

Behavioral responsiveness provides another early window into stress before overt disease emerges. In large yellow croaker subjected to a brief net-restraint challenge, consistent differences in recovery latency and exploration activity revealed proactive and reactive coping styles, with faster-recovering fish showing lower plasma cortisol and higher IgM at 7 days after stress (Li et al., 2024). Hypoxia studies show that restlessness, constant floating, and increased respiratory rate are accompanied by up-regulation of muscular movement and energy-generation genes, linking observable behavior with defined molecular pathways, which could be exploited for automated video-based stress surveillance during warm, low-oxygen nights (Chen et al., 2024).

8.2 Molecular biology and pathogen detection methods

Rapid pathogen diagnosis is essential because co-infections and temperature fluctuations can drive sudden mortalities in marine farms. A broad review of bacterial fish diseases emphasizes that molecular assays such as conventional PCR, real-time PCR, multiplex PCR, LAMP, microarrays, and sequencing provide faster and more sensitive identification of septicemic agents than traditional culture, supporting early intervention and targeted antimicrobial use. These tools also allow monitoring of pathogen abundance in asymptomatic carriers and the environment throughout the production cycle, which is critical for preventive health management under stressful summer conditions (Abdelsalam et al., 2022).

For large yellow croaker specifically, a duplex PCR assay targeting *ompA* genes of *Klebsiella pneumoniae* and *Chryseobacterium* enables simultaneous detection and discrimination of these emerging pathogens, which often produce similar clinical signs (Hu et al., 2024). The method detects as little as 20-200 fg genomic DNA or about 100 CFU, correctly identifies single and mixed infections in field samples, and is described as time-saving, specific, and convenient for epidemiological surveillance in aquaculture.

8.3 Construction of intelligent aquaculture and early warning systems

Modern disease control increasingly relies on integrated sensor and data-analytics platforms. Reviews of cutting-edge fish disease technologies highlight that IoT sensors, artificial intelligence, and machine-learning models can continuously track environmental parameters and fish activity, allowing farmers to predict disease outbreaks and intervene before large mortality occurs. Image-based systems using 2D/3D cameras under near-infrared light can capture swimming patterns and skin changes to detect early behavioral or external lesions, demonstrating practical noninvasive monitoring that can be embedded into early-warning workflows (Islam et al., 2024).

At the system level, IoT-ML architectures have proven capable of stabilizing water quality and reducing mortality in tropical aquaculture, even during high-temperature periods. One implementation using low-cost sensors to monitor temperature, dissolved oxygen, pH, and turbidity achieved extremely high predictive accuracy for water-quality parameters and enabled over 6000 automated corrective interventions, maintaining fish survival above 90% (Baena-Navarro et al., 2025). Complementary AIIoT reviews describe how networks of sensors and cameras feeding AI models can jointly support water-quality prediction, disease recognition, and smart feeding, forming the backbone of intelligent aquaculture farms that can issue timely alerts and automate responses under rapidly changing thermal conditions.

9 Conclusions and Prospects

High-temperature seasons pose a central constraint on large yellow croaker aquaculture by narrowing the thermal safety window, redistributing energy away from growth, and increasing the risk of oxidative stress, hypoxia, and disease. Across systems, maintaining water temperature within the species' optimal range, ensuring sufficient dissolved oxygen, and avoiding sharp daily fluctuations emerged as the core environmental requirements for sustaining performance during summer. At the same time, evidence from ship-based offshore systems and improved cage designs shows that environmental risks can be substantially reduced through better site selection, mobility, and stratification management. Nutritional and health management strategies can further buffer thermal stress. Optimized protein-energy ratios, together with functional additives such as inulin and fulvic acid, support growth, stabilize metabolism, and reshape gut microbiota in favour of beneficial taxa under high summer temperatures.