

systems. In areas with high stocking densities and strong pressure from tailwater discharge, pond-ecological ditch-constructed wetland recycling purification systems are more suitable. In ponds with suitable conditions for aquatic plant cultivation or aquaponic development, fish-aquatic plant-microorganism ecological regulation models can be prioritized. Relevant studies have shown that spatial and habitat suitability models integrating hydrodynamics, water quality, and geomorphological characteristics can identify areas suitable for specific aquaculture types and reveal the feasibility and potential risks of models such as pond aquaculture, integrated multi-trophic aquaculture (IMTA), and shellfish culture in different regions (Falconer et al., 2016). Species distribution models and multi-criteria evaluation methods, such as Mahalanobis models, Maxent models, and multi-indicator suitability assessments, can also help planners screen models based on the characteristics of successful farms and optimal environmental thresholds, thereby reducing the negative impacts of inappropriate siting and spatial conflicts on sustainability.

In the process of model selection, ecological suitability, production feasibility, and economic rationality should be integrated. Aquaculture operators need to fully assess pond carrying capacity, baseline water quality, sediment conditions, tailwater discharge requirements, and the characteristics of the main cultured species before determining suitable biological configurations and facility construction plans. For small-scale farmers, low-input and easy-to-manage measures such as plant purification, microbial regulation, and moderate polyculture can be prioritized. For large-scale aquaculture bases, regional closed-loop systems can be constructed through ecological ditches, sedimentation ponds, constructed wetlands, recirculating aquaculture facilities, and digital monitoring platforms. At the farm and pond scale, ecosystem models and bioeconomic models can be used to simulate the effects of different stocking densities, species combinations, feed inputs, and tailwater treatment measures on aquaculture profits, nitrogen and phosphorus removal, and system stability, thereby providing quantitative support for site-specific integrated pond configurations (Biswas et al., 2020; Dong et al., 2023). Studies have also shown that integrated multi-trophic systems and recirculating systems generally outperform monoculture systems in terms of combined economic, ecological, and social benefits, providing an evidence base for local model selection and technical route formulation. Therefore, the selection of ecological food chain closure models should shift from experience-based judgment to an integrated decision-making process of "environmental suitability assessment-carrying capacity estimation-ecological-economic simulation-technical route matching."

7.2 Strengthening standardized technical systems and digital management

To achieve stable promotion of ecological food chain closure aquaculture, it is necessary to strengthen the development of standardized technical systems. At present, some ecological aquaculture practices still rely mainly on experience-based operation and lack unified standards in species matching ratios, stocking density, feeding management, aquatic plant coverage, microbial application frequency, tailwater treatment processes, and operational performance evaluation, resulting in unstable application outcomes. Therefore, operational, replicable, and evaluable technical standards should be established around key links such as pond renovation, biological configuration, feed management, water quality regulation, sediment remediation, tailwater purification, disease prevention and control, and product quality traceability. Standardized management can lower the implementation threshold of ecological closed-loop models and improve technical consistency and management comparability among different aquaculture operators. Relevant reviews have pointed out that standardized technical systems and digital tools are essential for the reliable operation of closed food-chain ponds under variable conditions. In the context of Industry 4.0, sensor networks, automated equipment, and decision-support tools can replace traditional manual and subjective monitoring, enabling real-time and evidence-based management of water quality, feeding, and system operation (Bernal-Higuera et al., 2023).

At the same time, the deep integration of digital technologies with ecological food chain closure aquaculture should be promoted. Freshwater pond ecosystems are characterized by dynamic changes, and relying solely on manual pond inspection and experience-based judgment makes it difficult to detect problems such as declining dissolved oxygen, rising ammonia nitrogen, abnormal algal communities, and sediment deterioration in a timely manner. By deploying online monitoring equipment for water temperature, pH, dissolved oxygen, ammonia