

Review and Progress

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## Application Mechanisms and Practical Pathways of Ecological Food Chain Closure in Freshwater Pond Aquaculture

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**Abstract** Freshwater pond aquaculture is an important component of China's aquaculture system. However, long-term high-density feeding and intensive management can easily lead to the accumulation of residual feed, feces, organic detritus, and nutrients in the water column and sediment, resulting in water quality deterioration, sediment aging, eutrophication, and increased pressure from tailwater discharge. Ecological food chain closure is based on material cycling, energy flow, and trophic complementarity. By rationally configuring producers, consumers, and decomposers, aquaculture wastes can be reintroduced into the internal circulation of pond ecosystems, thereby achieving resource reuse and pollution reduction. This study explores the application mechanisms and practical pathways of ecological food chain closure in freshwater pond aquaculture, elaborates its roles in nutrient recycling, water self-purification regulation, and multi-trophic synergistic enhancement, and summarizes typical models including fish-shrimp-shellfish-algae coordinated aquaculture, fish-aquatic plant-microorganism ecological regulation, and pond-ecological ditch-constructed wetland recycling purification. The study suggests that ecological food chain closure can improve pond resource utilization efficiency, enhance water self-purification capacity, reduce pressure from tailwater treatment, and promote the transformation of aquaculture systems from high-input and high-discharge models toward ecological, circular, and efficient development. However, its promotion still faces challenges such as unreasonable biological configuration, fluctuations in environmental conditions, insufficient technical management capacity, and incomplete economic evaluation systems. In the future, green and sustainable development of freshwater pond aquaculture should be promoted through site-specific model selection, optimization of aquaculture species and trophic-level configuration, improvement of water quality monitoring and tailwater recycling systems, and strengthening of standardized and digital management.

**Keywords** Ecological food chain closure; Freshwater pond aquaculture; Nutrient cycling; Water self-purification; Green aquaculture

## 1 Introduction

Freshwater pond aquaculture is an important component of China's aquaculture system and also a major supporting form of global aquatic food production. It plays an important role in ensuring the supply of aquatic products, increasing farmers' income, and promoting the development of rural industries. In countries with large-scale freshwater aquaculture, such as China, pond aquaculture accounts for a substantial proportion of total aquatic product output. However, with the rapid intensification of pond aquaculture, traditional production methods that rely on manual feeding, mechanical aeration, frequent water exchange, and pharmaceutical disease control have increased yield per unit area to some extent, but they have also intensified the dependence of aquaculture systems on external inputs such as feed, water resources, energy, and drugs. As stocking density and feed input increase, residual feed, feces, dead algae, and other organic matter continuously accumulate in the water column and sediment, easily leading to increases in ammonia nitrogen, nitrite, total nitrogen, and total phosphorus. This, in turn, results in water quality deterioration, sediment aging, eutrophication, frequent disease outbreaks, and increased pressure from tailwater discharge. These problems not only constrain the sustainable development of freshwater pond aquaculture but may also adversely affect surrounding water bodies and ecosystems (Boyd et al., 2020; Liu et al., 2020; Duan et al., 2024). Meanwhile, the growing demand for green, low-carbon, and environmentally friendly food systems is driving pond aquaculture to shift from a high-input,