Aquaculture Reimagined: Modern Approaches to Sustainable Fish Farming
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Chapter 20

Common Bacterial Diseases in Aquaculture

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Abstract

Disease is a major threat in aquaculture production system. Among different diseases bacterial disease, creating significant impact on animal production, is a major issue influencing aquaculture productivity, growth and evolution. Bacteria are naturally present in the aquatic environment and whenever any environmental condition favours or host becomes immunologically suppressive, they take advantage and cause huge mortality. Some of the bacteria are essentially opportunist pathogen and very few appear to be obligatory parasites also. Early detection of pathogen and proper diagnosis is the key to successfully prevent and cure the diseases from the culture system. An extensive review of chief bacterial infection affecting aquaculture provided in this chapter. Furthermore, emphasis is given on an alarming global concern of antimicrobial resistance (AMR) and zoonotic potential of many bacterial species.

1. Introduction

Aquaculture is a blooming sector worldwide. Fish is considered as a cheap and easily digestible protein source and rich in different minerals and fat. To maintain the quality nutrition of the growing population in this present time, fish serves as a unique and inevitable source of protein. According to FAO, more than 40 percent of the world population cannot afford a healthy

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diet and malnutrition is a matter of serious concern among different counties (FAO, 2024). In this aspect, aquaculture sector is playing a huge role to ensure the supply of healthy food. Traditionally, extensive fish farming was primarily practiced where very low stocking density was maintained in a greater area. But over the decades, the requirement of fish has significantly elevated and to maintain an uninterrupted supply of fish, there was shift of farming practices from extensive to intensive. Intensification of the culture system has increased the production but leads to stress which increases the susceptibility to different microorganisms. Besides this, transportation of live animal and their products across the countries is one of the key factors of spreading different infectious diseases into the culture system. Stress refers to physical or chemical stimuli that trigger biological reactions that might guide to disease or death. The concept of host, pathogen and environment interaction comes into this point. The Snieszko Circle emphasises that disease outbreaks are often caused by an imbalance of these three factors. For example, poor environmental circumstances might weaken the host, increasing the pathogen's capacity to infect. Similarly, a highly virulent pathogen can overcome even a healthy host's defences, especially in harsh climatic conditions (Snieszko, 1974). This approach is critical for understanding disease management in aquaculture since it addresses not only pathogens but also host health and optimises environmental circumstances.

The environment of aquatic animals is entirely different from terrestrial animals. Fish are cold blooded animal and their physiology and health are influenced by several environmental factors like pH, dissolved oxygen, temperature *etc.* Fish is subjected to a various common disease which includes bacterial, viral, fungal and other ectoparasite-related illnesses. Bacteria are ubiquitous in aquatic environments. Most of the bacterial pathogens are typically found as a normal flora of water. Fish disease occurs when they are stressed from bad environmental conditions, inadequate nutrition, or poor husbandry procedures. Fish are exposed to a varied range of bacterial diseases.

The majority of bacterial pathogens causing disease in fish come under Gram-negative groups, however some are 'Gram-positive' rods and a few included in acid-fast group in the aquatic ecosystem. Major bacterial pathogens of economically important fish are given in figure 1. Bacterial infections raise public health concerns because some bacteria found in fish and their products have zoonotic potential. Several bacterial species have been transmitted from fish to humans due to consumption of raw or uncooked food or the handling of infected fish.

Traditionally, disease outbreaks were assigned to specific pathogens, with a single bacterium, virus, or parasite assumed to cause a particular disease. But in current situation, the transition from a "one pathogen, one disease" model to a "one disease, multiple pathogens" concept has come. According to current research, many aquaculture diseases are caused by interactions between numerous pathogens. Fish infections are frequently caused by bacteria, viruses, fungus, parasites, or a mix of these pathogens. Among this bacterial fish infection are thought to constitute a significant issue in the aquaculture industry (Mohd-Aris *et al.*, 2019). Fish disease causing bacteria can be broadly classified into two groups i.e. gram positive and gram negative. Majority of the fish pathogenic bacteria belongs to gram-negative groups including the families of aeromonadaceae, enterobacteriaceae, vibrionaceae or pseudomonadaceae. Members of the gram-positive bacterial group is less frequently seen but they are also potent pathogenic. Among the gram-positive group streptococcaceae, acid fast bacteria (mycobacteriaceae), *etc.* is important.

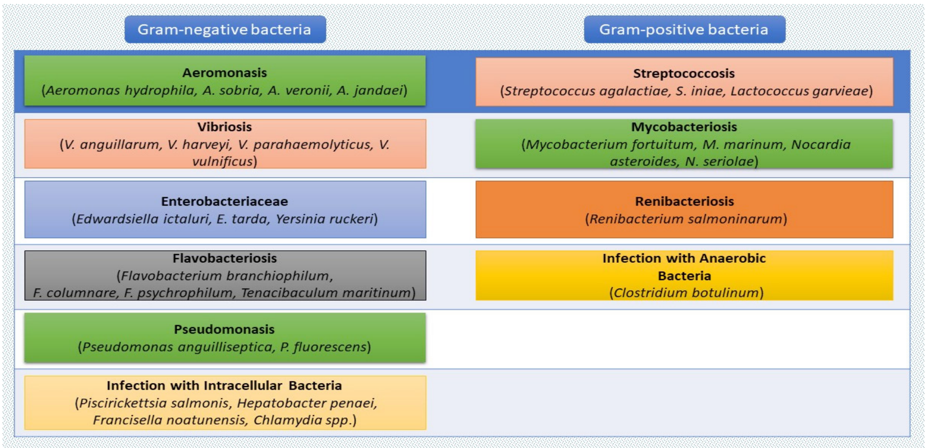

Figure 1: Principal bacterial pathogens in aquaculture

2. Common Bacterial Diseases

2.1. Motile Aeromonad Infection

Motile Aeromonad Infection (MAI) is linked to multiple members of the Aeromonas genus, with *Aeromonas hydrophila* being the most significant among them. *Aeromonas hydrophila* problem is the major economic problems that distressed fresh and warm water fish farming globally, particularly in China and India in the past ten years. It is frequently found in the mucus membrane and viscera of clinically healthy fish. The greatest occurrence is in waters contaminated with organic matter. The Fish are at risk of infection at any time due to the widespread presence of the organism, but carp are most frequently affected by severe outbreaks in summer when water temperatures are growing and the fish are stressed from unfavourable cold conditions (Bullock *et al.,* 1971).

2.1.1. Clinical Signs

Signs vary from skin lesions with or without skin lesions from superficial to profound skin lesions to a standard gram-negative bacterial septicemia.

Variably sized skin necrosis patches and bleeding surrounding the fin base (Wretlind *et al.,* 1973). Upon necropsy, internal organs reveal congestion and hemorrhages throughout the viscera. Usually, when the kidney and spleen are cut, the semifluid contents leak out, that is why the condition was previously known as *A. liquefaciens*.

2.1.2. Control and Treatment

In order to prevent MAI in fish, many vaccines have been created using lipopolysaccharide, outer membrane protein, entire cells and extracellular components. That being said, there is currently no commercial vaccination against *A. hydrophila* available. This is because it has extremely diverse biochemical and serological profiles, which is the primary obstacle to creating a successful commercial vaccine (Poobalane *et al.,* 2010).

2.2. Furunculosis

A dangerous septicemic bacterial disease mostly affecting salmonid fishes called furunculosis and it is also reported in other commercially cultivable species like gold fish and cyprinids. The existence of "blisters" or furuncules on the surface of salmonids with a persistent infection is the source of the disease's common name. Gram-negative *Aeromonas salmonicida*, which was identified by (Griftin *et al.,* 1953), is the bacterium that causes the infection. It was recently shown that a strain of *A. salmonicida* is actually responsible for the ulcer that was previously thought to be caused by *Hemophilus piscium*.

2.2.1. Clinical Signs

Clinically infected fingerlings typically show erosion of the pectoral fins and hemorrhages occurs near the base of the fins. On the ventral surface, petechial hemorrhages and bloody or hemorrhagic vents are commonly seen. Adults with a prolonged infection may develop typical "furuncules," or blisters on the skin that may contain blood and an ethereal yellow material. Since an acute infection typically results in significant bacteremia and death before macroscopic lesions emerge, this is rarely observed in small or fingerling fish (Snieszko and Bullock, 1975).

2.2.2. Control and Treatment

Maintaining a robust program of hatchery inspections and a disease classification system is a fundamental step in preventing significant infectious fish infections. Regularly disinfecting all eggs from vulnerable species with organic iodine compounds at 100 ppm of active iodine for 10 minutes is recommended (Amend, 1974).

2.3. Edwardsiellosis

Economically significant fish species, such as the Japanese eel (*Anguilla japonica*), channel catfish (*Ictalurus punctatus*) and turbot (*Scophthalmus maximus*), have been reported to be affected by Edwardsiellosis, which is caused by *Edwardsiella tarda. E. tarda* is a biochemically active species that produces hydrogen sulfide and indole, ferments glucose, is cytochrome oxidase negative, is catalase positive and reduces nitrate to nitrite. Although isolates from red sea bream is non-motile, it is normally motile. *E. tarda* has the following biochemical traits: it is cytochrome oxidase negative, catalase positive, produces hydrogen sulfide and indole, ferments glucose and reduces to nitrite from nitrate (Woo and Bruno, 2010).

2.3.1. Clinical Signs

Fish with an *E. tarda* infection exhibit strange swimming behaviors, such as spiraling around and hovering close to the surface of the water. Fish infected with this disease exhibit a variety of clinical indications depending on when the infection first manifests, including pigmentation loss, exophthalmia, opacity of the eyes, enlargement of the belly area, petechial bleeding in the fin and skin and rectal hernia (Egusa, 1976). Internal findings comprise of a clogged liver, spleen and kidney in addition to a bloated and bloody ascites in the abdominal cavity. The histological manifestations of edwardsiellosis in fish include purulent inflammation in the spleen and suppurative hepatitis (Miyazaki and Kaige, 1985).

2.3.2. Control and Treatment

The primary pathogens of warm water fish kept in ponds are *E. tarda* and *E. ictaluri*, which makes it challenging to stop disease outbreaks by adhering to strict management guidelines. One way to prevent outbreaks this disease is to give fish 2.5-3.0 g/ l00 kg of Terramycin each day for ten days (Hilton and Wilson, 1980).

2.4. Enteric Red Mouth Disease

Enteric redmouth disease (ERM), can also be named as yersiniosis, is a systemic bacterial infection caused by *Yersinia ruckeri*, a Gram-negative rod-shaped bacterium, first identified in rainbow trout (*Oncorhynchus mykiss*) in Idaho, USA (Ross *et al.*, 1966). This pathogen affects both salmonid and non-salmonid species, leading to significant economic losses, particularly in farmed rainbow trout. *Y. ruckeri* is widespread across North and South America, Europe, Australia, South Africa, the Middle East and China (Shaowu *et al.*, 2013). *Y. ruckeri* is a non-spore-forming facultative anaerobe with variable motility and is characterized by five O-serotypes and five outer membrane protein types (Kumar *et al.*, 2015).

2.4.1. Clinical Signs

The disease primarily affects younger fish, causing high cumulative losses and is marked by swimming restlessly, lethargic and reduced feed uptake. Other clinical signs include behavioral changes, exophthalmic condition in eye, skin becomes darker in colour and hemorrhages around the mouth (Tobback *et al.*, 2007). Histopathologically, it leads to systemic inflammation, especially in the liver, kidney, heart and gills (Tobback *et al.*, 2009).

2.4.2. Control and Treatment

ERM control includes antibiotic treatments like oxytetracycline and sulphonamides and vaccines, which have been successful in controlling outbreaks. Formalin-killed vaccines, including bivalent forms, have been developed to enhance immunity (Deshmukh *et al.*, 2012). Immunostimulants, such as β-hydroxy-β-methylbutyrate (HMB), also improve resistance to *Y. ruckeri* by boosting immune responses (Raida, 2003).

2.5. Vibriosis

Both wild and farmed marine fish are susceptible to vibriosis, a systemic bacterial infection brought on by species in the Vibrionaceae family that causes large financial losses for the aquaculture sector worldwide (Mancuso *et al.*, 2015). Environmental factors such as fluctuations in water quality and overpopulation contribute to vibriosis outbreaks in cultured fish (Kumar *et al.*, 2015). These Gram-negative bacteria are ubiquitous in marine and estuarine environments, where they exist freely in the water column, as biofilms, or in association with hosts (Thompson *et al.*, 2004). The number of Vibrio species has growing rapidly, with ten species now connected to human diseases such as skin rashes and gastrointestinal disorders (Andrews, 2004).

2.5.1. Clinical Sign

Infected fish typically exhibit symptoms like lethargy, necrosis, slow growth, tissue discoloration and melanisation (Aguirre-Guzman *et al.*, 2004). More severe signs include skin ulcerations, abnormal necrotic lesions in abdominal muscles and erythema around fins and the vent (Anderson and Conroy, 1970). Vibrio infections can also lead to impairing movement and competition for food, while mouth ulcerations can cause appetite loss, leading to death from starvation. Internally, infected fish may show haemorrhages in the kidney, liver and spleen (Zhang *et al.*, 2014).

2.5.2. Control and Treatment

The diagnosis of vibriosis often involves isolating *Vibrio* spp. in Thiosulfate-citrate-bile salts-sucrose (TCBS) agar plate (Yoon *et al.*, 2016), with PCR-based methods, especially 16S rRNA gene sequence analysis, being analysed to identify Vibrio in fish (Fukui and Sawabe, 2007). Biosecurity is crucial for the prevention of vibrio infection in fish culture system, with measures like using high-quality seeds, UV treatment, filtration systems and freshwater helping reduce Vibrio outbreaks (Kumara and Hettiarachchi, 2016). Early diagnosis, continuous monitoring, vaccines, probiotics and plant extracts with antimicrobial properties also contribute to effective control (Sommerset *et al.*, 2005).

2.6. Mycobacteriosis

Mycobacterial diseases, collectively known as mycobacteriosis, are prevalent in fish, particularly in intensive aquaculture systems and aquariums. Though historically referred to as “fish tuberculosis,” this term is now considered inaccurate. Mycobacteriosis in fish was first documented in carp (*Cyprinus* *carpio*) exposed to water certainly contaminated with *Mycobacterium tuberculosis*. Over time, various species of Mycobacterium have been associated with infections in fish. *Mycobacterium marinum*, identified from captive marine fish in 1926, has conventionally been linked to warm-water species, but infections in temperate and cold-water fish are also documented (Rhodes *et al.*, 2004). *M. fortuitum*, reported in neon tetra (*Paracheirodon innesi*) in 1953 and *M. chelonae*, first identified in a turtle and later found in salmonids, are also significant pathogens (Ashburner, 1977).

2.6.1. Clinical Signs

Clinical signs of mycobacteriosis are general and comprises of external symptoms like scale loss, ulcers and pigmention in skins, as well as internal signs such as organ enlargement and granulomas (Bruno *et al.*, 1998). Pathogenesis involves intracellular parasitism of phagocytes, with mycobacteria resisting normal phagolysosomal processes. Though the exact transmission routes are still under investigation, ingestion of contaminated food and water is believed to be a primary source of infection (Nenoff and Uhlemann, 2006). Diagnosis relies on the Ziehl-Neelsen acid-fast stain, which highlights the resistance of the bacterial cell wall to decolorization and PCR techniques are increasingly used to identify specific species (Talaat *et al.*, 1997).

2.6.2. Control and Treatment

Unfortunately, there has been no universally successful treatment for mycobacteriosis in fish and cases often necessitate the culling of infected stock and thorough disinfection of aquaculture systems. Antibiotics like rifampicin and streptomycin have shown limited success in some cases, but their effectiveness depends heavily on the specific strain and species involved (Roberts, 2001).

3. The Rising Threat of Bacterial Drug Resistance

Bacterial drug resistance is a critical global problem that creates a persistent challenge to public health, medical practices and healthcare systems worldwide. It occurs when bacteria evolve mechanisms that protect them from the effects of antibiotics, making standard treatments unsuccessful and infections tough to treat. The overuse and abuse of antibiotics, inadequate infection control practices and a slowdown in the development of novel antibiotics are some of the causes contributing to this issue. Addressing bacterial drug resistance is vital to avoid a future where common infections become untreatable, leading to higher mortality, prolonged issues and a substantial economic stress on healthcare systems. Antimicrobial resistance (AMR) has emerged as a significant public health issue in recent years (Figure 2). The far-reaching consequences of bacterial drug resistance extend not only to individual patients but also to global health. As bacterial pathogens become increasingly resistant to antibiotics, treatment options are limited. This issue is particularly alarming because it threatens to reverse decades of medical advances, making surgeries, cancer treatments and other medical interventions much riskier. Moreover, AMR exacerbates the spread of infectious diseases, contributing to the global rise in healthcare-associated infections. To combat this growing threat, it is crucial to understand the causes and consequences of bacterial drug resistance and implement effective strategies for its management.

3.1. Addressing Antimicrobial Resistance in Aquaculture and Healthcare

Bacterial drug resistance in fish is an increasing concern, affecting both aquatic life and public health. Consistent use of antibiotics in aquaculture allows certain bacteria in fish to provide resistance, which can be transferred to people through direct contact or consumption of contaminated fish. This issue is further exacerbated by the presence of faecal indicator bacteria (FIB), such as *Escherichia coli* and faecal streptococci, in water samples from retail fish markets. These bacteria multiply in contaminated water, which facilitates the spread of resistant strains. Some of the common bacteria that pose significant threats include *Vibrio* species, including *V. cholerae* and *V. vulnificus*, both of which can cause serious infections in humans, especially if the fish is improperly handled or undercooked. *Aeromonas* species, often found in aquatic environments, can infect both fish and humans, leading to conditions such as gastroenteritis or wound infections. Additionally, drug-resistant strains of *Escherichia coli* thrive in aquaculture environments, contaminating fish and causing food-borne infections in humans.

Figure 2: Antimicrobial resistance bacteria are shielded from ineffective antibiotics

Water samples from retail fish markets, particularly in regions like Navi Mumbai, have shown high levels of *E. coli*, faecal streptococci and other contaminants, further indicating the risk of bacterial transfer from water to fish and ultimately to humans (Visnuvinayagam *et al.*, 2019). In fish farms, antibiotics are frequently employing to treat or prevent infections, but this contributes to the selection of resistant bacterial strains. One of the primary mechanisms for this resistance is horizontal gene transfer, where resistant bacteria pass resistance genes to other bacterial species, spreading resistance. In a study from Rajasthan, isolates from fish faecal samples showed high resistance, particularly to streptomycin in *E. coli* spp. Additionally, *Staphylococcus aureus* exhibited high resistance to trimethoprim (Saharan *et al.*, 2020). This increasing issue of antibiotic resistance draws attention to the overuse of antibiotics in fish farming, a practice that is becoming more widespread in the sector. The impact on human health is significant. Direct consumption of undercooked or contaminated fish can result in infections that are difficult to treat with standard antibiotics. Furthermore, resistant bacteria from fish farms can spread into surrounding water bodies, affecting human health through recreational activities or consumption of contaminated water (Sivaraman *et al.*, 2022). When the same water is used repeatedly in fish markets without being replaced, levels of FIB and multi-drug-resistant (MDR) bacteria, such *E. coli*, rise, putting customers at considerable risk.

To address the growing threat of bacterial drug resistance, several strategies must be implemented at both local and global levels. Antibiotic stewardship programs are one of the most effective approaches to combating resistance. These initiatives encourage the safe use of antibiotics by making sure the right dosage and duration are taken and that they are only provided when absolutely necessary. Stewardship initiatives retain the efficacy of current medicines and slow the emergence of resistance by minimising the needless use of antibiotics. Successful implementation of these programs requires cooperation between healthcare providers, pharmacists and patients. Improving infection prevention and control measures is essential to reducing the spread of resistant bacteria.

4. Zoonotic Bacterial Infections in Fish

Infections known as zoonotic bacterial illnesses can spread from animals to people. An infectious disease that spreads from animal to humans is called a zoonosis (or zoonotic disease, with zoonoses as the plural) (Figure 3) (Han *et al.,* 2016). Numerous infectious agents, such as bacteria, viruses, parasites and fungus, can spread by a variety of methods, including direct animal-to-human contact, ingestion, animal bites, insect vectors and penetration through torn skin (Rahman *et al.*, 2020).

4.1. The Role of Fish in Zoonotic Disease Transmission

Among aquatic vertebrates, fish serve as an important vector for transmitting several zoonotic pathogens (Table 1). Zoonotic diseases in fish are particularly concerning in aquaculture, commercial fisheries and environments where humans closely interact with aquatic species (Figure 3). These diseases pose significant risks to public health and have economic implications for industries reliant on fish farming. Studying zoonotic diseases in fish is crucial for safeguarding human health, especially in areas where fish play a central role in food production. Moreover, understanding the biology, transmission and prevention of these diseases helps mitigate their spread and impact on both fish populations and human health. Although zoonotic bacterial diseases in fish are not always widely recognized, they have the capacity to cause severe health complications in humans. Some of the most common zoonotic bacterial diseases transmitted through fish include Aeromoniasis, Mycobacteriosis and Streptococcosis. These infections can result in various symptoms in humans, ranging from mild skin infections to severe systemic illnesses. Human cases often arise due to direct contact with contaminated water, fish, or fish products. Consequently, individuals working in aquaculture or the fishing industry, as well as consumers handling fish, are at a higher risk of contracting these diseases.

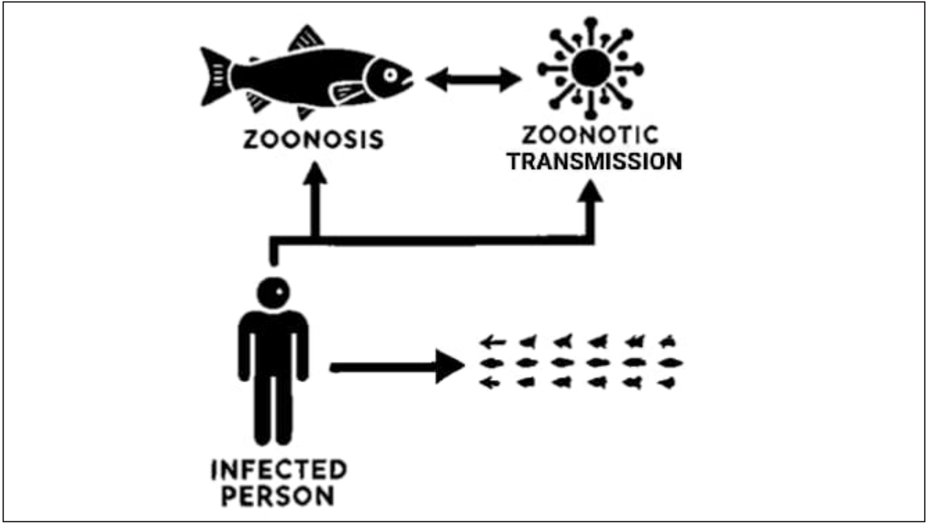

Figure 3: Zoonotic disease transmissions from fish to humans

The public health implications of zoonotic bacterial diseases in fish are profound, especially in regions where fish farming plays a crucial economic and nutritional role. Monitoring zoonotic diseases in fish is essential to prevent large-scale outbreaks that could impact both fish populations and human communities. The consequences of failing to control these diseases can be severe, ranging from economic losses in aquaculture to increased healthcare burdens due to human infections. Collaboration between researchers, public health officials and fish farmers are critical for controlling the spread of zoonotic bacterial diseases. Research into disease prevention, diagnostic tools and treatment options is essential, as is public awareness about the potential health risks associated with handling and consuming fish.

Table 1: List of bacterial zoonotic diseases associated with fish

Sl. No.	Family	Disease
1	Mycobacteriaceae	Mycobacterial Infections
2	Streptococcaceae	Streptococcosis
3	Erysipelotrichaceae	Erysipelas
4	Vibrionaceae	Vibriosis
5	Aeromonadaceae	Aeromoniasis
6	Pseudomonadaceae	Pseudomonas Infections
7	Enterobacteriaceae	Edwardsiellosis
8	Staphylococcaceae	Staphylococcal Infections
9	Campylobacteraceae	Campylobacteriosis
10	Clostridiaceae	Botulism
11	Listeriaceae	Listeriosis

Table Continue...

Sl. No.	Pathogen	Symptoms in Humans
1	*Mycobacterium marinum*	Skin lesions, fever, lymphadenopathy
2	*Streptococcus agalactiae*	Fever, chills, sore throat, skin infections
3	*Erysipelothrix rhusiopathiae*	Skin rash, fever, malaise
4	*Vibrio vulnificus*	Diarrhea, abdominal pain, vomiting
5	*Aeromonas hydrophila*	Gastroenteritis, wound infections
6	*Pseudomonas aeruginosa*	Respiratory infections, skin rashes
7	*Edwardsiella tarda*	Fever, abdominal pain, diarrhea
8	*Staphylococcus aureus*	Skin infections, abscesses, fever
9	*Campylobacter jejuni*	Diarrhea, fever, abdominal cramps
10	*Clostridium botulinum*	Muscle weakness, paralysis, respiratory failure
11	*Listeria monocytogenes*	Fever, muscle aches, gastrointestinal symptoms

(Source: Ziarati *et al.*, 2022)

4.2. Transmission Pathways and Prevention Strategies

Transmission of zoonotic bacterial diseases from fish to humans can occur through several routes, with the most common being close contact with infected fish or disclosure to contaminated water. Open wounds or cuts on the skin can provide a pathway for bacteria to enter the body, particularly for individuals who regularly handle fish. Additionally, ingestion of undercooked or raw fish is a significant transmission route, as certain bacteria can survive in improperly prepared seafood. Environmental factors such as water quality, temperature fluctuations and overcrowding in fish farms contribute to the spread of bacterial diseases, creating favourable conditions for growth of bacteria and increasing the likelihood for the disease outbreaks in both fish populations and human communities.

To reduce the transmission of zoonotic bacterial diseases from fish to humans, various prevention strategies must be implemented. Good hygiene practices, such as regular handwashing after handling fish and properly cleaning wounds, are essential. Fish farmers and fishery workers should adopt stringent biosecurity measures, including maintaining water quality, controlling fish population density and promptly removing sick or dead fish from the environment. Proper handling, cooking and processing of fish products also play a major role in minimizing the risk of bacterial transmission to consumers. Educating workers and the public about these risks and encouraging safe practices in fish handling and consumption can significantly reduce the incidence of zoonotic infections.

5. Conclusion

In conclusion, bacterial diseases present a major challenge to sustainable aquaculture, especially with increased fish density to meet global food demands. This intensification raises the susceptibility to diseases, driving the recurrent use of antibiotics. This, in turn, escalates antibiotic-resistant genes in disease causing bacteria, such as *Aeromonas hydrophila*, *Streptococcus iniae* and *Vibrio anguillarum*, some of which pose zoonotic risks to humans. To mitigate resistance and control emerging and existing bacterial threats, a combination of prophylactic approaches, like vaccines, probiotics and effective management practices, remains essential for sustainable and healthy aquaculture.

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