



One Health and Antimicrobial Resistance in Aquaculture: Implications for Interdisciplinary Public Health Education

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Abstract:

Antimicrobial resistance (AMR) in aquaculture creates public health risks through foodborne exposure, occupational contact, and environmental contamination. This literature review examined peer-reviewed evidence on the implications of aquaculture-related AMR for human and community health and evaluated the application of a One Health approach, while considering how the synthesis may inform interdisciplinary public health education. A systematic search was conducted using PubMed, ScienceDirect, and BMC Public Health for full-text articles published between 2010 and 2025 that linked One Health, AMR, and aquaculture or coastal communities. Five studies met the inclusion criteria and were synthesized thematically, supported by contextual literature. Four interrelated themes emerged: seafood-borne transmission of resistant bacteria; occupational exposure among aquaculture workers; environmental dissemination through aquatic systems and sediments; and gaps in cross-sector governance and surveillance. The findings indicate that aquaculture-related AMR extends beyond animal health and requires coordinated attention to food safety, worker protection, environmental health, antimicrobial stewardship, and integrated surveillance. These interconnected pathways also provide a relevant basis for interdisciplinary public health education, particularly for developing systems thinking and cross-sector collaboration. Integrated One Health responses are needed to reduce risks to coastal communities and public health.

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Introduction (مقدمة)

Antimicrobial resistance (AMR) is one of the most serious global public health threats of the twenty-first century. The 2019 Global Burden of Disease analysis estimated that bacterial AMR directly caused approximately 1.27 million deaths and was associated with 4.95 million deaths worldwide (Murray et al., 2022). A more recent analysis projected that more than 39 million deaths attributable to antibiotic-resistant infections could occur between 2025 and 2050, with annual attributable deaths rising by almost 70% to approximately 1.91 million in 2050 (GBD 2021 Antimicrobial Resistance Collaborators., 2024). These estimates show that AMR is not a distant threat but an active and expanding public health crisis.

The emergence and spread of resistance are driven by inappropriate antimicrobial use across human, animal, and environmental systems, creating conditions in which pathogens acquire and disseminate resistance genes (Milijasevic et al., 2024; Schar et al., 2020). Countries with limited technical capacity and fragmented institutional responsibilities face particular challenges in establishing cross-sector AMR surveillance. In Vietnam, differences in mandates, uneven resources, and weak coordination have hindered the development of a One Health surveillance system (Bordier et al., 2018). More broadly, One Health governance principles remain inconsistently standardized, and fragmented data continue to restrict coordinated action across jurisdictions (Aenishaenslin et al., 2024).

Aquaculture occupies a critical position within this problem because it is both a major source of animal protein and a potential node for AMR selection and dissemination. Global antimicrobial consumption in aquaculture was estimated at 10,259 tonnes in 2017 and was projected to increase by 33% to 13,600 tonnes by 2030. The Asia-Pacific region accounted for 93.8% of estimated consumption, with China contributing 57.9% (Schar et al., 2020). Intensive production frequently relies on antimicrobials for disease prevention and treatment (Milijasevic et al., 2024; Schar et al., 2020). In Chilean salmon aquaculture, the use of hundreds of tonnes of antibiotics annually has been associated with serious resistance in *Piscirickettsia salmonis* (Cabello & Godfrey, 2019). Across 11 Southeast Asian countries, *Escherichia coli*, *Aeromonas*, and *Vibrio* were among the most frequently reported resistant bacteria, while resistance to beta-lactams, tetracyclines, and sulfonamides exceeded 40% in each country reviewed (Suyamud et al., 2024).

The public health implications extend along the food chain. Seafood contaminated with resistant *Salmonella*, *Vibrio spp.*, or other pathogens may provide a route of human exposure, particularly when hygiene controls are inadequate across production, processing, and distribution (Brauge et al., 2024; Vergis et al., 2021). A *farm-to-fork* review showed that pathogenic *Vibrio* contamination reflects not only natural aquatic reservoirs but also anthropogenic activity, industrial pollution, and the circulation of resistance genes (Brauge et al., 2024). The European Food Safety Authority has also reported increasing detection of resistance to medically important and last-resort antimicrobials in seafood-associated *Vibrio*, including resistance genes carried on mobile genetic elements (EFSA Panel on Biological Hazards (BIOHAZ) et al., 2024).

A One Health framework is essential for interpreting these interconnected risks because it recognizes the interdependence of human, animal, and environmental health (Adesola et al., 2026; Milijasevic et al., 2024). Antibiotic residues released from aquaculture facilities can select for resistant organisms and disseminate resistance genes through water and sediment. Risk modelling in shrimp aquaculture indicated that tetracycline-resistant *Aeromonas hydrophila* may create human-health risks through linked environmental and production pathways (Lu et al., 2024). Aquaculture workers are also positioned at the human-animal-environment interface, where direct contact with aquatic animals, medicated feed, contaminated water, and biological hazards may increase occupational exposure and facilitate transmission into households or communities (Cavalli, 2025; Hosain et al., 2026).

These pathways also have implications for interdisciplinary public health education. Seafood transmission can connect food safety, risk communication, and antimicrobial stewardship; occupational exposure links worker protection with zoonotic and environmental health; environmental dissemination illustrates systems thinking across ecosystems and communities; and surveillance gaps demonstrate the need for cross-sector governance and communication competencies. These are educational implications of the evidence, not measured learning outcomes or evidence of an educational intervention.

Although previous studies have addressed national surveillance in Vietnam (Bordier et al., 2018), risk modelling in Taiwan (Lu et al., 2024), regional AMR patterns in Southeast Asia (Suyamud et al., 2024), and the Bangladesh context (Hosain et al., 2026), an integrated synthesis that explicitly maps the public health pathways of aquaculture-related AMR through a One Health lens remains limited. This literature review therefore examined peer-reviewed evidence on the implications of AMR in aquaculture for human and community health and evaluated how One Health approaches have been applied to address these challenges. The review also discusses, as a secondary implication, how the synthesized pathways may inform interdisciplinary public health education.



Method (منهج)

Study Design

This study used a Literature Review design with a systematic approach to identify, select, and analyze relevant articles. Reporting was guided by PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to support transparency and traceability (Page et al., 2021).

Literature Search

A systematic literature search was conducted using three electronic sources: PubMed, ScienceDirect, and BioMed Central (BMC Public Health). Publications were limited to January 2010 through December 2025. The search focused on three concepts: One Health, antimicrobial resistance, and aquaculture or coastal communities. Relevant keywords and Medical Subject Headings for each concept were combined using AND between concepts and OR within each group of related terms.

Eligibility Criteria

Eligible articles were peer-reviewed, available in full text, written in English or Indonesian, and explicitly addressed the relationship between One Health, AMR, and aquaculture or coastal settings. Empirical studies and review articles were eligible. Grey literature, including editorials, opinion pieces, and conference reports, was excluded, as were articles without accessible full text and studies focused on non-coastal zoonoses without a relationship to aquaculture.

Study Selection

The initial search identified nine articles. No duplicates were reported, and all nine records proceeded to title and abstract screening. All were considered potentially relevant and were assessed in full text. Four articles were excluded because they did not fully meet the inclusion criteria, leaving five studies for the qualitative synthesis. The original PRISMA figure is retained without altering the reported numbers.

Data Extraction and Thematic Synthesis

Data from the five included studies were extracted using a standard form covering author, publication year, location, study design, and principal findings. The evidence was synthesized thematically to identify recurrent patterns that addressed the review objective. Additional

supporting literature identified through non-systematic searches of PubMed, Scopus, and Google Scholar was used only for background and contextual comparison; these sources were not added to the five-study systematic corpus.

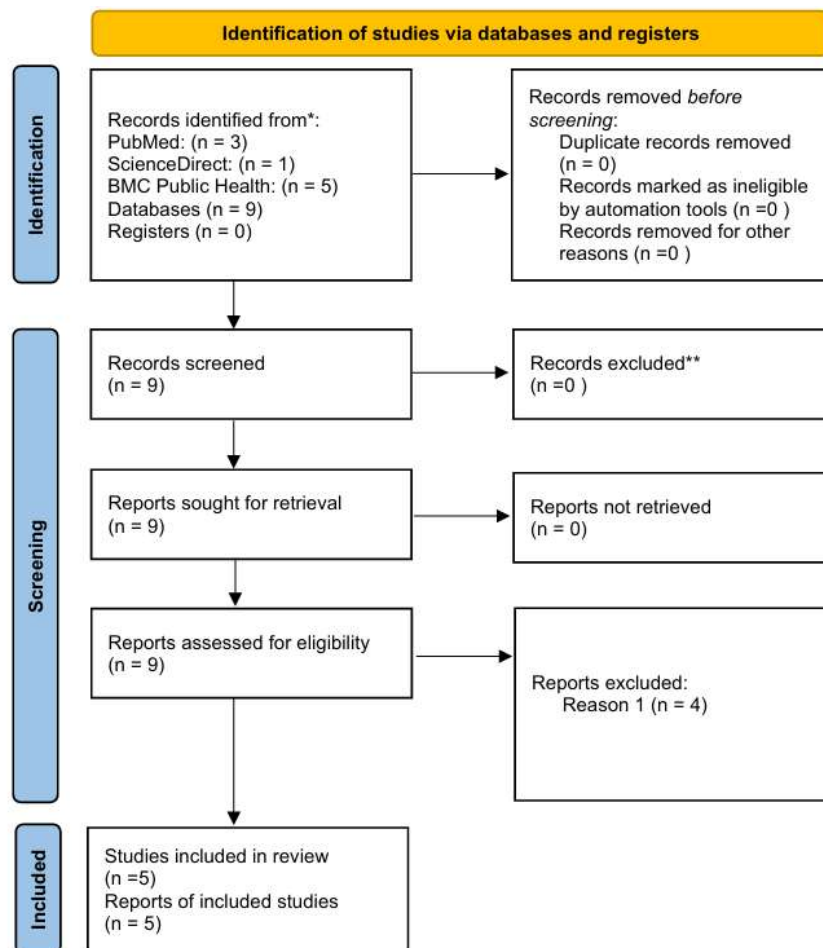


Figure 1. PRISMA Flow Diagram of the Article Selection Process

نتائج (Result)

The thematic synthesis of five included studies identified four pathways linking AMR in aquaculture with public health: seafood-borne transmission, occupational exposure among aquaculture workers, environmental dissemination, and gaps in governance and surveillance. These themes represent the scientific findings of the review.

Seafood-Borne Transmission

The reviewed evidence consistently identified aquaculture products as a potential route through which resistant pathogens may reach humans. A broad food-safety review described biological hazards from *Vibrio* and *Salmonella* along production and distribution chains, especially where hygiene controls are inadequate (Vergis et al., 2021). At the production level, intensive antibiotic use in Chilean salmon aquaculture has contributed to resistance in aquatic pathogens that may enter connected food and environmental pathways (Cabello & Godfrey, 2019). Risk modelling in shrimp aquaculture further suggested that, without substantial mitigation of antibiotic emissions, human exposure to resistant *Aeromonas hydrophila* through products and the surrounding environment may exceed acceptable thresholds (Lu et al., 2024). Collectively, these findings indicate that seafood-related exposure arises from conditions across the *farm-to-fork* continuum rather than from a single point of contamination.

Occupational Exposure among Aquaculture Workers

Aquaculture workers were identified as both a vulnerable population and a possible bridge between occupational settings and wider communities. One Health approaches to aquaculture recognize direct contact with aquatic animals, zoonotic pathogens, antimicrobial residues, and workplace chemicals as relevant occupational hazards (Cavalli, 2025). Worker hygiene is also a critical control point for product contamination and therefore affects both worker and consumer health (Vergis et al., 2021). In intensive salmon production, high antibiotic use and persistent disease problems can increase the duration and intensity of worker contact with resistant organisms (Cabello & Godfrey, 2019). Occupational health and safety should therefore be treated as an integral component of AMR prevention rather than as an isolated individual concern.

Environmental Dissemination

Aquatic environments surrounding aquaculture facilities can function as reservoirs and pathways for AMR. Intensive salmon farming may release antimicrobial residues and resistant bacteria into adjacent marine ecosystems, creating conditions that support the selection and persistence of resistance genes in sediments and coastal waters (Cabello & Godfrey, 2019). Quantitative risk modelling indicated that oxytetracycline emissions from shrimp ponds may contaminate aquatic environments at levels that facilitate resistance-gene transfer and increase exposure risks for coastal communities (Lu et al., 2024). Contamination can subsequently re-enter the human food chain through water, ice, equipment, and processing environments used for seafood products (Vergis et al., 2021).

Governance and Surveillance Gaps

Technical measures to control AMR were repeatedly constrained by systemic weaknesses in governance and surveillance. In Vietnam, differences in institutional mandates and cultures, limited technical capacity, conflicts of interest, and weak coordination among health, fisheries, and environmental authorities impeded One Health surveillance (Bordier et al., 2018). Across settings, inconsistent collaboration and non-harmonized standards restrict integrated reporting and audit mechanisms (Vergis et al., 2021). Occupational health is also frequently omitted from One Health policy, leaving worker-exposure indicators poorly standardized and weakly integrated into national surveillance frameworks (Cavalli, 2025). These governance gaps reduce the effectiveness of responses to aquaculture-related AMR.



Discussion (مناقشة)

Synthesis through a One Health Framework

This review identified four interconnected pathways through which aquaculture-related AMR may affect public health. Food products, workers, aquatic environments, and governance systems are not independent components; each can reinforce the movement and persistence of resistant organisms across the human-animal-environment interface. Similar integrated patterns have been described in contextual reviews of AMR in aquaculture (Adesola et al., 2026; Milijasevic et al., 2024). The findings therefore support interpretation of aquaculture-related AMR as a multidimensional One Health challenge rather than solely an animal-health or product-quality issue.

The seafood-transmission theme highlights weaknesses in protection across the *farm-to-fork* continuum. Intensive antimicrobial use can select for resistance at the production stage, while inadequate hygiene and processing controls may allow resistant organisms to reach consumers. EFSA estimated a prevalence of 19.6% for *Vibrio parahaemolyticus* in seafood and reported increasing resistance to several antimicrobials, including last-resort agents (EFSA Panel on Biological Hazards (BIOHAZ) et al., 2024). These observations strengthen the case for coordinated

antimicrobial stewardship, food-safety surveillance, and risk communication throughout seafood systems.

Occupational exposure adds a frequently neglected human dimension. Workers may be exposed through medicated feed, pond water, diseased aquatic animals, skin injuries, and contaminated equipment. Contextual evidence from Bangladesh suggests that farmers, hatchery workers, and fish handlers may experience repeated contact with these hazards, potentially facilitating colonization by resistant bacteria and transmission beyond the workplace (Hosain et al., 2026). Although direct disease-burden estimates remain limited, the available evidence supports incorporating worker protection and occupational surveillance into One Health AMR strategies.

Environmental dissemination demonstrates how aquaculture can create reservoirs that connect production systems with coastal ecosystems and communities. Antibiotic residues do not simply disappear after release; they may maintain selective pressure and support the transfer of resistance genes. Global evidence shows the co-occurrence of genes associated with resistance to tetracyclines, beta-lactams, quinolones, sulfonamides, aminoglycosides, and amphenicols in aquaculture environments, potentially contributing to multidrug resistance (Yang et al., 2020). Environmental monitoring and waste management are therefore central components of AMR prevention.

Governance gaps intensify the other pathways. Technical interventions are unlikely to be sustained when agencies use incompatible standards, data are not exchanged, and occupational or environmental indicators are excluded from national systems. A scoping review of One Health AMR governance emphasized the continuing need for harmonized standards, routine feedback, and regional data exchange (Aenishaenslin et al., 2024). Effective governance must therefore connect human health, veterinary services, aquaculture production, food safety, occupational health, and environmental monitoring.

Implications for Interdisciplinary Public Health Education

The educational relevance of this review is interpretive and should not be confused with evidence of educational effectiveness. No educational intervention, curriculum, student population, or learning outcome was examined. Nevertheless, the four themes provide a practical One Health case through which public health learners may examine how biological, occupational, environmental, and institutional factors interact within a single health problem.

Seafood-borne transmission may inform learning on food safety, *farm-to-fork* prevention, risk communication, and antimicrobial stewardship. Occupational exposure highlights competencies in worker safety, exposure assessment, preventive behavior, and communication with aquaculture communities. Environmental dissemination provides a basis for systems thinking about antimicrobial residues, ecological reservoirs, resistance-gene movement, and the return of environmental hazards to human food systems. Governance and surveillance gaps illustrate the importance of interdisciplinary collaboration, shared indicators, surveillance literacy, and cross-sector communication.

These implications may support case-based or problem-oriented discussion in public health education, particularly where learners must integrate epidemiology, environmental health, occupational health, food safety, health policy, and risk communication. The review does not establish that any particular teaching strategy improves knowledge or behavior. Instead, it identifies competencies and real-world connections that may be incorporated into future educational design and evaluated in dedicated educational research.

Public Health, Policy, and Practice Implications

The synthesis supports a coordinated policy response involving responsible antimicrobial regulation, integrated surveillance of human, animal, and environmental data, improved food-safety controls, and stronger protection for aquaculture workers. Non-antibiotic strategies—including vaccination, bacteriophages, *quorum quenching*, probiotics, prebiotics, and medicinal-plant derivatives—may reduce dependence on antimicrobials when accompanied by biosecurity and *specific-pathogen-free* stock (Bondad-Reantaso et al., 2023). These measures require governance arrangements that connect regulators, producers, health services, laboratories, workers, and coastal communities.

Limitations and Future Research

This review has several limitations. Only five studies were included, and the findings should therefore be generalized cautiously. The language eligibility criteria may have introduced geographical bias. The heterogeneity of study designs also meant that the synthesis was narrative and qualitative rather than quantitative. Future research should quantify the burden of AMR-related disease among aquaculture workers, an area in which data remain limited (Bang et al., 2025; Hosain et al., 2026). Intervention research is also needed to evaluate farm-level education, biosecurity, and alternatives to antibiotics (Bondad-Reantaso et al., 2023), while policy evaluations should assess the implementation of One Health principles and cross-sector data integration (Aenishaenslin et al., 2024). Dedicated educational studies would be required before drawing conclusions about curriculum effectiveness, One Health literacy, or learning outcomes.



Conclusion (خاتمة)

AMR in aquaculture is a multidimensional public health concern involving seafood-borne transmission, occupational exposure, environmental dissemination, and weaknesses in governance and surveillance. These pathways connect aquaculture practices with risks to workers, consumers, coastal ecosystems, and communities. The available evidence supports integrated One Health action that combines responsible antimicrobial use, cross-sector surveillance, food safety, worker protection, biosecurity, and waste management. The interconnected pathways also provide a relevant real-world context for strengthening interdisciplinary One Health perspectives in public health education, although the review did not evaluate educational interventions or learning outcomes. Future quantitative, intervention, and policy research is needed to estimate occupational disease burden, evaluate mitigation strategies, and assess the implementation of integrated surveillance and governance.



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