

Feature Review

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Water Quality Control and Fish Health Management in Recirculating Aquaculture Systems

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Abstract Recirculating aquaculture systems (RAS) have emerged as an important technology for sustainable aquaculture development due to their advantages in water conservation, environmental control, and high-density fish production. However, maintaining optimal water quality and preventing fish health problems remain major challenges in intensive RAS operations. This review focuses on the relationship between water quality control and fish health management in recirculating aquaculture systems. The fundamental mechanisms regulating water quality are first discussed, including the dynamics of dissolved oxygen, temperature, pH, ammonia, nitrite, nitrate, carbon dioxide, and microbial communities. The impacts of water quality fluctuations on fish physiological responses, growth performance, immune function, and disease susceptibility are further analyzed. Subsequently, advances in monitoring technologies, including sensor networks, Internet of Things (IoT) platforms, and data-driven approaches, are summarized for real-time environmental assessment and management. Strategies for maintaining stable water conditions, such as mechanical filtration, biological treatment, oxygen regulation, nutrient management, and microbial regulation, are evaluated. A case study framework is presented to demonstrate the integration of water quality monitoring, fish health assessment, and intelligent management strategies in commercial RAS facilities. Furthermore, the potential applications of artificial intelligence, predictive modeling, and automated control systems are discussed. Future research should focus on multi-source data integration, intelligent decision-support systems, and sustainable management technologies to improve production efficiency, fish welfare, and environmental sustainability in recirculating aquaculture.

Keywords Recirculating aquaculture systems; Water quality control; Fish health management; Intelligent aquaculture; Biofiltration technology

1 Introduction

Recirculating aquaculture systems (RAS) have emerged as a major technological pathway for intensifying aquaculture while reducing its dependence on large volumes of water and limiting effluent release. Their development has accelerated because RAS can operate in controlled indoor environments, recycle most of the culture water, improve biosecurity, and support more predictable production under environmental and climate-related constraints (Gupta et al., 2024). Earlier and more recent reviews alike describe RAS as high-control, high-reuse production systems whose core value lies in decoupling fish farming from local water availability while improving waste management and nutrient recycling. At the same time, the importance of RAS is not only environmental but strategic: these systems are increasingly viewed as a means to expand aquaculture production with lower ecological impact, stronger containment of escapees and pathogens, and greater resilience to drought, salinity shifts, and other external stressors that threaten open systems (Ahmed and Turchini, 2021). This combination of production control and environmental performance has made RAS central to discussions of sustainable aquaculture, even though energy demand, capital cost, and managerial complexity still constrain broader adoption.

The advantages of RAS, however, depend on maintaining water quality within narrow and species-specific limits, because fish in intensive recirculating environments are continuously exposed to the same water matrix and to the consequences of any treatment failure. Water quality in RAS includes physical, chemical, and biological dimensions, and the key variables routinely monitored include temperature, dissolved oxygen, pH, salinity, oxidation-reduction potential, turbidity, and suspended solids, all of which shape fish growth, stress, and disease risk (Dai et al., 2025).