Pathogen transmission in aquaculture systems: emerging threats and control strategies

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Abstract

Aquaculture is the world's most rapidly growing food production sector, representing one-third of total food output. Similar to all intensive agricultural systems, the rise in infectious illnesses has negatively affected the expansion of marine aquaculture globally. Viral infections result in significant economic detriment to marine farming. The research presents an overview of the primary obstacles hindering managing and avoiding viral infections in marine aquaculture, while emphasizing potential remedies. The primary challenges are the rise in new viral diseases, wild dams, species that migrate, human activities, deficiencies in diagnostic instruments and knowledge, the transfer of virus-contaminated water from ships, and trade across borders. The suggested remedies for these issues encompass the formulation of biosecurity regulations at both global and national tiers, the execution of biosecurity protocols, vaccine innovation, the application of antiviral medications and probiotics to address infections caused by viruses, selectively breeding of immune to disease seafood, the utilization of enhanced diagnostic instruments, disease monitoring, and the advocacy of sound animal husbandry and handling practices. A comprehensive strategy that integrates many control methods will yield more effective and enduring solutions for reducing viral infections in aquariums than relying on one control method, such as vaccination.

Keywords: Pathogen, Aquaculture, Emerging threats, Strategies, Food production

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Introduction

Aquaculture has become vital to the world food supply (Boyd *et al.*, 2022). As global populations increase, more individuals depend on fish and other shellfish as their primary protein sources. Worldwide, seafood constitutes 16% of total animal protein intake, with an average annual consumption growth rate of 3.2% from 1960 to 2022, and worldwide consumption of fish is projected to treble by 2040. Seafood needs are satisfied by two sectors: wild-caught fishery and farmed. Over the past three decades, farmed fish cultivation has consistently risen by approximately 5.2% yearly, accounting for over fifty percent of global seafood consumption.

Aquaculture, or "underwater farming," is globally the most rapidly expanding food production sector (Heredia-Azuaje *et al.*, 2022). By 2018, it had surpassed beef and poultry output. It accounts for one-third of all world agricultural output, encompassing over 250 cultivated varieties of fish. Like other intensive farming systems, the effects of infectious illnesses in intensive aquaculture have resulted in significant consequences. Aquaculture, which is progressing and expanding, encounters obstacles akin to other livestock cultivation systems, including security, elevated stocking density, and access to water.

Aquaculture faces obstacles absent in other animal systems, notably the necessity for lifesaving equipment to maintain water quality (Ubina and Cheng, 2022). Each of these difficulties directly affects the danger of pathogenic microbes, jeopardizing animal health and adversely impacting the long-term viability of farmed techniques. Avoiding disease incidence is crucial for the fishing business (Hartigan, 2023). Antimicrobial substances are frequently employed to regulate and eradicate populations of microbes to alleviate the effects of disease outbreaks produced by pathogenic bacteria (Endale *et al.*, 2023). In this application, the term antimicrobial denotes any substance that inhibits or eradicates microbial proliferation, encompassing biocides utilized as cleaning agents and medicines for disease management (Anjum *et al.,* 2021). Several pathogens can adapt to and withstand these good's inhibiting or lethal effects, exacerbating the challenges of controlling illnesses in farmed animals (Shurson *et al.*, 2022).

This category includes illnesses caused by viruses, which result in substantial financial losses. Moreover, viral illnesses diminish fish welfare by inducing situations that negatively impact their wellbeing, including decreased feed consumption, atypical swimming behavior, mortality of infected fish, and detrimental relationships with others (Moreira *et al.*, 2021). Numerous scientists have indicated that viruses are the most prevalent entities in marine ecosystems. Their prevalence in oceans varies from 3×10^6 mL^-1 Virus Particles (VPs) in the deep sea to 1×10^8 mL^{-1} VPs in the coasts, diminishing in quantity with further distance from the coastline. Only a few viruses induce illnesses in aquacultured fish and are associated with significant financial losses, making these viruses prominent in numerous nations. It is essential to highlight that the most harmful fish infections have been identified. Countless harmful viruses probably remain unidentified due to insufficient surveillance (Buchheister and Bleich, 2021). The article identifies significant concerns about viral infections in agriculture and proposes solutions to these issues.

The difficulties of disease in agriculture are complex, primarily including novel pathogens and the rise of Antimicrobial Resistance (AMR) (Anjum *et al.*, 2021). For fisheries to prosper and sustain food supply, comprehensive plans and effective therapies are essential to address the threat of new and resistant diseases (Raman *et al.*, 2024). This research aims to elucidate the contemporary strategies employed by US finfish farmed operators to avert pathogen emergence and manage disease outbreaks (Hossain *et al.*, 2024; Leu and Tjoa, 2014). This strategy can be delineated into three tiers of defense that farmers use to safeguard their fish: complete protocols, sound husbandry techniques, and efficacious AMR (Milijasevic *et al.*, 2024). The effectiveness of several antibiotics is compromised by the rise of AMR, constraining therapeutic alternatives for infections. The article will emphasize the ongoing research domains aimed at enhancing preventative measures in farming without employing conventional antimicrobial agents. Exploring different methods is essential, as new and resistant diseases will continue (Padhi and Maurya, 2024). The options examined herein encompass vaccination, nutritional products (antibiotics, prebiotics, and immune-stimulating agents), innovative antibiotics (antimicrobial agents, peptides, and antivirulence agents), and choosing livestock for resistance to illness (selective development, genomic choice). The fishing industry's sustainability needs to discover strategies that minimize the reliance on antibiotics while enhancing and safeguarding the well-being of animals.

Contemporary Strategy for Disease Detection and Mitigation

Ensuring an efficient defense mechanism against infections is crucial for the overall viability and long-term viability of all forms of farming. The current disease prevention and mitigation strategy employed by finfish farming can be categorized into three tiers. Each stage contributes uniquely to the animal's overall defense against infections. Full instructions standardize how facility personnel employ to avert pollution and enhance their readiness for disease occurrences. Procedures are implemented on a facility-wide basis to limit the entry of pathogens into an aquaculture structure, prevent their dissemination inside, and avoid contamination of external habitats. Effective husbandry tactics pertain to the management of animals within aquaculture systems and promote the overall well-being of fish. These measures can alleviate stress, bolster the fish’s immune system, augment resistance to illness, and successfully prevent pathogens from abusing the fish and adversely affecting their well-being. If a virus successfully circumvents regulations and infiltrates an aquaculture structure, and the fish's innate immune defenses fail to eradicate the disease, suitable antimicrobial agents neutralize the danger and safeguard fish health.

Level 1: Thorough Protocols

The United States Department of Agriculture's (USDA's) Animal and Plant Health Inspection Services (APHIS) published a comprehensive strategy for managing the health of farmed aquatic animals. The National Farming Health Policy and Specifications (NAHP&S) is a collaborative, interagency governmental initiative to safeguard aquatic animal well-being. It was established to offer guidance to diverse parties involved in farming. All fishing businesses implement standardized guidelines that are easily accessible to all employees at the place of business. These guidelines must be tailored to each site, contingent upon the species cultivated and the obstacles encountered by the administration. Two essential sets of protocols for safeguarding the welfare of animals are biosecurity and illness response procedures. When executed correctly, aquaculture activities will mitigate the danger of pollution and illness (biological safety) and enhance the efficiency and readiness of responses to diverse livestock health hazards (illness management) (Figure 1).

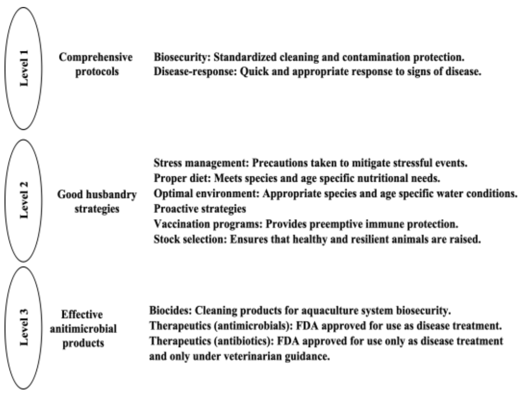

Figure 1: Levelled workflow of the model.

Biosecurity procedures denote measures implemented to avert the ingress of infections or contaminants into an aquaculture establishment and their dissemination within and beyond the facility. These represent common biosecurity issues, as the problems are typically universal across all aquaculture establishments. Elements of biosecurity procedures that mitigate standard risks encompass, but are not confined to, accessible personal safety gear (e.g., gloves, boots, face masks); sterilization foot baths; staff limitations in specific areas; quarantine measures for ill animals; and disinfection procedures for washing instruments and supplies utilized in proximity to life support networks or manufacturing animals. These procedures must delineate the appropriate timing for executing various cleaning processes. For instance, information regarding the suitable timing for cleaning tanks post-fish harvest and the procedures for sanitizing equipment utilized between various tanks or locations helps mitigate the transmission of harmful pathogens among fish populations.

Level 2: Effective Husbandry Tactics

Although rules are essential for safeguarding aquaculture systems, effective husbandry methods are crucial for fostering robust and resilient animals that can effectively combat infections. Good husbandry methods encompass several measures that improve or enhance animal health and well-being in aquaculture operations. Daily routines encompass managing anxiety, maintaining a balanced diet, and optimizing the outside environment. Proactive elements of adequate husbandry implemented before or at the onset of the breeding cycle encompass establishing vaccination protocols against probable infections and choosing disease-resistant livestock.

In the aquaculture industry, as in other food-animal production sectors, everyday stressors are frequently inevitable, making handling stress crucial for the health of animals. The biological impacts of stress on different fish species are extensively recorded, encompassing immunity repression, diminished growth and digestion efficiency, impaired reproductive procedures, and heightened mortality rates. Stresses in agriculture are diverse and can be categorized as physical (e.g., temperatures, dissolved oxygen), chemical (e.g., pH, insecticides), biological (e.g., stocking weight, worms), or operational (e.g., fish handling, shipping). In the realm of disease control in aquaculture, it is crucial for producers to comprehend the effects of stressors on their livestock and to recognize and mitigate these sources of strain. The most foreseeable adverse consequence of stress is weakening the immune response, resulting in increased vulnerability to disease and deaths in aquaculture systems for fish.

Fishery producers must guarantee that the water's environmental variables (e.g., temperatures, oxygen concentration, viscosity, pH, ammonium, etc.) remain within the appropriate range for their cultured species to mitigate observed chemical and physical stresses. Likewise, stocking density must align with industry standards to alleviate the stress caused by overcrowding.

Level 3: Efficacious Antibacterial Agents

The tertiary level of defense against disease consists of chemical agents with established antibacterial efficacy. These products significantly vary in their chemical makeup, mode of behavior, application methods, types of bacteria targeted, chemical retention and degrading processes, and the threats they bring to environmental, living things, and human well-being. Antimicrobial goods can be categorized into chemicals for sanitation and medicines for disease management.

Biocides, including disinfectants like bleach, exhibit broad-spectrum lethality and are employed for general sanitation and extensive eradication of undesirable bacteria and pests. These agents generally exhibit indiscriminate lethality towards many organisms, possess several molecular targets, and demonstrate variable efficacy contingent upon the targeted pathogen. It is imperative to adhere closely to the usage directions on the item's label to mitigate unwanted impacts on organisms that are not the target, including fish from farms. These biocidal antibacterial products are crucial elements of a security program, as outlined in the initial tier of disease abatement.

In contrast to biocides, medicinal antimicrobial agents exhibit more excellent selectivity in their mechanisms of action, specifically targeting microbes such as the cell wall, enzymatic functions, and genes. They are suitable for application in aquaculture and are efficacious in managing particular diseases, including bacteria, fungi, and protozoan worms. These goods are classified as pharmaceuticals by the Food and Drug Administration (FDA), defined as a material designed to evaluate, cure, reduce, treat, or protect illnesses in humans or other creatures. Sixty-eight Bacteria belong to this category of medicinal antibiotics that have transformed modern medicine's capacity for curing diseases in both people and animals.

Biosecurity Protocols in Aquaculture

Biosecurity encompasses any oversight measures implemented to avert the entry of pathogens into aquaculture facilities. Farm-level biosecurity precautions encompass a range of activities, including stringent quarantine protocols, equipment hygiene, egg sterilization, traffic regulation, water treatment, utilization of uncontaminated feed, and proper disposal of deceased animals. These protocols must be enacted during the arrival of new stock to mitigate infections and prevent their transfer between stocks. The diligent implementation of security protocols can mitigate many aquaculture illnesses. Reducing the amount of stocking is a crucial strategy for managing fish illnesses in farming. Reduced stocking densities serve as an effective preliminary measure during ectoparasite outbreaks, complemented by enhanced water flow to facilitate a more efficient flushing of the worms.

Quarantine and Travel Restrictions in Aquaculture.

Quarantine involves isolating aquatic animals of unknown well-being brought from external sources before integrating them into the existing stock. During this period, meticulous observation of pets and the application of suitable diagnostic tests are essential. The quarantine period varies from fourteen days to three months. Upon identifying the condition, therapy should be administered using effective medications for the designated duration. Prophylactic therapies can prevent clinical signs, but the misuse of antibiotics can lead to the development of antibacterial resistance.

Disinfectants and Chemicals in Fisheries

Disinfection entails the application of chemical or biological treatments to eliminate bacteria, often from inanimate surfaces. In fishing, disinfecting agents encompass substances utilized to eliminate germs on the exterior of fish eggs. These compounds are employed in aquatic animal husbandry facilities as components of biosecurity protocols to mitigate the dissemination of aquatic animal illnesses. Proper cleaning and airing of the pond might be an exceptional way to control several fish infections in agriculture. A pond with high-quality, fresh, and well-aerated water is essential for cultivating healthy fish and is crucial for species endemic to oligotrophic waterways, such as the salmonids.

Aqueous ammonium substances, formalin, peroxide of hydrogen, isopropyl alcohol, glucoprotamine, chlorinated iodine, and iodine are predominantly used as disinfectants in farming. In addition to their toxicity to fish, the quaternary ammonium compounds are proficient at eliminating organisms on inanimate surfaces. Chlorine is utilized, but it must be sufficiently mitigated to prevent fish mortality. Equipment treated with iodine-based chemicals must be washed before use due to their potential toxicity.

Monitoring for Fish Infections in Farming

Aquatic health strategy or policy formulation for aquatic animal welfare is unfeasible without high-quality health information. This data is applicable for disease management, quarantine measures, and health accreditation, attainable through the implementation of aquatic animal monitoring. Surveillance to prevent the spread of illnesses is a crucial component of any biosecurity tactics, aimed at identifying potential pathways for disease entry into aquatic facilities and detecting the appearance of new diseases, thereby enabling the implementation of control measures before infectious agents proliferate. Regular monitoring is essential to mitigate the risk of contagious agent dissemination. Monitoring for diseases must be a fundamental and critical component of all governmental health programs.

- *Passive Monitoring*

Data gathered for alternative purposes can be employed to assess the health state of aquatic animals and to devise suitable strategies to mitigate the spread of diseases. Information can be acquired via labs, field visits, research initiatives, farmers, and aquaculturists. Continuous monitoring is effective for the early identification of developing diseases. Its shortcoming lies in its inability to estimate the prevalence and frequency, and its incapacity to establish independence from sickness.

- *Proactive Monitoring*

Active monitoring involves conducting surveys to ascertain the state of a particular disease. Indications of sickness within a designated community, and, in some instances, offer evidence to demonstrate that the defined community is devoid of a specific disease. The outcomes of active monitoring are skewed unless meticulously developed and examined. Proper analysis can yield accurate assessments of illness occurrence and prevalence in a particular area. The benefits encompass superior quality of data, lower expense, and quicker data collection compared to passive monitoring.

Significance of Diagnostic Techniques in the Treatment and Control of Viral Diseases in Aquaculture

Diagnosing aquatic animals based on clinical signs is nearly impossible due to their marine environment and rapid movement, which hinder close visualization and inspection for clinical aberrations. Fast and precise tests are essential for avoiding and managing infectious illnesses. Diagnostic testing for the diagnosis of fish diseases encompasses standard microbiology, immunoserological, and molecular techniques. Molecular-based approaches that are rapid and precise have emerged as significant diagnostic instruments. Lateral flow antibodies, DNA microarrays, proteins, or carbohydrates can be deposited on a solid microarray surface to detect various target molecules tagged with fluorescent. In fish disease diagnosis, pathogens are identified in tissue samples using fatal sampling instead of antibody identification, which indicates a specific disease; however, nonlethal testing is advised for high-value species such as decorative fish.

Diagnostic procedures are not anticipated to achieve complete sensitivity and specificity. Diagnostic test procedures must be chosen and evaluated according to their efficacy in the specific application conditions to prevent incorrect classification. Diagnostic methods in biosecurity programmes are employed to identify the development and monitor the spread of infectious pathogens in fish populations. Four primary biosecurity goals for which diagnostic procedures are frequently used include: demonstrating infection-free status in fish farming for accreditation purposes, screening fish before their introduction to a facility, detecting infected fish promptly during an incubation time frame, and confirming suspected or clinical cases.

Disease Control Policies

Disease prevention measures are strategies, frameworks, or actions governments, organizations, and individual aquaculturists implement to avoid or mitigate disease incidence. International nations and organizations have created multiple papers addressing disease control policy. Figure 2 illustrates a framework comprising global organizations, multinational corporations, national entities, and farm-level groups executing disease control programs. The model is an intergovernmental organization at the global level tasked with implementing fish disease management programs.

Member countries are required to report all instances of diseases enumerated in the aquatic animal health code. Multinational unions formulate fish health policies to provide uniform disease management tactics among all member nations. The European Union (EU) has established a fish health code, whereby its member nations concur on the list of infections to be managed by mutually accepted control and prevention measures. International unions sometimes establish cross-national teams tasked with illness surveillance and study. Such endeavors facilitate the flow of information and technical proficiency.

National disease management strategies must encompass the prevention of exotic disease outbreaks, early illness detection, wellness tracking, licensing of live seafood and aquatic goods exported, movement restrictions, and zoning. Qualified professionals must endorse all health certificates. National strategies must incorporate legal restrictions for inspections of aquaculture facilities, testing and sampling initiatives, epidemic inquiries, and enforcement of prevention and control protocols. National regulations are tasked with ensuring that all pertinent records are maintained for designated periods. To ensure the efficacy of a disease tracking structure, it is imperative to maintain movement data of live seafood and its derivatives for a while, allowing access for fish safety inspections. Likewise, fish behaviour and death data should be kept for multiple years.

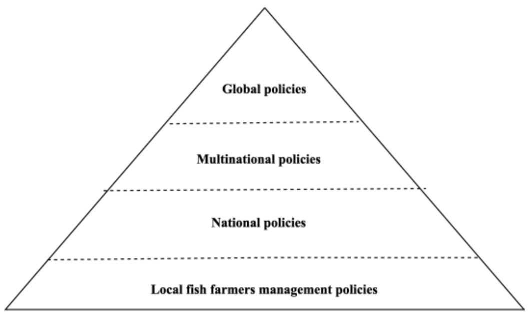

Figure 2: Disease control policies.

Obstacles in the Prevention and Management of Ichthyic Pathologies

In comparative terms, it is accurate to assert that infectious disease management in fish farming is more complex than in earthly animal husbandry due to the aquatic environment in which fish reside and the inherent characteristics of fish themself. Fish cannot be monitored as closely as terrestrial animals; their surroundings can rapidly propagate spreading illnesses, fish are not readily captured without inducing stress, frequently congregate in schools, and diseases are often challenging to identify and define. Another significant challenge lies in identifying fish diseases; in land animal illness diagnostics, the specific animal serves as the unit of concern. The situation differs in terms of agricultural illness inquiry due to the characteristics of the aquatic environment in which fish reside. A sickness can spread rapidly, potentially becoming the entire tank a source of infection for healthy animals. In this instance, the focus is not on an individual fish but the whole tank, which requires examination and assessment. Tests must be obtained from fish and liquid to assess critical parameters such as pH, substrate illnesses, and viscosity, complicating the identification of aquatic animals.

Conclusion

Marine aquaculture has substantial potential to enhance human livelihoods and significantly contribute to achieving the Sustainable Development Goals (SDGs). To do this, it is essential to surmount various obstacles impeding effectiveness in managing and avoiding viral illnesses that result in significant economic losses in aquaculture. This research illustrates that an integrated strategy incorporating multiple approaches, including vaccine growth and vaccinations, interest in antiviral-nature drug utilization, breeding selectively for resistance to disease, monitoring, policy development, and the execution of biological safety measures execution, is likely to provide a more efficient and enduring remedy.

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