MARINE REPORTS
e-ISSN: 2822-5155
Journal homepage: https://scopesscience.com/index.php/marep/

Received: 28 March 2025; Received in revised form: 13 May 2025
Accepted: 13 May 2025; Available online: 28 June 2025
REVIEW PAPER

Citation: Karga, M. (2025). Effects of some common bacterial fish diseases on fish behavior in aquaculture: a Review. *Marine Reports*, *4*(1), 68-79. https://doi.org/10.5281/zenodo.15764098

EFFECTS OF SOME COMMON BACTERIAL FISH DISEASES ON FISH BEHAVIOR IN AQUACULTURE: A REVIEW

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Abstract
Aquaculture is of increasing importance and economic value in global food production. Sustainability and productivity of aquaculture are directly related to the health of the fish farmed. Bacterial diseases in fish are common in the aquaculture sector and cause significant economic losses. Therefore, it is of substantial to understand the agents, prevalence and effects of bacterial diseases on fish health. Fish behavior is an important indicator of their health status. Behavioral changes can be an early sign of disease and therefore careful observation is vital for timely diagnosis and control of diseases. This review discusses common bacterial fish diseases, their agents and specific behavioral changes observed in infected fish. In addition, potential mechanisms by which bacterial infections affect fish behavior are examined.

Keywords: Behavioral change, disease indicators, fish farming, fish health

Introduction
With the world population continuously increasing and natural fish stocks decreasing, aquaculture plays a critical role in meeting the demand for seafood. There is no doubt that in order for aquaculture to play a permanent role in the food sector, fish health and welfare must be kept at the highest level. Protecting fish health not only prevents economic losses, but also ensures environmental sustainability and consumer health. Bacterial diseases in fish are very common in aquaculture and cause direct economic losses (Irshath et al., 2023). Various bacterial infections can cause significant damage to fish species, leading to fish mortality as well as to increased farming costs and reduced product quality. Therefore, it is of great importance to understand the pathogens that cause bacterial diseases and their effects on fish behavior and fish health. The behavior of fish is an important indicator of whether they are healthy or not. Healthy fish are generally active, alert and sensitive to their environment. However, when an infection or disease occurs, significant changes in the behavior of fish can

be observed (Lee et al., 2015). Abnormalities in fish behavior are important for early diagnosis of disease, and therefore, diseases can be diagnosed head of time in fish that are kept under careful surveillance, and mass fish deaths can be prevented with early application of treatment methods. Bacterial infections can affect the physiology, hence the behavior of fish in various ways. These effects may vary depending on the type and severity of infection, the species of fish and environmental conditions.

The main objective of this review is to address common bacterial fish diseases, their causative agents, and specific behavioral changes observed in infected fish, by examining available scientific literature. Additionally, potential mechanisms by which bacterial infections affect fish behavior were investigated, including direct effects on the nervous system, the role of the immune system response, and the contribution of hormonal changes.

Common Fish Bacterial Diseases and Associated Behavioral Changes

- ***Aeromonas salmonicida* (Furunculosis)**

Furunculosis is a highly contagious disease affecting fish and is caused by the bacteria *Aeromonas salmonicida* (Cipriano & Bullock., 2001). This disease causes high mortality, especially in salmonid species, and results significant economic losses in aquaculture practices. Infection with *Aeromonas salmonicida* may lead to a variety of behavioral changes in fish. Infected fish often swim lethargically or remain motionless just below the water surface. Anorexia is a common symptom of furunculosis, and infected fish may stop ingesting food. In some cases, fish may also experience respiratory distress (Baset, 2022; Rao & Lahari, 2024). In the later stages of the disease, fish may exhibit jumping behavior from the water. Furunculosis infection can also lead to changes in the coloration of fish, with infected fish having a darker color than normal (İkiz & Kekeç, 2024). Erratic swimming is another behavioral change frequently seen in infected fish (Kipp et al., 2018). As the disease progresses, fish may appear weak and lethargic (Izadi & Vajargah, 2022). Furunculosis is a systemic infection that significantly affects the general activity and feeding habits of fish. Behavioral changes may vary depending on whether the disease is acute or chronic, but in general, infected fish exhibit an apparent decrease in energy levels and responsiveness to the environment.

- ***Vibrio* Species and Vibriosis**

Vibriosis is a bacterial disease that can be caused by various Vibrio species, especially *Vibrio anguillarum* and *Vibrio salmonicida*, and affects especially marine and brackish water fishes (Irshath et al., 2023). Vibriosis infection can cause a number of specific behavioural signs in infected fish. Anorexia, or loss of appetite, is a common symptom of vibriosis, and infected fish may refuse to eat. Lethargy is also common in fish with vibriosis; the fish may be less active and unresponsive than normal. Vibriosis can also cause changes in the external appearance of fish; including a red coloration of their skin, fins, and tails. Some Vibrio species can also cause corneal opacity (Sanders, 2022). Exophthalmos is one of the non-specific clinical indications of fish with Vibrio infection may display (Zin Eldin et al., 2023). In the later stages of the disease, a significant weight loss can be observed (Frans et al., 2011). Moreover, infected fish may swim near the water surface or the bottom (Manchanayake et al., 2023). Vibriosis is a serious disease that adversely affects the appetite and general vitality of fish. It is particularly important to note that some Vibrio species can also cause infections in humans, posing a zoonotic risk (Sanders, 2022).

- ***Flavobacterium columnare* and Columnaris Disease**

Columnaris is a disease frequently seen in freshwater fish and is caused by the *Flavobacterium columnare* bacteria (Irshath et al., 2023). It is typically more common in warm water conditions. Various behavioral changes can be observed in fish having Columnaris disease. Infected fish usually become lethargic and inactive. Loss of appetite is also a common symptom of columnaris disease. In some cases, infected fish may hang at water surface (Lafrentz et al., 2012). Additionally, a significant decline in swimming speed can be observed in sick fish (Francis-Floyd, 1998). Accordingly, Columnaris disease is an infection that reduces the energy levels and general activity of fish, usually associated with stressful conditions and high water temperatures. This can also negatively affect the fish's response to the environment and their escaping behavior.

- ***Edwardsiella* Species and Edwardsiellosis**

Edwardsiellosis is a bacterial infection caused by various species of bacteria belonging to the genus *Edwardsiella* (e.g., *E. ictaluri*, *E. tarda*) and can affect a wide range of freshwater and marine fish (Irshath et al., 2023). Several behavioral abnormalities can be observed in fish infected with Edwardsiellosis. One of these abnormalities is lethargy; infected fish are usually in a lethargic and immobile state (IACUC, 2021). Infected fish may stay motionless at water surface (Bullock, 1985). Loss of appetite is another common condition in fish with Edwardsiellosis (Rousselet et al.,2018). In general, edwardsiellosis can significantly affect the swimming behavior of fish and lead to a generalized state of lethargy. Different Edwardsiella species can cause similar behavioral changes, indicating the widespread impact of these bacteria on the physiology of fish.

- ***Yersinia ruckeri* and Enteric Red Mouth Disease (ERM)**

Enteric red mouth disease (ERM) is an important bacterial infection caused by the bacterium *Yersinia ruckeri* and particularly affecting salmonid species (Hedge et al., 2023). Various behavioral changes can be observed in fish infected with ERM. Diseased fish often swim near the surface and exhibit signs of lethargy. Loss of appetite is commonly seen in ERM, and the fish may refuse to ingest food. Darkened color is also observed in infected fish (Zorriehzahra et al., 2017). In the early stages of the disease, some fish may isolate themselves from others (Warren, 1983). In rare cases, abnormal swimming behavior may also be observed (Kumar et al., 2015). ERM appears to be a systemic infection that affects the general behavior and activity level of fish. Behavioral changes may occur in the early stages of the disease and become more pronounced as the disease progresses.

- ***Renibacterium salmoninarum* and Bacterial Kidney Disease (BKD)**

Bacterial kidney disease (BKD) is a chronic infection caused by the bacterium *Renibacterium salmoninarum* and specifically affects salmonids (Delghandi et al., 2020). Fish with severe *R. salmoninarum* infections may show no obvious external signs, or they may exhibit one or more of the following: lethargy; skin darkening; abdominal distension due to ascites; pale gills associated with anaemia; exophthalmia; haemorrhage around the vent; and cystic cavities in the skeletal muscle (Wiens, 2011). Externally, fish infected with *R. salmoninarum* tend to lose equilibrium, and display irregular swimming behaviour. BKD is a chronic condition and is typically associated with sustained occurrence of low levels of mortality, which can make detecting the presence of the problem difficult (Delghandi et al., 2020).

- ***Streptococcus* Species and Streptococcosis**

Streptococcosis is a bacterial disease caused by various species of bacteria belonging to the genus Streptococcus (*S. iniae*, *S. agalactiae*, etc.) and can affect both freshwater and marine fishes (Irshath et al., 2023). Various specific swimming behaviors can be observed in fish infected with streptococcosis. The most notable of these is that fish swim in a spiral or spinning pattern (Shoemaker et al., 2020). Infected fish may also lose control of their balance. Lethargy and anorexia are other symptoms often seen in fish with streptococcosis (A El-Noby et al., 2021). Streptococcosis is an infection that can specifically affect the nervous system of fish, and this appears to lead to characteristic abnormal swimming behaviors. These behaviors may be due to a direct effect of the bacteria on the brain and nervous system (Baums et al.,2013).

- ***Mycobacterium* Species and Mycobacteriosis**

Mycobacteriosis is a chronic disease caused by various bacterial species belonging to the genus *Mycobacterium* (*M. marinum*, *M. fortuitum*, *M. chelonae*) and can affect both aquarium fish and cultured fish (Irshath et al., 2023). Various behavioral changes can be observed in fish infected with mycobacteriosis. Lethargy and immobility are common (Palmeiro & Roberts, 2009). Loss of appetite is also common in fish with mycobacteriosis; infected fish may stop ingesting food (Francis-Floyd, 2011). In some cases, balance problems and abnormal swimming behavior can also be observed (Astrofsky et al., 2000).

- **Other Important Bacterial Diseases and Their Behavioral Effects**

In addition to the common bacterial diseases mentioned above, there appears many other bacterial diseases in fish such as pseudomonadiasis (winter disease) caused by *Pseudomonas anguilliseptica* (Doménech et al., 1997), flexibacteriosis caused by *Tenacibaculum maritimum* (Fernández-Álvarez et al., 2019), lactococcosis caused by various species such as *Lactococcus garvieae* (Patel et al., 2020), *Streptococcus parauberis* (Haines et al., 2013), *Streptococcus phocae* (Nikolaisen et al., 2021), piscirickettsiosis caused by *Piscirickettsia salmonis* (Marshall et al., 2007), cold water disease caused by *Flavobacterium psychrophilum* (Starliper, 2011), motile aeromonas septicemia (MAS) caused by *Aeromonas hydrophila* (Albert et al., 2000), winter ulcer caused by *Moritella viscosa* (Karlsen et al., 2017), pseudomonas septicemia caused by *Pseudomonas fluorescens* (De Guzman et al., 1986), diseases caused by *Flexibacter* spp. (De Guzman et al., 1986), diseases caused by *Vibrio harveyi* (Hedge et al., 2023) and diseases caused by *Tenacibaculum maritimum* (Hedge et al., 2023). It should be noted that each of these diseases can lead to unique behavioral changes. However, in general, it can be said that symptoms such as lethargy, loss of appetite and abnormal swimming are commonly seen in fish infected with these infections.

Common fish bacterial diseases and the associated behavioral changes observed are summarized in Table 1.

Table 1. Behavioral changes in fish infected with various bacterial diseases

Disease Name	**Pathogen**	**Host Fish Species**	**Observed Behavioral Changes**	**References**
Furunculosis	*Aeromonas salmonicida*	Salmonids (trout, salmon), Goldfish, koi and several other fish species	Lethargic swimming, swimming below the water surface, loss of appetite, difficulty in respiration, jumping out of the water, dark coloration, erratic swimming, weakness, lethargy.	Cipriano & Bullock., 2001; Baset, 2022; Izadi & Vajargah, 2022; İkiz & Kekeç, 2024; Kipp et al., 2018; Rao & Lahari, 2024
Vibriosis	Various *Vibrio* speciesi (*V. anguillarum*, *V. salmonicida*, etc.)	Salmonids, turbot, sea bass, striped bass, eel, ayu fish, codfish, red sea bream, grayfish, abalone, sea bream, flounder.	Anorexia, lethargy, weight loss, swimming near the surface.	Egidius, 1987; Afonso et al., 2005; Muniesa et al., 2005; Frans et al., 2011; Sanders, 2022; Zin Eldin et al., 2023; Manchanayake et al., 2023; Irshath et al., 2023
Columnaris Disease	*Flavobacterium columnare*	Carps, salmonids, catfish, eel, sturgeon.	Lethargy, anorexia, hanging at surface, slow swimming.	Bullock, 1986; Francis-Floyd, 1998; Lafrentz et al., 2012; Nguyen et al., 2022
Edwardsiellosis	*Edwardsiella ictaluri*, *E. tarda*	Catfish, tilapia, salmon, carps, sea bass, flounder.	Lethargy, hanging at surface, spiral/erratic swimming, anorexia, abnormal swimming.	Bullock, 1985; Blanch et al., 1990; Rousselet et al.,2018; IACUC, 2021
Enteric Red Mouth Disease (ERM)	*Yersinia ruckeri*	Salmonids, rainbow trout, cryfish, yellowtail, sturgeon.	Swimming near the surface, lethargy, loss of appetite, dark coloration, isolation, abnormal swimming.	Warren, 1983; Shaowu et al., 2013; Kumar et al., 2015; Zorriehzahra et al., 2017; Gabel et al., 2018; Hedge et al., 2023
Bacterial Kidney Disease (BKD)	*Renibacterium salmoninarum*	Salmonids.	Lethargy, darkening of the skin, abdominal distension,	Wiens, 2011; Delghandi et al., 2020

			exophthalmos, loss of equilibrium, irregular swimming..	
Streptococcosis	Various *Streptococcus* species (*S. iniae*, *S. agalactiae*, etc.)	Pinfish, nile tilapia, flounder, rainbow trout, eel, sturgeon, turbot, atlantic salmon.	Spiral/whirling swimming, loss of balance, drowsiness, disorientation.	Baums et al.,2013; A El-Noby et al., 2021; Shoemaker et al., 2020; Irshath et al., 2023
Mycobacteriosis	Various *Mycobacterium* species (*M. marinum*, *M. fortuitum*, *M. chelonae*)	Sea bass, turbot, atlantic salmon, various aquarium and aquaculture fishes.	Lethargy, loss of appetite, balance problems, weakness, abnormal swimming.	Colorni et al., 1998; Astrofsky et al., 2000; Dos Santos et al., 2002; Palmeiro & Roberts, 2009; Francis-Floyd, 2011; Zerihun et al., 2011

Mechanisms by which Bacterial Infections Affect Fish Behavior

- **Direct Effects on the Nervous System**

Some bacterial pathogens have been shown to penetrate the nervous system to directly affecting fish behavior. For example, the bacterium *Streptococcus iniae* can cause meningoencephalitis, or inflammation of the brain and membranes, in fish (Baums et al.,2013). This can lead to apparent behavioral changes in infected fish, such as spiral or round swimming and disorientation. Nervous system infections can profoundly affect the fish's motor control and response to the environment. Similarly, the bacterium *Yersinia ruckeri* has also been detected in the brain and it has been hypothesized that this may cause encephalitis (Strøm, 2018). This may be one reason for the high mortality rates of enteric red mouth disease (ERM) and the observed behavioral changes. Brain infection and associated neurological effects may contribute to the lethality of ERM. It has been shown that *Aeromonas salmonicida* infection can also lead to neuroinflammation and neural dysfunction in the brain (Liu et al., 2022). This can cause "sickness behaviors" such as anorexia and lethargy in infected trout. These information indicate that bacterial infections can not only cause direct tissue damage but also affect brain function and cause behavioral changes. *Aeromonas salmonicida* is thought to cause neuroinflammation by activating toll-like receptors in the brain, which in turn leads to behavioral symptoms such as anorexia and lethargy (Liu et al., 2022).

- **The Role of the Immune System Response on Behavior**

When a bacterial infection occurs in fish, the immune system activates a series of response mechanisms. Proinflammatory mediators, especially cytokines, secreted during this response can significantly affect the behavior of fish (Liu et al., 2022). These mediators can cross the blood-brain barrier or activate glial cells in the brain, causing changes known as “sickness behavior,” such as lethargy and loss of appetite. This systemic immune response to infection can lower the fish’s energy levels and reduce their regular activity. Interestingly, fish can also use behavior to fight infection. Infected fish can raise their body temperature, preferring warmer environments, a phenomenon known as behavioral fever (Boltana et al., 2018). This behavioral

change may positively impact the immune response and inhibit pathogen proliferation. For example, higher temperatures may increase lymphocyte proliferation and expression of proinflammatory cytokines (Boltana et al., 2018). However, some bacterial pathogens can develop various mechanisms to evade the immune system. Some bacteria, such as *Vibrio anguillarum*, can escape the immune system and increase their chances of survival within the host by inhibiting the respiratory burst and causing apoptosis of leukocytes (Sepulcre et al., 2007). This situation demonstrates the complex strategies of pathogens against host defense mechanisms.

- **Contribution of Hormonal Changes to Behavior**

Bacterial infections can affect the levels of hormones such as cortisol, known as stress hormones in fish, and these hormonal changes can lead to various changes in the fish's behavior (Liu et al., 2022). Stress and hormonal imbalances can significantly affect the general behavior of fish and their susceptibility to disease. For example, it has been shown that *Aeromonas salmonicida* infection can regulate the color change behavior of fish by affecting melanocyte-stimulating hormone (MSH) and melanin-concentrating hormone (MCH) levels (Yi et al., 2021). This suggests that infection may affect not only general behavior but also more specific physiological processes at the hormonal level. It has also been reported that catecholamine stress hormones (e.g., dopamine and norepinephrine) can increase the growth, motility, and virulence of *Yersinia ruckeri* (Torabi Delshad et al., 2019). This information suggests that the host stress response may affect the severity of infection by increasing the virulence of the pathogen. Moreover, it has been suggested that stress hormones may promote bacterial growth and thus increase the risk of infection. *Aeromonas salmonicida* infection has also been observed to affect color change behavior by increasing cortisol levels (Yi et al., 2021). This is an important example of how infections can affect the physiological processes and related behaviors of fish at the hormonal level.

- **Behavioral Reflections of Metabolic Disorders**

Bacterial infections can also affect the energy metabolism of fish, which can cause behavioral changes such as lethargy and loss of appetite (Liu et al., 2022). For example, it has been shown that *Aeromonas salmonicida* infection can suppress neural functions in the kidney (Liu et al., 2022), this can affect metabolic processes and lead to behavioral changes. Additionally, it has been determined that metabolic changes may also affect the immune response of fish (Jiang et al., 2019). This suggests that there is a complex interaction between metabolism and the immune system, and that infections can disrupt this interaction. Studies on the interaction of water temperature on metabolism and the immune system, and how this may affect susceptibility to *Edwarsiella tarda* infections, highlight the importance of this complex relationship (Jiang et al., 2019).

Conclusion and Recommendations

This review shows that the effects of bacterial pathogens on fish behavior are complex and multifaceted. Many factors, such as the type and severity of infection, the species of fish and environmental conditions, play a role in the emergence and shaping of behavioral changes. The observed behavioral changes can be used as a potential tool for early diagnosis of diseases in aquaculture and may play an important role in fish health management. Behavioral signs such as lethargy, loss of appetite, abnormal swimming and color changes may indicate the presence and severity of bacterial infections. Therefore, understanding and regularly monitoring

behavioral changes due to bacterial infections is of great importance for aquaculture management and fish welfare. However, when looking at the effect of bacterial pathogens on fish behavior, it is difficult to identify the pathogen with just this. This is due to the fact that similar behavioral symptoms can manifest across various diseases, making pathogen-specific diagnosis difficult based solely on behavior. However, behavioral monitoring is a feasible method to determine whether the fish is under risk.

Several suggestions for future research can be made. First, specific behavioral changes caused by different bacterial pathogens and infection levels need to be examined thoroughly. This will enable more accurate and earlier diagnosis of diseases. Second, it can be useful to develop non-invasive and automated monitoring technologies to use behavioural changes as early detection tools. Such technologies could help achieving continuous and effective monitoring of fish health in large-scale aquaculture facilities. Third, comparing behavioral responses among different fish species and age groups and identifying host-specific responses may guide us to understand interspecies and age-related differences in diseases. Fourth, a more comprehensive study of the interactions of stress factors (water quality, temperature, stocking density, etc.) and bacterial infections on fish behavior is critical to develop strategies for disease prevention and control. Finally, studies to better understand the effects of bacterial infections on the nervous system, immune system and hormonal system at the molecular level will contribute to the elucidation of the mechanisms underlying these effects and the development of more effective treatment methods. Advances in this area are of great importance for the sustainability of the aquaculture sector and for improving fish welfare.

Acknowledgements
Not available

Ethical approval
Not applicable

Informed consent
Not available

Data availability statement
The authors declare that data can be provided by corresponding author upon reasonable request.

Conflicts of interest
There is no conflict of interests for publishing this review.

Funding organizations
No funding available for this review.

Contribution of authors
The author contributed to conceptualization, data curation, formal analysis, writing the original draft, investigation, methodology, resources, validation, visualization, and finalizing the paper.

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