8.3 Practical implications for system optimization and industry scaling

For system optimization, the strongest practical lesson is that each farming mode should be improved around its main constraint rather than replaced wholesale. Pond and cage systems remain commercially important because they are already embedded in China's sea bass industry, but their scaling is constrained by exposure to open-environment variability, storm risk, and site limitations (Huang et al., 2025). RAS offers a strategic pathway where land, water, pollution limits, or climate instability constrain expansion, because it is water-efficient, highly productive, and largely decoupled from external climatic shocks (Ahmed and Turchini, 2021). This makes RAS particularly attractive for high-value commercial Chinese sea bass operations targeting standardized production and secure supply.

Industry scaling, however, depends on solving operational bottlenecks rather than assuming that recirculation alone guarantees better outcomes. Interviews across the RAS sector identify poor system design and weak management capacity as major barriers, and they emphasize the need for commercial-scale equipment optimization and skilled personnel responsible for water quality and mechanical reliability. Broader sustainability reviews reach a similar conclusion: despite clear environmental advantages, RAS still contributes a small share of total production because high initial investment requires high stocking density and production to recover costs. In commercial Chinese sea bass farming, the most scalable pathway is therefore likely to be a hybrid industry structure in which ponds and cages remain dominant for lower-cost volume production, while RAS expands selectively in regions and market segments that reward tighter environmental control, product consistency, and climate resilience.

9 Integrated Strategies for Improving Farming System Efficiency

Precision aquaculture can improve the farming efficiency of Chinese sea bass by replacing intermittent manual checks with continuous measurement of critical water-quality variables such as temperature, pH, and dissolved oxygen. Real-time monitoring is especially relevant because instability in these parameters increases disease risk, mortality, and production losses, whereas IoT-based sensing allows faster detection of deteriorating conditions and more timely management responses. In *Asian seabass* farming specifically, low-cost IoT sensor platforms have already shown strong practical value, with calibrated systems achieving 76%-97% accuracy and supporting reliable real-time visualization for farm management. The next step is to connect monitoring with prediction and automated control so that environmental deviations can be corrected before they suppress growth or survival. Recent work shows that IoT systems coupled with machine learning can maintain stable water conditions, reduce mortality, and sustain survival above 90% during stressful periods, while fuzzy-logic control can autonomously regulate key variables such as dissolved oxygen and salinity to improve operational efficiency.

System hybridization offers a pathway to higher efficiency by redesigning Chinese sea bass farming systems so that wastes from fed fish become inputs for other cultured organisms. In integrated multi-trophic aquaculture (IMTA), finfish are cultured alongside extractive species such as seaweeds, mollusks, or deposit feeders, which recapture organic and inorganic nutrients, reduce waste discharge, and convert lost nutrients into additional biomass of market value. The main advantage of ecological intensification is that it can improve both environmental performance and farm diversification, but implementation depends on site design and economic feasibility. Open-water IMTA has been proposed as a way to combine biomitigation with added output from extractive crops, yet offshore settings impose technical and economic constraints, while spatially separated but ecologically linked regional IMTA may offer a more realistic model where direct co-culture is difficult in marine fish farming.

Long-term efficiency in Chinese sea bass farming depends not only on biological performance but also on economic optimization of inputs, infrastructure, and resource use. Across aquaculture systems, improved production efficiency has been associated with lower greenhouse-gas intensity, reduced land and freshwater use per unit output, and better feed management, indicating that environmental and economic sustainability often improve together rather than acting as opposing goals. Broader comparative evidence likewise shows that economic, social, and environmental outcomes are often mutually reinforced, although performance still varies substantially among production systems and leaves room for targeted innovation and investment. At the farm level, economic optimization requires matching