculture Water Quality Management

Several studies have found that polyculture systems outperform monocultures in terms of water quality indicators. (Khan et al., 2010; Michael and Wagner, 2017). The findings of these investigations are as follows. (Figure. 1).

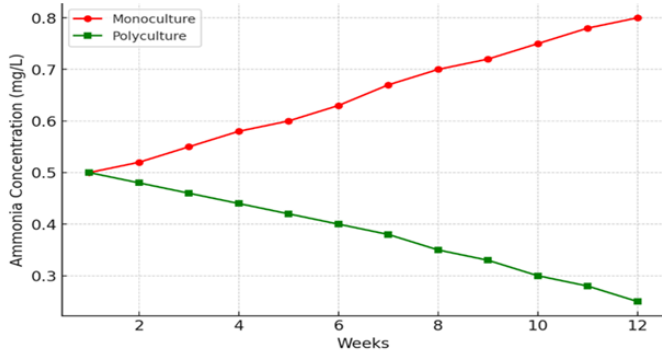


Figure 1: Ammonia Concentration Trends in Monoculture vs. Polyculture Ponds.

1.4 Role of Nile Tilapia and Freshwater Prawns in Water Quality Management

Tilapia is the world's second most widely cultivated fish. Tilapia is expected to become the dominant species in global aquaculture in the coming decades due to its widespread cultivation in tropical and subtropical locations highlighted rusticity, omnivorous habits, rapid growth, and great meat quality as important factors contributing to its global popularity (FAO 2018a; Grassi et al., 2016). Nile tilapia is a robust, fast-growing fish commonly employed in aquaculture (Tacon et al., 2011). It makes a substantial contribution to water quality management by controlling algal blooms via filter-feeding activity, which helps maintain oxygen. Tilapia's primary contributions to water quality are as follows: i. Limits algal growth and prevents oxygen depletion. ii. Consumes detritus, lowering organic matter accumulation. iii. Increases Pond aeration through active swimming behaviour. Giant freshwater prawns have a consolidated and developing production chain because of their adaptability, quick development, disease resistance, and suitability for polyculture with fish. (FAO 2018b; Hossain and Islam, 2006; Haque et al., 2018).

Freshwater prawns contribute to sediment management and organic waste decomposition, reducing the production of harmful chemicals such as ammonia and nitrite. Their digging habits encourage water circulation and reduce organic waste buildup. The main contributions of freshwater prawns to water quality are as follows: i. They serve as bottom scavengers, eating uneaten feed and trash. ii. Reduces organic sludge formation, hence reducing oxygen deprivation. iii. Improves sediment quality and microbiological balance (Hisano et al., 2019).

Nevertheless, polyculture system is the cultivation of various aquatic species in the same body of water, which increases production and profitability for fish and prawn farmers. Fish and prawn culture improves pond ecology by lowering algal blooms and limiting environmental impact when compared to monoculture (Santos and Valenti, 2002; Rohmana et al., 2015; Li and Dong, 2000; Uddin et al., 2006).

1.5 Challenges in Sustainable Water Quality Management

Despite the benefits of polyculture systems, challenges remain in implementing sustainable water quality management strategies, such as: Stocking Density Optimization; Managing the ideal ratio of tilapia to prawns to ensure optimal water quality; Nutrient Load Balance: Preventing excess nutrient accumulation while maximizing growth efficiency; Water Exchange and Filtration; Implementing natural and mechanical filtration methods to maintain long-term sustainability (Michael and Wagner, 2017). Sustainable water quality management is essential for successful aquaculture. Monoculture systems provide simplified management but often result in higher nutrient loads and disease risks, necessitating additional water treatment interventions. In contrast, polyculture systems, particularly Nile tilapia and freshwater prawn integration, offer a biological approach to managing water quality by promoting nutrient cycling and organic matter reduction (Tidwell et al., 2010; Wagner and Michael, 2000).

2. CHALLENGES OF WATER QUALITY MANAGEMENT IN AQUACULTURE

2. Challenges of Water Quality Management in Aquaculture

Water quality management is a critical aspect of aquaculture, directly

affecting the health, growth, and survival of aquatic organisms. Poor water quality can lead to reduced productivity, increased disease outbreaks, and significant economic losses. The challenges associated with maintaining optimal water conditions in aquaculture systems arise from biological, chemical, and physical factors, requiring effective management strategies to sustain production. This section explores the key challenges in water quality management, emphasizing their impact on aquaculture and potential solutions. This study emphasizes the need for further research on optimizing species ratios, feeding strategies, and ecological monitoring in aquaculture systems. By adopting polyculture techniques, aquaculture operations can enhance water sustainability, improve fish health, and increase overall productivity (Claude et al., 2020; Yusoff et al., 2024).

2.1 Nutrient Overloading and Eutrophication

One of the most pressing challenges in aquaculture is the accumulation of organic trash and excess fertilizers in ponds. Uneaten feed, fish excrement, and decomposing organic matter resulted in elevated levels of ammonia (NH₃), nitrite (NO₂), nitrate (NO₃⁻), and phosphorus, which can cause eutrophication - the excessive growth of algae and aquatic plants. Nutrient excess can lead to the following consequences: i. Oxygen depletion - At night, algal blooms consume large amounts of oxygen, causing in hypoxia (low oxygen levels), which can kill fish. Poisonous compound formation - The decomposition of organic materials produces toxic compounds like as ammonia and hydrogen sulphide, which are harmful to fish health. Water quality deterioration: High nutrient levels create turbidity (cloudiness), which reduces light penetration and disrupts pond habitats. Table 4 illustrates the implications. (Smith et al., 1999; Boyd, 2012).

| Nutrient Accumulation | Impact on Aquaculture Systems |
|--|---|
| High Ammonia (NH ₃) | Fish toxicity, reduced growth rates |
| Elevated Nitrite (NO ₂ ⁻) | Disrupts oxygen transport in fish blood |
| High Phosphorus | Causes harmful algal blooms |
| Excess Organic Matter | Leads to oxygen depletion and water fouling |

Management strategies use of biofilters and recirculating aquaculture systems (RAS) to reduce nutrient build-up such as: i. Optimizing feeding practices to minimize excess feed waste; ii. Water exchange and aeration techniques to improve oxygen levels and flush out excess nutrients (Boyd and Craig, 2012).

2.2 Dissolved Oxygen Depletion

Since dissolved oxygen (DO) promotes fish respiration and microbial activity, it is a crucial water quality metric. Aquaculture pond oxygen levels can change due to a number of reasons, including: i. high stocking densities, which result in oxygen demand exceeding replenishment. ii. The decomposition of organic stuff increases the oxygen demand of microbes. iii. Algal respiration, particularly when photosynthesis is inhibited at night. Fish experience stress when DO levels drop below 3 mg/L, which can lead to poor growth, increased susceptibility to disease, and even mass mortality. Notably, methods for preserving DO levels include water circulation to avoid stagnation and stratification, stocking density optimization to balance oxygen demand, and aeration using diffusers or paddle wheels to boost oxygen transport (Boyd, 2017; Boyd and Craig, 2012; Bulbul et al., 2022).

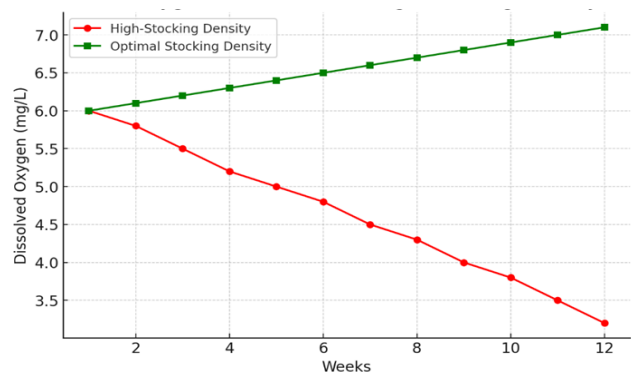


Figure 2: Dissolved Oxygen Fluctuations in High-Stocking-Density Ponds

2.3 pH Fluctuations and Alkalinity Issues

A pH of 6.5 to 8.5 is appropriate for aquaculture water because it affects fish physiology, microbial activity, and food availability. The aquaculture system's pH fluctuates due to photosynthesis, respiration, CO₂ levels, algal blooms, and the accumulation of acidic waste. It has been demonstrated that high pH levels increase fish stress, compromise immunological function, and result in metal toxicity. Fish gill function is hampered by high pH values (>9.0), which also enhance ammonia toxicity and interfere with enzyme activity. The impact of pH extremes in aquaculture is summed up in Table 5. To maintain consistent pH values, buffering materials such as crushed coral and lime are available as pH control solutions. By altering nitrogen sources to prevent excessive algal growth, routine monitoring can identify early differences (Boyd, 2017).

| pH Level | Impact on Fish Health |
|----------|--|
| <6.0 | Acidic stress, poor growth, metal toxicity |
| 6.5-8.5 | Optimal range for aquaculture |
| >9.0 | Ammonia toxicity, enzyme disruption |

2.4 Ammonia and Nitrite Toxicity

Biological filtration (nitrifying microorganisms) converts ammonia to nitrate; probiotics are used to improve the microbial breakdown of waste; frequent water exchange and aeration dilute harmful substances; and ammonia is a common by-product of fish metabolism and organic matter breakdown. High ammonia levels (>0.05 Mg/L) are dangerous, causing gill damage, respiratory distress, decreased immunity, and an increased chance of disease transmission. Growth inhibition and low feed conversion ratios are also affected (Boyd and Zimmermann, 2000).

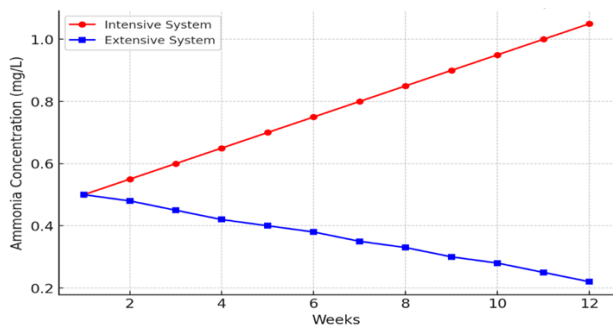


Figure 3: Ammonia Concentration Trends in Intensive vs. Extensive Aquaculture Systems.

2.5 Temperature Variability and Climate Effects

Temperature directly affects fish metabolism, immunological function, and dissolved oxygen availability. The fluctuations in water temperature can alter fish feeding rates, with low temperatures resulting in less food consumption. Furthermore, it induces stress reactions, lowering fish susceptibility to sickness and reducing oxygen solubility, particularly during warmer months. Adaptive strategies may be based on these criteria: i. Shade and deeper ponds to moderate warmth. ii. Monitoring seasonal changes and changing feeding regimens. iii. Use temperature-controlled recirculating systems. (Edwards, 2015; Boyd, 2012).

| Temperature Range | Effect on Fish Growth |
|-------------------|---------------------------------|
| 15-20°C | Slow growth, reduced metabolism |
| 24-30°C | Optimal range for most species |
| >32°C | Heat stress, oxygen depletion |

2.6 Disease Outbreaks Due to Poor Water Quality

Poor water quality increases the prevalence of disease in aquaculture systems. Common diseases associated with poor water conditions include bacterial infections (e.g., *Columnaris*, *Aeromonas spp.*) caused by excessive organic loads. ii. Parasitic infestations (e.g., *Ichthyophthirius multifiliis*) caused by insufficient oxygen and excessive ammonia levels. iii. Fungal infections (e.g., *Saprolegnia*) in fish weakened by pH stress and inadequate nutrition. This disease can be treated by maintaining appropriate water parameters to prevent stress-related infections; using probiotics and

biosecurity measures to boost fish immunity; and implementing quarantine and vaccination programs to reduce disease spread (Boyd, 2017; Sherry et al., 2022).

Effective water quality management in aquaculture is critical for preserving fish health, increasing productivity, and minimizing environmental effect. Proactive monitoring and adaptive management solutions are required to handle challenges such as nutrient buildup, dissolved oxygen depletion, pH changes, ammonia toxicity, and temperature instability. Aquaculture producers can ensure long-term environmental sustainability by adopting sustainable water quality management techniques, including as biofiltration, aeration, and balanced polyculture systems (Jana and Sarkar, 2005; Gao et al., 2019).

3. MONOCULTURE VS. POLYCULTURE IN SUSTAINABLE WATER QUALITY MANAGEMENT IN POND AQUACULTURE

Aquaculture sustainability is largely dependent on effective water quality management, as it directly influences the health, growth, and productivity of cultured species. Among the various cultivation approaches, monoculture and polyculture systems are the two dominant methods used in freshwater pond aquaculture. Each system has unique advantages and challenges that impact water quality management. This section explores the scientific basis, comparative efficiency, and ecological implications (Michael and Wagner, 2017).

3.1 Monoculture Systems: Implications for Water Quality

Monoculture is the process of rearing a single species in a controlled setting, which enables precision feed management, disease monitoring, and production planning. This approach is frequently used in commercial aquaculture because it is predictable and easy to administer. Monoculture systems, on the other hand, present major water quality concerns, particularly in terms of waste accumulation, oxygen depletion, and increased pathogen vulnerability. The absence of species that naturally regulate nutrient cycling and organic matter decomposition causes fast degradation of water quality (Wagner and Michael, 2000). Table 7 summarizes the effects of monoculture systems on water quality.

| Parameters | Effect in Monoculture Systems | Consequences |
|-----------------------------------|--|--|
| Dissolved Oxygen (DO) | Declines due to lack of oxygen-producing species | Increased fish stress and mortality |
| Ammonia (NH ₃) Levels | Increases due to fish excretion without natural filtration | Toxic buildup, poor growth rates |
| pH Fluctuations | Unstable due to organic waste accumulation | Reduced immune response in fish |
| Organic Matter Load | High, as no scavenger species are present | Increased risk of hypoxia and algal blooms |

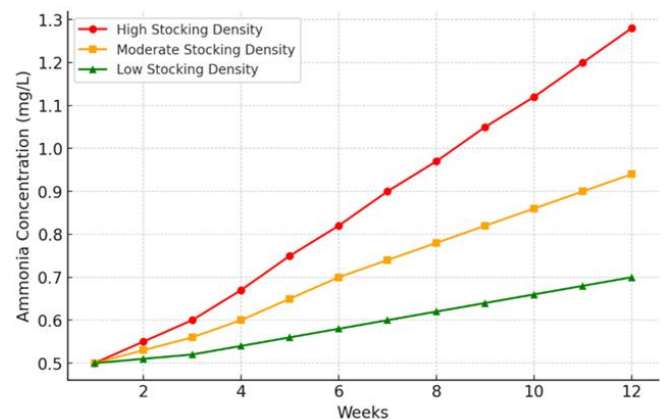
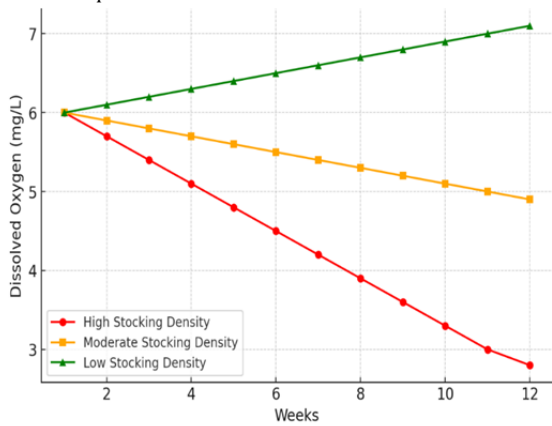


Figure 4: Ammonia Accumulation Trends in Monoculture Ponds

3.1.3 Challenges of Monoculture in Sustainable Aquaculture

Several challenges arise in monoculture systems that threaten long-term sustainability. Such as Nutrient Overloading. The excessive accumulation of nitrogenous waste compounds (NH₃, NO₂⁻, NO₃⁻) leads to toxicity and

oxygen depletion. i. Disease Susceptibility ii. Single-species environments facilitate the spread of pathogens without ecological buffers. iii. High Dependency on Water Exchange and Aeration iv. To maintain water quality, monoculture systems require external interventions such as aerators and frequent water renewal.



Graph 5: Dissolved Oxygen Fluctuations in High-Stocking-Density Monoculture Ponds

3.2 Polyculture Systems: A Sustainable Approach to Water Quality Management

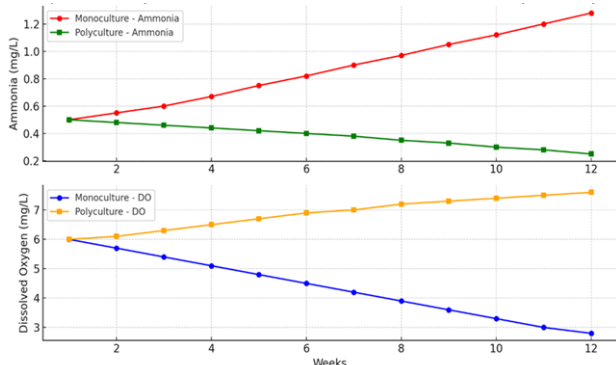
3.2.1 Characteristics of Polyculture

Co-cultivating several species that enhance one another's ecological roles is known as polyculture. Water quality is improved through polyculture, which maintains a balanced aquatic ecosystem by combining species with varying eating habits and habitat requirements. When freshwater prawns (*Macrobrachium rosenbergii*) and Nile tilapia (*Oreochromis niloticus*) are combined, for instance, suspended organic waste can be filtered, with the prawns serving as scavengers. Notably, Tilapia can prevent algal blooms by consuming surplus algae. Improved nutrient cycling (species occupying different ecological niches) (Wang and Maixin, 2016; Khan et al., 2010; Sergio and Michael, 2000).

3.2.2 Impact of Polyculture on Water Quality Parameters

Polyculture offers more ecological stability than monoculture by maximizing nutrient utilization and reducing the build-up of hazardous waste.

| Table 8: Water Quality Improvements in Polyculture Systems | | |
|--|--|--------------------------------|
| Parameters | Effect in Polyculture Systems | Consequence |
| Dissolved Oxygen (DO) | Higher due to improved water circulation and algal control | Reduces hypoxia risk |
| Ammonia (NH ₃) Levels | Lower due to increased nitrogen assimilation by prawns | Enhances fish growth |
| pH Stability | More stable due to improved microbial diversity | Healthier fish immune response |
| Organic Waste Load | Reduced as prawns consume excess detritus | Prevents pond eutrophication |



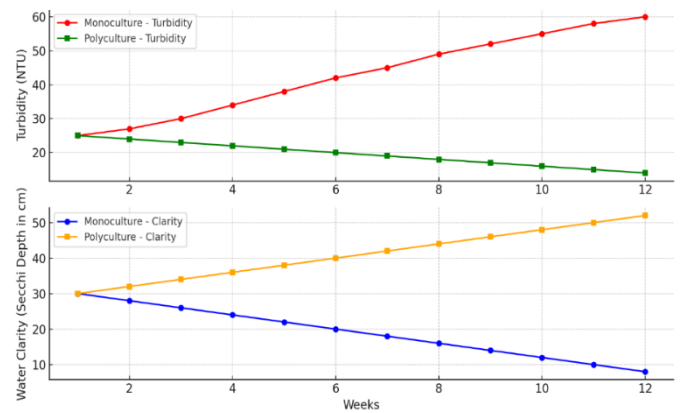
Graph 6: Comparative Analysis of Ammonia and DO Levels in Monoculture vs. Polyculture Systems

3.2.3 Key Benefits of Polyculture in Sustainable Water Quality Management

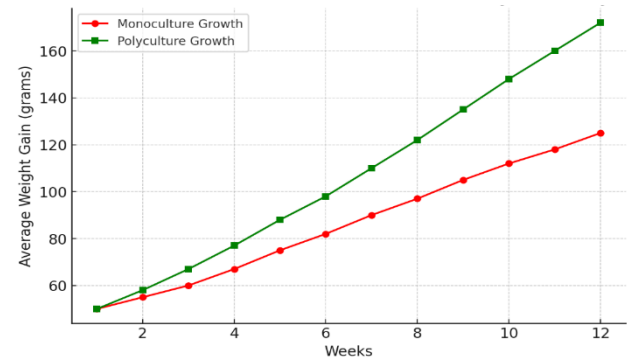
The following are some benefits of polyculture in sustainable water quality management: i. Biological Filtration: Through the natural cycle of nutrients, biological variety keeps waste from building up. Reliance on artificial aeration is reduced. iii. Higher dissolved oxygen levels are naturally maintained in polyculture systems. iii. Disease outbreaks are decreased by ecological competition created by resilience to pathogens that are involved with diverse pond systems (Wagner et al., 2011).

3.3 Pragmatic Studies on Monoculture vs. Polyculture Water Quality Efficiency

Several studies have assessed the long-term ecological and economic feasibility of monoculture vs. polyculture system. It was found that polyculture ponds exhibited 30% lower turbidity levels compared to monoculture, indicating better water clarity and lower organic sedimentation rates. According to another research, tilapia-prawn polyculture increases fish growth rates by 15% to 20% because of improved water quality and reduced stress (Michael and Wagner, 2017; Wang and Maixin, 2016; Hossain and Islam, 2006).



Graph 7: Water Clarity and Turbidity in Monoculture vs. Polyculture Systems



Graph 8: Fish Growth Performance in Monoculture vs. Polyculture Systems

3.4 Future Research and Innovation in Sustainable Polyculture Systems

Despite its benefits, polyculture still faces issues such as species selection, proper stocking ratios, and ecosystem balance. Future research should focus on i. Creating AI-powered water quality monitoring systems to optimize species interactions. ii. Investigating novel polyculture combinations that incorporate additional aquatic organisms to improve nutrient cycling. iii. Evaluating the economic feasibility of expanding polyculture to commercial scale while ensuring sustainability. Water quality control is still a major challenge in aquaculture, affecting fish health, productivity, and environmental sustainability. While monoculture systems are easier to operate, they contribute to nutrient overload and deterioration of water quality, resulting in greater aeration and filtration input costs. Polyculture systems, on the other hand, offer a more

sustainable solution, relying on species interactions to preserve ecological balance, reduce organic waste, and improve overall water quality (Uddin et al., 2007; UN, 2015; Wagner et al., 2011).

4. ADVANTAGES OF MONO AND POLY CULTURE OF FRESHWATER PRAWN WITH TILAPIA FISH IN WATER QUALITY MANAGEMENT

The monoculture and polyculture of freshwater prawns (*Macrobrachium rosenbergii*) with Nile tilapia (*Oreochromis niloticus*) is one of the many freshwater aquaculture techniques that has been well researched because of its effects on ecosystem stability, organic waste reduction, and nutrient cycling. The benefits of monoculture and polyculture systems for these species are examined in this part, with an emphasis on how they contribute to sustainable pond management, nitrogen regulation, and improved water quality. (Wagner and Michael, 2000; Wang and Maixin, 2016; New, 2002).

4.1 Monoculture of Freshwater Prawns and Tilapia in Water Quality Management

4.1.1 Monoculture of Freshwater Prawns

The raising freshwater prawns alone (monoculture) is a common practice, particularly in commercial prawn farms, due to their high market demand and export value. However, managing water quality in prawn monoculture systems presents both benefits and challenges. The advantages of prawn monoculture in water quality management are relevant to some factors such as: i. Scavenger behaviour. ii Freshwater prawns consume excess organic matter, reducing sediment buildup. iii. Minimal algal blooms.

Since prawns do not feed on phytoplankton, they prevent excessive algal growth, maintaining a stable pH. Oxygen utilization optimization: Prawns exhibit low metabolic oxygen demand, reducing the risk of oxygen depletion. On the side of the coin, the challenges of prawn culture have been observed on the followings i. Ammonia accumulation: High stocking densities result in increased ammonia and nitrite production, requiring water exchange. ii. Limited oxygen production: Unlike tilapia, prawns do not regulate algae populations, which can lead to fluctuating oxygen levels (Wagner and Michael, 2000; Jose et al., 1992).

4.1.2 Monoculture of Tilapia

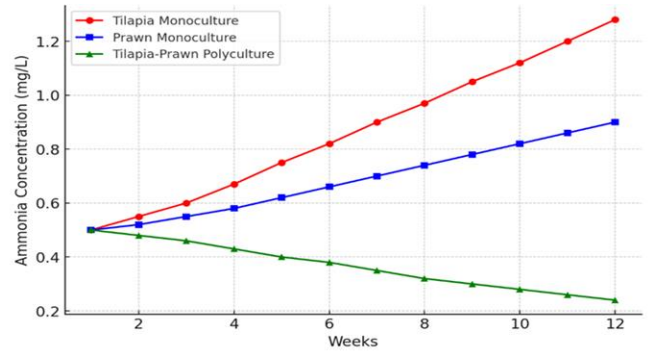
Nile tilapia monoculture is frequently used because of its resilience to a variety of environmental conditions and rapid development rates. However, tilapia alone has the potential to impact water quality dynamics. Tilapia monoculture has several advantages in water quality management, including i. Algae control; Tilapia consumes surplus algae, preventing oxygen deficiency caused by algal decomposition. They can endure low oxygen and variable pH levels, which reduces the need for aeration systems. Furthermore, high ammonia tolerant 'Tilapia' may survive at moderate ammonia concentrations, making them less susceptible to poor water quality. On the contrary, the principal problems of Tilapia Monoculture are focused on i. Increased organic waste caused by excess feed and metabolic waste contributes to excessive organic matter accumulation. ii. Oxygen fluctuations are a problem because bottom-dwelling scavengers and uneaten feed collect (Avnimelech, 2007; Avnimelech and Kochba, 2009).

| Parameters | Freshwater Prawn Monoculture | Tilapia Monoculture |
|----------------------------|------------------------------|---|
| Ammonia Levels | Moderate to high | High |
| Dissolved Oxygen (DO) | Stable but requires aeration | Variable, depends on algal growth |
| pH Stability | Maintains neutral pH | Slight fluctuations due to algae |
| Organic Waste Accumulation | Moderate due to scavenging | High, requiring frequent water exchange |

4.2 Polyculture of Freshwater Prawns and Tilapia: A Sustainable Approach to Water Quality Management

Polyculture is a biological technique for improving water quality that uses the complementing interactions of numerous species. The tilapia-prawn polyculture system is gaining popularity for its capacity to optimize nutrient cycling, reduce organic waste, and increase dissolved oxygen

levels. Tilapia and prawns interact to improve water quality through some factors. Such as: i. Tilapia act as algae regulators; ii. By lowering their consumption of surplus phytoplankton, tilapia avoid algal blooms, which can lead to oxygen shortage during decomposition. iii. Prawns as bottom scavengers. Freshwater prawns consume uneaten feed, organic debris, and detritus, which reduces silt accumulation and ammonia production. The combined action of these species optimizes the nitrogen cycle by balancing ammonia, nitrite, and nitrate levels (Uddin et al., 2007; Islam et al., 1999).



Graph 9: Ammonia Reduction in Tilapia-Prawn Polyculture vs. Monoculture Systems

4.2.1 Advantages of Tilapia-Prawn Polyculture in Water Quality Management

Ammonia accumulation in monoculture systems is a big issue. However, research has shown that polyculture alleviates this problem by creating a balanced nitrogen cycle. Prawns devour uneaten feed, which reduces ammonia production from decaying organic waste. Tilapia fish reduce oxygen depletion by promoting nitrifying bacteria, which convert ammonia into less dangerous nitrates. It was discovered that DO levels remain higher in polyculture systems than in monoculture, minimizing the requirement for artificial aeration. Tilapia activity aerates the water and improves oxygen exchange in the pond environment. In contrast, without bottom feeders such as shrimp, uneaten feed and fish waste build, resulting in oxygen depletion and pH variations in a monoculture system containing solely Tilapia fish. Prawns digest organic materials, which reduces anaerobic deterioration. These variables minimized the need for frequent water changes, kept pH steady to prevent algal blooms, and lowered operational costs. Tilapia fish regulate algae growth, minimizing oxygen depletion from algal breakdown, whilst prawns reduce silt formation and stabilize pH changes in polyculture ponds (Uddin et al., 2007; Alam et al., 2001; Michael and Wagner, 2016) (Table 10).

| Parameters | Tilapia-Prawn Polyculture | Benefit to Water Quality |
|----------------------------|---------------------------|--|
| Ammonia Levels | Low | Reduces fish stress and improves growth rates |
| Dissolved Oxygen (DO) | Higher than monoculture | Reduces hypoxia risk |
| pH Stability | More stable | Prevents extreme fluctuations |
| Organic Waste Accumulation | Low | Enhances pond health and reduces maintenance costs |

4.3 Empirical Studies Supporting Tilapia-Prawn Polyculture

Several studies have demonstrated the benefits of polyculture systems in enhancing water quality and reducing environmental impact. It was reported that ammonia levels were 40% lower in polyculture ponds compared to tilapia monoculture. DO levels in polyculture systems were consistently 15-20% higher than in monoculture, reducing the need for artificial aeration. Algal bloom occurrences were 60% lower in polyculture, preventing oxygen depletion and improving fish survival rates. Water quality management is a crucial factor in aquaculture sustainability. While monoculture systems offer simplicity in management, they pose challenges related to nutrient buildup, ammonia accumulation, and organic waste deposition. In contrast, tilapia-prawn polyculture provides a natural solution to these issues, improving oxygen availability, reducing ammonia levels, and enhancing sediment quality. The adoption of polyculture

systems can significantly enhance aquaculture sustainability, reducing environmental impact while optimizing fish and prawn growth. (Mateus et al., 2007; Wagner et al., 2011; Huq et al., 2004).

4.4 Need for Responsible on Farm Feed Management

The study freshwater fish species make up more than 83.6% of the world's total farmed fish production, which was 44.66 million metric tons in 2017 (FAO, 2019; Halwart et al., 2007). A growing percentage of these species are raised in intensive net-cage farming systems in public water bodies like lakes, reservoirs, and rivers. Concern over these intense open agricultural techniques' possible detrimental effects on the environment is growing. Fish disease outbreaks and their spread to natural fish populations, water pollution and silt accumulation beneath cages, uneaten feed and nutrient loss from feed, and general ecosystem stability and health are the foundations of these problems (Herath and Satoh, 2015). The aquaculture sector will therefore be under more pressure to manage these dense net-cage farms in a sustainable and ecologically friendly way. A common public resource used by other stakeholders for municipal, agricultural, and/or recreational purposes is the water in which the fish are reared (Kassam, 2014; FAO, 2024).

Future farming systems must be self-contained to address biosecurity, disease exclusion, water reuse, and fertilizer outflow (Bostock, 2012; Bregnballe, 2015). Notably, local feed manufacturers can play an important role in promoting environmentally friendly production systems and producing local feeds such as Black soldier fly larva (BSFL) meal, which is a promising, sustainable, and nutritious alternative to traditional fishmeal for fish feed, offering a high protein content and the ability to utilize organic waste. This natural locally produced feed can provide adequate nutrients and contributed to finfish and crustacean aquaculture sector to create a balanced aquatic ecosystem and ensure long-term sustainability by lowering costs for socioeconomic benefit (Hossain and Paul, 2007; Mitra et al., 2005).

4.5 Key findings from this review comprise of following factors:

- i. Ammonia Control – Polyculture systems maintain 40–50% lower ammonia concentrations compared to monoculture due to efficient nutrient cycling facilitated by species interactions.
- ii. Dissolved Oxygen Stability – In monoculture ponds, DO levels decline significantly over time, whereas polyculture systems maintain higher oxygen levels due to improved biological aeration and organic matter decomposition.
- iii. Organic Waste Reduction – Freshwater prawns act as bottom scavengers, consuming uneaten feed and organic debris, thereby reducing sediment accumulation and preventing hypoxia.
- iv. Water Clarity and pH Regulation – Polyculture systems demonstrate enhanced water and pH stability, mitigating fluctuations caused by algal overgrowth and organic decomposition.
- v. Fish Growth Performance – Tilapia and prawns achieve better growth rates in polyculture environments due to improved water conditions and reduced physiological stress.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Sustainable water quality management in aquaculture is critical for ensuring optimal fish health, growth rates, and environmental sustainability. The comparison between monoculture and polyculture systems, particularly involving Nile tilapia (*Oreochromis niloticus*) and freshwater prawns (*Macrobrachium rosenbergii*), has revealed substantial differences in nutrient cycling, organic waste management, and overall water quality dynamics. Monoculture systems, while simpler to manage, tend to accumulate ammonia and organic matter at higher rates, leading to oxygen depletion, pH fluctuations, and increased risks of disease outbreaks. In contrast, polyculture systems offer significant advantages by leveraging species interactions to enhance water quality, reduce waste accumulation, and improve dissolved oxygen levels.

The findings of many aquaculture-based research suggest that polyculture systems, notably the combination of tilapia and freshwater prawns, provide an ecologically and economically viable alternative for enhancing water quality in freshwater ponds. Aquaculture stakeholders may help to make the aquaculture industry more resilient and productive by applying integrated management techniques, improving technology adoption, and

promoting sustainable regulations. By implementing these guidelines, aquaculture producers, academics, and policymakers may strive toward a more sustainable, environmentally friendly, and commercially successful aquaculture system, guaranteeing that future generations benefit from responsible fish farming techniques to achieve relevant Sustainable Development Goals (SDGs).

5.2 Recommendations

Based on the findings of this study, several recommendations are proposed to enhance sustainable water quality management in aquaculture:

a. Promote Polyculture Systems in Aquaculture

- i. Encourage adoption of tilapia-prawn polyculture as a cost-effective and environmentally friendly alternative to monoculture.
- ii. Develop species-specific stocking density guidelines to optimize nutrient utilization and prevent overcrowding.

b. Improve Water Quality Monitoring and Management

- i. Implement real-time water quality monitoring using automated sensors to track DO levels, ammonia concentrations, and pH stability.
- ii. Encourage the use of probiotics and biofiltration systems to enhance microbial nutrient cycling.

c. Optimize Feeding and Waste Management Strategies

- i. Implement precision feeding techniques to minimize excess feed waste and reduce organic matter accumulation.
- ii. Encourage research into sustainable feed formulations that reduce nitrogenous waste output.

d. Develop Policy and Research Frameworks for Sustainable Aquaculture

- i. Support government policies that promote integrated aquaculture practices and sustainable water resource management.
- ii. Encourage long-term studies on polyculture species compatibility, economic feasibility, and ecological impact.

e. Encourage Technological Innovations in Sustainable Aquaculture

- i. Explore AI-based aquaculture management systems to optimize stocking density, feeding regimes, and water quality parameters.
- ii. Incorporate floating wetlands and aquatic plants in polyculture setups to further enhance nutrient cycling and biodiversity.

5.3 Future Research Directions

This review emphasizes the advantages of tilapia-prawn polyculture, more research is needed to fine-tune stocking tactics, optimize feeding regimens, and analyze long-term environmental effects. Future investigations should focus on:

- i. Comparing the economic viability of monoculture vs. polyculture systems at different production scales.
- ii. Exploring alternative species combinations (e.g., mollusks, aquatic plants) for enhanced nutrient cycling.
- iii. Investigating climate resilience strategies for sustainable aquaculture practices under changing environmental conditions.
- iv. Water quality management can be used as fundamental challenge in aquaculture, influencing environmental sustainability, fish productivity, and economic viability.

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