

and culture environments (Şerban et al., 2025). Nutrition further shapes these outcomes by influencing digestive efficiency, metabolic allocation, gut health, and appetite regulation. Early nutritional programming can produce persistent effects on nutrient utilization, enzyme activity, immunity, and later growth, while specific dietary interventions can improve protein deposition and resilience to environmental stress. In addition, recent work has shown that feeding behavior itself is closely tied to growth performance, with faster feeding activity, stronger appetite signaling, and altered brain expression of orexigenic factors associated with improved growth in cultured carp. Taken together, these findings indicate that feeding efficiency is not a single isolated trait, but rather the phenotypic expression of interconnected biological processes operating across multiple organizational levels.

A further layer of complexity arises because feeding efficiency is also mediated by the digestive and microbial environment, the quality and acceptability of formulated diets, and dynamic responses to husbandry conditions. In practical aquaculture, the transition from traditional feeds to compound diets often exposes major differences in feed acceptance and performance, and these differences can substantially alter production cost and culture duration. In one marine species, poor acceptance of formulated feed was associated with slower production progress, whereas integrating microbiome and metabolome data revealed key microbial-metabolite signatures linked to better feed conversion and growth performance. Similar evidence from systems-level prediction studies shows that feed efficiency is difficult to measure directly in individual fish and cannot be adequately explained by single biomarkers alone; instead, integrated models using proteomic, metabolomic, microbiomic, and clinical covariates provide better predictive power than single-layer data (Young et al., 2023). These results support the view that growth and feed utilization are emergent traits arising from many weakly and strongly interacting factors. They also reveal why conventional empirical management, although still useful, is often insufficient for optimizing modern aquaculture systems in which biological regulation, feed formulation, animal behavior, and environmental variability must all be considered simultaneously.

Against this background, computational analysis provides a necessary framework for transforming complex aquaculture data into actionable knowledge on growth performance and feeding efficiency. Recent studies show that machine learning, deep learning, and adaptive statistical modeling can predict growth trajectories, feed intake, and feed conversion outcomes with useful accuracy when they integrate biological, environmental, and management data. Transformer-based growth models trained on Monte Carlo-generated datasets have reported low prediction errors for fish weight and growth rate, while algorithmic feeding systems combining visual monitoring and multimodal reasoning have improved feed conversion ratio and specific growth rate in recirculating systems (Lan et al., 2025). Likewise, automated feeder research in barramundi has shown that nonlinear and multimodel approaches can explain daily feed intake accurately by combining environmental, fish, feed-composition, and pellet-characteristic variables, reinforcing the value of integrated computational frameworks for precision feeding. Therefore, the objective of this paper is to develop a computational perspective on how growth performance and feeding efficiency can be analyzed across aquaculture species using multidimensional biological and production data. The research framework focuses on three linked tasks: identifying the major biological and environmental determinants of growth and feed utilization, evaluating quantitative indicators and predictive variables associated with performance, and summarizing computational methods capable of supporting precision feeding, selective improvement, and sustainable production management. In this way, computational analysis is positioned not merely as a technical tool, but as a bridging framework that connects biological understanding with practical decision-making in modern aquaculture.

2 Data Acquisition and Computational Framework for Aquaculture Growth Analysis

2.1 Sources and characteristics of aquaculture production datasets

Aquaculture growth analysis relies on datasets that combine biological, environmental, and management information collected at different temporal and spatial scales. At the farm level, production datasets often include fish weight, feeding decisions, and pond- or workshop-specific operating conditions, because differences in environment, equipment, and operator behavior can cause substantial deviations in growth characteristics across culture units (Li et al., 2021). More recent smart-aquaculture studies have expanded these records by linking real-