

production objectives, forming a spatial pattern in which the main culture zone, ecological buffer zone, plant purification zone, sedimentation zone, and tailwater collection and treatment zone are interconnected.

Ecological engineering practices in China indicate that eco-engineered pond recirculating systems generally integrate ecological ditches, ecological ponds, subsurface-flow constructed wetlands, and culture ponds to control water replenishment, regulate algal communities, and improve water quality (Liu et al., 2020). In these systems, constructed wetlands and ecological ditches can reduce harmful algal groups and increase the proportion of diatoms, thereby optimizing phytoplankton structure while removing nitrogen and phosphorus from tailwater (Liu et al., 2020). In the design of pond ecological structure, attention should also be paid to water-layer utilization, habitat diversity construction, and spatial planning at the regional scale. Different cultured organisms vary in their use of water space, and the upper, middle, and bottom water layers, as well as nearshore shallow-water areas, can all undertake different ecological functions. For example, the main cultured fish mainly provide economic output, aquatic plant zones are responsible for nutrient uptake and ecological buffering, sediment remediation zones undertake organic matter sedimentation and microbial decomposition, and ecological ditches and sedimentation zones provide preliminary tailwater purification. Through spatial zoning and functional allocation, niche conflicts among different organisms can be reduced, internal resource utilization efficiency in ponds can be improved, and system stability can be enhanced.

Pond cascade systems represent another important structural pathway. Through a series of interconnected ponds managed by batch discharge and refilling, they can achieve strong self-purification, reducing total phosphorus and total nitrogen in the terminal pond to approximately half of their initial concentrations, while supporting advanced fry production and multiple stocking-harvesting cycles (Kajgrová et al., 2023). At a broader scale, ecosystem-based spatial planning and functional zoning help arrange ponds rationally within watersheds, enabling them to meet ecological and social carrying capacity requirements while coordinating biosecurity, water resource management, and disease management among clustered farms. Remote-sensing assessments also show that pond siting, density, and the conversion of surrounding habitats affect sustainability at the landscape scale; therefore, scientifically determining the location and spatial configuration of pond areas is an important prerequisite for constructing ecological food chain closure.

5.2 Optimization of aquaculture species and trophic-level configuration

The key to constructing ecological food chain closure lies in optimizing aquaculture species combinations so that different organisms form complementary relationships in feeding habits, activity layers, and ecological functions. Traditional pond aquaculture often centers on a single main cultured species, which can easily lead to insufficient feed resource utilization, accumulation of residual feed and feces, and increased pressure on water quality regulation. Ecological closed-loop aquaculture should, on the basis of clearly identifying the main cultured species, reasonably combine functional organisms such as filter-feeding fish, omnivorous fish, benthic animals, aquatic plants, and beneficial microorganisms, so that formulated feed, plankton, organic detritus, and dissolved nutrients can be utilized stepwise by different trophic levels. This can improve comprehensive output per unit water body and reduce the impact of aquaculture wastes on water quality and sediment conditions. Studies on ecological engineering and fish polyculture have shown that, compared with single-species intensive ponds, polyculture systems based on species' ecological niches and feeding habits can significantly improve nitrogen utilization, energy conversion efficiency, and environmental performance. Cases of traditional multi-pond shrimp systems in China combined with bivalves and macroalgae have also shown higher equivalent shrimp output and increased input nitrogen utilization by more than 80%, indicating that carefully designed multi-trophic combinations have strong potential for nutrient recovery (Liu et al., 2020).

In specific configuration, the principles of "moderate polyculture, functional complementarity, and controllable density" should be followed. The stocking density of the main cultured species should match the carrying capacity of the pond and should not exceed the regulatory capacity of the ecosystem in pursuit of high yield. Companion species should be selected according to their ecological functions: filter-feeding fish can be used to regulate