Fungal Zoonotic Infections in Fish an emerging threat to Aquatic and Terrestrial life

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ABSTRACT

Fish fungal infections represent an emerging threat with important implications for both animal and human health. Several primary fish pathogens have zoonotic potential, underscoring the relevance of fish mycoses for public health issues globally. Fungal pathogens of free-living and farmed fish are ubiquitous in aquatic environments. They cause superficial to disseminated infections and play a significant role in morbidity and mortality events in cultured and wild fish stocks. Although most published cases of fungal infections in fish refer to opportunistic pathogens that take advantage of compromised host immunity to invade the host, some fungi can behave as primary pathogens, able to cause disease even in apparently immunocompetent fish. The genera with the greatest number of pathogenic species for fish include Aphanomyces, Aspergillus, Candida, Chrysosporium, Exophiala, Fusarium, Ichthyophonus, Paecilomyces, Penicillium, Phoma, Saprolegnia, Trichophyton, and Trichosporon although zoonotic species are described mainly within genera Chrysosporium, Histoplasma, Paracoccidioides, Sporothrix or Cryptococcus. Yeasts play a role in algun pseudomycoses and mycoses. Saprolegniasis, epizootic ulcerative syndrome, branchiomycosis and dermal pseudomycoses are some examples of emerging fungal infectious diseases causing morbidity and mortality in farmed fish and amphibians and economic losses to aquaculture. This chapter examines the incidence and distribution of clinically relevant fungi in fish hosts, pathological findings associated with infection, and present knowledge on transmission routes. Challenges related to therapy and preventive strategies are discussed. Finally, the zoonotic potential and possible implications for public health will be addressed.

Keywords: Fish, Fungi, Zoonotic infections, Challenges, Preventive strategies

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1. INTRODUCTION

1.1. FUNGAL ZOONOTIC INFECTIONS IN FISH

A fungus-related zoonosis in fish, caused by several pathogenic fungi, is a very serious health problem for both aquaculture and humans. This chapter provides an in-depth analysis of common fungal pathogens affecting fish, their modes of transmission, clinical manifestations in humans, and strategies for the prevention and management of fungal pathogens. Fungal zoonosis in fish is complex and requires an understanding of its dynamics in order to implement effective control measures and protect aquatic ecosystems and human health.

1.2. FUNGAL ZOONOTIC DISEASES OF FISH

Non-photosynthetic microorganisms that live as saprophytes in dead organic material and soil are known as fungi. Only 300 out of 1.5 million identified fungal spp. are pathogenic to humans (Abara et al. 2017). The most commonly known fungal diseases with their etiological agent are presented in Table 1.

Table 1: The most commonly known fungal diseases of fish

Disease	Causative Agent	Common Name
Basidiobolomycosis	*Basidiobolus ranarum*	*Subcutaneous zygomycosis or subcutaneous phycomycosis*
Sporotrichosis	*Sporothrix schenckii*	Rose gardener's disease
Shrimp Mycosis	*Lagenidium spp.*	Larval mycosis
Aspergillosis	*Aspergillus spp*.	Common mold
Icthyophonosis	*Ichthyophonus hoferi*	White spot disease
Branchiomycosis	*Branchiomyces demigrans*	gill rot
Saprolegniosis	*Saprolegnia parasitica*	Cotton moulds
Dermocystidiosis	Dermocystidium	A gill disease
Exophialiasis	*Exophiala salmonis, E. psychrophila*	Black yeast like fungi

The epidemiology of fungal diseases in fishes is complex and varies depending on the type of fungus and the environmental conditions. Fungal spores can be found in many aquatic environments but infection typically occurs when fish are stressed or injured, allowing the fungus to penetrate the skin or gills. Factors that can increase the risk of infection include poor water quality, overcrowding, and poor nutrition. Saprolegniosis, caused by the fungus Saprolegnia spp. is one of the most common fungal diseases in fishes. This infection can affect a wide range of fish species, and outbreaks often occur during the spawning season when fish are most vulnerable. The fungus can be spread through contact with infected fish, water or equipment and it can survive in the environment for a long time period.
Achlya infections are caused by the fungus Achlya spp. and these are typically associated with freshwater environments (Chauhan et al. 2012; Chauhan et al. 2013). This infection can occur in both wild and farmed fish populations and outbreaks are often linked to poor water quality and

overcrowding. Fusarium infections are caused by the fungus Fusarium spp. and are less common in fishes than Saprolegnia and Achlya infections (Ke et al. 2016). These infections are typically associated with warmer water temperatures and can be transmitted through contact with infected fish or water.

Fungal infections in fish can be caused by a variety of different types of fungi. They can occur in both wild and farmed fish populations and can cause serious health problems, including mortality (Iqbal et al. 2012). Some of the common fungal diseases that affect fish include saprolegniasis, ichthyophthiriasis and cryptococcosis (Van Den Berg et al. 2013).

Saprolegniasis, also known as water mold disease, is caused by the fungus Saprolegnia. This fungus thrives in cool, oxygen-rich water and can infect fish that have weakened immune systems due to poor nutrition, overcrowding, or other stressors. Infected fish may develop grayish-white cotton like growths on their skin and fins (Barde et al. 2020).

Ichthyophthiriasis also known as white spot disease, is caused by the parasite *Ichthyophthirius multifiliis*. Although it is not a true fungus but often included in discussions of fungal diseases due to its similarities in presentation and treatment. Infected fish may develop white spots on their skin, fins, gills and may exhibit respiratory distress with certian behavioral changes (Von Gersdorff Jørgensen 2017).

Cryptococcosis is caused by the fungus Cryptococcus neoformans and can affect both freshwater and marine fish. This disease is less common than saprolegniasis and ichthyophthiriasis but it can be serious and difficult to treat. Infected fish may develop skin lesions, neurological symptoms and other health problems (Sato et al. 2015).

1.3. BASIDIOBOLOMYCOSIS

Basidiobolomycosis is a fungal infection caused by the fungus *Basidiobolus ranarum* (Al-Shanafey et al. 2012; Shreef et al. 2018). The mode of transmission of the fungus is not fully understood but it is believed to enter the body through minor cuts, abrasions or insect bites (El-Shabrawi and Kamal 2011). *Basidiobolus ranarum* is commonly found in soil, decaying vegetation and the digestive tracts of reptiles and amphibians. The fungus may be acquired by ingestion of contaminated soil or by direct inoculation of the fungus through the skin or mucous membranes (Shreef et al. 2018).

Fig. 1: Rainbow trout with symptoms of Basidiobolus infection. a) abdomen distension, b) Lesions on ventral part, c) pigmentation on skin, and d) necropsy (Shahi et al. 2023).

Risk factors for the infection include immunosuppression, diabetes mellitus and malnutrition. Basidiobolomycosis is more common in tropical and subtropical regions and is often associated with exposure to agricultural land or bodies of water (Geramizadeh et al. 2015).

The fungus enters the skin of the fish through cuts, abrasions or insect bites. It then spreads to the deeper tissues and forms a granulomatous lesion (Sackey et al. 2017). The fungi produce hyphae which release enzymes and cause tissue damage. The lesion may ulcerate, leading to secondary bacterial infections (Mendiratta et al. 2012; Anaparthy and Deepika 2014).

The clinical signs involved skin lesions with raised edges and central necrosis. Ulceration of skin with inflammation. Reddened and swollen areas with poor healing.

1.4. SPOROTRICHOSIS

Sporotrichosis is a fungal infection caused by the fungus *Sporothrix schenckii* (Barros et al. 2011). The fungus is found in soil and on plant matter such as sphagnum moss, rose bushes and hay (Barros et al. 2011). The mode of transmission is through direct inoculation of the fungus into the skin usually through a small cut or scratch. The infection is most commonly associated with activities that involve handling contaminated materials such as gardening or handling of animals (e.g., cats with sporotrichosis). The infection can also be acquired by inhalation of fungal spores or through the bites of infected animals (e.g. cats). Risk factors for sporotrichosis includes having a weakened immune system, working with plants or soil, and living in areas where the fungus is endemic. Sporotrichosis is not contagious and cannot be transmitted from person to person.

The fungus enters the skin of the fish through wounds or punctures. It then spreads to the lymphatic system and forms nodules in the skin and subcutaneous tissues (Valente et al. 2020). The fungi produce spores that are released from the nodules and can infect other areas of the body. In severe cases, the infection can spread to internal organs such as the liver, spleen and lungs.

The clinical signs involved small papules or nodules on the skin. Ulcers or abscesses with draining pus. Lymph node enlargement. Fever, anorexia, weight loss and lethargy.

1.5. SHRIMP MYCOSIS

Shrimp mycosis is caused by a fungus called *Lagenidium callinectes* (Uddin et al. 2013). The fungus is commonly found in marine and estuarine environments and infects a variety of shrimp species (Lee et al. 2016). The mode of transmission is through direct contact with infected water or another infected shrimp. The fungus can penetrate the exoskeleton of the shrimp and infect the gills, causing black discoloration, reduced oxygen uptake and ultimately death. Environmental factors such as high salinity, high temperature and low dissolved oxygen can increase the prevalence of shrimp mycosis. Shrimp mycosis is primarily a problem in shrimp aquaculture and can result in significant economic losses for the industry.

Control measures for shrimp mycosis include maintaining good water quality, avoiding overcrowding and using antifungal treatments. The fungus enters the shrimp through the cuticle or damaged exoskeleton. It then invades the underlying tissues and organs of the shrimp. The fungi produce hyphae that grow rapidly and cause tissue damage. The infection can spread throughout the shrimp's body and cause systemic disease (Czeczuga et al. 2012).

Clinical signs involved red or brown discoloration on the shell. Black spots or blotches on the carapace or appendages. Abnormal behavior such as lethargy, loss of appetite and reduced movement.

1.6. ASPERGILLOSIS

Aspergillosis is caused by the Aspergillus species of fungi, found in soil and indoor environments (Panackal et al. 2010; Hany et al. 2015). The infection is transmitted by inhaling fungal spores during activities like gardening or construction. Individuals with weakened immune systems are at higher risk for infection. Aspergillosis can present in various forms and symptoms depend on severity. The fungus enters the fish through the respiratory tract (Tsantes et al. 2022). It then grows and produces spores that can cause inflammation and necrosis of the lung tissue. The fungi can also invade other organs such as the liver and spleen. In severe cases, the infection can lead to sepsis and death (Arastehfar et al. 2021).
The clinical signs are respiratory distress and gasping (Bariteau et al. 2014). Coughing, sneezing, and nasal discharge weight loss anorexia, weakness, lethargy and depression.

1.7. ICHTHYOPHONOSIS

Ichthyophonosis is a fungal infection that affects fish caused by the fungus *Ichthyophonus hoferi* (Zuray et al. 2012; Hershberger et al. 2016; Gregg et al. 2016). The fungus is found in marine and freshwater environments and infects a variety of fish species (Jafarizadeh et al. 2014). The mode of transmission is through ingestion of infected tissue or through direct contact with infected fish. The infection can cause lethargy, weight loss and ultimately death in infected fish. Humans are not at risk of contracting ichthyophonosis from infected fish.
The fungus enters the fish through the skin or gills. It then invades the deeper tissues and causes necrosis and inflammation. The fungi produce spores that can spread to other parts of the body and cause secondary infections. The infection can lead to systemic disease and death in severe cases.
Clinical signs involved ulcerative skin lesions. Hyperemia and necrosis of the fins. Discoloration of skin and eyes. Loss of scales and skin shedding. Lethargy, anorexia, and weight loss (Jafarizadeh et al. 2014).

1.8. BRANCHIOMYCOSIS

Branchiomycosis is a fungal infection that affects fish, caused by the fungus *Branchiomyces sanguinis* (Sheikha and Mankodi 2021; Shinn et al. 2023). The fungus is commonly found in freshwater environments and infects a variety of fish species. The mode of transmission is through inhalation of fungal spores or through direct contact with infected fish or contaminated water. The infection can cause respiratory distress, skin lesions, and ultimately, death in infected fish. Humans are not at risk of contracting branchiomycosis from infected fish.
The fungus enters the fish through the gills (Pauland and Sahoo 2018). It then invades the gill tissue and causes inflammation and necrosis (Roberts 2012). The fungi produce spores that can spread to other parts of the body and cause secondary infections. The infection can lead to respiratory distress, anemia and death.
Clinical signs involved are respiratory distress and gasping. Increased mucus production and gill discoloration. Difficulty in feeding and lethargy. Anemia, weight loss, poor growth and mortality.

1.9. SAPROLEGNIOSIS

Saprolegniosis is a fungal infection that affects fish and other aquatic animals, caused by the fungus *Saprolegnia spp*. (Van Den Berg et al. 2013). The fungus is commonly found in freshwater environments and infects a variety of fish and amphibian species (Shinn et al. 2023).

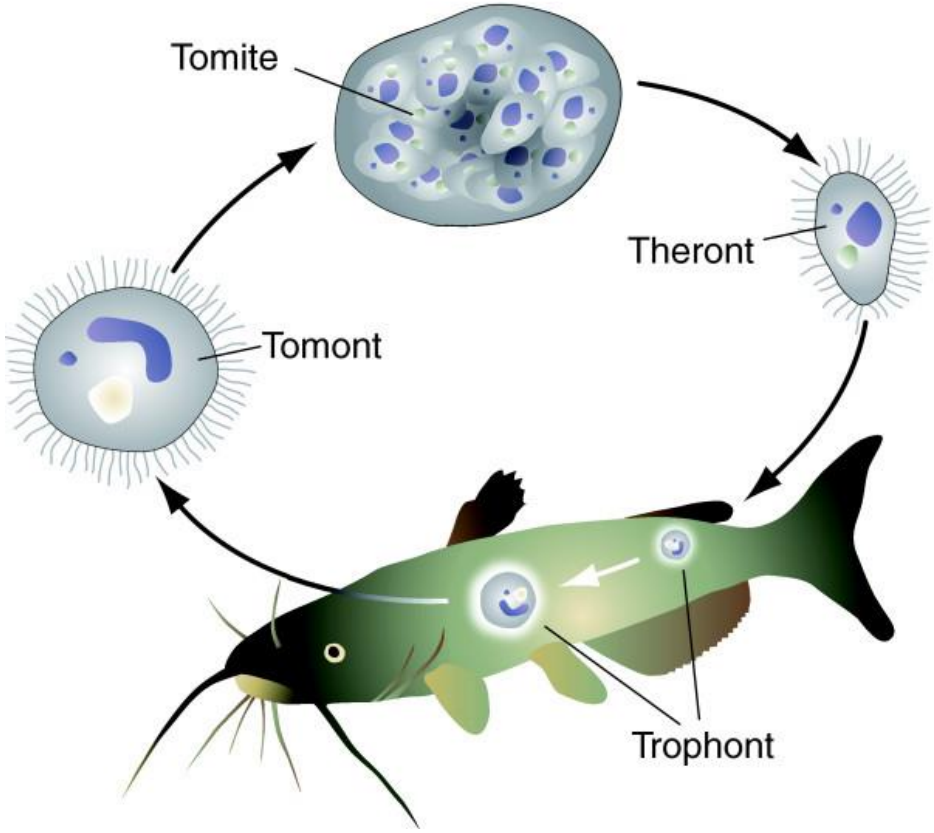

Fig. 2: Life cycle of Ichthyophonosis (Coyne et al. 2011).

Fig. 3: Branchiomycosis in fish (Abduhalilova et al. 2023).

The mode of transmission is through direct contact with infected animals or contaminated water. The infection can cause white cotton-like growths on the skin and fins of infected animals as well as systemic infections that can be fatal. Saprolegniosis can also affect eggs and larvae, causing reduced hatching and survival rates.

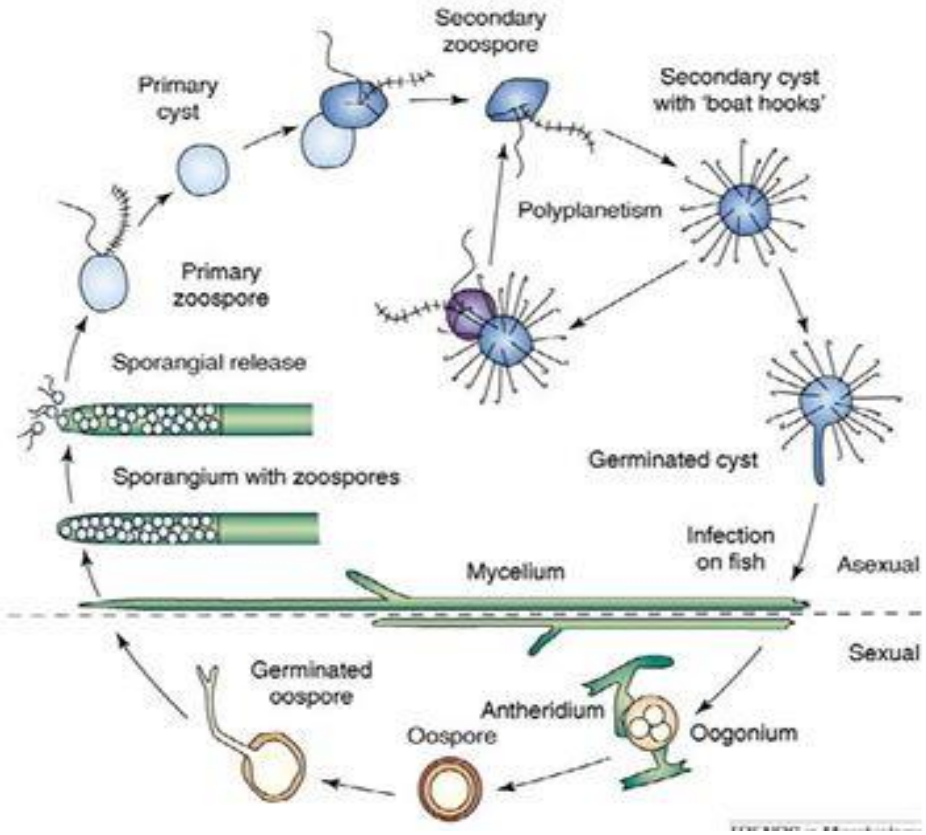

Fig. 4: Life cycle of Saprolegnia (Lone and Manohar 2018).

The fungus enters the fish through damaged skin or fins. It then invades the tissues and causes necrosis and inflammation. The fungi produce hyphae that grow rapidly and can cover the skin and fins with a cotton-like growth. The infection can lead to secondary bacterial infections and death in severe cases. Clinical signs include white or grayish cotton-like growth on skin and fins. Lesions with raised edges and central ulceration. Necrotic tissues with inflammation. Lethargy, anorexia, weight loss and mortality.
Use of potassium permanganate, formalin and provision of iodine solutions are common therapies for fungal illness. It is recommended to provide a bath therapy using NaOH (10–25 gm/L for 10–20 min), KmNO4 (1 gramme in 100 L of water for 30–90 min), or CUSO4 (5–10 gm in 100 L of water for 10–30 min). Overtreatment may result in fish tissues damage, which can lead to recurring infections. The proper control of the environment is of the utmost importance for an efficient treatment of chronic diseases. Don not transport the contaminated fish if an infection is present (Barde et al. 2020).

1.10. DERMOCYSTIDIOSIS

Dermocystidium spp. is a genus of fungus that infects fish and amphibians (Mahboub and Shaheen, 2020; Sellyei et al. 2020). The exact mode of transmission of dermocystidiosis is not fully understood, but it is thought to be through direct contact with infected animals or contaminated water. The fungus can infect a variety of fish and amphibian species but some are more susceptible than others. The infection can cause skin lesions, swelling, and ultimately death in infected animals. The fungus can also infect eggs and larvae, causing reduced hatching and survival rates. Control measures for dermocystidiosis include maintaining good water quality, avoiding overcrowding and using antifungal treatments. Humans are not at risk of contracting dermocystidiosis from infected animals (Plaul et al. 2018).

The fungus enters the fish through the skin or fins. It then invades the deeper tissues and forms cysts. The fungi can also cause inflammation and necrosis of the surrounding tissue. The infection can lead to systemic disease and death in severe cases.
Clinical signs involve multiple cysts on the skin and fins. Raised, nodular lesions on the body. Thickening and darkening of the skin. Lethargy and anorexia.

1.11. EXOPHIALIASIS

Pathogenic *Exophiala* spp. causing infection in cold-blooded animals generally belong to the 'salmonis clade' and the '*E. angulospora* complex (De Hoog et al. 2011; Thitla et al. 2022).
The fungus enters the fish through the skin or fins. It then invades the deeper tissues and causes necrosis and inflammation. The fungi produce melanin which can cause black or brown discoloration of the skin and fins. The infection can lead to systemic disease and death in severe cases.
Clinical signs include black or brown discoloration on skin and fins. Small nodules or papules on the skin. Lesions with necrosis and inflammation. Lethargy anorexia, weight loss and mortality.

2. CONTROL STRATEGIES OF FUNGAL ZOONOSIS IN FISH

- Averting is the most common control for branchiomycosis
- Effective management practices will create an environment that is unsuitable for the growth of fungus.
- Particular caution must be taken to prevent the spread of the disease to unaffected areas. All tanks, raceways, and aquaria must be sanitized and dried in order to prevent mortalities. Copper sulphate and formalin have been used in this case.
- Ponds need to be dried and treated with copper sulphate (2–3 kg/ha) and quicklime calcium oxide (Ganguly et al. 2016).
- An extended term bath in Acriflavine neutral or forma green for 7 days helps in reduction of this condition.
- It's best to bury dead fish.
- The greatest way to prevent Saprolegniasis is by skilled leadership practices
- Observation and correction of sanitation is required when Saprolegnia is detected in an aquatic system.
- Avoiding crowds to reduce injuries, especially during spawning, maintaining enough nutrition, and maintaining excellent water quality and circulation can all help avoid the spread of the disease.
- Fish infected with Icthyophonus hoferi will always harbour the infection; there is no treatment.

3. FACTORS OF FUNGAL ZOONOSIS

Fish-to-human transmission of infectious diseases caused by fungus is referred to as fungal zoonosis. Fish infections by fungi are rather common and can have a big impact on both the aquaculture sector and public health. There are several elements that influence the development and spread of fungal zoonosis in fish:

3.1. AQUATIC FUNGAL PATHOGENS

Aquatic environments, such as freshwater, marine and brackish water habitats are accessible to a variety of fungi. These fungi can infect fish through direct contact with polluted water or by entering their skin and mucous membranes (Zhang et al. 2022). Fish are frequently infected by organisms of the genera Saprolegnia, Achlya, Aphanomyces, and Fusarium.

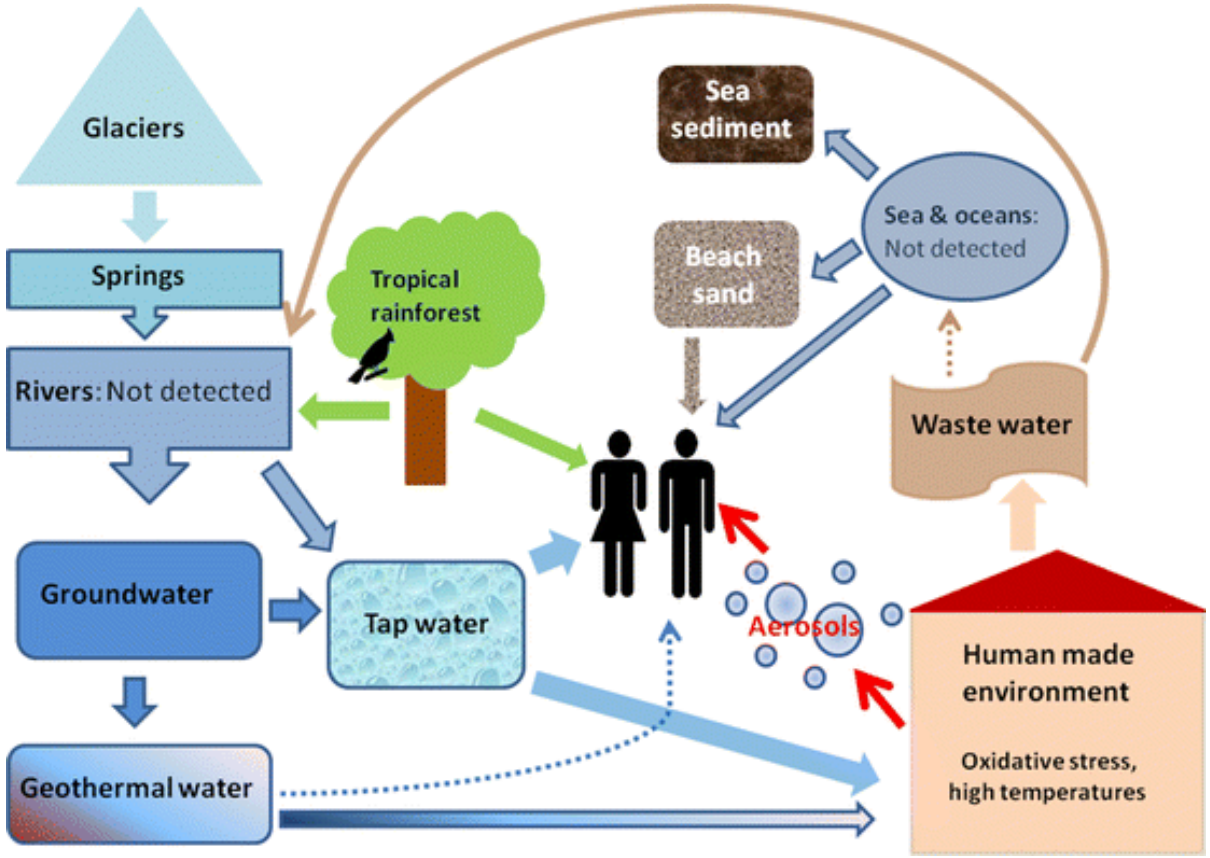

Fig. 5: Presence of Exophialaosis in natural and man-made environment (Babič et al. 2018).

3.2. POOR WATER QUALITY AND STRESS

Fish with fungal diseases are far more likely to experience stress. The fish immune system is weakened by stressors such as overpopulation, poor water quality, temperature changes, and inadequate diet which makes them more vulnerable to fungus-related infections. High fish density aquaculture environments can produce circumstances that favor the proliferation of fungi. (Tedesco et al. 2022).

3.3. WOUNDS AND INJURIES

Fish are susceptible to wounds and injuries brought on by a variety of things, including handling, predation, and environmental dangers. Fungal pathogens can enter the body through open wounds, causing isolated or systemic ailments. Injury during handling and transportation in fisheries and fish farms is a risk factor for zoonotic fungal disease (Beckmann et al. 2020).

3.4. IMMUNE SUPPRESSION

Fish may experience immunosuppression like other animals as a result of a variety of factors such as environmental stresses, inadequate nutrition, and exposure to toxins. Fish with weakened immune systems are more susceptible to fungal infections because they are less able to establish a robust immunological response to pathogens (Tedesco et al. 2022).

3.5. INTERSPECIES TRANSMISSION OF DISEASE

Fungal diseases can spread from diseased fish to human. Workers in fisheries, aquaculture or fish farms may come into direct contact with diseased fish or polluted water which might result in sickness (Li et al. 2019).

3.6. HANDLING AND PROCESSING PRACTICES

Due to inappropriate handling and processing practices, aquaculture employees, fish handlers, and fishermen may be at risk of developing a fungal zoonosis. Humans may get fungal diseases through contact with fish tissues and contaminated surfaces, particularly if they sustain wounds or cuts to the skin (de Silva et al. 2023).

3.7. IMMUNOCOMPROMISED INDIVIDUALS

Fungal zoonotic infections are more likely to affect immunocompromised individuals such as those with underlying medical issues, the elderly, and those receiving immunosuppressive medications. If these individuals are exposed to fungal infections from fish, they are more likely to experience serious consequences (Narayan et al. 2023).

4. PREVENTIVE MEASURES FOR FUNGAL ZOONOSIS

Fish can experience less stress and have stronger immune systems due to appropriate feeding and maintained water quality, which reduces the danger of fungus diseases. It is possible to stop the spread of fungal infections among fish populations and lower the danger of transmission to humans by implementing good hygiene and sanitation practices in fisheries and fish farms (Rahman et al. 2020).
In aquaculture settings, regular checkups and disease surveillance can aid in the early detection of fungal infections and speed up treatment and control procedures. The danger of direct contact with fungal diseases can be reduced by providing workers with protective clothing and equipment. Consumers and industry workers can become more aware of the dangers of fungal zoonosis and the value of safe fish handling and eating practices through public health education (Ziarati et al. 2022).
It is crucial to recognize and manage the causes of fish fungal zoonosis in order to improve both fish and human health. The danger of fungal infections can be decreased by applying preventative measures and upholding great aquaculture practices, resulting in safer fish consumption and a better aquatic ecosystem (Rossow et al. 2020)
To protect both human health and aquatic ecosystems, it is essential to prevent and manage fish fungal zoonosis. Fish may transmit zoonotic fungal infections to humans, and certain fungal pathogens can seriously harm aquaculture's bottom line. The risk of fungal infections can be reduced, and their effects can be minimized, by setting control measures into action. Here are some crucial methods for preventing and managing fish fungal zoonosis:

4.1. WATER QUALITY Management

Maintaining high water quality is essential for keeping fish free of fungus infection. Fish may become stressed and have their immune systems weakened by poor water quality which includes high levels of ammonia, nitrite or organic matter, leaving them more susceptible to fungus and its infections. Fungal outbreaks may be prevented by regular monitoring and effective water quality management

techniques such sufficient filtration and water exchange (Teshome and Addis 2019).

4.2. PROPER NUTRITION

Giving fish a healthy, balanced diet boosts their immune system and increases their resistance to fungus infections. The use of high-quality feeds and avoiding overfeeding are two feeding techniques that can improve fish health and lessen their sensitivity to fungi-related ailments.

4.3. BIOSECURITY AND QUARANTINE

Fungal infections can be prevented by using quarantine procedures for newly imported fish into aquaculture operations. The spread of illnesses can be controlled by properly monitoring and isolating new fish before reintroducing them to the main population. Additionally, the entry and spread of fungal diseases can be stopped by following strict biosecurity precautions such as limiting access to aquaculture facilities and sanitizing equipment (Mocho et al. 2022).

4.4. ENVIRONMENTAL HYGIENE

In order to prevent fungal infections, it's essential to keep fish farming facilities clean and hygienic. Reducing the fungal burden and lowering the risk of transmission can be accomplished by routinely cleaning and disinfecting surfaces, equipment, and tanks. Quick removal of dead or diseased fish also helps to stop the spread of fungi (Lõhmus and Björklund 2015).

4.5. WATER TREATMENT

Treatments like ultraviolet (UV) sterilization or ozone treatment can be used to control the fungal growth in water. These techniques can reduce the risk of new infections and limiting the spread of fungal diseases.

4.6. DISEASE SURVEILLANCE

Early diagnosis of fungal infections in fish populations depends on routine monitoring and disease surveillance. Initial detection of infection enables rapid intervention and control measures. Monitoring fish behaviour, appearance, and general health can aid in spotting any early-stage health problems (Shamsi 2016).

4.7. MEDICATION AND TREATMENTS

Fish with confirmed fungal infections can be treated with the right antifungal medicines. In order to prevent residues of drugs in fish intended for human consumption, it is essential to know about the dose limit and its half-life in water.

4.8. EDUCATION AND RESEARCH

Continued research practices and their epidemiology in fish is necessary to develop more effective prevention and control strategies for fungal zoonosis in fish. Providing knowledge to fish farmers, aquaculture managing workers and the general public about fungal zoonosis may lead to public

awareness from the protection of diseases caused by fungus (Zadoks et al. 2020).

5. CONCLUSION

In conclusion, a combination of effective management practices, strict biosecurity controls, early identification and suitable medication is required to prevent and control fungal zoonosis in fish. We can lessen the effect of fungal diseases on fish populations, maintain human health and encourage sustainable aquaculture practices through implementing these ideas into practices.

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