Antibiotic Overuse in Aquaculture : Unveiling the Curse on Ecosystem Health

Vajagathali Mohammed

Department of Forensic Science, Yenepoya Institute of Arts Science Commerce and Management, Yenepoya University, Mangaluru 575013, Karnataka, India

Email: vajasmash@gmail.com

Introduction

Recently, the escalating concern over antibiotic overuse in aquaculture has become a focal point, raising serious questions about its impact on the delicate equilibrium of ecosystem health. The backdrop of this issue lies in the pivotal role of aquaculture within the global food production landscape, where the growing demand for seafood has driven the industry to new heights. However, this success story is tainted by the increasing reliance on antibiotics to combat the challenges of intensive aquaculture practices. The use of antibiotics has surged due to factors such as overcrowded aquatic environments, stressful conditions, susceptibility to diseases, and the pursuit of high yields. Yet, the effects of this widespread antibiotic use extend far beyond the boundaries of aquaculture farms, infusing marine ecosystems and posing a considerable threat to their intricate balance. The intensification of antibiotic usage in aquaculture exacerbates ecological concerns and jeopardizes the health of the target species and non-target aquatic organisms. As antibiotic residues leach into water bodies, they contribute to the development of antibiotic-resistant bacteria, thus amplifying the global crisis of antimicrobial resistance. Consequently, addressing antibiotic overuse in aquaculture is not merely a matter of industry regulation; it emerges as an urgent imperative for safeguarding ecosystem health and preserving the delicate equilibrium of our oceans. The significance of this issue cannot be overstated, as unchecked antibiotic use not only jeopardizes the sustainability of aquaculture but also endangers the biodiversity and overall resilience of aquatic ecosystems.

This paper explores the multifaceted dimensions of antibiotic overuse in aquaculture, aiming to unravel its origins, consequences, and the imperative need for a paradigm shift towards more sustainable practices. By exploring the complex interplay between aquaculture practices and ecosystem health, this research sheds light on the intricate web of consequences that extend beyond the confines of fish farms. The paper will also scrutinize existing regulatory frameworks, assess their effectiveness, and propose actionable strategies to curtail antibiotic overuse while promoting a balanced and sustainable coexistence between aquaculture and its inhabitable ecosystems. Through this comprehensive examination, the paper aspires to contribute to the ongoing discourse on responsible aquaculture practices and environmental stewardship amid burgeoning global food demands.

Antibiotic Utilization in Aquaculture

Antibiotics are commonly used in aquaculture to treat and prevent bacterial infections in fish and other aquatic organisms. Oxytetracycline, a broad-spectrum antibiotic, is administered at a rate of 50-100 mg/kg body weight either orally through medicated feed or via immersion baths. Treatment duration may vary but is usually around 5-10 days. It is commonly used in aquaculture to treat various bacterial infections in fish, such as bacterial hemorrhagic septicemia and furunculosis. Florfenicol is administered orally via mediated feed at 10-20 mg/kg body weight effectively against a wide range of Gram-negative and some Gram-positive bacteria. Treatment duration may vary but is typically around 10 days. A fluoroquinolone antibiotic named enrofloxacin administered orally via mediated feed at 10-20 mg/kg is effective against many Gram-negative and some Gram-positive bacteria. Treatment duration may vary but is typically around 5-10 days. Trimethoprim, often combined with sulfonamides, is used in aquaculture to treat bacterial infections, particularly those caused by Gram-negative bacteria. They are administered orally via mediated feed at a rate of 100-200 mg/kg body weight. Treatment duration may vary but is typically around 7-10 days. A tetracycline antibiotic named Doxycycline administered orally via mediated feed at a rate of 10-20 mg/kg is used to treat bacterial infections in fish, particularly those caused by Gram-negative bacteria, by also being effective against some intracellular pathogens. Treatment duration may vary but is typically around 7-10 days. Amoxicillin is also used to treat bacterial infections and is administered orally via mediated feed at 10-20 mg/kg body weight. Treatment duration may vary but is typically around 7-10 days.

Aquaculture operations often use antibiotics to prevent and treat bacterial infections in fish populations. Overcrowded conditions, high stocking densities, and stressful environments can increase the susceptibility of fish to diseases, leading to a perceived need for antibiotic use. Economic factors, such as the desire to maximize production and profits, can drive the use of antibiotics in aquaculture. Many aquaculture producers, especially small-scale farmers, may have limited knowledge about the risks associated with antibiotic overuse and the importance of responsible antibiotic stewardship. Education and outreach efforts are needed to raise awareness about alternative disease management strategies and the potential consequences of antibiotic misuse. Pressure from supply chain actors, such as processors, retailers, and consumers, to meet demand for cheap and readily available seafood products can incentivize fish farmers to use antibiotics indiscriminately to maintain production levels and meet market demands.

Environmental consequences

Antibiotic residues in aquatic environments can promote the development and spread of antibiotic-resistant bacteria. Bacteria in the water, sediment, and biofilms may be exposed to sub-lethal concentrations of antibiotics, leading to the selection of resistant strains. Antibiotic-resistant genes can be transferred horizontally between bacteria in aquatic environments, including those in sediment and biofilms. This genetic exchange can contribute to the dissemination of antibiotic resistance within aquatic ecosystems. Antibiotic residues can alter the composition and function of microbial communities in aquatic ecosystems. This disruption can affect nutrient cycling, decomposition processes, and ecosystem stability (Figure 1). Some antibiotics can exhibit ecotoxic effects on aquatic organisms, even at low concentrations. These effects may include toxicity to fish, inhibition of algal growth, and disruption of aquatic food webs. Antibiotic residues in water systems can enter the food chain by consuming contaminated seafood or water. Prolonged exposure to low levels of antibiotics may contribute to the development of antibiotic resistance in human pathogens, posing risks to human health. Antibiotic residues in water systems can harm non-target organisms, including aquatic plants, invertebrates, and fish. Exposure to sub-lethal concentrations of antibiotics may disrupt physiological processes, impair growth and development, and increase susceptibility to diseases. Antibiotic use creates selective pressure on bacteria present in aquaculture settings. Bacteria susceptible to antibiotics are killed off, while those with genetic mutations or mechanisms that confer resistance to antibiotics survive and multiply. Bacteria can exchange genetic material through conjugation, transformation, and transduction. Antibiotic-resistant bacteria and resistance genes can spread beyond aquaculture facilities and potentially impact wild aquatic species.

Aquatic environments contaminated with antibiotic-resistant bacteria can serve as reservoirs for resistant pathogens that may harm human health. Consumption of contaminated seafood or recreational activities in polluted water can result in human exposure to antibiotic-resistant bacteria. The spread of antibiotic resistance in aquaculture environments can diminish the effectiveness of antibiotics used for both veterinary and human medicine. This can complicate the treatment of bacterial infections in both animals and humans and may lead to increased morbidity, mortality, and healthcare costs. When oxytetracycline enters aquatic ecosystems through discharge from aquaculture facilities or runoff from fish farms, it can persist in sediments and water bodies. This persistence can lead to the development of antibiotic-resistant bacteria in the environment, disrupting the natural balance of microbial communities. Florfenicol can accumulate in sediments and water bodies, persisting for extended periods. Sulfadiazine and trimethoprim are often used to treat bacterial infections in fish. These antibiotics can enter aquatic ecosystems through discharge from aquaculture facilities or effluent runoff. Enrofloxacin can enter aquatic ecosystems through discharge from fish farms or via runoff from surrounding agricultural areas.

Human health concerns

Antibiotic resistance transmission pathways pose significant human health concerns, as they contribute to the spread of antibiotic-resistant bacteria and compromise the effectiveness of antibiotics in treating infections. Environmental reservoirs within healthcare settings, such as sinks, drains, and medical devices, can harbor antibiotic-resistant bacteria and serve as transmission sources. Antibiotic-resistant bacteria can be transmitted to humans by consuming contaminated food, particularly meat, poultry, and seafood, from animals treated with antibiotics in agriculture and aquaculture (Figure 1). Inappropriate use of antibiotics in human medicine, agriculture, and veterinary medicine contributes to the selection pressure for antibiotic-resistant bacteria (Table 1). Non-compliance with prescribed antibiotic regimens or failure to complete the entire course of treatment can promote the survival and proliferation of antibiotic-resistant bacteria within the human host, facilitating transmission to others. The use of antibiotics in aquaculture can lead to the presence of antibiotic residues in seafood products.

Aquaculture operations may use various chemicals, such as disinfectants, pesticides, and antifungal agents, to maintain water quality and control diseases. Residues of these chemicals can accumulate in aquaculture products and may pose risks to human health if consumed excessively. Aquatic environments can be contaminated with heavy metals and POPs from industrial activities, agricultural runoff, and atmospheric deposition. Seafood products can be contaminated with bacteria, viruses, parasites, and other pathogens during production, processing, and handling. Consumption of contaminated seafood can lead to foodborne illnesses, such as bacterial infections, viral infections, and parasitic infections. Cross-contamination of seafood products with allergens, such as crustacean shellfish, fish, and mollusks, can occur during processing and handling.

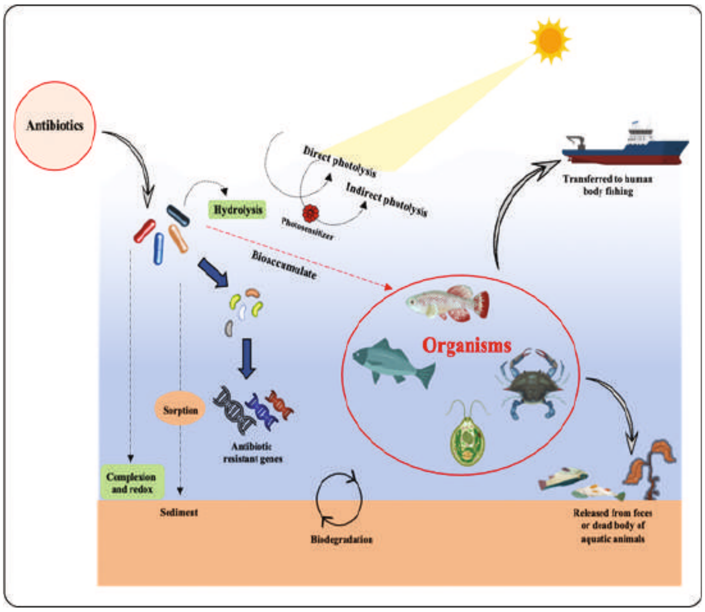
Table 1. Ecological and human health effects of antibiotics.

Individuals with allergies to seafood allergens may experience allergic reactions upon consuming contaminated products, even in trace amounts. Mislabeling and fraudulent practices in the seafood industry, such as species substitution and misrepresenting country of origin, can compromise the safety and authenticity of aquaculture products. Workers may be exposed to these chemicals through inhalation, dermal contact, or accidental ingestion, leading to acute or chronic health effects, such as respiratory irritation, skin rashes, or systemic toxicity. Aquaculture workers may be exposed to various biological hazards, including bacteria, viruses, parasites, and fungi, in water bodies and aquatic organisms. Contact with contaminated water or infected fish can lead to the transmission of infectious diseases, such as bacterial infections, viral diseases, and parasitic infections. Through repeated exposure, some aquaculture workers may develop allergic reactions or sensitivities to aquatic organisms, such as fish, shellfish, or algae. Allergic reactions can manifest as skin rashes, respiratory symptoms, or anaphylaxis.

Table 1. Ecological and human health effects of antibiotics.

S.No.	Antibiotic name	Target organisms		Residue compound	Antibiotic resistant genes	Human health risks
		Gram positive	Gram Negative			
1	Oxytetracycline	Staphylococcus, Streptococcus, Clostridium	E. coli, Salmonella, Vibrio	Oxytetracycline and 4-Epitetracycline	tet(A), tet(B), tet (C)	Gastrointestinal disorders
2	Florfenicol	Streptococcus spp., Staphylococcus spp.	Aeromonas spp., Edwardsiella spp.	Florfenicol amine	floR, fexA	Hepatotoxicity and nephrotoxicity
3	Enrofloxacin	Streptococcus, Staphylococcus	E. coli, Psuedomonas, Aeromonas	ciprofloxacin	qnr, aac(6')-Ib-cr, oqxAB	Gastrointestinal disturbances, hypersensitivity reactions
4	Sulfonamides	Streptococcus spp., Staphylococcus spp.	E. coli, Haemophilus	Sulfamethazine and Sulfamethoxazole	sul1, sul2, sul3, sul4, sul5, dfrA, dfrB	Allergic reactions, hemolytic anemia
5	Trimethoprim	Staphylococcus aureus, Streptococcus pneumoniae	E. coli, Klebsiella pneumoniae, Haemophilus influenzae	1,3,5-triazine derivatives	dfrA, dfrB	Headache, vomiting, kidney damage
6	Quinolones	Streptococcus pyogenes, Clostridium perfringens	Shigella spp. Pseudomonas aeruginosa, Klebsiella pneumoniae	Oxolinic acid	qnr, aac(6')-Ib-cr, qepA	Gastrointestinal upset and hypersensitivity reactions
7	Doxycycline	Staphylococcus aureus, Enterococcus	Haemophilus influenzae, Neisseria gonorrhoeae, Acinetobacter	Doxycycline hydrochloride	bla, qnr	Gastrointestinal disturbances and photosensitivity
8	Nitrofuranes	Streptococcus spp.	Aeromonas spp., Edwardsiella ictaluri, Flavobacterium spp.	Semicarbazide and 3-Amino-2-oxazolidinone	nfsA, nimA, nimB, nimC, nimD, nimE, fubA	Gastrointestinal disturbances, hypersensitivity reactions

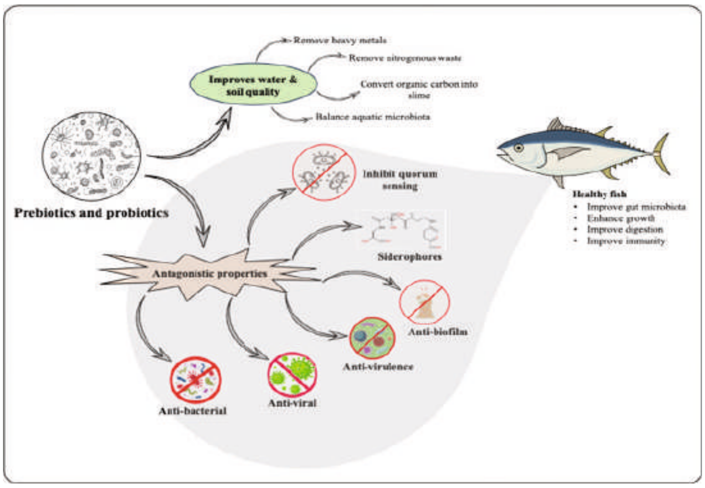
Figure 1. Effects of antibiotics on aquatic organisms.



Alternatives to antibiotics use

Probiotics and prebiotics offer promising alternatives to antibiotic use in aquaculture by promoting the growth of beneficial microorganisms in the gut microbiome of farmed fish, enhancing immune function, and reducing the risk of disease (Figure 2). Probiotics are live microorganisms that confer health benefits when administered in adequate amounts. In aquaculture, probiotics are typically administered orally or added to fish feed. *Lactobacillus* species are commonly used probiotics in aquaculture due to their ability to produce lactic acid and other antimicrobial compounds. *Bifidobacterium* species are another group of probiotics used in aquaculture. They contribute to gut health and immune function. *Bacillus* species are spore-forming bacteria that produce enzymes that aid in digestion and compete with pathogenic bacteria. Examples include *Bacillus subtilis* and *Bacillus licheniformis*. The yeast species *Saccharomyces cerevisiae* is used as a probiotic in aquaculture to improve nutrient utilization, enhance immune function, and reduce stress. It can also help mitigate the effects of toxic compounds in the gut. *Enterococcus* species are lactic acid bacteria that contribute to gut health and immune modulation in fish. They can inhibit the growth of pathogenic bacteria through competitive exclusion and the production of antimicrobial compounds.

Figure 2. Application of prebiotic and probiotics in aquaculture.



Probiotics and prebiotics can be administered through fish feed, water additives, or direct application to the aquaculture environment. Encapsulation techniques may be used to protect probiotic bacteria from harsh environmental conditions and ensure their survival until they reach the gut. Prebiotics can be incorporated into fish feed or provided as supplements to promote beneficial gut bacteria growth. Prebiotics are non-digestible fibers that serve food for beneficial gut microorganisms. They encourage the development and activity of probiotic bacteria, enhancing their beneficial effects. Fructooligosaccharides (FOS) are naturally occurring prebiotics in fruits, vegetables, and certain grains. They stimulate the growth of beneficial bacteria, such as *Lactobacillus* and *Bifidobacterium*, in the gut. Mannanoligosaccharides (MOS) are derived from yeast cell walls and have prebiotic properties. They help support gut health by binding to harmful bacteria and preventing their attachment to the intestinal lining. Galactooligosaccharides (GOS) are oligosaccharides composed of galactose molecules. They promote the growth of beneficial bacteria in the gut and help maintain a healthy microbial balance. Immunostimulants stimulate the immune system to enhance the host's ability to fight off infections and diseases.

In aquaculture, immunostimulants are used to boost the immune response of farmed fish and shellfish, thereby improving disease resistance and overall health by enhancing immune response, increasing resistance to pathogens, and activating immune cells. Immunostimulants may stimulate the production of immune factors, such as cytokines, interferons, and antimicrobial peptides. These play critical roles in orchestrating the immune response and combating infections by adaptive immunity priming and reduced reliance on antibiotics. Integrated Pest Management (IPM) in aquaculture involves using various strategies to control pests and diseases while minimizing dependence on antibiotics. Introducing natural predators, parasites, or pathogens that target pest species can help control their populations. Breeding programs to select disease-resistant strains of aquaculture species can help reduce susceptibility to common diseases, reducing the need for antibiotics. Providing a balanced diet with optimal levels of essential nutrients can improve aquaculture species' overall health and immune function, reducing their susceptibility to diseases.

Combining aquaculture with other farming activities, such as horticulture or livestock farming, in an integrated system can create ecological balances that naturally control pest populations, reducing the need for chemical interventions. Advanced diagnostic techniques such as PCR (Polymerase Chain Reaction) and ELISA (Enzyme-Linked Immunosorbent Assay) can help identify diseases early, allowing prompt intervention with targeted treatments rather than broad-spectrum antibiotics.

Future directions and conclusions

Future directions and conclusions regarding antibiotic use in aquaculture are heavily influenced by the need for sustainable and responsible practices in the industry. As outlined in integrated pest management (IPM) approaches, there will be increasing emphasis on developing and implementing alternative strategies to antibiotics in aquaculture. Collaboration between aquaculture producers, researchers, government agencies, and environmental organizations will be crucial in addressing antibiotic resistance and promoting sustainable aquaculture practices.

Growing consumer awareness of antibiotic use's environmental and health impacts in aquaculture will drive demand for sustainably produced seafood. There will be increased investment in research and development to discover new methods for disease prevention and control in aquaculture. International collaboration and cooperation will be essential given the global nature of aquaculture production and antibiotic resistance issues. Forums such as the Food and Agriculture Organization (FAO) of the United Nations and regional aquaculture organizations will facilitate information exchange and policy development on a global scale. Economic factors, including the cost-effectiveness of alternative strategies compared to antibiotics, will influence their adoption by aquaculture producers. In conclusion, the future of antibiotic use in aquaculture is moving towards greater sustainability, responsibility, and innovation. While antibiotics will likely continue to play a role in disease management in the short term, there is a clear trend toward reducing reliance on them in favor of alternative approaches that prioritize animal health, environmental protection, and public health. By embracing these principles and working collaboratively, the aquaculture industry can ensure a more resilient and sustainable future for seafood production.