

Regression models remain central when the objective is to estimate environmental-growth relationships quantitatively and test predictive usefulness. Simple linear regression has been used to model production parameters and to run sensitivity simulations, showing how changes in dissolved oxygen, temperature, and management factors could alter final output (Ruiz-Velazco et al., 2022). Other shrimp-environment studies extended linear regression to longer monitoring datasets and multiple life-cycle periods, showing that temperature, salinity, dissolved oxygen, and even meteorological variables can explain part of the variability in shrimp abundance or performance, although explanatory power varies by period and outcome.

3.3 Advanced modeling techniques for prediction and risk assessment

Advanced modeling techniques are increasingly used when environmental effects are nonlinear, high-dimensional, or time dependent. In commercial shrimp growth prediction, artificial neural networks outperformed eight traditional regression forms after training and validation on farm datasets, indicating that flexible models can better capture complex production environments (Yu et al., 2005). More recent machine-learning work using eco-green aquaculture data compared neural networks, support vector regression, decision trees, and random forest models, and identified dissolved oxygen, nitrate, and total *Vibrio* as the most important predictors of daily shrimp growth (Arfiati et al., 2025).

Risk assessment applications have also expanded from growth prediction to environmental alert systems and disease forecasting. Real-time shrimp farm analytics now combine sensors, cloud storage, multivariate regression, and classification algorithms to predict next-day water conditions and categorize production levels, with reported performance of $R^2 = 0.94$ for regression and 97.84% accuracy for random forest classification (Ahmed et al., 2024). At the disease level, machine-learning and deep-learning studies have used physicochemical plus spatial variables to map white spot disease susceptibility and historical environmental time series to forecast outbreak risk, shifting farm management from reactive response toward proactive prevention (Tuyen et al., 2023; Udayakumar et al., 2025).

4 Statistical Evaluation of Environmental Effects on Shrimp Growth Performance

4.1 Relationship between environmental conditions and growth indicators

Statistical evaluation of shrimp growth performance consistently shows that environmental conditions are closely linked to core production indicators such as average body weight, specific growth rate, survival, and biomass yield. In semi-intensive farms, dissolved oxygen showed a strong positive correlation with average body weight, whereas water temperature was negatively correlated with both survival and average daily growth, indicating that even narrow thermal variation can measurably affect performance outcomes (Srinivasan et al., 2025). A separate multivariate analysis using canonical correlation likewise found a significant first canonical root between water quality and shrimp growth, with temperature emerging as the main environmental contributor and specific growth rate dominating the biological response side.

Evidence from pond-scale production studies further suggests that growth indicators respond not only to single variables but to the combined structure of environmental variation across ponds and time. In a commercial farm dataset, final weight was positively related to both temperature and dissolved oxygen, while temperature and dissolved oxygen also showed the greatest between-pond variability, supporting their value as explanatory variables in growth evaluation (Ruiz-Velazco et al., 2022). Daily monitoring in intensive ponds also showed that shrimp growth was strongly influenced by salinity, nitrite, alkalinity, and pH, with estimated contributions of 80.4%, 75.6%, 67.8%, and 55.7%, respectively, demonstrating that statistically relevant growth predictors extend beyond temperature alone.

4.2 Modeling growth responses under different environmental scenarios

Modeling shrimp growth under different environmental scenarios has progressed from conventional regression toward approaches that explicitly accommodate changing pond conditions and nonlinear responses. Linear mixed-effects models have been used to assess how temperature exposure patterns influence shrimp performance while accounting for repeated observations within ponds and yearly clustering, allowing fixed environmental effects and random farm-level variation to be separated statistically. In freshwater intensive culture, a parameterized Gompertz