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Endoparasitic challenges in freshwater fish aquaculture: insights into the life cycle, transmission, and management

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Abstract

Aquaculture plays a crucial role in meeting the growing global demand for seafood, particularly fish, but faces significant challenges from fish diseases. Pathogens like bacteria, viruses, fungi, and parasites cause diseases that result in economic losses and threaten fish health. Endoparasites, including protozoa, helminths (worms), and metazoans, have emerged as a major concern in aquaculture. Trematodes, cestodes, and acanthocephalans are notable examples of these parasites. Understanding the life cycles of these endoparasites is essential for developing effective prevention and control strategies. This review aimed to contribute to understanding these parasites' life cycles, which is crucial for implementing targeted prevention and control measures. Various fish species serve as intermediate and definitive hosts, influencing the transmission dynamics of these parasites. Implementing appropriate management measures is vital to maintaining fish health, promoting sustainable aquaculture practices, and meeting the increasing global demand for seafood.

1. Introduction

Aquaculture is a vital source of protein and livelihood, but parasites significantly challenge its sustainability. Parasite infections in finfish aquaculture can hinder growth, reduce yields, and increase mortality, threatening food security. Infections have caused major economic losses, such as $193.6 million in Chilean Atlantic salmon due to *Caligus rogercresseyi* and $16.93 million in U.S. tilapia, with mortality rates reaching up to 50% (Shinn *et al*., 2015b). Endoparasites, which live inside hosts, can use fish as intermediate or definitive hosts, with other species like birds or dogs also serving as definitive hosts.

Endoparasites dominate aquaculture systems due to their life cycles and waterborne infectious stages (Paladini *et al*., 2017). Understanding these cycles is essential for effective prevention and control measures to minimise outbreaks. Proper management of endoparasitic diseases can improve fish health, boost productivity, and ensure food security. This review focuses on the life cycles, transmission routes, and control strategies for endoparasites, highlighting their impact on the economic stability of aquaculture.

2. Common endoparasites in freshwater fish

Endoparasites, including flukes, tapeworms, nematodes, and acanthocephalans, live in the internal organs of fish and may encyst in various tissues. Helminth endoparasites primarily damage the digestive system but can also affect other organs, contributing to financial losses in warm-water aquaculture (Gebremedhn and Tsegay, 2017). Their diversity in freshwater aquaculture depends on factors like location, fish species, and environmental conditions, with many having complex life cycles involving multiple hosts (Orobets *et al*., 2019). Carlson *et al*. (2020) estimate there are 100,000–350,000 species of helminth endoparasites in vertebrates, with 85–95% still unknown. Table 1 classifies adult endoparasites by taxonomic families, listing their host fish species and geographic distribution. It highlights regional variations and potential environmental factors affecting parasite prevalence.

2.1 Monogeneans

Dactylogyridae is a family of monogeneans with five genera, including ectoparasites like *Cichlidogyrus*, *Onchobdella*, and *Scutogyrus*, which feed on fish gills or skin. Some genera, like *Enterogyrus* and *Urogyrus*, are

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Table 1. Some of adult endoparasites in aquatic fish checklist.

Endoparasite	Host	Distribution	References
Trematode			
Acanthostomidae: *Stunkardiella minima*	*Rhamdia guatemalensis*	Mexico	Salgado-Maldonado *et al*. (2005)
Allocreadiidae: *Creptotrema agonostomi*	*Agonostomus monticola*		
Clinostomum sp.	*Oreochromis* sp.	Japan	Blahoua *et al*. (2020)
Cestoda			
Bothriocephalidae *Bothriocephalus cuspidatus*	*Gobiomorus dormitor*	Mexico	Salgado-Maldonado *et al*. (2005)
Diphyllobothrium latum	*Oreochromis* sp.	Japan	Blahoua *et al*. (2020)
Nematoda			
Camallanidae: *Procamallanus*	*Dorosoma petenense*	Mexico	Salgado-Maldonado *et al*. (2005)
Capillariidae: *Paracapillaria teixeirafreitasi*	*Dormitator maculatus*		De Leon *et al*. (2010)
	Gobiomorus dormitor		
Paracamallanus cyathopharynx	*Oreochromis* sp.	Japan	Blahoua *et al*. (2020)
Contracaecum sp.	*Oreochromis* sp.		
Acanthocephalan			
Acanthocephala gen. sp.	*Ophisternon aenigmaticum*	Mexico	Salgado-Maldonado *et al*. (2005)
Acanthogyrus tilapiae	*Oreochromis mossambicus*	South Africa	Mokonyane (2020)
Monogeneans			
Enterogyrus coronatus	*Hemichromis* sp.	Mexico	Mendoza-Franco *et al*. (2018)
Enterogyrus malmbergi/ Enterogyrus sp.	*Oreochromis niloticus*		
	Oreochromis sp.		

endoparasites found in the stomach and urinary bladder, respectively (Mendlová *et al*., 2010; Madanire-Moyo and Avenant-Oldewage, 2014). *Enterogyrus*, a stomach monogenean, infects the digestive tract, including the stomach and anterior intestine, in various fish species (Assane *et al*., 2021). Internal monogenean infections are rare compared to external ones.

Enterogyrus sp. worms are small, flattened, pear-shaped parasites that attach to the stomach mucosa with a convex dorsal side and concave ventral side (Mendoza-Franco *et al*., 2018). They have a thick tegument to protect against digestive fluids and the stomach's acidic pH. Morphologically, *Enterogyrus* can be identified by two pairs of central anchors, a transverse bar, and marginal hooklets on the opisthaptor's fold (Figure 1), with the first pair's central anchor featuring a long handle and curved blade (Bayoumy and El-Monem, 2012).

2.2 Helminths

There are many reports on helminth endo-parasites of fish. Helminths, worms, and fluke parasites are commonly found in the gastrointestinal system, body cavities, internal organs, and muscles (Edeh and Solomon, 2016). Trematodes (flukes), monogeneans (flatworms), cestodes (tapeworms), nematodes (roundworms), and acanthocephalans (spiny-headed worms) are all part of this category. All these parasites, except roundworms from Phylum Nematoda have a head region with a particular attachment mechanism, followed by a body section.

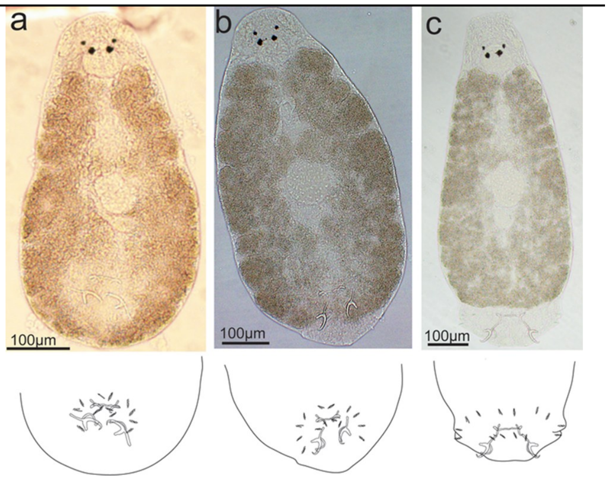

Figure 1. Different body shapes of *Enterogyrus malmbergi* Bilong Bilong, 1988 under the coverslip and the motion of opisthaptoral sclerotized parts depicted in drawings (Source: Zhang *et al*., 2019).

2.2.1 Trematodes

Trematodes, or Digenea, are parasitic flatworms of the phylum Platyhelminthes with a heteroxenous life cycle typically involving a mollusc as the first intermediate host (Edeh and Solomon, 2016). Their leaf-like or oval bodies have oral and ventral suckers, with the oral sucker surrounding the mouth (Madhavi and Bray, 2018). Most digenetic trematodes require three hosts, though some species need four to reach sexual

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maturity. Their tegument provides secretory and absorptive functions, protecting them from the host environment.

The typical trematode life cycle (Figure 2) begins with an egg, releasing a free-swimming ciliated larva called a miracidium (Paladini *et al*., 2017). Inside an intermediate host, the miracidium develops into rediae or sporocysts, which produce motile cercariae larvae (Poulin, 2001). Cercariae can infect a vertebrate or another intermediate host, where they mature into metacercariae or mesocercariae. Depending on the trematode species, the mature forms infect the final host or are expelled through the host's feces or urine (Poulin, 2001).

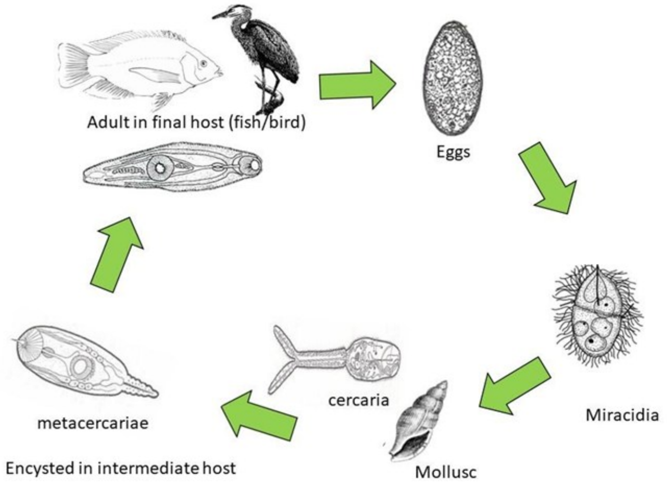

Figure 2. Life cycle of digenea trematode in a fish pond environment.

2.2.2 Cestodes

Cestodes, or tapeworms, are flatworms found in various water systems and are known for their high host specificity. They are bilaterally symmetrical, ribbon-shaped, and lack a mouth, absorbing nutrients through their body wall (Edeh and Solomon, 2016; Ageze and Menzir, 2018). Larval forms, such as plerocercoids, can damage vital organs in freshwater fish, with the Asian tapeworm, *Bothriocephalus acheilognathi*, being one of the most harmful adult cestode infections affecting fish.

The cestode life cycle includes eggs, larvae, and adults. Eggs excreted in faeces are ingested by intermediate hosts like fish, where larvae mature into adults in the intestines of definitive hosts like carnivores and humans (Beveridge, 2014). Some species can have definitive hosts and also act as intermediate hosts if they ingest eggs. Adult tapeworms are multisegmented and lack a digestive tract, absorbing nutrients from the host’s small intestine (Beveridge, 2014).

2.2.3 Nematodes

Nematodes from the phylum Nematoda are known as roundworms as they are slender, unsegmented worms and round in cross-section, very distinctive in shape, with solid resistant cuticles, which enables them to last longer than flatworms in post-mortem conditions (Abiyu *et al*., 2020). They are an amazingly abundant and successful animal group, particularly in the aquatic environment. The common nematodes affecting fish are *Camillanus, Capillaria* (Figure 3), *Anisakis*, *Contraceacum*, and *Eustrongiloides*.

Nematodes occur worldwide, particularly the species utilizing fish as intermediate or transient hosts. They can infect all organs of their hosts, with heavier infections in predatory fish, the majority occurring in the alimentary system and a few in tissues or inner cavities (Ogbeibu *et al*., 2014). Some signs of nematodiasis include anemia, emaciation, unthriftiness, and reduced vitality.

Figure 3. Adult *Capillaria* nematode (Source: Pouder *et al*., 2005).

2.2.4 Acanthocephalans

Acanthocephalans, or thorny-headed worms, are parasitic organisms that lack an alimentary canal and parasitize the intestines of freshwater fish, such as cichlids (Gebremedhn and Tsegay, 2017). They are characterized by a hooked proboscis (Figure 4), with species identified based on the arrangement of hooks and other anatomical traits (Imran *et al*., 2021). These worms cause tissue damage and encapsulation of larval stages in fish, with severity depending on the depth of proboscis penetration (Sakthivel *et al*., 2016).

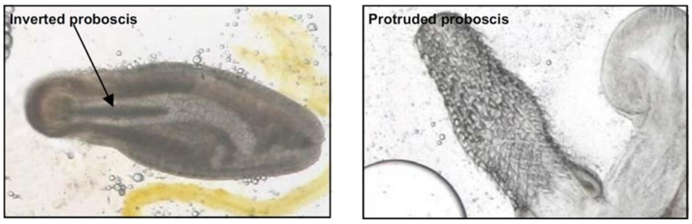

Figure 4. *Acanthocephala spp.* showing inverted proboscis (arrow) (A) and with protruded proboscis (B). (Source: Pouder *et al*., 2005).

Acanthocephalans have a complex life cycle involving an intermediate arthropod host that consumes eggs from the definitive host’s faeces. Inside the arthropod, larvae develop into cystacanths, which remain dormant until the intermediate host is eaten by a definitive host. Once ingested, the cyst bursts and the parasite attach to the intestines of the host. Many acanthocephalans alter intermediate host behaviour to increase their chances of being consumed by a suitable definitive host (Perrot-Minnot *et al*., 2019; Crompton, 2009).

3. Modes of transmission of endoparasites in aquaculture

Fish diseases in aquaculture are influenced by poor water quality, high stocking density, stress, and exposure to pathogens like bacteria, viruses, fungi, and parasites. Endoparasites, which live inside hosts, significantly affect fish survival and production, with their transmission depending on environmental factors, food chain dynamics, and host traits (Anderson and Sukhdeo, 2010).

Endoparasites spread through the food web when hosts consume infected prey, making them indicators of biodiversity and food-web structure (Yamba *et al*., 2013; Koepper *et al*., 2022). They are transmitted through waterborne stages, infected prey, or contaminated feed, particularly in open-water systems vulnerable to wildlife introduction (Choisy *et al*., 2003; Hoseinzadeh *et al*., 2021; Buchmann, 2022). Aquaculture near natural water bodies is at higher risk of these infections.

4. Management of aquaculture in controlling endoparasites

Aquaculture faces challenges from infections as fish hosts naturally harbour specialized parasites (Woo *et al*., 2020). Even disease-free fish can contract pathogens in exposed farms, leading to environmental spillover and increased parasite multiplication in confined systems, potentially harming fish health and aquaculture economies (Shinn *et al*., 2015a). Control strategies include preventive measures, chemotherapeutics, and biological controls.

4.1 Mechanical control

Mechanical control in aquaculture focuses on using physical methods to reduce or eliminate parasitic infections by maintaining clean environments and physical barriers. One key method is controlling intermediate hosts, which are necessary for the life cycles of many endoparasites. For example, trematodes rely on snails as intermediate hosts, and controlling snail populations can significantly reduce parasitic infections in fish (Buchmann, 2022).

To control digenetic trematodes, preventing access to the first intermediate host and final hosts is essential. Snails, which release infective cercariae, can be removed from ponds to reduce infection pressure, as each snail can produce up to 58,000 cercariae daily (Buchmann, 2022). Pond treatments like draining or applying lime or chlorine can eliminate cestode eggs and intermediate copepod hosts.

4.2 Biological control

Biological control in aquaculture uses natural organisms to manage endoparasite populations by enhancing the host's natural defences. Fish species like Black Carp, which prey on snails, can help control digenean parasites, while invertebrates like blue mussels, copepods, and turbellarians reduce parasite levels by filtering or preying on parasitic stages (Ben-Ami and Heller, 2001; Buchmann, 2022). This approach reduces the need for chemical treatments, lowers toxicity risks, and minimizes environmental impact.

4.3 Chemotherapeutants and biocides

In aquaculture, biocides and chemotherapeutants are key to managing endoparasite infestations. Chemotherapeutants, like anthelmintics, target specific parasites, such as helminths (e.g., Niclosamide disrupts energy metabolism in helminths) (Athanassopoulou *et al*., 2009). Fenbendazole and Levamisole treat nematodes, while praziquantel is effective against trematodes and cestodes, including eye flukes (Buchmann, 2022). Biocides, including disinfectants with formalin or chlorine, help control parasite eggs and larvae by improving water hygiene. Organophosphates, like Dipterex, control waterborne crustaceans, reducing Acanthocephala spread but raising environmental concerns. Though chemotherapeutants may lose effectiveness against some parasites, they remain essential for sustainable aquaculture (Redman *et al*., 2015; Buchmann, 2022).

4.4 Immunological control

Immunostimulants are used in aquaculture to boost fish immune systems, reducing infection levels from protozoans and metazoans. However, their effectiveness is typically lower than vaccination. Vaccination is the most sustainable disease control method, with 1.3 billion fish vaccinated annually in Europe (Buchmann, 2022). While fish may develop protective immunity after surviving parasitic infections, no antiparasitic vaccines are currently licensed for commercial aquaculture.

Research suggests that immunity against parasites involves both cellular and humoral components, which are difficult to induce with vaccines. The role of gut microbiota in parasite resistance is being explored, with functional feed additives showing potential for controlling infections like myxozoan in seabream.

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Additionally, dietary supplements such as vitamin C, E, and omega-3 fatty acids can enhance fish immunity, making them more resistant to endoparasitic infections (Lieke *et al*., 2020).

5. Endoparasitic outbreak cases in fish aquaculture

Endoparasite outbreaks in fish aquaculture pose a significant threat, affecting fish health, production, and financial sustainability. These parasites, including nematodes, cestodes, and trematodes, invade vital organs such as the kidneys and intestines, causing symptoms like reduced growth, poor feed conversion, anaemia, deformities, and high mortality rates.

One of the ongoing challenges in aquaculture, particularly in North America and Europe, is the impact of the myxozoan parasite *Tetracapsuloides bryosalmonae*, which causes Proliferative Kidney Disease (PKD) in salmonids (Carraro *et al*., 2016). This disease primarily affects species like trout and salmon, leading to severe symptoms such as swollen kidneys, anaemia, and ascites, with high mortality rates, particularly in juvenile fish during warm water temperatures (Okamura *et al*., 2011).

Nematode infections, such as those caused by *Eustrongylides* spp., are also reported in wild-caught and farmed freshwater fish in North America and Europe, including bass, perch, and catfish (Ljubojević-Pelić *et al*., 2023). Infected fish show abdominal swelling, ulcers, and significant organ damage, especially to the liver and kidneys, leading to high mortality in juveniles. Human cases have been reported in the USA and South Sudan, with symptoms of severe abdominal pain following ingestion of infected fish (Novakov *et al*., 2013).

Few studies, compiled in Table 2, highlight the impact of endoparasites on fish production, growth, and market value, as well as their potential risks to human health. Parasites such as fish-borne zoonotic trematodes (FZT) and *Gnathostoma spinigerum* pose a threat to humans if infected fish are consumed raw. Understanding past outbreaks helps identify risk factors, including environmental conditions and host susceptibility, and can guide the development of management practices to mitigate these infections.

6. Economic impacts of endoparasite infections in freshwater fish

Disease poses a significant challenge to sustaining aquaculture production and trade, with transboundary aquatic animal diseases (TAADs) causing widespread economic and societal losses over the past 30 years. These diseases have introduced and spread viruses into new geographic areas (Carella *et al*., 2023). Endoparasite infections also have substantial economic impacts on aquaculture. By consuming nutrients, blood, or tissues from the host, endoparasites slow growth and reduce overall production, leading to longer production cycles and higher operating costs. Infected fish or shellfish may not reach marketable size as quickly as healthy ones.

Endoparasite infections can also affect the quality and appearance of aquaculture products. Infected organisms may show physical defects, discolouration, or other undesirable traits that reduce their market value (Scarfe and Palic, 2020). This can lead to reduced market access, lower prices, and diminished consumer confidence in the product's safety and quality. Persistent endoparasite issues may decrease demand and erode the market share of affected aquaculture operations.

7. Conclusion

In conclusion, endoparasitic diseases pose a significant threat to aquaculture's success and profitability. To minimize their impact, it is crucial to understand their life cycles, transmission, and control methods. By addressing these challenges, the aquaculture industry can continue to provide a sustainable seafood source. Future research should focus on advancing parasite control techniques to improve fish health, productivity, and reduce environmental effects.

Table 2. Documented cases of endoparasite infections in freshwater fish aquaculture.

Fish Host	Endoparasites	Location	Year	Impact	References
Clarias gariepinus	*Camallanus* sp.	Nigeria	2016	The main cause of loss in fish production in selected farms	Okoye *et al*. (2016)
Cyprinus carpio *Ctenopharyngodon idellus*	Fish-borne Zoonotic Trematode (FZT)	Vietnam	2008	Pose a greater threat to humans if consumed raw fish	Chi *et al*. (2008)
Farmed Eel	*Gnathostoma spinigerum*	Thailand	2012	Humans could become accidental hosts by ingestion of raw fish	Saksirisampant and Thanomsub (2012)
Oreochromis sp. *Clarias gariepinus*	Internal Cestode	Kenya	2017	Mass mortality, retarded growth and weight loss and eventually low market value	Haji *et al*. (2017)

Conflict of interest

The authors declare no conflict of interest.

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