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Water Quality Regulation for Sustainable Production of Giant Freshwater Prawn (*Macrobrachium rosenbergii*)

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Abstract Giant freshwater prawn (*Macrobrachium rosenbergii*) is an important freshwater aquaculture species worldwide. However, with the increase in farming density and intensification, problems such as water eutrophication, dissolved oxygen fluctuations, ammonia nitrogen accumulation, and algae imbalance have gradually become major factors limiting the sustainable development of the industry. This study summarizes the effects of temperature, dissolved oxygen, pH, nitrogen compounds, water transparency, and algal dynamics on the growth, survival, and health of *M. rosenbergii*. It also analyzes the application effects of water environment management strategies, including aeration management, biofloc technology, probiotic regulation, precise feeding, and integrated multi-trophic aquaculture. Based on practical cases of pond culture, biofloc farming, ecological polyculture, and rice–prawn integrated farming in Zhejiang Province, China, this study discusses the positive effects of water quality improvement on growth performance, immune health, feed utilization efficiency, and economic benefits. Optimization of a single water quality indicator is difficult to meet the requirements of high-density aquaculture. A comprehensive management model combining microbial regulation, ecological circulation, and digital monitoring can effectively improve pond environmental stability, reduce farming risks, and achieve coordinated improvement of production and ecological benefits. In the future, precise water quality regulation systems based on the Internet of Things, artificial intelligence, and climate-adaptive management will become an important direction for promoting the green, efficient, and sustainable development of the *M. rosenbergii* industry.
Keywords *Macrobrachium rosenbergii*; Water quality regulation; Biofloc technology; Probiotics; ecological aquaculture; Sustainable production

1 Introduction

Giant freshwater prawn (*Macrobrachium rosenbergii*) is one of the most important freshwater crustacean aquaculture species worldwide. Due to its relatively fast growth, large body size, high market value, and strong environmental adaptability, it has developed into an extensive aquaculture industry in Asia and other tropical and subtropical regions. Global production has remained at a high level for a long time, although fluctuations occur among different years and statistical methods. In 2018, the aquaculture production reached 237 124 t with a production value of more than 1.93 billion US dollars (Pillai et al., 2022). The global production in 2018 was also reported as 234 400 t (Tan and Wang, 2022), while in 2021 it reached 313 756 t with a production value exceeding 2.45 billion US dollars, of which China accounted for 54.4% (Pillai and Panda, 2024). This species has important economic value in countries such as China, Bangladesh, Thailand, Myanmar, India, and Malaysia, and is considered an important species for increasing farmers' income, expanding the supply of high-quality aquatic products, and promoting the diversification of inland aquaculture.

During the culture of *M. rosenbergii*, water environmental conditions are the key driving factors determining growth, survival, immunity, and final yield. Among these factors, temperature, dissolved oxygen, pH, salinity, and nitrogen metabolites are particularly important. Integrated multi-trophic aquaculture can provide a more stable ecological environment for *M. rosenbergii* by using plants, filter-feeding fish, and bivalves to jointly absorb nitrogen and phosphorus, regulate phytoplankton biomass, and increase dissolved oxygen. This approach has shown potential for achieving both ecological and economic benefits (Dong et al., 2018).

Traditional monoculture and high-density farming often lead to organic matter accumulation and nitrogen and phosphorus enrichment due to uneaten feed, feces, and excessive feeding. These problems can further cause water quality deterioration, pathogen proliferation, algal community imbalance, and environmental pollution from discharge. The ecological stability of ponds is not only affected by water parameters but also influenced by sediment conditions and water-soil interactions. As the culture period progresses, the waste carrying capacity decreases, organic matter continuously accumulates, and water quality and soil conditions undergo dynamic coupling changes, which ultimately affect production patterns (Ariadi et al., 2025). After applying intelligent monitoring and water quality control systems, *M. rosenbergii* achieved a survival rate of 93.3% within 120 days and reached healthy marketable size, indicating the practical value of precise management strategies (Songpayome et al., 2024).

Based on these considerations, this study aims to systematically summarize the regulation mechanisms of key water quality factors in *M. rosenbergii* aquaculture based on current farming practices. It compares the effects of different management approaches, including biofloc technology, probiotics, integrated aquaculture, and intelligent monitoring, on growth performance, health status, and ecological stability. Furthermore, this study explores the relationships among maintaining pond ecological stability, improving resource utilization efficiency, and reducing environmental risks. The results are expected to provide a basis for establishing a water quality management framework for *M. rosenbergii* aquaculture that integrates production, health, environmental sustainability, and economic feasibility. It may also provide theoretical support for the transition of this industry from experience-based management toward evidence-based and ecological management.

2 Water Environmental Factors in *Macrobrachium rosenbergii* Aquaculture

2.1 Dissolved oxygen and temperature

Dissolved oxygen is a fundamental condition for maintaining metabolism, feeding activity, and normal growth of *Macrobrachium rosenbergii*. Both field observations and experimental studies have shown that fluctuations in dissolved oxygen directly affect aquaculture performance. In a hatchery in Indonesia, during larval cultivation, dissolved oxygen maintained at 7~8 mg/L and temperature at 27 ℃~28 ℃ resulted in a hatching rate of 54.7% and a survival rate of 40.6% (Wiguno and Dewi, 2022). In a comparison of juvenile culture systems in Brazil, dissolved oxygen levels in both recirculating aquaculture systems (RAS) and biofloc systems were approximately 7.16~7.19 mg/L, and no significant differences were observed in survival rate, specific growth rate, or weight gain during the 30-day experiment (Ballester et al., 2017). In ponds in Bangladesh, when dissolved oxygen ranged from 5.33 to 6.17 mg/L, different stocking densities still achieved survival rates of 61.01%~75.02%, while the low-density group showed higher weight gain and production (Samad et al., 2016).

Temperature has a more direct influence on *M. rosenbergii* because it determines metabolic intensity and environmental stress thresholds. Under air-saturated dissolved oxygen conditions, within the range of 20 ℃~30 ℃, growth almost doubled with every 5 ℃ increase in temperature, while the feed conversion ratio showed little change (Farmanfarmaian and Moore, 1978). Late-stage larvae of *M. rosenbergii* grew well at both 27 ℃ and 30 ℃, with no significant difference in growth rate between the two temperatures. The suitable temperature range is generally considered to be 26 ℃~31 ℃ (Tay et al., 2022). Individuals showed normal behavior between 22 ℃ and 30 ℃, but abnormal behavior and mortality occurred at 34 ℃. At 38 ℃, the 24 h survival rate decreased to 33.33%, and all individuals died within 72 h. Meanwhile, total hemocyte count and differential hemocyte count significantly decreased at temperatures ≥34 ℃ (Bir et al., 2024). A temperature of 30 ℃ resulted in the fastest molting and the highest growth increase. Although individuals could survive outside this range, growth efficiency declined (Habashy and Sharshar, 2020).

2.2 pH and nitrogen compounds

Maintaining pH balance is essential for pond environmental stability and successful early development, especially for larvae and juvenile prawns (Figure 1). A 30-day larval experiment showed that under neutral pH conditions (7.7±0.4), larvae began metamorphosis into postlarvae on day 23. Mild acidic conditions (pH 6.4±0.5) significantly inhibited feeding, growth, and survival, and delayed metamorphosis until day 30. Under strongly acidic conditions (pH 5.4±0.2), all larvae died within 48 h (Liew et al., 2022). Studies on PL5 to early juvenile prawns showed that pH 5 significantly reduced body length and weight, while pH 4 prevented normal metamorphosis, caused extremely uneven body size distribution, and resulted in thinner shells. In contrast, growth performance at pH 6 was similar to the control pH 7.5 group, and the highest survival rate was observed at pH 6 (Kawamura et al., 2015). Laboratory studies indicated that pH 8 promoted the fastest molting and highest growth increase. However, in pond environments, pH fluctuates due to daily photosynthesis and respiration processes, making continuous monitoring more important than single measurements (Habashy and Sharshar, 2020).

Nitrogen compounds, especially total ammonia nitrogen and nitrite, are among the most common water quality risks in *M. rosenbergii* aquaculture. Ammonia nitrogen and nitrite are important monitoring indicators during farming. Even small amounts of ammonia accumulation can disrupt growth stability, while high concentrations may affect enzyme activity, cell membrane permeability, excretion systems, and osmotic balance. In a 165-day experiment in the Philippines, the biofloc system did not change dissolved oxygen, temperature, or pH, but significantly reduced total ammonia nitrogen and nitrate levels while improving weight gain, net production, and specific growth rate (Camarin et al., 2023).

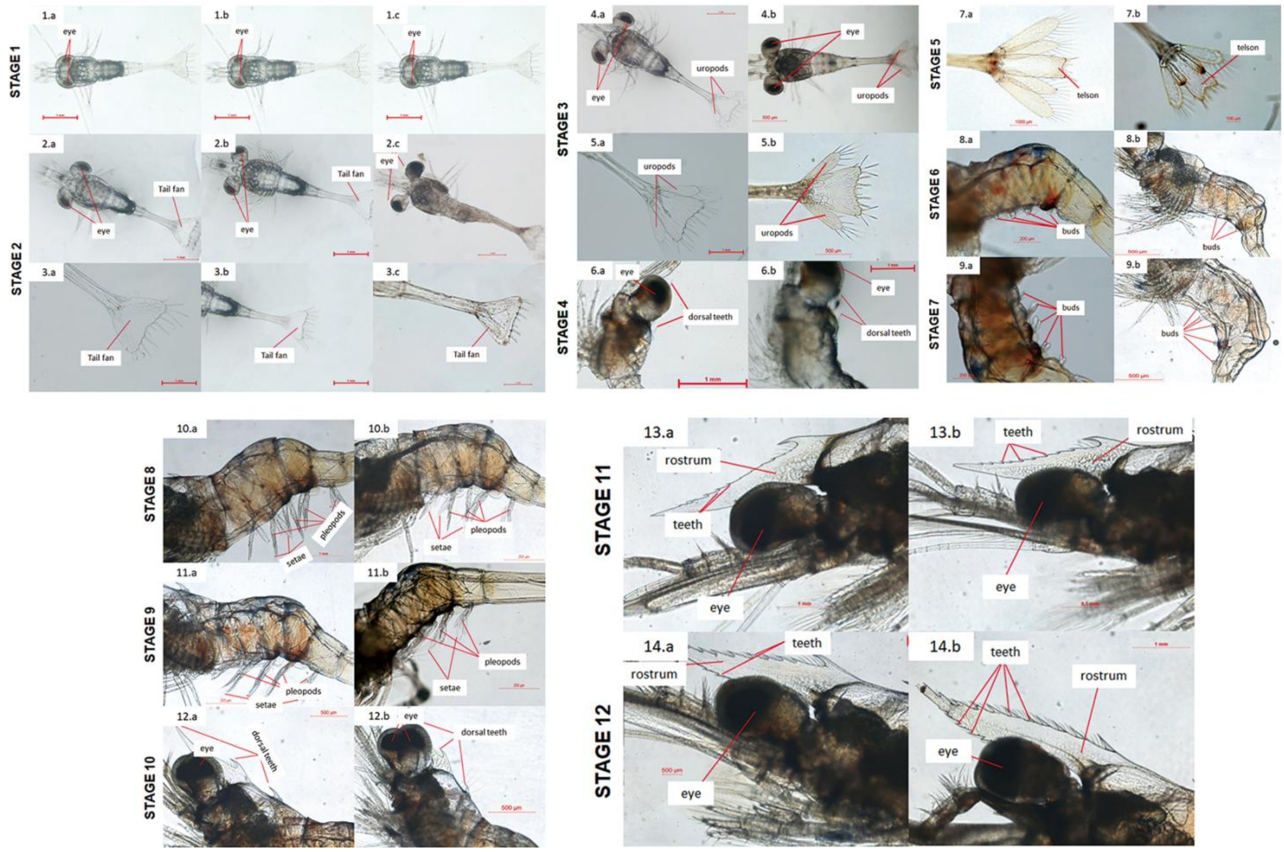

Figure 1 1-14 Stage 11 and 12 developmental stages of *M. rosenbergii* larvae exposed to (a) neutral (pH 7.7 ± 0.4) and (b) mild-acidic (pH 6.4 ± 0.5) conditions (Adapted from Liew et al., 2022)

2.3 Transparency, algae, and ecological balance

Water transparency and algal dynamics reflect the balance between pond primary productivity and organic loading, and they are also important ecological indicators connecting dissolved oxygen, pH, and nutrient cycling. In 195-day pond culture systems in the Koraput mountainous region of India, continuous monitoring of transparency, chlorophyll a, nitrate, phosphate, and organic carbon showed significant differences among ponds with different feeds during the culture period. Growth curves showed rapid growth during the first 90 days followed by stabilization, indicating that pond optical properties and nutritional conditions changed together with the culture stage (Khemundu and Banerjee, 2019).

Algal management requires not only controlling algal biomass but also maintaining a reasonable ecological structure. The introduction of plants and filter-feeding animals can regulate nutrient cycling in ponds and reduce the risk of excessive algal proliferation. The key point of transparency and algal management is not simply reducing algal quantity, but maintaining a certain level of primary productivity while preventing nutrient over-enrichment and algal community imbalance.

3 Pond Environmental Management of *Macrobrachium rosenbergii*

3.1 Aeration management

The main sources of oxygen in ponds include photosynthesis by algae and aquatic plants, as well as oxygen input from mechanical aeration equipment. Meanwhile, oxygen is continuously consumed by prawn respiration, microbial decomposition of organic matter, and sediment oxygen demand. Although mechanical aeration can rapidly increase dissolved oxygen levels, the oxygen diffusion capacity in the bottom layer of ponds is limited. Therefore, relying only on surface aeration equipment is often insufficient to completely solve low oxygen problems in bottom waters. In practical aquaculture, aeration equipment should be properly configured according to pond depth, stocking density, and water quality changes.

Regarding aeration strategies in *M. rosenbergii* ponds, Sheng et al. (2023) compared pond depths of 1.2 m and 1.8 m and analyzed the effects of traditional surface aeration and combined surface-bottom aeration systems on water environmental conditions. The deeper pond system combined with both surface and bottom aeration effectively improved pond ecological conditions. Compared with the traditional mode, this approach significantly reduced the dominance of cyanobacteria and increased phytoplankton community diversity, with phytoplankton species numbers increasing by 30.43%~136.84%. Under this system, total nitrogen, ammonia nitrogen, total phosphorus, and active phosphate concentrations in the water were also reduced.

3.2 Microbial regulation

During high-density *M. rosenbergii* farming, uneaten feed, feces, and dead biological residues continuously enter the water and release large amounts of nitrogen-containing compounds during decomposition. If these substances cannot be effectively transformed, ammonia nitrogen and nitrite accumulation may occur. Biofloc Technology (BFT) uses microbial communities in water to convert inorganic nitrogen from feed residues and excretion products into microbial protein, while forming natural feed particles that can be utilized by prawns. However, in practical production, the performance of biofloc systems is affected by carbon source input, microbial maturity, and stocking density. Water quality improvement cannot be achieved simply by adding microorganisms.

Under different stocking densities, Ly et al. (2024) evaluated the effects of the red algae (*Gracilaria tenuistipitata*)-biofloc system on water quality and juvenile growth. With increasing stocking density, total ammonia nitrogen (TAN), nitrite, heterotrophic bacteria, and Vibrio populations showed increasing trends. However, under the combined effects of biofloc and red algae, water quality indicators remained within suitable ranges for aquaculture. Among the tested treatments, a stocking density of approximately 1 500 individuals/m^3 achieved better overall farming performance.

Probiotics are also an important approach for microbial regulation. A biofloc system based on *Lactococcus lactis* showed that although probiotic addition did not significantly alter the microbial community structure of the water or *M. rosenbergii* intestine, combining probiotics with biofloc improved farming performance, achieving 100% survival and increasing final body weight (Kathia et al., 2022). Attached microbial communities can absorb ammonium salts and phosphate from water while forming stable microbial structures, providing additional natural nutrient sources for cultured animals (Sow et al., 2024).

3.3 Feeding reduction and waste control

With increasing stocking density, feed input continues to rise to meet the rapid growth requirements of prawns. However, uneaten feed and prawn excretion enter the water and are decomposed by microorganisms, producing metabolic products such as ammonia nitrogen and nitrite. When the self-purification capacity of ponds is insufficient, these substances accumulate and cause water quality deterioration. Therefore, reasonable control of feeding amount and improvement of feed utilization efficiency are important measures for reducing pond pollution loads.

In a biofloc experiment with *M. rosenbergii* ponds, reducing conventional feeding by 20% did not affect growth or production. The 80% feeding treatment achieved the lowest feed conversion ratio (1.40), while the non-biofloc control group showed a value of 2.13. This indicates that microbial natural feed can simultaneously reduce feeding pressure and pollution load (Islam et al., 2023).

Different carbon sources and co-fermentation strategies also influence the effectiveness of partially replacing feed with microbial biomass. In a 35-day late-stage larval experiment, the symbiotic system using pretreated rice bran maintained suitable water quality while achieving the highest final body weight and weekly weight gain. A nursery study using rice bran and mixed probiotics found that longer anaerobic-aerobic pretreatment did not change the stabilization time of nitrogen compounds but improved final average weight and production per unit volume (Dos Santos et al., 2022).

3.4 Ecological management

Compared with relying only on water exchange and aeration, ecological aquaculture models improve water quality by using plants, filter-feeding organisms, and other cultured species to absorb and transform nutrients in the water. An integrated multi-trophic aquaculture (IMTA) study of *M. rosenbergii* established six culture systems, including *M. rosenbergii* monoculture, *M. rosenbergii* + duckweed, *M. rosenbergii* + silver carp, *M. rosenbergii* + bivalves + silver carp, *M. rosenbergii* + bivalves + duckweed, and *M. rosenbergii* + bivalves + duckweed + silver carp. The experiment lasted 64 days, and water quality parameters and prawn growth were monitored every 10 days (Dong et al., 2018) (Table 1). The bivalve + duckweed + silver carp combination system (PMPF) showed better ecological performance, with the highest dissolved oxygen level. Duckweed could absorb nitrogen and phosphorus from water and reduce the risk of excessive phytoplankton growth. Compared with monoculture systems, multi-trophic combinations improved nutrient utilization efficiency and increased system stability.

Plant co-culture and the introduction of cleaning organisms provide more direct pond purification effects. Co-culture of *M. rosenbergii* with Hydrilla verticillata showed that dissolved oxygen, pH, nitrogen, phosphorus, total ammonia nitrogen, nitrite, and nitrate levels were significantly lower than those in monoculture systems. Under a stocking density of 20 individuals/m² and 80% of conventional feeding, the survival rate reached 96.2%, with an average final weight of 68.5 g and a production of 879.1 kg/ha. Marketable size was achieved within six months (Ma et al., 2020). This system reduced commercial feed requirements to 20% of those in conventional farming and significantly improved profit and internal rate of return, demonstrating that water quality improvement and cost control can be achieved simultaneously.

Table 1 Mean ± SE weight gain of the prawn *Macrobrachium rosenbergii* and final weight of the prawns and output of carp and mussels (with shells) in different experimental treatments after 64 d. Treatment groups are as follows: MP: monoculture prawn; PP: prawn in culture with aquatic plants (duckweed Lemna minor); PF: prawn with fish (silver carp Hypophthalmichthys molitrix); PMF: prawn with mussels (Anodonta sp.) and fish; PMP: prawn with mussels and aquatic plants; PMPF: prawn with mussels, aquatic plants and fish (Adopted from Dong et al., 2018)

Group	Initial weight (g)	Final weight (g)	Weight gain (%)	Specific growth rate (% d^{-1})	Survival rate (%)	Silver carp output (g)	*Anodonta* sp. output (g)
MP	7.07 ± 0.86	19.26 ± 0.04	172.11 ± 0.59	2.93 ± 0.00	72.96 ± 4.92		
PP	7.07 ± 0.86	18.18 ± 3.88	156.86 ± 54.82	2.81 ± 0.39	80.94 ± 11.80		
PF	7.07 ± 0.86	22.44 ± 2.10	216.93 ± 29.69	3.07 ± 0.09	68.02 ± 3.69	403 ± 37.0	
PMF	7.07 ± 0.86	23.98 ± 2.56	238.69 ± 36.20	3.13 ± 0.11	62.21 ± 7.92	561 ± 0.05	307 ± 93.6
PMP	7.07 ± 0.86	17.91 ± 0.79	153.03 ± 11.27	2.85 ± 0.04	84.27 ± 3.10	250 ± 74.3	
PMPF	7.07 ± 0.86	22.96 ± 4.16	248.48 ± 47.62	3.07 ± 0.17	76.94 ± 8.09	740 ± 37.0	492 ± 58.0

4 Case Studies of *Macrobrachium rosenbergii* Aquaculture in China

4.1 Zhejiang: intensive pond aquaculture

The development of *M. rosenbergii* aquaculture in China has experienced a transition from small-scale experimental farming to regional and large-scale pond production. After *M. rosenbergii* was introduced into China in 1976, cultivation was first carried out in regions such as Guangdong and later expanded to the Yangtze River Delta areas, including Jiangsu and Zhejiang. Around 2009, China had established a relatively complete system for seed production and commercial prawn farming. The national farming area of *M. rosenbergii* approached 30,000 ha, with an annual production of approximately 135 000 t, and the Yangtze River Delta became one of the major production regions (Yang et al., 2012).

Hai et al. (2015) selected five *M. rosenbergii* farms in Zhejiang Province and investigated 19 ponds. Water quality monitoring was conducted during the peak farming period from July to September 2013. The study measured water temperature, dissolved oxygen (DO), transparency, total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and chlorophyll a to evaluate environmental conditions in different ponds. The results showed that pond water temperature ranged from 26.13 ℃ to 34.2 ℃, and exceeded the optimal growth temperature range of *M. rosenbergii* during some periods. During high-temperature summer conditions, elevated water temperature increased prawn metabolism while reducing the oxygen-holding capacity of water. Dissolved oxygen levels varied greatly, ranging from 1.21 to 8.36 mg/L, with clear differences among farms. Some ponds maintained suitable oxygen conditions, whereas others experienced low oxygen problems during cultivation.

In addition, most ponds showed relatively high total nitrogen and total phosphorus levels. Nutritional status evaluation indicated that ponds in different farms experienced mild, moderate, or even severe eutrophication. Changes in chlorophyll a content suggested that algal growth was influenced by nutrient availability, and some ponds faced risks of excessive algal proliferation. With increasing feed input and prolonged culture periods, nutrient accumulation may occur, requiring aeration, feeding control, and water quality regulation to maintain suitable farming conditions.

4.2 Changes in environmental management of Chinese pond aquaculture systems

Water quality management problems in *M. rosenbergii* aquaculture are not only related to this species but also represent common environmental challenges during the rapid development of Chinese pond aquaculture. In traditional pond farming systems, long-term feeding practices result in uneaten feed and animal excreta entering the pond environment, increasing nutrient accumulation such as nitrogen and phosphorus and further affecting water quality. Chinese pond aquaculture is gradually shifting from simply increasing production toward greater emphasis on water environmental management and ecological regulation (Liu et al., 2021).

Duan et al. (2024) analyzed long-term monitoring data to evaluate changes in water quality trends in Chinese ponds. During decades of aquaculture expansion, some regions experienced declining water environmental quality, mainly characterized by nutrient accumulation and increased eutrophication risks. However, with the promotion of ecological aquaculture technologies, pond renovation, and green farming practices, pond water environments in China have shown improvement after 2012. Enhancing the environmental carrying capacity of aquaculture systems is an important approach for reducing farming risks.

Because *M. rosenbergii* ponds also rely on feed input to maintain high production levels, problems such as ammonia nitrogen accumulation, nitrite accumulation, and organic matter enrichment gradually appear with extended culture periods. Experiences from Chinese ecological pond management indicate that optimizing farming inputs, strengthening water quality monitoring, and applying ecological regulation measures can effectively reduce the risk of water deterioration.

4.3 Regulation of *M. rosenbergii* water quality using biofloc and probiotics

In recent years, biofloc technology and probiotic applications have become important approaches for water quality regulation in *M. rosenbergii* aquaculture. Qiu et al. (2023) conducted a biofloc culture experiment in Huzhou, Zhejiang Province, to investigate the effects of different microbial treatments on water quality, growth performance, and health status of *M. rosenbergii*. The experiment was conducted in a biofloc system with a carbon-to-nitrogen ratio (C/N) of 15 and included different treatments: no microbial addition, Bacillus subtilis addition, and compound effective microorganism addition. During cultivation, total nitrogen changes in the water were monitored, and growth parameters of *M. rosenbergii*, including final body weight, weight gain rate, specific growth rate, and feed conversion ratio, were measured.

Compared with the treatment without microorganisms, both B. subtilis and compound effective microorganisms reduced total nitrogen levels in the culture water. The probiotic treatment significantly increased final body weight and growth rate while reducing feed conversion ratio, indicating that improved water conditions promoted prawn growth and feed utilization. Health indicators showed that B. subtilis treatment increased superoxide dismutase (SOD), lysozyme, and acid phosphatase activities while reducing malondialdehyde (MDA) content. These results indicate that probiotics not only improve pond water quality but also enhance antioxidant capacity and immune function of *M. rosenbergii*. By reducing water pollution through microbial regulation and decreasing dependence on water exchange, aquaculture stability can be improved.

4.4 Practical cases of ecological aquaculture models for water environment improvement

In addition to microbial regulation, Chinese *M. rosenbergii* aquaculture has increasingly adopted polyculture and integrated farming systems to improve pond environments. Xu et al. (2024) studied the effects of co-culture of *M. rosenbergii* and *Macrobrachium nipponense* on pond water environments. The study compared *M. rosenbergii* monoculture and *M. rosenbergii–M. nipponense* polyculture systems, monitoring ammonia nitrogen, nitrite, phosphate, sulfide, and other water quality indicators, while also analyzing phytoplankton community changes. During the later culture period, phosphate, nitrite, sulfide, and ammonia nitrogen concentrations were lower in the polyculture ponds than in monoculture ponds. Meanwhile, phytoplankton diversity increased and the occurrence of cyanobacterial blooms was significantly delayed. *M. nipponense* could utilize some organic debris and residual feed from the pond bottom, reducing pollutant accumulation and improving water quality.

Ni et al. (2021) conducted a white shrimp-*M. rosenbergii* polyculture experiment in the Hangzhou Bay region to evaluate the effects of different stocking combinations on production performance and health risks. Under suitable stocking densities, the polyculture system did not reduce shrimp survival or growth performance and improved economic benefits. The study recommended a stocking density of approximately 900 000 white shrimp/ha and 150 000 *M. rosenbergii*/ha. However, when the density of *M. rosenbergii* increased further, the abundance of Aeromonas and Pseudomonas in the culture water increased, indicating that excessive stocking density may increase disease risks.

Hou et al. (2025) studied the effects of stocking density of all-male *M. rosenbergii* on production performance in rice-prawn integrated farming systems (Figure 2). Different stocking densities of 0.5, 1.0, 2.0, 4.0, and 8.0 individuals/m² were established to compare changes in prawn growth, rice yield, and economic benefits. Low-density treatments produced larger individuals but lower total production, whereas high-density treatments increased total yield but reduced prawn size. Considering rice production and aquaculture benefits together, approximately 2.0 individuals/m² achieved better economic performance, and model analysis suggested an optimal density range of 0.90~1.85 individuals/m². Benthic organisms are an important food source for *M. rosenbergii* in rice-prawn systems, contributing more than supplementary artificial feed. This indicates that maintaining a favorable ecological environment can improve natural feed utilization efficiency and reduce dependence on external inputs in integrated rice-prawn farming systems.

4.5 Case Study of Shangyu Xinda Ecological Agricultural Development Co., Ltd. in Shaoxing City

Shaoxing Shangyu Xinda Ecological Agriculture Development Co., Ltd. is a leading agricultural enterprise in Shaoxing City, with a contracted total breeding area of approximately 1 500 mu. The company has long collaborated with the Institute of Hydrobiology at Zhejiang Academy of Agricultural Sciences, continuously introducing advanced ecological breeding technologies, water quality regulation solutions, green disease prevention and control, and refined feeding management models to fully replace traditional extensive breeding methods. By scientifically managing breeding density, purifying aquaculture water, and standardizing breeding processes, the company effectively enhances standardized breeding levels, ensures safe and controllable aquatic products, and achieves a win-win situation for both ecological environmental protection and high-efficiency breeding (Figure 3).

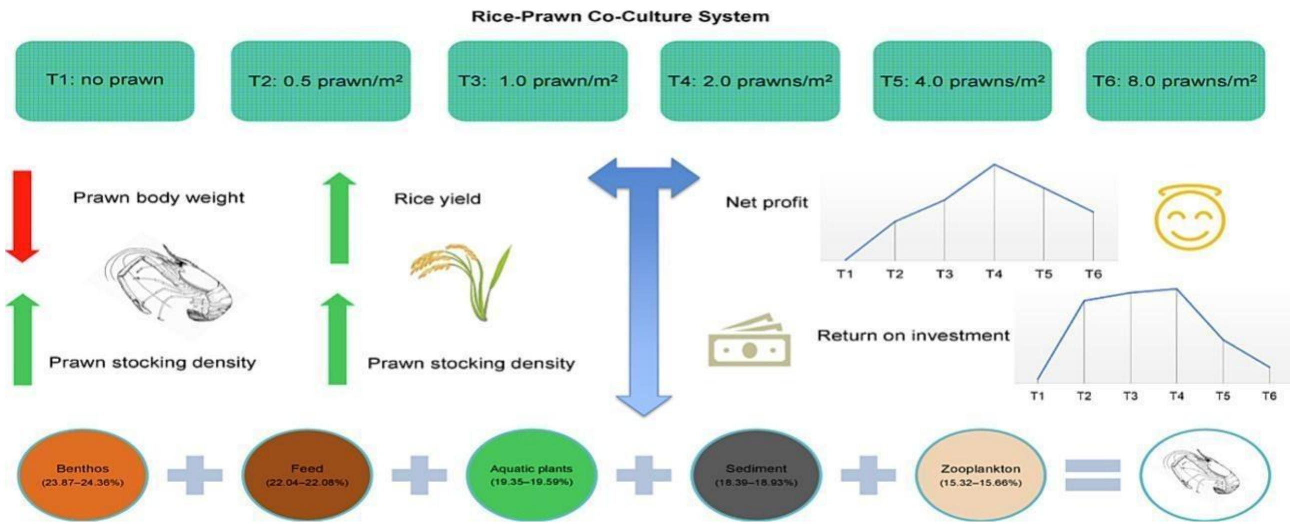

Figure 2 Optimal stocking density optimizes production and economic benefits in the rice-prawn co-culture system (Adapted from Hou et al., 2025)

Figure 3 Shangyu Xinda Ecological Agricultural Development Co., Ltd. Breeding Base (Left: High-Quality Water Body; Right: High-Quality Shrimp)

5 Production Responses after Water Environment Improvement

5.1 Growth and health

The most direct production responses after improving water conditions are increased weight gain, higher specific growth rate, and improved production performance of *Macrobrachium rosenbergii*. Biofloc technology promotes microbial utilization of organic matter and inorganic nitrogen in water, reduces the accumulation of pollutants such as ammonia nitrogen, and simultaneously produces microbial protein that provides additional nutrition for prawns. In a *M. rosenbergii* farming experiment in Bangladesh, all growth indicators in the biofloc treatment group were significantly higher than those in the non-biofloc control group. The highest production reached (939.02±6.61) kg/ha, while the control group only reached (779.67±7.50) kg/ha (Islam et al., 2023). During the nursery stage, symbiotic systems regulated by different organic carbon sources also improved water conditions and promoted growth. Among them, the raw rice bran pretreated symbiotic system (RBf) achieved the highest final body weight (122.85±12.50 mg) and weekly weight gain (22.26±2.97 mg) (Batista Santos et al., 2021).

However, improvement of water conditions does not always result in simultaneous increases in all production indicators. The effects depend on farming systems, management levels, and culture stages. A 119-day summer culture experiment in Korea showed that biofloc systems stabilized changes in ammonia nitrogen and nitrite, but final production, survival rate, and feed conversion ratio were similar to those in traditional pond culture (Park et al., 2024). Probiotics have shown positive effects in health management by regulating microbial balance, inhibiting potential pathogens, and enhancing immune responses. These effects improve the stress resistance of *M. rosenbergii* and reduce the risks of viral, bacterial, and fungal diseases (Ahmmed et al., 2023).

5.2 Efficiency and market performance

Another important result of water environment improvement is enhanced feed utilization efficiency and reduced production costs. In *M. rosenbergii* aquaculture, feed input not only determines growth rate but also represents an important factor affecting water pollution. By regulating the carbon-to-nitrogen ratio, microorganisms can better utilize residual organic matter and nitrogen-containing substances, thereby reducing pollution loads and improving feed conversion efficiency. In a zero-water-exchange biofloc nursery system, different C/N ratios significantly affected production performance and water quality. The treatment with a C/N ratio of 20 achieved better overall performance, with a feed conversion ratio of 2.65, while total ammonia nitrogen and nitrite concentrations were significantly lower than those in the clear-water control group (Hosain et al., 2021). Proper regulation of water nutrient structure can therefore achieve simultaneous improvement of water quality and production efficiency.

In addition to water quality regulation technologies, long-term environmental optimization can also improve economic returns from aquaculture. A full production-cycle probiotic application experiment showed that continuous probiotic use improved growth performance, protein utilization, production output, and net income of *M. rosenbergii*. The continuous probiotic treatment group showed better growth patterns and economic performance (Azad et al., 2023). In a *M. rosenbergii* farming system in the mountainous region of India, optimized feed management combined with suitable water environmental conditions improved production and economic returns. The benefit-cost ratio of the formulated feed group reached 1.62, higher than the 1.23 observed in the conventional feed group, with production levels of 865 kg/ha and 637 kg/ha, respectively (Khemundu and Banerjee, 2019). Water environment management not only reduces aquaculture risks but also directly improves the economic benefits of family farms and large-scale aquaculture systems by reducing pollution, improving feed utilization efficiency, and stabilizing production.

6 Sustainable Water Quality Management and Future Development Directions

6.1 Water quality management system based on culture stages

For prawn farms, establishing a stable water quality monitoring system is the foundation for reducing aquaculture risks. The pond environment of *Macrobrachium rosenbergii* changes rapidly, and relying only on visual observation of water color or experience-based judgment often makes it difficult to detect potential problems such as oxygen deficiency and increasing ammonia nitrogen levels in time. Therefore, aquaculture management should establish a hierarchical monitoring system based on risk levels. In daily management, temperature, pH, and dissolved oxygen are the basic indicators requiring the most attention and should be monitored according to daily variations. Transparency, ammonia nitrogen, nitrite, and turbidity can be measured regularly according to stocking density and feeding amount to evaluate organic matter accumulation and algal changes. During high-temperature seasons, feed transition periods, and late culture stages, additional attention should be paid to total nitrogen, total phosphorus, and chlorophyll a to assess the overall nutrient status of ponds. Even when monitoring systems do not have automatic control functions, using water quality data to guide manual aeration and management decisions can effectively reduce oxygen deficiency risks (Vaughan and Ankumah, 2018).

Water quality management should also be adjusted according to different growth stages of *M. rosenbergii*. During the seedling and juvenile stages, temperature, pH, and ammonia nitrogen levels should be carefully controlled because early-stage individuals are more sensitive to environmental changes. During adult prawn culture, increasing feed input requires greater attention to dissolved oxygen, organic matter accumulation, and algal community stability. For small-scale farms, it is not necessary to establish complex automated systems at the beginning. Instead, priority should be given to developing a management process of “regular monitoring, timely evaluation, and rapid adjustment.” Aeration time can be adjusted according to dissolved oxygen changes, feeding amount can be modified according to transparency and water color, and water exchange, microbial regulation, or feed reduction can be applied according to ammonia nitrogen changes. This basic management approach is essential for achieving stable production.

6.2 Low-cost ecological regulation and digital management technologies

For most prawn farms, water quality improvement should first consider cost and operational feasibility. Low-cost and easily applicable ecological regulation measures remain the most practical approaches. Supplementary aeration, reasonable feed reduction, plant co-culture, and polyculture systems can all reduce environmental pressure in ponds. Diversified farming systems can improve resource utilization efficiency in small-scale aquaculture. A survey of 624 small-scale farms in Myanmar found that farmers using diversified production methods, such as polyculture and pond-edge planting, generally achieved higher production, economic benefits, and phosphorus utilization efficiency (Wang et al., 2022). These approaches do not require large investments in equipment but can reduce water quality fluctuations by improving ecological cycling capacity.

Based on ecological regulation, digital monitoring technologies are becoming important tools for improving management efficiency in family prawn farms. Pond monitoring systems based on NB-IoT technology can remotely collect indicators such as temperature, pH, and dissolved oxygen and provide auxiliary control for aeration equipment. In practical tests, the system achieved temperature control accuracy of ±0.12 ℃, dissolved oxygen control accuracy of ±0.55 mg/L, and pH control accuracy of ±0.09, indicating that low-cost sensor technologies are already suitable for aquaculture applications (Huan et al., 2020). For *M. rosenbergii* nursery production, an automatic monitoring system based on ESP32, MQTT, and Node-RED can continuously record temperature, pH, TDS, and turbidity parameters and improve data stability through data processing and sensor error reduction (Ramli, 2024). Future digital upgrading of prawn farms does not necessarily require large intelligent aquaculture platforms but can gradually develop from simple functions such as mobile water quality monitoring, abnormal condition alerts, and automatic aeration control.

6.3 Intelligent, ecological, and climate-resilient aquaculture models

The future development direction of *M. rosenbergii* aquaculture will gradually shift from traditional “scheduled management” toward continuous sensing, risk prediction, and precise control. With the development of the Internet of Things (IoT), artificial intelligence, and machine learning technologies, water quality management is changing from post-event treatment to early warning. Data analysis systems based on IoT and machine learning can continuously collect environmental data such as temperature, pH, and dissolved oxygen, predict water quality trends, and allow early actions such as aeration adjustment, feeding regulation, or environmental improvement. An intelligent *M. rosenbergii* farming system in Bangladesh combined sensors, cloud platforms, and machine learning models to achieve real-time water quality monitoring and production prediction. The regression model achieved a coefficient of determination (r^2) of 0.94, while the random forest model achieved 97.84% accuracy in production grade classification (Ahmed et al., 2024). An intelligent management system developed in the Pak Phanang region of Thailand combined dissolved oxygen, pH, and temperature monitoring with automatic control devices, achieving a 93.3% survival rate and marketable size within a 120-day culture period (Songpayome et al., 2024). Intelligent technologies have gradually moved from experimental research into practical aquaculture applications.

In addition to digital management, sustainable *M. rosenbergii* production in the future will require further development of ecological ponds and climate-resilient farming models. Systems such as biofloc technology (BFT), periphyton systems, and integrated multi-trophic aquaculture (IMTA) can improve system stability and reduce pollution discharge by promoting nutrient utilization among microorganisms, plants, and filter-feeding organisms. Biofloc systems are more suitable for nursery stages, while periphyton-based and ecological polyculture systems are more suitable for grow-out stages. The combination of different ecological technologies may become an important direction for low-emission aquaculture in the future (Halim et al., 2026). At the same time, climate change-related challenges, including high temperatures, extreme rainfall, and increased disease occurrence, require aquaculture systems to have stronger recovery capacity. Rising temperatures can affect growth, molting, immunity, and survival of crustaceans and increase disease risks (Daunde et al., 2025). Future *M. rosenbergii* industries need to integrate intelligent monitoring, ecological regulation, and climate adaptation strategies to improve the self-regulation capacity of ponds and achieve more stable and sustainable production.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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