



Artificial Intelligence for One Health in Aquaculture: A Review of Applications and Connections

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How to cite this article:

Mali, P., Bhowmick, S., Chettri, A., Kishore, J. G. and Rohan, R. 2026. Artificial Intelligence for One Health in Aquaculture: A Review of Applications and Connections. *Blue Spectrum*. 1(1): 36-48.

ABSTRACT

In recent years, the rapid expansion of aquaculture as a major food source highlights the interconnectedness of animal health, ecosystem sustainability, and public health, the core of the One Health approach. Simultaneously, Artificial Intelligence (AI) provides unprecedented tools to understand, monitor, and optimize these complex systems. This comprehensive review illustrates AI's transformative applications in aquaculture and assesses their direct contributions to One Health. It explores how AI-driven precision aquaculture enhances food safety through real-time monitoring of animal welfare and environmental conditions. The review covers AI's role in managing veterinary drug residues, a key One Health challenge, via predictive analytics and smart residue tracking. It analyzes AI's capacity to strengthen biosecurity through early pathogen detection and dynamic risk assessment for safer production. Furthermore, the article examines AI's adoption for sustainable aquaculture, ensuring long-term supply through resource efficiency and ecosystem monitoring. Finally, it details AI's critical function in controlling feed quality for fish health and product safety. By synthesizing current research, this article argues that strategically deploying AI is an essential enabler for operationalizing the One Health framework, ultimately safeguarding and sustaining global aquatic food systems.

KEYWORDS

Artificial Intelligence, One Health, Food Safety, Biosecurity, Sustainable Aquaculture.

Introduction

Aquaculture production around the world has surpassed capture fisheries as the largest source of fish for human consumption, due to stagnant wild stocks and increased protein demand from a growing population (FAO, 2024). This high level of production occurs under a delicate triad however: the health of cultured organisms, ecological integrity of the environment and the safety of the final product to the consumer (Boyd et al., 2022). Stress in one domain simply feeds one another, and stressors in one domain inevitably feed on to the other. Disease outbreaks cause the consumption of pharmacological drugs that may result in residues in products and affect the environmental microbiota (Wannasand Mohammed, 2025). Bad water quality stresses animals and is bad for their health and nutritional quality. Enormous feed usage contributes to nutrient loading to the environment. This interdependence is the crux of the One Health approach, a single, transdisciplinary approach that understands that the health of people, animals, plants and their common environment are inextricably linked (Danasekaran, 2024). Traditional aquaculture management usually includes manual sampling, reactive intervention, broad-spectrum treatment and so on, which is inefficient, can worsen the problems, and is not coping with dynamic systems in the long run (Yusoff et al., 2024). Artificial Intelligence (AI) including machine learning, deep learning, computer vision and Internet of Things (IoT) can handle large multivariate datasets in real time. Combining data from underwater imaging and acoustic signals, water quality sensors and genomic information, AI generates actionable, real-time insights (Rather et al., 2024; Lim, 2024; Ou, 2025). This review argues that AI is the essential enabler for making One Health to be operationalized in aquaculture. We have systematically reviewed AI across 5 key domains (Fig 1):

- 1) AI in Aquaculture Practices and Food Safety: A link between animal health, environment, and human health.
- 2) Residues of Veterinary Drugs: AI for predictive pharmacodynamics, residue monitoring, and antibiotic stewardship.
- 3) Biosecurity: AI-based for early, precise pathogen detection and dynamic risk assessment.
- 4) Sustainable Aquaculture: The application of AI for feed-precision optimization, stock monitoring and environmental impact reduction to drive long-term safe fish supply.
- 5) Feed Quality: AI for better feed formulation, for contaminant detection, and for efficient feed for animal health, and product safety.

The purpose of this article is, through a recent evaluation of present applications and future opportunities, to help present a panoramic view of intelligent systems for a more resilient, safe and sustainable aquaculture industry that is in line with One Health principles.

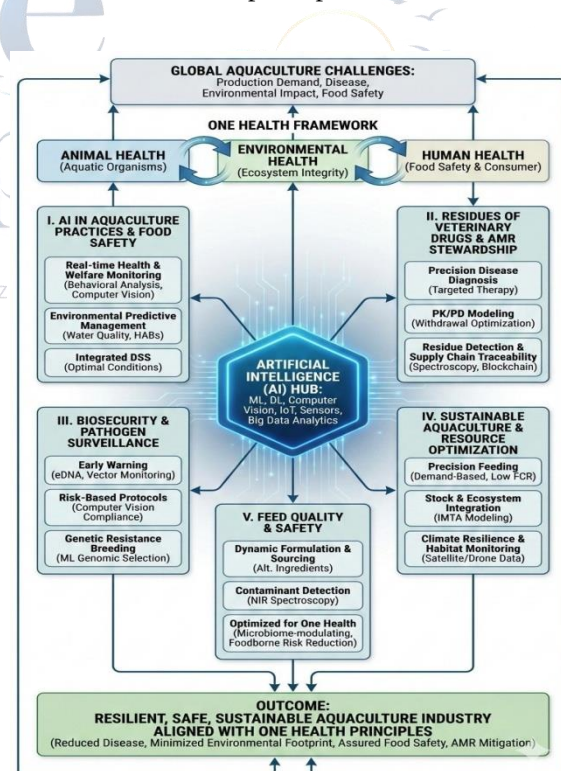


Fig 1: Artificial Intelligence in Aquaculture and One health

AI in Aquaculture Practices and Food Safety: A link between animal health, environment, and human health.

In aquaculture, food safety, health and safety in aquaculture extends long before harvest and is inextricable from the use of agricultural practices which dictate animal welfare and environmental conditions in the field of practice on-farm (Turlybek et al., 2025). AI functions as a central nervous system in farming, establishing a feedback loop between all decision making, in which the animal status, environmental conditions, management, and environment have a connection to the farm's data in a feedback loop (Michielon et al., 2024).

Health and welfare monitoring in real-time

Safe food starts with healthy animals. Computer vision with AI is changing the face of behavioral and physiological tracking (Pandey and Mishra, 2024).

Behavioral analysis: AI models that are trained on video feeds can identify and analyze fish behaviors (e.g. feeding practices, swimming behaviors, breathing mechanisms (e.g. piping) indicating water-quality problems) using deep learning (DL) approaches. The behavioral deficits of those involved in collaborative efforts are typically the first sign of stress, disease, or poor conditions. For example, decreased feeding behaviors or erratic swimming can create automated alerts to farmers for inspection (Xiao et al., 2025). This moves health management from reactive to proactive.

Individual health assessment: With modern visual systems, physical signs of disease (lesions, ulcers, parasites like sea lice) can be detected and biometric indices (length, weight) can be quantified in a noninvasive manner. Recently, high accuracy of *Aeromonas hydrophila* infection detection in carp and sea lice on salmon were found by using convolutional neural networks (CNNs) (Islam et al., 2024). This is used to allow selective culling or treatment rather than spreading the disease and unnecessary chemical usage.

Environmental monitoring and predictive management

Water quality parameters (dissolved oxygen, temperature, pH, ammonia, nitrite) are essential for fish health and impact the presence of pathogens and toxins (e.g., algal blooms). IoT sensor networks report continuous, high-frequency data (Jan et al., 2021).

Predictive analytics: ML models (e.g., regression trees, neural networks) on historical and real-time sensors provide predictions for high-hazard events, such as hazardous drops in dissolved oxygen (hypoxia) and ammonia spikes (Hridoy et al., 2025). Farmers are early aware of the impending events, which may help prevent aeration or water exchange leading to mass mortality events that may affect welfare as well as food security.

Ecosystem linkages: AI can incorporate off-farm environmental data (e.g., satellite imagery for sea surface temperature, chlorophyll-a) for risk prediction of harmful algal blooms (HABs) that may generate biotoxins, i.e., saxitoxins, accumulating in shellfish (Muhammad et al., 2026). Predictive models assist in the management of harvest closures, reducing the risks associated with paralytic shellfish poisoning (PSP) on human health (Paturi et al., 2025).

Integrated decision support systems (DSS)

AI power is in integration. DSS solutions combine data from vision, environmental sensing as well as feeding systems. Reinforcement learning methods can learn the correct controls for aeration, feeding, and stocking density which helps to ensure optimal growth and health and has a minimum environmental impact as well as resource consumption. Such comprehensive farm management contributes to safe, quality fish production as it establishes optimal living conditions across the production cycle which minimizes stress-induced disease and quality degradation (FAO and ICRISAT, 2022).

One health linkage: This continual smart monitoring provides a direct digital link between farm environment and animal health

and product safety. It reduces the requirement for medical interventions by preventing disease outbreaks and stress. Through predicting environmental threats, it protects both the cultured organism and the ecosystem, protecting native aquatic organisms and human populations that depend on those ecosystems from pollution and pathogens (Benis et al., 2023; Vlaicu et al., 2024).

Residues of Veterinary Drugs: AI for predictive pharmacodynamics, residue monitoring, and antibiotic stewardship.

The incorporation of veterinary drugs, especially antibiotics, in aquaculture constitutes a classic One Health problem. It is associated with the development of antimicrobial resistance (AMR) in water-borne bacteria, which may be transferred to humans and animals through mobile genetic elements and to the potential toxicity of residues in edible tissues exceeding Maximum Residue Limits (MRLs), where they represent a direct toxicological threat to consumers (Caneschi et al., 2023).

Precision disease diagnosis and targeted therapy

Use of indiscriminate or prophylactic antibiotics is a leading factor in residue and AMR problems. AI increases precision in diagnosis (Verma et al., 2025).

AI-powered disease detection: AI helps us spot sickness in fish quickly and accurately. Instead of guessing or using broad treatments, machine learning (ML) can look at data from simple test kits, analyze the microbes living in the water or inside the fish, or even notice unusual fish behavior. That helps pinpoint exactly what germ is causing the problem and which antibiotics might work against it. Farmers can then use the right medicine, in the right amount, which cuts down on how much and how many kinds of antibiotics are needed (Pennisi et al., 2025).

In predicting outbreaks before they take place: AI can also act as an early warning system for disease spread. Special computer models that use information about how fish

move, water currents, and previous disease history will guide how an illness might travel within a farm or jump to neighboring ones. So farmers have a chance to take smart, specific steps to stop the disease early on. By doing so, health care for the whole farm is often not needed, and fish and the environment are healthier (Rahman et al., 2024).

Pharmacokinetic/Pharmacodynamic modelling and optimization of withdrawal period

It is essential for residue compliance to find the correct dose and ensure adherence to the withdrawal period (the time from last treatment to harvest).

Personalized medicine for fish with AI: Right now, most methods for figuring out how medicines work in fish are designed for an "average" population. But AI changes the game. It can use specific details about a group of fish, like their size, the water temperature and saltiness, and how healthy they are to create customized models. These smart models then predict exactly how the drug will break down in those specific conditions and when it will be safely out of the fish's system (Pereira et al., 2022).

Smart withdrawal compliance: Blockchain combined with AI can provide immutable records for treatment. Smart feeders connected to IoT can be programmed to prevent medicated feed after a treatment cycle, and farm management software can automatically calculate and enforce a dynamic, data-based withdrawal period, detecting any stock for harvest prior to deeming it safe (Zou et al., 2020).

Residue detection and supply chain assurance

AI builds capacity for regulatory and self-monitoring.

Spectroscopic analysis: ML-based algorithms are applied to analyze complex data from hyperspectral imaging or biosensors to rapidly and non-destructively identify and quantify chemical residues in fish fillets, making

substantial progress compared with expensive and time-consuming laboratory techniques (Wang et al., 2026).

Supply chain traceability: AI algorithms can process blockchain or RFID-enabled traceability data to detect patterns suggesting non-compliance or high-risk batches before targeted inspections and recalls are implemented (Adamashvili et al., 2024).

One health linkage: AI tackles the trilemma of drug residue head-on: it's designed to ensure effective treatment for animal health, reduce environmental AMR selection pressure, and ensure residue-free food for human consumption. AI supports precision treatment and rigorous oversight, underpinning antibiotic stewardship in aquaculture, which is an important area of concern in the worldwide battle against AMR (Kasse et al., 2025).

Biosecurity: AI-based for early, precise pathogen detection and dynamic risk assessment.

Biosecurity is all actions taken to prevent introduction and/or spread of pathogens. The best sustainable defense against disease is robust biosecurity, which protects the health of animals and the safety of the food (Ahmadivand et al., 2025).

Early warning and pathogen surveillance

Environmental DNA (eDNA) and AI: The eDNA sampling for the detection of genetic traces of pathogens in water is an effective method of surveillance without the need to be invasive. For example, AI algorithms (e.g., anomaly detection models) can analyze temporal data of eDNA sequences for the detection of new or established pathogens at ultra-low concentrations, well earlier than clinical signs (Yoon et al., 2025). This enables proactive quarantine or husbandry repositioning.

Wildlife vector monitoring: Drones equipped with cameras, combined with computer vision technology, can monitor wildlife (e.g., birds, marine mammals) around farm sites, assessing their number and behavior as potential vectors of disease. This guide-posts the development of

barrier and deterrence strategies at risk (Aly and Fathi, 2024).

Risk-based inspection and biosecurity protocol optimization

Computer Vision for Compliance: Cameras at farm entrances can employ object recognition to monitor that vehicles, machinery and human operators adhere to disinfection guidelines (in this case, the use of footbaths and changing of clothes) (Rygało-Galewska and Kołnierzak, 2025).

Dynamic biosecurity risk scoring for each farm site or zone: ML models can incorporate heterogeneous risk factors (temperature changes, historical disease data, water currents, proximity to other farms, where farm stock comes from, etc.) to create dynamic biosecurity risk scores for each specific farm or zone, incorporating predictive risk models based on the risk factors and predictability. This enables prioritizing resources (for example, frequency of health checks, investment in infrastructure) according to measurable risk (MohsinRaza et al., 2025).

Genetic resistance and breeding

AI also speeds up selective breeding for disease resistance, a key biosecurity strategy. ML-based genomic selection can analyze high-density SNP (Single Nucleotide Polymorphism) chip data to correlate the genotypes and disease resistance phenotypes to accurately predict the breeding value of candidates. This leads to stocks with endogenous resilience, which lowers the population level burden of disease and then drug usage (Garcia-Oliveira et al., 2026).

One health connection: Robust AI-powered biosecurity can defend cultivated stocks, prevent pathogen contamination of wildlife populations from emerging, as well as limit human pathogen spillovers into the animal-induced wild populations, and decrease the necessity for antimicrobial treatments. It will provide the health of wild ecosystems (environmental health) and a stabilized, disease-free food production system that is disease-free

(animal health to human health) (Kasse et al., 2025).

Sustainable Aquaculture: The application of AI for feed-precision optimization, stock monitoring and environmental impact reduction to drive long-term safe fish supply.

One Health incorporates sustainability and addressing existing demands in a sustainable way that allows a healthy environment for generations to come. AI powers accuracy in precision aquaculture, optimising productivity and reducing ecological impact (Yang et al., 2025).

Precision feeding and nutrient management

Feed is also the foremost operational expense and sources of nutrient pollution (nitrogen, phosphorus) by far in our supply (Dalbem Barbosa et al., 2024).

Demand-based feeding: Computer vision systems simulate a fish appetite based on their behaviors and competition. Reinforcement learning (DL)-based controllers respond to demand in the field by altering feed to the right amount. Feed conversion ratio (FCR) and wastage decrease dramatically because of this (Thornburg, 2025). Low FCR implies less uneaten feed, which pollutes the water.

Fecal waste monitoring: Underwater cameras and images of the waste can track outflow and accumulation. This information is used to construct models that maximize waste recovery and decision about fallow (protect benthic ecosystems), for example (Ning et al., 2024).

Stock management and optimized production

AI vision system achieves accurate, frequent stock counts and size distribution analysis without the stress factor. This enhances inventory control, harvest scheduling, and grading practices, minimizing losses and providing a steady stream of goods into the market (Çaylı and Oralhan, 2024).

Integrated multi-trophic aquaculture (IMTA) modelling: IMTA co-cultures fed species (fish, etc.) with extractive species (seaweed, shellfish) that use waste nutrients.

Through the modeling of these intricate interactions between species and environmental conditions AI can lead to the establishment of strategies that maximize the nutrient recycling and economic yields through better IMTA designs in integrated systems that contribute to a more closed-loop, sustainable system (Nissar et al., 2023).

Ecosystem integration and climate resilience

AI enables farms to adapt to and address the impacts of climate change (Nikhitha and Prasanth, 2025). Climate Impact Modeling: ML can scale climate models to forecast local impacts, including on-site water temperatures, oxygen solubility, and storm frequency, to contribute to site selection, species selection and to infrastructure design that is suitable for long-term adaptation (Holt et al., 2025).

Habitat monitoring: AI analysis of satellite and drone imagery can assess the impact of farm operations on seagrass beds, mangrove forests, or coral reefs in the wild to provide adaptive management strategies for these vital ecosystems, supporting coastal protection and wild fisheries maintenance (Mohan, 2025).

One health linkage: AI-enforced sustainable practices will ensure long-term survival of aquaculture as such. Through — reducing pollution, preserving biodiversity and boosting resource efficiency, AI underpins planetary environment robustness. The reliable, safe, and nutritious food supply for global human health rests on a stable, sustainable production system (Utku and Kutlu, 2025; Bala et al., 2024).

Feed Quality: AI for better feed formulation, for contaminant detection, and for efficient feed for animal health, and product safety.

The quality of feed is the key to nutrition, health, even products. Feed sources of contaminants (mycotoxins, heavy metals, dioxins) may have a risk of accumulation in fish, resulting in human health concerns. The fish immunity and flesh quality are compromised by suboptimal formulation (Puvača et al., 2024).

AI in feed and component formulation and sourcing

Least-cost dynamic formulation: Traditional least-cost formulation uses linear programming. AI improves this by dynamically calculating real-time prices of ingredients and how varied there are with nutrients, while also measuring sustainability scores (e.g., carbon footprint, soybean sourcing). By applying chemical composition as predictive factor, ML based models can also calculate nutritional value of new alternative ingredients (e.g., insect meal, single-cell proteins) to promote its adoption (Akintan et al., 2024; Zhang et al., 2023).

Predictive nutrition: AI models link specific dietary formulations with growth metrics, for example, but also with health outcomes (e.g., gut microbiome profile, immune gene expression) and final product attributes (e.g., fillet fatty acid profile, texture). As a result, the "functional feeds" that are conducive to good healthy state and desired characteristics of a product can be developed (Agrawal et al., 2025).

Contaminant detection and supply chain integrity

Rapid feed analysis: Just like fish residues detection, applying NIR spectroscopy with ML to incoming feed batches can detect macronutrient composition and potential contaminants, like aflatoxins, at feed mill or farm reception in real time (Wang et al., 2025).

Blockchain and AI for traceability: For some high-risk ingredients such as fishmeal isolated from certain areas, for example, blockchain-based provenance information can be mined by AI for assessing the risk of contamination (e.g., history of mercury concentration) to test or source for contamination at a time before (Dhal and Kar, 2025).

Optimizing feed for health and safety results

AI can assist tailoring feeds targeting One Health objectives especially (Rather et al., 2024).

Microbiome-modulating feeds: AI can analyze a mixture of feeding components, gut microbiome data (in the form of sequencing), and disease resistance to identify prebiotic or probiotic feed strategies, which strengthen innate immunity leading to a decline in susceptibility to disease (Probul et al., 2024).

Minimizing risk of foodborne risks: A higher concentration of histamine-producing bacteria in fish species susceptible to scombroid poisoning can be minimized by making an optimized formulation, or in aquaculture with sufficient antioxidant levels that improve shelf-life and food safety would not only lead to a better outcome (Visciano et al., 2014), it also provides the best possible shelf-life as well as to be an improvement in food safety.

The one health linkage: Quality, safe, nutritious feed directly produces healthier animals (decreasing disease burden), reduces the transport of unwanted environmental contaminants to the human food chain, and thus a more food-producing product (Danasekaran et al., 2024). AI improves feed to be not only cost effective but also a vector from which health promotion through One Health can take place (Pandey et al., 2025).

Challenges, Ethical Considerations, and Future Directions

The introduction to aquaculture of AI is full of opportunities yet also challenges (Fernandes and D-Mello, 2025).

Availability and quality of data: AI can be effective only when the datasets being used are large, standardized and annotated (in aquaculture these volumes are often limited). We need collaborative data-sharing platforms (Rather et al., 2024).

Cost and accessibility: Initial investments in sensors, connectivity and expertise can be too expensive for small-scale farmers, presenting a possibility of a "digital divide" (Yang et al., 2025).

Interpretability and trust: In many cases, as many complex AI models are "black boxes," farmers and regulators might distrust these

models. We need to build explainable AI (XAI) (Saarela et al., 2024).

Cybersecurity: Secure farms are at risk of cyber threats to disturb operation, or to fabricate data with significant impacts on food safety (Maraveas et al., 2024).

Ethical and employment implications: While monitoring and decision-making are automated, the role of skilled husbandry knowledge and the threat of job displacement for workers remain in the future (Yang and Zhang, 2024).

First, we need sensors that are both affordable and tough enough for real farm life. Next, there's federated learning, a clever way to train powerful AI models without farms having to hand over their private, raw data. It's like getting the benefits of shared knowledge while keeping your own information safe. The idea of digital twins is also exciting. This means creating a live, virtual copy of the farm is a kind of simulator where different strategies can be tested (like changing feed schedules or stocking density) on the computer first, without any risk to your real fish. Finally, none of this will reach its full potential without the right policies and rules. We need smart regulations that encourage innovation but also make sure the technology is used fairly, safely, and in a way that truly protects the environment (Fernandes and DMello, 2025).

Conclusion

Artificial Intelligence in aquaculture reaches far beyond efficiency and sustainability. It has offered the tool of the trade for the interdependence and complexity of the One Health paradigm-like challenges. By allowing for real-time, in-depth oversight of animal welfare and environment, AI establishes a baseline for pre-harvest food safety. It provides a precise mechanism for dealing with the important issue of veterinary drug residues, tackling AMR. It strengthens biosecurity through intelligent monitoring and risk forecasting. It promotes production system sustainability and food security in the long term. Last but not least, it maximizes the essential feed input for the purpose of the health and

safety results. The evolution of AI is not a nice to have option when it comes to technology, but an imperative evolution for an aquaculture industry that needs to expand to support the world and to protect ecosystems and animals and people. Safe, sustainable and resilient aquatic food systems of the future are shaped by the crossfire of biological understanding and digital intelligence, all of which are anchored in the integrative philosophies of One Health.

Conflict of interest: The authors declare that they have no conflict of interest.

Data Availability Statement: Data sets are available from the corresponding author upon reasonable request.

Author's contribution: PM: Conceptualization, Writing original draft, performed editing of manuscript; SB, AS, JGK, RR: Writing original draft, performed editing of manuscript.

Use of artificial intelligence tools: No artificial intelligence tools were used to write the manuscript, except the single diagram used.

Acknowledgements: The authors gratefully acknowledge the Hon'ble Vice Chancellor, West Bengal University of Animal and Fishery Sciences, for providing the necessary facilities to prepare the manuscript.

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