

growth model was used across multiple stocking densities and temperatures, showing that predictive statistical-mathematical modeling can estimate growth trajectories while evaluating the likely effect of external environmental drivers over time (Araneda et al., 2020).

More flexible predictive models appear to perform better when shrimp farms operate under complex and fluctuating environmental conditions. In a commercial dataset, artificial neural networks outperformed eight regression functional forms and produced the most accurate growth predictions, indicating that nonlinear interactions among environmental factors are important in real-world culture systems. More recent machine-learning comparisons in eco-green aquaculture similarly found that growth could be modeled as a function of water-quality variables, and that dissolved oxygen, nitrate, and total *Vibrio* had the highest importance for predicting daily shrimp growth, reinforcing the usefulness of data-driven scenario modeling for environmental assessment (Arfiati et al., 2025).

4.3 Identification of optimal environmental conditions for growth enhancement

Statistical optimization studies indicate that shrimp growth enhancement depends on identifying environmental ranges that maximize growth while avoiding survival loss or water-quality deterioration. Response surface analysis of temperature-salinity interactions in biofloc nursery production found that the optimum conditions for maximizing final weight, specific growth rate, productivity, and survival were a temperature of 27.25°C and salinity of 25.5 g/L, showing the value of multivariable optimization rather than one-factor-at-a-time interpretation (Figure 1). In intensive freshwater culture, predictive growth modeling further showed that the best productivity yield occurred above 26°C, while culture below 22°C was least efficient, supporting the view that optimal thermal conditions are both system-specific and statistically identifiable (Araneda et al., 2020).

Optimization also depends on maintaining environmental variables within acceptable operational ranges through continuous monitoring and classification. Real-time monitoring work identified temperature, pH, dissolved oxygen, salinity, and related indicators as key water-quality variables for production assessment, and machine-learning classification achieved high accuracy in assigning shrimp production levels from these measurements (Ahmed et al., 2024). Complementary pond monitoring showed that dissolved oxygen and pH can fluctuate toward critical thresholds while ammonia and nitrite can rise abruptly, suggesting that optimal growth enhancement requires not only target conditions but also early-warning detection of deviations before they suppress growth performance (Nazarudin et al., 2025).

5 Statistical Analysis of Environmental Effects on Shrimp Survival Rate

5.1 Environmental stress factors associated with shrimp mortality

Shrimp mortality is strongly shaped by environmental stress, particularly when ponds experience unstable temperature, salinity, oxygen, or nitrogenous waste conditions. Evidence from disease-focused reviews shows that abiotic conditions influence shrimp susceptibility to white spot disease, and that stressors in farm settings usually occur simultaneously rather than in isolation, which increases the difficulty of attributing mortality to a single factor (Millard et al., 2020). Experimental studies likewise show that common toxicants in culture water reduce survival directly: ammonia, nitrite, and sulfide all lowered the survival rate of *Litopenaeus vannamei*, with tissue damage increasing as stress concentration rose and nitrite causing the most severe overall damage (Han et al., 2025).

Nitrogen-related stress appears especially important because it compromises both physiology and disease resistance before outright mortality occurs. Elevated ammonia beyond tolerance limits inhibits molting, growth, phenoloxidase activity, and antimicrobial defenses, thereby weakening innate immunity and increasing vulnerability to loss (Zhao et al., 2020). Multi-factor experiments further show that survival declines at higher ammonia-N and nitrite-N concentrations, and that survival rate is most strongly affected by ammonia-N among the tested factors, while interaction effects with temperature can significantly alter biological response (Li et al., 2024).

5.2 Survival analysis and mortality prediction models

Statistical models for shrimp survival increasingly treat mortality as a dynamic response to water quality, disease pressure, and management conditions. Dynamic stock modeling of white spot disease in intensive *L. vannamei*