

Current predictive models in aquaculture are increasingly designed to reduce redundant inputs and extract the most informative features from complex time-series data. Hybrid deep-learning frameworks for RAS combine convolutional layers, recurrent units, and attention mechanisms so that local patterns, sequential dynamics, and critical features can be learned together, while feature-selection work in outdoor recirculation systems shows that a small subset of routinely measured variables can effectively support prediction of dissolved oxygen, TAN, nitrite, and alkalinity (Jongjaraunsuk et al., 2024). Even so, predictive performance remains parameter-specific, since the same outdoor study found strong prediction for several variables but substantially weaker performance for pH, indicating that model reliability still depends on the biological and chemical behavior of the target parameter (Yang et al., 2023).

AI is also expanding beyond water chemistry prediction into growth modeling and operational optimization. In a smart aquaculture management system, deep learning linked environmental and system parameters to California bass growth with high predictive accuracy, and the resulting model was proposed for integration into autonomous feeding to reduce leftover feed. More generally, systematic reviews conclude that AI now supports decision-making, optimization, and automation across feeding, disease monitoring, production modeling, and environmental management, suggesting that future RAS platforms will increasingly connect fish performance prediction with water-quality control in a single analytical framework (Aung et al., 2024).

AI-based analytics are also being adapted for practical use in lower-cost and resource-constrained environments rather than only in highly capitalized farms. IoT-linked analytics systems have identified strong correlations among water variables, including substantial associations of pH with dissolved oxygen and temperature, which can guide simpler predictive control rules, while other smart aquaculture systems report that Random Forest models can outperform alternative algorithms for classification-based water-quality prediction tasks (Matkarimov et al., 2025). This suggests that the future of predictive RAS management will likely include both advanced deep-learning architectures for large datasets and lighter-weight models that are easier to deploy where infrastructure, computing capacity, or technical expertise are limited.

7.2 Automation and smart control systems in RAS

Automation in RAS is moving from isolated sensors toward connected systems that both detect change and trigger corrective action. Recent reviews note that many farms still rely on manual measurements or disconnected devices despite the availability of real-time sensing, while cost-effective RAS platforms now outline the transition from passive monitoring to closed-loop control through continuous feedback, error calculation, and actuator commands (Grandez-Yoplac et al., 2025). In this architecture, smart control depends on linking sensors, communication networks, cloud or edge processing, and actuators into a single operational loop rather than treating monitoring and intervention as separate tasks (Malandrakis, 2025).

Prototype and commercial-oriented systems already show how this logic can be implemented in practice. RAS automation platforms based on Raspberry Pi, cloud connectivity, and modular sensor networks have been designed to support real-time acquisition, intelligent aeration, and visualization, while a tilapia RAS prototype automatically monitored and controlled pH, temperature, salinity, and dissolved oxygen with measurements accessible through a web application (Libao et al., 2024). These systems indicate that smart RAS control is no longer limited to theory, because they connect environmental sensing directly to user interfaces and operational responses that can be accessed remotely (Shodiq et al., 2023).

A central benefit of automation is that it reduces the biological risk created by delayed human response. Recent IoT monitoring reviews report that sensor-based water monitoring improves growth, reduces mortality, and enables rapid prediction and detection of atypical TAN levels, while integrated IoT-ML systems have carried out thousands of corrective interventions and maintained fish survival above 90% under demanding conditions (Baena-Navarro et al., 2025; Flores-Iwasaki et al., 2025). This matters particularly in RAS because pumps and aerators are life-support components, and automation can shorten the time between deviation detection and intervention when oxygen depletion or ammonia accumulation develops rapidly (Malandrakis, 2025).