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Understanding and Managing Gill Infections in Fish

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Abstract

Gill diseases, including those associated with gill infections, are some of the most common and severe health issues in farmed and wild fish. The occurrence of disease in the same location can result in fish from different phylogenetic groups presenting with similar pathological changes, suggesting that the disease is likely multifactorial. Gill diseases are therefore usually the result of complex interactions between the infectious agent, the host, and the environment. While gill diseases are often associated with microbial infections, they can also be exacerbated by environmental stress without microbial involvement. Indeed, primary gill infections are rare in fish, while an immune response detected in gill tissue of affected animals is common. This suggests that the environment plays a significant role in gill disease outbreaks. The aim of this review is to contribute towards a better understanding of the factors associated with gill infections in fish, as this is an important step in the management of gill diseases.

In wild and farmed fish, gill diseases are some of the most common and severe health issues. These diseases are often associated with microbial infections and can be exacerbated by environmental stress. Loss of osmoregulatory function, mechanical damage, and hypoxia are among the harmful effects these diseases have on fish gills. Therefore, managing gill diseases is an important aspect of fish health management. To do this, we need to develop an understanding of the factors that influence gill disease outbreaks, including how the composition of the gill microbiome changes and what effect the wider aquatic microbiome has on gill health. This knowledge can then be used to develop preventative measures or treatments that help to mitigate gill disease in affected animals.

Keywords: Gill Infection, Gill Health, gas exchange

1. Introduction

A gill infection can be defined as any change or damage to the gill which adversely affects the functioning of the organ. It is usually initiated by the invasion of a foreign agent, either of a physical nature (grit, sand, organic material) or pathogen. The gill is a delicate and complex organ which serves a number of vital functions. It is the primary site of oxygen uptake and carbon dioxide expulsion, being richly supplied with blood to facilitate the exchange of these gases. It also plays a role in osmoregulation and waste excretion and is a common site for hormone injection/implantation in fish used in aquaculture (Emam et al.2022)(Foyle et al.2020)(Dias et al., 2021).

Any interference with these functions can have a serious impact on the fish's health and in severe cases a gill infection can be fatal. Even if the fish manages to survive an infection there may be permanent damage to the gill tissue which impairs its function and reduces the overall performance of the fish. Gill infections are difficult problems to diagnose and treat and some of the pathogenic agents involved are

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capable of infecting fish at other sites or in systemic fashion so it is possible that they can continue to affect the gill at a later time. (Suliman et al.2021)(Padrós & Constenla, 2021)(Marcos-López & Rodger, 2020)

1.1. Definition of Gill Infection

Definition of gill infection is hard, especially the one concerning the gill infection in fish because until now there has yet been a solid case that shows a fish suffers from infection of its respiratory organ. Generally, there are some symptoms of gill infection. The fish feels uneasy in a quiet state, excessive production of mucus in the gills or pus, gill may be discolored to pale red, swollen, or if severe gill rakers can be anter backward even lost and accompanied by rapid breath. In the world of fish illness, all symptoms are only categorized and not only for gill infection, but this understanding can make a general outline. (Andersen et al.2023)(Sun et al., 2023)(Stilwell et al.2023)
In a case of contact with new fish or fish that were just bought from a shop, it turns out there are a variety of different organisms that cause infectious diseases of the gill. These organisms can be bacteria, viruses, fungi, etc., and each of these organisms attacks different parts in gill organs which will cause different symptoms too. Because it is impossible for us to know what organisms attack, and need to do an expensive gill biopsy test to know it, providing irritation protection against all possibilities of gill infections is the best way that is far more easily and economically such as giving a drug into the water that is used to treat fungus. (Boerlage et al.2020)(Wu et al., 2021)(Dar et al.2020)

1.2. Importance of Gill Health in Fish

A fish's ability to exchange gases with its environment is critically dependent on the structural and functional integrity of the gill. A significant reduction in gill function can result in increased susceptibility to disease, poor growth, and increased mortality. In acute cases, reduced gill function can result in death within a few hours. Fisheries biologists and fish culturists are frequently concerned with gill health in fish because poor gill function can result in significant economic loss. In a recent study assessing the causes of pre-release mortality in hatchery-reared steelhead trout, it was reported that an average of 21% of the fish that died had gill myxobacterial gill infection. This disease was believed to be a major factor in the poor survival of the fish after release into the wild. Gill health is also a major concern in the commercial fish industry. An example of this is the catfish industry in the Southern United States where off-flavor problems caused by algal blooms and the occurrence of numerous parasitic and bacterial gill diseases can significantly reduce fish growth and feed conversion. Because more than 90% of produced catfish are sold live, infections that negatively affect fish appearance and behavior result in downgrading of the product and reduced profits for the producer. In wild fish stocks, poor gill health can reduce the ability of fish to evade predators, affect migration and reproductive success. This can have significant effects on fish populations and the greater ecosystem. (Komane, 2021)(Ashwath et al.2024)

1.3. Common Causes of Gill Infection

Gill infection is very serious and, without treatment, can kill fish. While parasites are sometimes the cause of infection, more often the agent is bacteria such as Aeromonas, Pseudomonas or the often fatal Flavobacterium branchiophilum. In severe cases it may not be possible to identify the exact cause of the infection. Gill flukes are tiny parasites that infect the gills of the fish. They can often be found in low numbers in fish without causing any problems. However, in certain situations such as overcrowding, poor water quality and stress they can rapidly multiply resulting in heavy infections that lead to serious damage of the gill tissue. Infections caused by bacteria and parasites are often secondary to other health problems such as stress resulting in damaged or weakened gills. (Wang et al.2023)(Padrós & Constenla, 2021)(Suliman et al.2021)

This damage to the gill tissue and associated scarring can make the fish more susceptible to further infections, often leading to long term gill problems and in some cases, death. Fungal spores are present in most aquatic environments and are a common cause of gill infection. Usually the skin and gills of fish are well protected from fungal attack by mucus which contains substances that inhibit fungal growth. However, when fish are stressed the production of mucus is reduced leaving them vulnerable to fungal infections. Chronic and severe infections can be very damaging and may result in overgrowth of gill

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tissue by the fungus. Certain chemical water pollutants such as heavy metals and organic solvents can directly damage gill tissue, leading to swelling, hyperplasia and lamellar fusion. This damage greatly increases the susceptibility of the fish to other forms of gill infection. High concentrations of ammonia and low concentrations of free ion calcium in the water have also been shown to increase the severity of gill infections caused by parasites. (Magray et al.2021)(Sheikha and Mankodi2021)(Sarkar et al.2022)(Iqbal et al., 2023)

2. Symptoms and Diagnosis

Visible signs of gill infection
Behavioural changes in gill infection
Diagnostic techniques for gill infection
2.1 Visible signs of gill infection
Proliferation of the gill tissue: This can often appear like white tufts of cotton, or with advanced infections, similar to deformed cauliflower.
Gill discoloration: Normal healthy gills are a light red to pinkish color. Discoloration in gill infections is often the first visible sign. This can range from pale pink, red patches, brown and in severe cases almost black.
Mucous accumulation: Often the gills will show excessive mucous covering. Evident mucous external to the gills can also be an indicator of gill infections. (Novotny, 2021)(Bhat et al.2023)(Padrós & Constenla, 2021)(Abbas et al.2023)

Hemorrhaging: This is often associated with gill inflammation as a result of damage caused by the infectious agent. This can cause blood to accumulate within the gill, or there may be visible blood in the fish's external environment.
Gill erosion: In severe and chronic cases, the infectious agents can cause damage or erosion to the gill tissue and filaments, sometimes even to the point of gill filament fusion. (Bhat et al.2023)(Nisa et al.2021)(Rao, 2021)

2.1. Visible Signs of Gill Infection

Although there are no known visible symptoms of gill infection specific to the disease, general signs of an affected fish can be seen. These can be a change in colour of the gills (possible increase of blood), excessive mucus production, gill curling or a change in rate of operculum movement. Additionally, there may be signs of secondary infection such as swelling and reddening of the gill filaments. These signs are however non-specific and can be indicative of other gill diseases or environmental stress. Excessive mucus production can make it difficult to discern if the fish is infected and can be a sign of parasite infection as well as a non-specific response to infection. Gill curling and operculum movement change is indicative of respiratory distress which can be due to poor environmental conditions as well as general gill infection. Changes to the gill's appearance are extremely difficult to ascertain in live fish and diagnosing the specific disease is usually only possible when there is a chronic infection and near lethal damage to the gill tissue. (Ngamkala et al.2020)(Singh et al.2023)(Dang et al.2020)

2.2. Behavioral Changes in Infected Fish

Changes in behavior can be indicative of gill infection. Affected fish may exhibit an increased frequency of gill ventilation. This behavior resembles rapid respirations, but the fish actually opens the operculum more frequently when it is trying to rid itself of debris and parasites from the gills or to increase oxygenation. The rate of buccal pumping increases when oxygen uptake through the gills is compromised. Fish may eventually resort to air breathing to satisfy oxygen demands. A shift to air breathing can occur at lower water temperatures when oxygen tensions are depressed. Erosive gill diseases result in discomfort and pain, and it is common to see fish shaking their heads or rubbing their gill chambers on the bottom or sides of the tank in an attempt to dislodge irritants. Smothering the gill irritant with sand to produce a softer substrate is a preferred behavior in affected fish. Fish may be less active and may congregate at the water inlet where oxygen concentrations are highest. Social status may decline, and affected fish may be unable to sustain dominant behavior. (Vermeylen et al.2023)(Leonard & Skov, 2022)(Eom and Wood2020)

2.3. Diagnostic Techniques for Gill Infection

Routine tests should always include a thorough clinical examination of the fish in question. This is a primary suspect fish/fish population in that it does not feed as to be normal. Clinical inspections may reveal no other possible cause for the abnormal behaviour that can be attributed to gill health. If gill disease is suspected, anaesthetized fish should be examined for precise identification of the problem and its severity. Kelly and Woo (2002) suggest using a clinical grading system to quantify gill pathology. This involves scoring the severity of primary and secondary lesions of a number of gill diseases. (Janssen et al.2021) (Jabari et al.2022) (Ghosein et al.2021).

Gill health play critical role for respiration and general survival. may not always be possible to diagnose a gill infection based on visible symptoms, and therefore some form of diagnostic test will be needed. There are a number of methods by which a diagnosis can be reached: these include the uses of clinical tools, examining tissue under a microscope, and conducting laboratory analysis of fish and water samples. (Foyle et al.2020) (Plaul et al., 2021) (Chen et al.2023) (Shamsi et al.2024)

3. Treatment and Prevention

Diagnosis of gill infection and identification of the causative agents is an important first step in the treatment. Many different types of disease exhibit similar symptoms. Examination of infected gill tissue under a microscope often is necessary to diagnose the causes of the problem. Gill biopsy or sampling is a technique that should be performed by a veterinarian. Several medications are effective against different types of gill parasites and bacteria. Many are safe and effective when used as a bath treatment. However, without fish availability to a licensed vet, medication in food form is difficult to accurately dose and often is less effective. Consultation with a fish veterinarian is the best way to determine whether to treat the fish and if so, what medication to use. (Gill et al., 2022)(Flores-Kossack et al.2020) Some of the most common types of gill parasites are the protozoans trichodina, chilodonella, and ich. Trichodina and chilodonella are often called "slime coat" disease because fishes infected with these parasites often produce excess slime. Fishes with trichodina or chilodonella may benefit from a salt treatment, as many parasites are unable to osmoregulate and will be killed at a lower dose than is harmful to the fish. However, the margin of safety between a therapeutically effective and a harmful dose of salt is narrow for some species, and advice from a veterinarian is recommended. Osmoregulation is a major issue for fish infected with ich and a full life cycle of ich requires treatment of the entire aquarium. Medications effective against ich parasites include organic dyes, formalin and copper, and consultation with a veterinarian is recommended.

(Mougin & Joyce, 2023)(Boerlage et al.2020)

3.1. Medications and Treatments for Gill Infection

Copper sulphate is cheap and effective for many external parasites and some protozoan infections of gills (remember that sometimes these parasites are secondary invaders of gills damaged by other infections). Formalin is used for similar infections; however, it is more toxic to fish than copper and so less preferable in some circumstances. Humane treatment of fish at the end of a disease outbreak, though unpleasant, is sometimes necessary when seriously affected fish are unlikely to recover. (Younis et al.2020)(Zhou et al., 2023)(Rao, 2021)(Martins et al.2021)

Medications of gill diseases are available and effective for some infections. However, it is difficult to treat many bacterial and most viral gill infections once fish are showing serious clinical signs. Viral infections causing a systemic disease are often untreatable. Water-soluble antibiotics like oxytetracycline and florfenicol are the most effective for bacterial gill disease and are best administered as a medicated feed. It is often necessary to move sick fish to a clean, low-density environment for treatment to show any noticeable effect. (Sutili & Gressler, 2021)(Zhao et al., 2022)(Abu-Zahra et al., 2024)(Dien et al.2023)

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3.2. Environmental Factors Affecting Gill Health

The prevention of gill disease is much easier than the treatment of clinical cases. It involves establishing an environment that is devoid of disease-causing agents to prevent infection of gill tissues. It so includes minimize the risk of mechanical damage to gills. If gill disease is present in a population of fish, it is very important to be able to identify the cause of the disease and the mechanisms that are resulting in gill damage. This isnt always an easy task and may require the skills of fish health specialist. Identification of the cause of gill disease will allow for the implementation of specific control. (Chellapandian et al.2021) (Paul, 2024)(Ben et al.2021) (Rahimoon et al.2023) (Pothiraj et al.2024).

Disease-causing agents can be divided into primary and secondary pathogens. Primary pathogens are the cause of the disease directly and reproduce in the host, causing further tissue damage. Secondary pathogens invade tissue that has already been compromised by mechanical injury, environmental insult, or the activity of another disease. In many cases, it is difficult to determine whether the sole cause of gill damage is from a primary or secondary pathogen. (Østevik et al.2022)(Boerlage et al.2020)(Gjessing et al.2020)(Marcos-López & Rodger, 2020)

3.3. Preventive Measures for Gill Infection

The most effective way to combat gill infection is to avoid it altogether. It is always harder to cure a disease than to prevent its inception. Preventive measures incorporate both maintaining good water quality and using immunostimulants to toughen the fish's resistance to disease. A fish with high resistance to disease is less likely to become infected. If conditions are ideal, the fish will actually recover from gill disease without the necessity for further treatment. It is important to understand that an unhealthy environment can make a fish more susceptible to gill disease. Therefore, an unhealthy environment is often a primary cause of gill disease. By avoiding the conditions which cause gill infection, it can be prevented. It is also important to understand that in minor cases of gill infection, the fish may exhibit no abnormal behavior. This may give the false impression that treatment is effective, when in reality symptoms may reappear days later if the cause of the infection has not been resolved. Therefore, it is necessary to continue preventive measures for some time following treatment of a gill infection. (Vanamala et al.2022)(J2024)(Suresh et al., 2022)

4. Research and Future Directions

In terms of gill health research future directions, it is clear that trends in global aquaculture and wild fisheries will shape the priorities for research and how research findings can be applied. For example, changes in the types of aquaculture systems may necessitate a shift in focus of research in specific gill conditions for different fish species if the impacts of those conditions on fish fitness and production are to be assessed. This will also present opportunities for studies on preventative measures for gill conditions in new environments with the development of new treatment methods. A shift in focus to global research on fish gill health should see an increase in collaboration between fish health researchers and aquatic scientists not currently engaged in fish health, as there is a wealth of knowledge available to be tapped from analogous studies of pollutant effects on macro water organisms and pollutant-mediated damage to fish gill tissue. (Foyle et al.2020)(Lorgen-Ritchie et al.2022)(Verma et al.2023)

Funding to support research in fish gill health specifically has often been limited as gill conditions are viewed as purely a production issue that does not result in a specific diagnosis and a treatment to return the fish to market. Demonstration of the significant impacts of some gill conditions on fish fitness and production is key to achieving this. A UK study aimed to investigate the effects of gill disease in sea bass with the induction of acute temperature challenge. This was conducted to determine how the oxygen uptake ability by the fish is impaired during typical chronic exposure to gill disease, with results indicating reduced oxygen uptake could be a causative factor for the reduced activity and feed utilization seen in affected fish. (Mocho et al.2022)(Godoy et al.2023)(Gill et al.2024)(Carrillo-Larco et al.2022)

Gill health is important for fish health and welfare, and it is known that in some situations fish experience compromised gill health but do not express an overt disease state. There is a paucity of information on the early stages of gill disease in fish and how this may progress to more serious major health impacts.

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This is an area where significant research is needed. For example, one study found that Atlantic salmon first exposed to the amoebic gill disease agent at smolt entry to seawater displayed changes in gill function without apparent histological changes, indicating some form of sub-lethal damage to this organ. Although specific studies on gill disease were not conducted, there are numerous examples in the fish health related to other disease states where advances in understanding of early non-specific responses to pathogens and tissue damage would assist the development of diagnostic tests for those conditions. An example of this in the salmonid research is work on the response of the fish's immune function to infection which could be applied to study immune-mediated pathology during gill disease. In summary, there is a need for basic research on the mechanisms of pathogenesis for specific gill diseases which complements work on gross pathology and impacts on fish fitness. (Boerlage et al.2020)(Mc et al.2021)(Hoem & Tveten, 2023)

4.1. Current Studies on Gill Infection

Where the concept becomes limited is in the ability to measure sub-lethal effects, particularly in relation to an overall improvement in fish condition. If we take for example improvements in water quality, this has often been aimed at reducing burden of pathological conditions on fish without considering that fish affected will often have reduced condition and fitness that may not recover simply through removal of the cause. The concept also does not consider that individuals within a population are often exposed to multiple stressors at once. An experiment at comparison between the effects of individual stressors on fish at times may produce different results to what would be expected in nature due to interactions between stressors. Data often seems to come to the same general conclusion that improvement in environment will reduce negative impact on gill health. While the validity of this is not to be questioned and generally holds true, where the concept becomes most useful is in exploring ways that gill health can be improved in situ. One recent study by Clark et al. (2014) looked to enhance the ability of Atlantic salmon gills to cope with high water temperatures through preconditioning fish at a lower temperature, with success of this method offering new means to improve fish resistance to environmental stressors. (Stiller et al.2020)(Reusch et al.2021)(Fuller et al.2022)

A useful concept, but one not without its limitations. We know that gill infections can affect fish at multiple levels, from individual to population, and gill health can be a major factor in population dynamics and contributing to success or failure of a fish population. Generally speaking, research into gill health has been largely aimed at investigating the health of individual fish. There is an abundance of literature reporting on the effects of environmental stressors on gill structure and function, which often use pathological endpoints as evidence of gill health. This kind of research provides a platform to make important links between factors in the environment and gill health, and coupled with molecular techniques that allow better understanding of cause and effect, such research can be built upon to improve management and conservation of fish populations through maintenance of gill health. (Ajasa et al., 2024)(Holzer et al.2021)(Damania et al.2023)

4.2. Potential Solutions for Gill Infection

As presented in the section above, gill infection in fish can be a serious problem. One critical gap in our knowledge is understanding the gill's capacity to repair itself following a disease challenge. In mammals, there is evidence of bronchial associated lymphoid tissue facilitating a local immune response, followed by epithelial repair . The gill is lined with gill filament and lamellae which provide an extensive surface area (Klesius et al. 2008). (Holzer et al.2021)(Chapman et al.2021)(Slinger et al.2021)

When considering the cost of fish gill damage to the holder and the fact that gill tissue has been described as the most consistently utilized site of gaseous exchange in teleost f, we can envisage the importance of epithelial repair in its capacity for normal respiration and ionoregulation. It is known that the avian and mammalian lung can repair itself following injury, often resulting in full structural and functional restitution of damaged tissue, as long as the insult is not overwhelming and/or chronic . (Wright2021)(Wood et al.2020)(Sackville et al., 2022)(Frommel et al.2021)(Plaul et al., 2021)

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This may be the case with mild gill disease in fish, however current evidence suggests that even mild sublethal gill insults are enough to affect haematology and elicit a systemic stress response in fish likely due to damage and/or hypoxia in the gill's capacity for ionoregulation. Dictated in both mammalian and avian lung injury repair is the part it takes in preventing infection due to greater salt permeability leading to leakage of cell nutrients and potential site for pathogen colonization (Berthiaume et al. 1993). In this instance lung infection is better understood, but there is limited description of gill infection sequel to injury in fish. This would undoubtedly be a priority within gill health research, given that prevention of secondary infection would take place in order to facilitate the specific treatment of the initial disease. (Clinton et al.2021)(Farag et al.2022)(Araújo et al.2023)

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