

Stress can also alter survival indirectly by weakening the fish before pathogen or environmental insults occur. In striped catfish, increasing stocking density elevated un-ionized ammonia and nitrite while lowering dissolved oxygen, and survival decreased significantly as density increased, linking environmental deterioration to physiological stress and mortality (Zaki et al., 2023). In marine fish more broadly, high stocking density produces chronic stress, raises plasma cortisol about fourfold, and depresses immune function, which helps explain why intensive systems can show mortality even when outright disease is not initially apparent. For *L. maculatus*, stress-induced mortality under different farming systems therefore appears to arise from the interaction of crowding, reduced water quality, impaired immunity, and increased susceptibility to opportunistic infection.

6 Water Quality and Environmental Regulation Effects

6.1 Dissolved oxygen, ammonia, and nitrogen accumulation

Dissolved oxygen and nitrogenous waste are among the main environmental constraints separating pond, cage, and recirculating systems. Across aquaculture systems, production is progressively limited by oxygen supply and the accumulation of growth-limiting wastes such as ammonia, while in RAS the removal of nitrogen pollutants remains difficult because wastewater typically has high dissolved oxygen but low organic carbon for denitrification (Ott et al., 2025). This matters directly for Chinese sea bass because high-density holding already shows the expected deterioration pattern: during simulated live transport, higher density reduced dissolved oxygen and increased total ammonia nitrogen, indicating how quickly confined systems can shift toward stressful water chemistry (Zhang et al., 2021). In pond systems, the pattern is somewhat different because natural biogeochemical processes buffer part of the ammonia load, but that buffering weakens as feed input and aeration intensity rise.

System design determines whether added nitrogen accumulates as toxic reduced forms or is pushed into less harmful oxidized forms. In intensively aerated earthen ponds, average total ammonia and un-ionized ammonia did not increase with higher stocking density, while nitrite and nitrate increased, indicating that nitrification became a more important ammonia-removal pathway under high loading. Similarly, ponds managed at a higher minimum dissolved oxygen concentration produced fish that were 35% larger, and the higher-oxygen treatment also had higher nitrite and nitrate, consistent with greater oxidation of ammonia through nitrification (Ott et al., 2025). In RAS, oxygen management can also directly suppress reduced nitrogen compounds: microbubble aeration stabilized dissolved oxygen at 4.28 mg/L and reduced both carbon dioxide and ammonia, while optimized MBBR operation reached 50% TAN removal once dissolved oxygen conditions supported biofilm performance.

6.2 Temperature fluctuation and seasonal variability

Temperature fluctuation affects farming systems not only through direct fish physiology but also by altering the stability of the rearing environment. Across aquaculture species, temperature is a major abiotic driver of growth and survival, and temperatures above species-specific thermal thresholds reduce performance, health, and productivity (Mugwanya et al., 2022). Extreme temperature events are also becoming more frequent and more intense, and they influence metabolism, immunity, and stress responses across cultured fish, which means that systems with poor thermal buffering are more exposed to seasonal production losses. For Chinese sea bass, this issue is especially relevant because open ponds and cages are more directly affected by ambient seasonal variation than industrialized land-based systems.

Evidence from Chinese sea bass and other farmed fish suggests that both average temperature and short-term fluctuation matter. During temporary holding and transport, *L. maculatus* was maintained at 20 °C–22 °C before cooling to 12 °C, illustrating that temperature is actively controlled to reduce stress in intensive handling conditions rather than left to fluctuate freely (Zhang et al., 2021). More broadly, daily fluctuation between 27 °C and 18 °C in Nile tilapia suppressed immune function, elevated heat-shock responses, and increased mortality after bacterial challenge to 35%–40%, showing how unstable temperature can worsen disease vulnerability even when mean conditions appear acceptable. Seasonal water instability can interact with nitrogen dynamics as well: in an aquaponics comparison, the control system experienced sharp ammonia accumulation followed by a nitrite spike to 13 mg/L, and all fish died, whereas the regulated system maintained more stable water quality and avoided those losses (Huang et al., 2025).