

6.3 Need for improvement in technical management and economic evaluation systems

Ecological food chain closure involves multiple links, including aquaculture species configuration, water quality monitoring, feed management, microbial regulation, aquatic plant management, tailwater treatment, disease prevention and control, and ecological benefit assessment. Therefore, it places higher requirements on the comprehensive management capacity of aquaculture operators. Compared with traditional pond aquaculture, ecological closed-loop aquaculture relies more heavily on process management and dynamic regulation and cannot be conducted through extensive experience-based operation alone. For example, feeding amounts need to be adjusted in a timely manner according to weather, water temperature, feeding behavior, and water quality indicators; aquatic plant coverage should be maintained at an appropriate level to avoid excessive growth or decomposition; and microbial agents should be applied based on dissolved oxygen, sediment condition, and organic load. If management is inadequate, ecological closed-loop models may not only fail to achieve expected results but may also increase production risks. Although ecological food chain closure and IMTA are considered to have the potential to improve sustainability and profitability, related studies indicate that current technical management systems remain insufficient. Reviews of IMTA economics show that there is still a lack of bioeconomic models and tools for comparing different systems and fully internalizing environmental externalities, and that economic incentive mechanisms and eco-certification frameworks require further improvement (Knowler et al., 2020). A comprehensive assessment of freshwater aquaculture in China found that its average ecological efficiency was only 0.702, indicating considerable room for improvement and clear regional differences. This suggests that current management has not yet fully coordinated production efficiency with environmental performance (Wang et al., 2024).

Meanwhile, the current economic evaluation system for ecological food chain closure aquaculture remains insufficient. Some practices place greater emphasis on water quality improvement, tailwater emission reduction, and ecological demonstration effects, while lacking systematic accounting of economic factors such as facility investment, labor costs, management costs, culture cycles, comprehensive output, product premiums, and long-term maintenance expenses. Economic evaluations of eco-friendly technologies and closed-loop systems remain fragmented. Systematic reviews of cost-benefit analysis in aquaculture show that, although related studies are increasing, environmental impacts and social costs are still insufficiently considered, and most studies have not yet incorporated ecological benefits into formal cost-benefit frameworks. Life cycle and economic analyses of aquaponics and aquaponics-IMTA systems also indicate that infrastructure, energy, and labor costs account for a relatively high proportion; for certain species or production scales, the benefit-cost ratio may be marginal or even negative, and profitability depends on the precise optimization of technical parameters, species selection, production scale, and market matching. Case studies of eco-friendly management show that such technologies have the potential to increase yield and reduce water and electricity use, but they also emphasize the need to establish standardized performance indicators, such as Aquaculture Performance Indicators, to simultaneously reflect environmental, economic, and social outcomes. For aquaculture operators, whether ecological models can be continuously promoted depends not only on whether their ecological benefits are evident, but also on whether their economic returns are stable. Therefore, in the future, a comprehensive evaluation system that integrates ecological, production, economic, and social benefits should be established to provide clearer decision-making support for pond aquaculture across different regions, species, and scales.

7 Countermeasures for Optimizing Ecological Food Chain Closure Aquaculture

7.1 Establishing a site-specific model selection mechanism

Optimizing ecological food chain closure aquaculture first requires establishing a site-specific model selection mechanism based on the natural conditions, aquaculture foundation, technical capacity, and industrial needs of different regions. Freshwater pond aquaculture is affected by multiple factors, including climate, water sources, sediment conditions, pond size, main cultured species, market positioning, and regional environmental carrying capacity. Therefore, the same ecological closed-loop model should not be simply applied across different regions. For example, in areas with good water sources, large pond areas, and a foundation for multi-species coordinated aquaculture, priority may be given to multi-trophic coordinated models such as fish-shrimp-shellfish-algae