

shrimp farming models also shows that pond IMTA and recirculating systems perform better in terms of comprehensive, economic, ecological, and social benefits, but their results are sensitive to indicators such as survival rate, pH, and dissolved oxygen. This indicates that evaluation systems must incorporate both production process indicators and environmental process indicators. Therefore, evaluation of ecological food chain closure should integrate bioeconomic models, life cycle assessment, energy analysis, cost-benefit analysis, and social indicators to provide a decision-making framework for measuring model performance, internalizing environmental externalities, designing policy incentives, and promoting the sustainable transformation of freshwater pond aquaculture (Nobre et al., 2010; Biswas et al., 2020; Knowler et al., 2020; Dong et al., 2023).

8 Conclusion and Prospects

Ecological food chain closure is based on the principles of material cycling and energy flow in ecosystems. Through the rational configuration of producers, consumers, and decomposers, feed, residual feed, feces, organic detritus, and dissolved nutrients generated during freshwater pond aquaculture can be transformed and reused across multiple levels within the system. Compared with traditional pond aquaculture models characterized by high input and high discharge, this model places greater emphasis on functional complementarity among organisms and the regulation of ecological processes. It can, to a certain extent, reduce the accumulation of aquaculture wastes, improve water quality and sediment conditions, and enhance resource utilization efficiency. Especially in the context of increasing requirements for green development and tailwater emission reduction in aquaculture, ecological food chain closure provides an important pathway for freshwater pond aquaculture to shift from a production-oriented model to an ecologically efficient model. Its value is reflected not only in yield improvement, but also in comprehensive benefits such as enhanced ecological stability, reduced disease risk, and lower environmental load. Ecological food chain closure aquaculture is not simply multi-species polyculture or the application of a single purification technology. Rather, it is a systematic engineering approach involving pond ecological structure design, aquaculture species configuration, water quality regulation, sediment remediation, tailwater recycling, and production management optimization. Therefore, in practical promotion, technical support, refined management, and market transformation need to be integrated. On the one hand, suitable ecological closed-loop models should be selected according to water source conditions, climatic characteristics, pond foundations, and main cultured species in different regions, and standardized operating procedures should be established to improve the stability and replicability of model application. On the other hand, training for aquaculture operators and the development of digital management should be strengthened. Online monitoring, intelligent aeration, precise feeding, and tailwater treatment facilities can be used to improve system operation efficiency. Meanwhile, attention should also be paid to transforming the market value of ecological aquaculture products. Green certification, brand building, and quality traceability can enhance consumer trust, allowing ecological benefits to be converted into sustained economic returns and thereby increasing the willingness of aquaculture operators to participate in ecological closed-loop construction.

In the future, freshwater pond aquaculture will further develop toward ecologicalization, intelligentization, standardization, and circularization. Ecologicalization emphasizes the construction of more stable multi-trophic structures in pond systems to enhance water self-purification and ecological regulation capacity. Intelligentization emphasizes the use of IoT sensors, data analysis platforms, and intelligent equipment to achieve precise management of water quality, feeding, aeration, and tailwater treatment processes. Standardization requires the formation of technical specifications and evaluation systems applicable to aquaculture scenarios involving different regions, species, and scales. Circularization emphasizes the reuse of aquaculture tailwater, nutrients, and biological resources, promoting the connection of pond aquaculture with crop production, wetland purification, and regional ecological governance. Overall, ecological food chain closure is not only an important technical pathway for the green transformation of freshwater pond aquaculture, but will also become an important support for modern aquaculture to achieve efficient resource utilization, environmentally friendly production, and sustainable industrial development.