PARASITIC DISEASES OF FISH

Muhammad Imran[1*], Muhammad Sohail Sajid[1], Sara Omer Swar[2], Muhammad Kasib Khan[1], Muhammad Abdullah Malik[1] and Amna Ahmad[1]

[1]Department of Parasitology, University of Agriculture, Faisalabad, Pakistan
[2]Department of Food Technology, College of Agricultural Engineering Sciences, Salahuddin University Kurdistan, Iraq
Corresponding author: imran.asghar@uaf.edu.pk; Cell: +92-333-8387702

INTRODUCTION

The fishes (Phylum: Chordata) are the most diversified group of aquatic organisms known as cold-blooded vertebrates. They have gills and fins for breathing and swimming, respectively. Different kinds of fishes protect themselves with scales and have an efficient body for convincing movement in water (Tedesco et al. 2017). Moreover, fish is considered as an important part of human food and playing a significant role in the economy of various states worldwide (Essetchi et al. 2003; Andronova and Yakimovich 2019). There are around 28,900 species of fish present in the world, 13,000 species are known as freshwater, having 170 families and 2,513 genera, which are found in rivers and lakes (1% of the total water available on earth), whereas the remaining 16,000 species are found in saline medium (covering 70% of the earth) (Leveque et al. 2008). This chapter describes the parasitic threats to profitable fish farming around the globe.

Parasitic fauna of fish

Fish is directly or indirectly affected by different kinds of parasites, which cause high mortality in this species. Four major groups of parasites that cause infections in fish are: Protozoa (ciliates, flagellates, microsporidians, myxozoans), platyhelminthes (monogenean, digenean, cestodes), nemathelminthes, and acanthocephala. The physiology of fish facilitates the occurrence of various lethal diseases, which lead to mass mortality (Al Marjan and Abdullah 2009; Lerssutthichawal et al. 2015). Furthermore, fish act as hosts for numerous parasites; especially gastrointestinal (GI) helminths which are considered major fish parasites, causing intensive losses to the fish industry. Parasites affect the diet, metabolism, and secretory functions of the digestive system, which causes severe damage to the nervous system and interrupts the normal reproduction of the fish. The parasitic threats are the major reason for the reduction in the fish population (Habib 2007). Parasitic fauna infecting various systems of fish is given in Table 1.

Protozoan parasites of fish

Protozoans are the significant parasites of fish kept under intensive fish culture. The major groups of protozoa infecting the fish are myxozoans, microsporidians, ciliates, and flagellates (Wang et al. 2019). These parasites can increase their number when the host fish is overcrowded, resulting in weight loss, emaciation, and mortality (Gomes et al. 2017). Among different groups of protozoans, ciliates and flagellates have a direct life cycle and mostly infect the pond water fish. On the other hand, microsporidians are intracellular and require tissue of the host for reproduction (FAO 2015). The fish became infected by ingesting spores from the infected fish or food sources (Manbe et al. 2020). The cells having the parasites start to increase in size to accommodate the proliferation (merogonous and sporogonous development) of the parasite (Wang et al. 2019; Agboola et al. 2021). The multiplication of these sporozoites inside the cell causes the development of tumor-like masses in various tissues of the fish (Saha and Bandyopadhyay 2017). The pathological lesions that occur due to these cancer-like growths include multiple whitish nodules on the tissues, and thickening of the wall of gall bladder (FAO 2015). Acute anemia may result in the case of microsporidian infection of haemopoietic cells (Maciel et al. 2018).

Myxozoan parasites infect many groups of fish, including Cichlidae, Cyprinidae and Mugilidae (FAO 2015). In Africa, more than 135 species of myxozoans are known to cause infection in fish of all habitats i.e., freshwater, brackish water and marine water habitats (Santos et al. 2018). More than 17 species from four different genera of parasites including *Henmeguya*, *Myxobolus*, *Myxobilatus* and *Parahenmeguya* have been reported to infect the fish. Infra-communities and component communities are being formed by the myxozoan parasites which can surpass the colonies formed by other parasites (Balta et al. 2019). These myxozoan parasites can cause histozoic and coelozoic infections (FAO 2015). The signs of the former include, whitish cyst containing milky fluid with microscopic spores, which can be seen on the scales, fins, lips, and around eyes. It has been further reported that the infection may cause breaking of the cartilage of gills, resulting in disturbed breathing and inadequate gaseous exchange (Maciel et al. 2018). In cultured fish, several Myxozoan infections have been reported i.e, skeletal deformities, locomotory disturbances, emaciation, sunken eyes in the brain, and circulatory dysfunctions at the base of the gill lamellae (Santos et al. 2018; Manbe et al. 2020). The simplified life cycle of protozoan parasites infecting the fish has been elaborated in Fig. 1.

Table 1: List of parasitic fauna harboring various fresh and salt-water fish fauna around the world

Sr. #	Parasite Name (Common name)	Site of Infection	Host	Disease	Source
Parasites of integument & skeletal system					
1.	*Amyloodinium Ocellatum*	Gills & Skin	All types of fishes	Amylodiniosis/Marine velvet disease	(Moreira 2017)
2.	*Trichodina*	Gills & Skin	All	Trichidiniasis	(Nofal 2017)
3.	*Cryptocaryon irritans*	Skin, Fins, Gills	Marine Fishes	Cryptocaryonosis/White spot disease	(Liu 2020)
4.	*Ichthyophthirius multifiliis*	Skin	All	Ichthyophithiriasis/white spot disease / Ich	(Buchmann 2020)
5.	Monogeneans	Skin & Gills	Goldfish, channel catfish, angelfish	Skin and gill monogean disease	(Neves 2020)
6.	Isopods	Gills & Body surface	*Epinephalus (Ep.) coidois, Ep. malabaricus*	-	(Purivirojkul 2020)
7.	*Brooklynella hostilis*	Skin & Gills	Damselfish, Amphiprioninae	Brooklynellosis/Clownfish Disease	(Anshary 2020)
Parasites of eye					
1.	*Diplostomum spathaceum* (Eye Fluke)	Eye	Fresh water and brackish water fishes	Diplostomiasis	(Vyhlídalová 2020)
Parasites of vascular system					
1.	*Sanguinicola occidentalis*	Heart	*Perca jlavescens*	Sanguinicoliasis	(Muzzall 2000)
2.	*Paradeonta cylix*	Heart	Greater amberjack	Blood fluke disease	(Repullés-Albelda 2008)
3.	*Cardicola*	Blood	Northern Bluefin tunna thynnus	-	(Shirakashi 2016)
4.	*Trypanoplasma sp.*	Vascular system, kidneys	Blue tilapia fish	-	(Carrington 2017)
5.	*Crassiphiala bulboglossa*	Blood	Vermont fish	-	(Achatz 2019)
6.	*Aporocotylid digenean*	Heart, Gills, Cranial & mesenteric Blood vessels	Fresh and marine water fish	Black grub	(Poddubnaya 2021)
Parasites of the central nervous system					
1.	*Tetrahymena corlissi*	Skin, Eye & Muscles	Fresh water fishes' guppies	-	(Imai 2000)
2.	*Uronema Nigricans*	Connective tissues (Skin, Fins & Nervous Tissues)	Bluefin tuna · Thunnus maccoyi	-	(Arévalo 2018)
3.	*Myxosoma (My.) cerebralis/ Myxobolus (M.) cerebralis*	Head, Cartilage & backbone	Salmon and trout	Whirling disease	(Alexander 2020)
Parasites of viscera and musculature					
1.	*Contracaecum rudolphii*	Body Cavities & visceral organs	All types of fishes	-	(Baruš 2001)
2.	*Sphaerospora renicola*	Kidneys	Cyprinids	Renal dropsy	(Eszterbauer and Székely 2004)
3.	*Posthodiplostomum cuticula*	Viscera, Heart & Posterior kidney	Freshwater fishes	Black spot disease	(Ondračková 2004)
4.	*Diphyllobothrium latum* (Broad fish tapeworm)	Viscera & Musculature	Fresh water fishes	Diphyllobothriasis	(Scholz 2009)
5.	*Proteocephalus ambloplitis*	Ovary	Freshwater fishes	-	(Scholz 2019)
6.	*Bolbophorus confuses*	Skeletal muscle & Viscera	Channel catfish	Channel virus disease or enteric septicemia like condition	(Doffitt 2020)
7.	*My. cerebralis / M. cerebralis*	Head, Cartilage & backbone	Salmon and trout	Whirling disease	(Alexander 2020)
Parasites of the alimentary canal					
1.	*Glugea (Gl.) hertwigi & Gl. stephani,*	Submucosa of GI & Mesentery	Smelt, marine flatfishes	Non-functional, granulomatous bulged out abdomen	(Ogawa 1998)
2.	*Bothriocephalus acheilognathi*	Intestine	Carps and other cyprinids	Haemorrhagic enteritis/ Gowkongensis	(Salgado-Maldonado 2003)
3.	*Cryptobia iubilans*	Stomach	African cichlids	Cryptobiosis	(Woo 2003)
4.	*Balantidium*	Intestinal lumen	Marine and Fresh-water fish	Catarrhal enteritis and ulceration	(González 2005)

| 5.	*Goussia (G.) subepithelialis, G. Carpelli*	Intestinal epithelial cells	Carps, marine and freshwater fishes	Coccidiosis	(Pasnik 2005)
6.	*Cryptosporidium*	Stomach	Marine tropical fish	Cryptosporidiosis (necrosis of gastric epithelium)	(Méndez-Hermida 2007)
7.	*Ceratomyxa shasta*	Posterior Intestine	Salmonids	Ceratomyxosis	(Bjork 2010)
8.	*Pseudophyllid Triaenophorus*	Intestine	Wild and cultivated salmonids	Chronic haemolytic Anaemia	(Hoole 2010)
9.	*Spironucleus*	Intestine	Salmonids, All cichlids, bettas, gouramis, other aquarium snd freshwater fishes	"Hole in the head" disease	(Williams 2011)
10.	*Caryophyllidea*	Intestine	Cyprinid and catostomid fish,	Intestinal nodules and ulcers	(Barčák 2014)
11.	*Contracaecum*	Alimentary tract	Largemouth bass, centrarchids	Anisakidosis	(Younis 2017)
12.	*Camillanus*	Alimentary tract	Largemouth bass, other centrarchids	-	(Manickam 2018)
13.	*Philometra*	Body cavity, Tissues & Ovaries	Marine fish	"Parasitic Castration" in female fish	(Ali 2018)
14.	*Eustrongylides*	Viscera & Muscles	Angelfish, other aquarium and freshwater species	Eustrongylidosis	(Guagliardo 2019)
15.	*Capillaria*	Intestine	Angelfish, discus, other aquarium fish	Capillariasisis	(Abdel-Rahman 2019)
16.	*Crepidostomum*	Intestine	Salmonids In the Nearctic and Palearctic regions	Enteritis	(Faltýnková 2020)
17.	*Enteromyxum (E.) leei, E.scophthalmi*	Intestinal Epithelium	Tiger puffer fish, marine and fresh-water fish	Enteritis	(Picard-Sánchez 2020)
18.	*Acanthocephalus*	Intestinal lumen	Wild-caught freshwater fishes, wild-caught marine fish	Necrotic haemorrhagic Ulcers	(Nakao 2021)
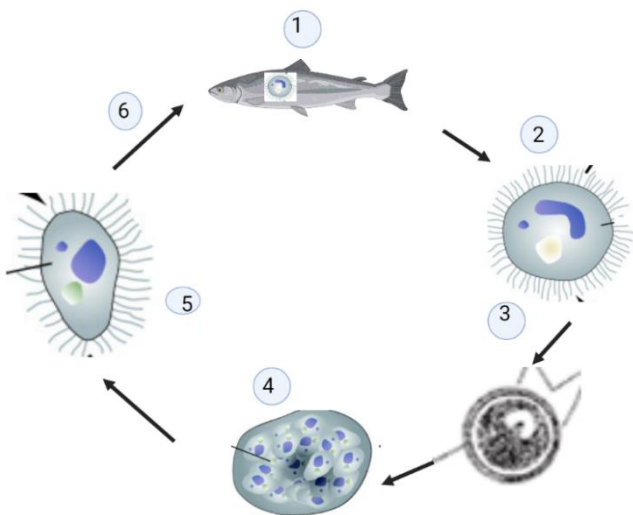
Fig. 1: Simplified life cycle of protozoan parasites infecting the fish: 1=Trophont feeds on fish, 2=mature tomont leaves the host, 3=Tomont secretes gelatinous cyst wall, 4=Tomont undergo cell division and produce daughter tomites, 5=Tomites differentiate into infective Theronots, 6=Theronts bore through the cell wall and infect the fish (Source: Modified from Roberts 2012).

Helminths parasites of fish

Helminths are the biggest group of parasites infecting the fishes. More than 30,000 helminth species are infecting the sea and freshwater fish and some of them are known to cause serious fish diseases or may represent an important public health concern (Williams and Jones 1994). Platyhelminthes (flatworms: cestodes, monoge-neans and digeneans); Nemathelminthes (roundworms: nematodes) and Acanthocephalan (thorny-headed worms) are major groups of helminths parasites (Nguyen et al. 2020).
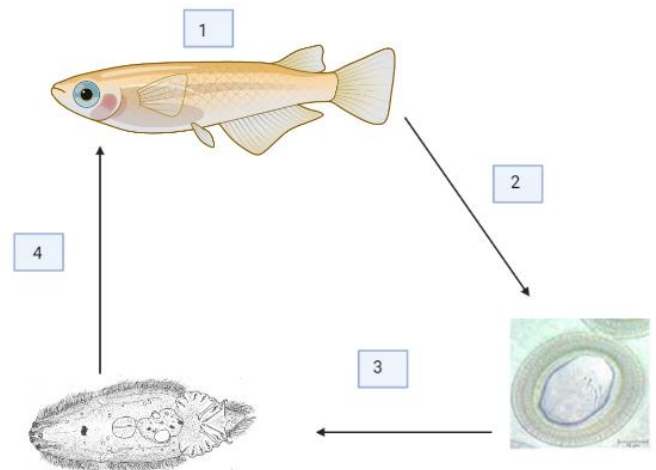

Fig. 2: Simplified life cycle of Monogeneans parasites infecting the fish: 1=Adults present on fish skin and gills, 2=Eggs laid by adult, 3=Eggs hatch ad release oncomiracidium, 4=Free swimming oncomiracidium attaches to the host (Source: Modified from Roberts 2012).

Trematodes

Trematodes, also known as flatworms or flukes, are a class of helminths which are further classified into monogeneans and digeneans. Their site of infection is the skin, fins and gills of the teleost that inhabit freshwater and brackish water (Antar and Gargouri 2018).

Monogeneans

Naturally, monogeneans are host-specific (Saad-Fares 1992). They are hermaphrodites and at the anterior end possess sensory structures, a mouth with or without accessory suckers, special glands and clamps for the

attachment to the host. Mostly they reside on the body surface of the host like epidermis, scales, fins, gills, lip folds, nares, and branchiostegal membranes. They have a direct life cycle, without the involvement of an intermediate host (Buchmann 2002).

There are three main taxa of monogeneans; Dactylogyroidae, Caspaloidae and Polyopisthacotylea. Dactylogyroidae family members are relatively smaller in size and are usually present in inland fishes as compared to the Caspaloidae and Polyopisthacotylea, which are larger and mostly found in marine fishes. Due to their different taxa, they are slightly different in their structure and nature of infection like Dactylogyroids are oviparous, while Gyrodactylidae is viviparous. The former consists of one or two anterior-dorsal pairs of eyes and posterior-ventral opisthaptor, while later possesses no eyespots and two pairs of anchor hooks. Dactylogyroids inhabit the gills of fish, while gyrodactylidae reside on the skin and fins. Some of them occasionally infest nasal cavities, stomach, or urethra of freshwater fishes (Šimková 2017). In their natural habitats, fish can co-exist with monogeneans but some of them like gonodactylids can be pathogenic, predominantly to the young fishes.

Dactylogyrus (D.) vastator is the parasite of carp fry fish and infests the gills of the host, causing epithelial hyperplasia intervening in the respiratory system that leads to death of the host. *D. extensus* is also a deadly parasite of the young, as well as adult, fishes (Dzika 2009). *D. groschefti* has shown more than 90% mortality rates in young *Clarias gariepinus* (Hansen 2003). Macrogylodactylus mostly affect aquaculture fishes viz *Clarias*, *Lates niloticus,* and Anabantidae species (Iyaji 2008). Parasitic infestation is dependent on several physical and chemical factors. Physical components may include temperature and depth of the pond, while oxygen and salinity levels are the main chemical features. Temperature is generally the main element for seasonal parasitic prevalence (Gopko 2020).

Digeneans

Digeneans trematodes are a very diverse group of fish parasites, belonging to 15 families and more than 50 species (Selbach 2020). They mostly parasitize freshwater fishes and can act as internal or external parasites involving several organs. They have complex, indirect life cycle and are heteroxenous in nature due to the involvement of multiple intermediate hosts and larval stages in their life cycle. Bivalves and gastropod mollusks act as their intermediate hosts. Their metacercariae are present in large numbers within-host and affect several tissues and organs. Lesions appear depending upon the organ involved. *Sanguinicola* species are parasites of *Synodontis schall* and *Auchinoglanus occidentalis*. It is commonly known as blood fluke because worms and eggs are present in blood and may cause thrombosis and subsequent necrosis. On the other hand, migration of miracidia through the gills epithelium leads to direct blood loss, followed by anemia. They cause damage to the heart, brain, eyes, and other soft organs (Kirk 2012).

Syphodera ghanensis and *Aspidogaster africanus* infect the intestines of *Chrysichthyes nigrodigitatus* and cause intestinal destruction of the host (Kohn et al. 2007). The general life cycle of trematode parasites is elaborated in Figs. 2 and 3.

Cestodes

Cestodes are commonly called as tapeworms due to their ribbon-like and multisegmented body structure. Their characteristic feature is host specificity; cestodes generally affect members of siluriform. They are mainly divided into two forms namely, the monozoic forms notably *Caryophyllaeidae,* and the amphilinid represented by the segmented Pseudophyllideans and Proteocephalideans.
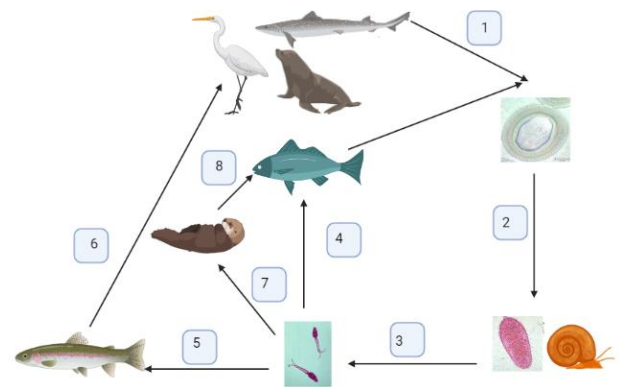

Fig. 3: Simplified life cycle patterns of Digeneans parasites infecting the fish: 1=Eggs released from final host, 2=Egg hatch into miracidium which invades molluscan host, 3=Larval development resulting in the production of cercariae, 4= Cercariae direct invaded final host, 5=Cercariae released invades fish intermediate host, 6=Cercariae develop into metacercaria in intermediate host and this metacercaria invades final host, 7= Cercariae invades invertebrates intermediate host, 8=Encysted metacercaria eaten by final host (Source: Modified from Roberts 2012).
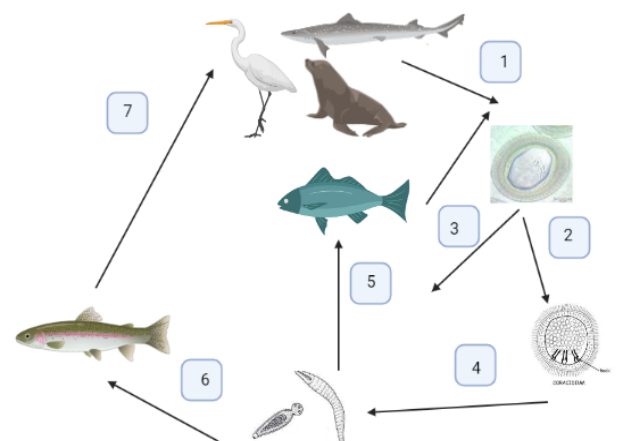

Fig. 4: Simplified life cycle patterns of cestodes parasites infecting the fish, 1=Eggs laid by final adult host, 2=Egg hatch and release coracidium, 3=Eggs eaten by invertebrate intermediate host, 4=Coracidium eaten by intermediate hots and develop into procercoid/plerocercoid stage, 5=Plerocercoid stage is eaten by fish final host, 6=Procercoid eaten by fish intermediate host and development to plerocercoid occurs, 7= Eaten by final hosts (Source: Modified from Roberts 2012).

They are predominantly found in farmed and wild fish in Asia, Africa and Europe (Rocka 2017). Cestode infestation occurs in the alimentary tract, muscles, or other internal organs. Some of the most damaging parasites of freshwater fish are larval cestodes called Plerocercoids. If Plerocercoids are present in muscles, they damage the skeleton system, and when they are present in gonadal tissue, they damage the reproductive system. Cestodes also become a major issue when they affect vital organs such as the brain, eye, or heart (Dove and Fletcher 2000). The digestive tract is the predominant site for their residence, but they do occur in other parts of the host body. For instance, *Bothriocephalus acheilognothii* resides in the digestive tract of host fish families Cyprinidae, Poecillidae, Cichlidae and Centrachidae (Pérez-Ponce de León et al. 2018), while *Nesolecithus africanus* resides in the coelomatic cavity of mormyrid *Gymnachus niloticus* host and *Polyonchobothrium clarias* resides in the gall bladder of *Clarias and Oreochromis* specie *(*Ali 2020*)*.

Adult cestodes do not cause much damage to their host but some of them cause severe damage to fish, resulting in compromised fish quality. Like *Eubothrium*, chronically affect the quality of farmed fish. *Polyoncho-bothrium clarias* infests the gut mucosa of host fish and causes an inflammatory response in the gut. It also migrates towards the gall bladder and produces granulomatous nodules and fibrous tissues. Larval forms of plerocercoids and cysticercoids cause damages in freshwater fishes. In African fish, predominant infection is due to ligula plerocercoids in the body cavity of *Barbus*, *Cyprinid* species and *Cyclophyllidean cysticercoids* infect the mesenteries of siluriform, *Clarias* and *Bagrus* species (Song 2018). They have piscivorous birds such as gulls and cormorants as their definitive hosts. *Ligula plerocercoid* infects *Barbus* species and causes abdomen distention along with the formation of hemorrhages in the abdominal wall of the host and may also result in reproductive impairment (FAO 2015). The general life cycle of cestode parasites is elaborated in Fig. 4.

Nematodes

Nematodes are important parasites of several species of both aquaculture and wild fish. They use fish as intermediate or transient hosts and result in heavy infection, involving almost all organs of their hosts (Ali et al. 2014). Nematodes have a distinctive shape, having resistant cuticles which make them hardy and relatively last longer as compared to platyhelminths in post-mortem conditions (FAO 2015). There are 40 species of nematodes, severely infecting the digestive system of various fish species in Africa. Adult nematode usually resides in the fish digestive tract. However, different life stages may be present in internal organs, coelomic cavity, external muscle layers, the swim bladder, and inside the skin or fins, depending upon different species of nematode and infected fish (Dick and Choundury 1995). In Pakistan, 13 species of nematodes, 8 of which are new, were recovered from 15 species of fish at the Karachi coast. *Camallanus cotti, Tetrahymena corlissi,* and *Anisakis simplex* were the

most common nematodes found in the intestine of wild marine (Khan and Begum 1971). In healthy fish, nematodes are often present in low numbers but can increase in number to produce serious illness or even death. If the fish is the final or conclusive host, then the nematode will go into another organism, generally a marine invertebrate like a side swimmer, side copepod, or insect larva, in which it will grow before being eaten by a fish. Upon ingestion, nematode species sexually mature and reproduce in the fish. In this situation, the fish is named as the definitive or final host (Ali et al. 2014). Nematodes, that have an indirect life cycle, use the fish as intermediate hosts. The conclusive host (that comprises the propagative adult phase of the nematode) could be a fish-eating fish, mammal, or bird. Fish nematodes have
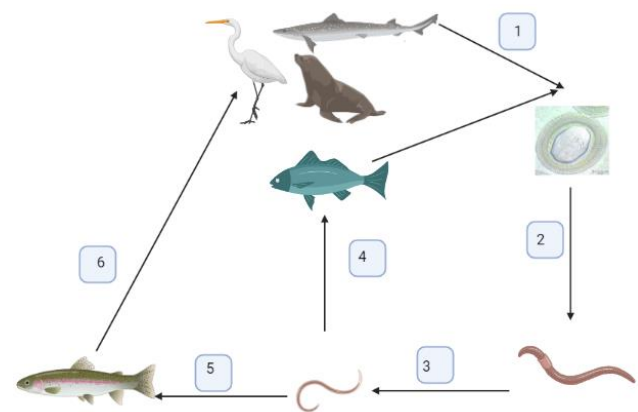

Fig. 5: Simplified life cycle patterns of nematodes parasites infecting the fish: **1**=Eggs laid by adults hatch to release free-swimming larvae, **2**=Larvae eaten by invertebrate intermediate host, **3**=Further larval development occurs in invertebrate host, **4**=Infective larvae eaten by fish final host, **5**=Larvae encyst in fish intermediate or paratenic host, **6**=Infective larvae eaten by final host (Source: Modified from Roberts 2012).
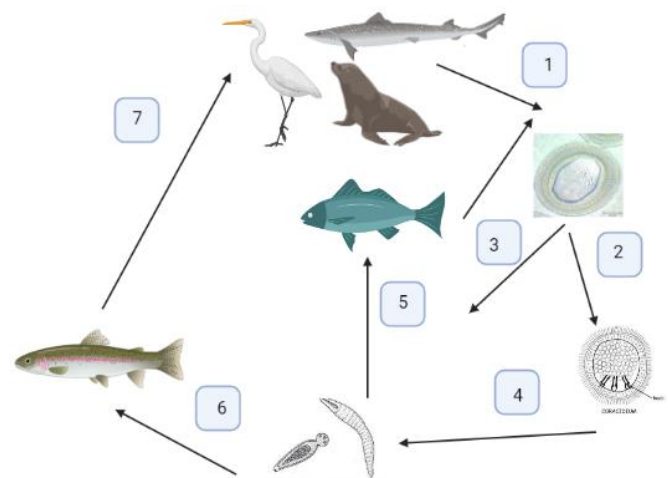

Fig. 6: Simplified life cycle patterns of acanthocephalan parasites infecting the fish: **1**=Eggs laid by final adult host, **2**=Eggs hatch and release coracidium, **3**=Eggs eaten by an invertebrate intermediate host, **4**=Coracidium eaten by intermediate hots and develop into procercoid/plerocercoid stage, **5**=Plerocercoid stage is eaten by fish final host, **6**=Procercoid eaten by fish intermediate host and development to plerocercoid occurs, **7**=Eaten by final hosts (Source: Modified from Roberts 2012).

the capability to persist in alternate individuals, recognized as paratenic hosts. Such hosts are not necessary for the completion of the life cycle, but they can comprise infected nematode life stages and be a basis of infection. They can be worms, fish or further marine organisms which feed on the nematode larvae or eggs (Pazooki et al. 2012). The general life cycle of nematode parasites is elaborated in Fig. 5.

Acanthocephala

Acanthocephalans are internal parasites of fish and amphibians and are characterized by the presence of an armed and eversible proboscis used to pierce the gut wall of fishes. These gastrointestinal parasites can cause pathological changes which may result in deterioration of the host health (Taraschewski 2008). Parasites have the characteristic feature of a proboscis which can evaginate and is crowned with many rows of recurved hooks. Acanthocephalans are heteroxenous and they don't have alimentary canal. Eggs laid by the adult worm in the intestinal lumen are passed out through feces and enter the body of the first intermediate hosts, such as amphipods, isopods, and copepods by ingestion. Here, the hatching of eggs takes place into acanthella or acenthar, which is the first-stage larva (Kennedy 2006). Larvae develop into adult worms when an intermediated host is ingested by the definitive host, such as fish amphibians or reptiles. Due to the encapsulation of larvae in the tissue and penetration of the proboscis of adult worms in the muscular layer of the digestive tract of the host, pathological changes take place (Oniye 2004), such as widespread granuloma, followed by fibrosis inflammation, peritonitis, obstruction, and perforation of the digestive tube (Sanil 2011). African fishes *(Tilapia, Barbus, Heterotis* niloticus and *Citherinus, Synodontis)* are the final host of Acanthochala. *Acanthocephlus, Paragorgorhynchus, Termisentic* and *Neoechinorhynchus* (Valladao 2020) are the genera of acanthocephalan, which infect *Tilapia, Barbus, Heterotis niloticus* and *Citherinus synodontis* species of fish, respectively (Taraschewski 2008). The general life cycle of acanthocephalan is elaborated in Fig. 6.

Some significant parasites of fish

Cryptocaryon irritans

Cryptocaryon (C.) irritans is the cause of white spot disease in wild and cultivated marine fishes (Yin et al. 2018). It is a ciliated protozoan parasite that can survives at temperatures, ranging between 15℃ and 30℃ (59°F–86°F). Cryptocaryon is known to infect several fish species and its different strains have been isolated from various parts of the world. Although, some of them possess many similar characteristics like life cycles and salinity tolerances, however, many of them are beyond the previously described "normal" ranges (Yambot et al. 2003). The parasite has a direct life cycle and transmission of infection within a group of fish does not require any other

animal or host for its development (Colorni and Burgess 1997). However, complex life cycle phases develop on and off the fish host, which eventually leaves the cyst as theronts, the infective and the free-swimming stage. Theronts dynamically seek fish hosts. The trophont is the "nourishing step" and the parasite is embedded inside the tissues of the fish at this step. After leaving the fish, the trophont becomes a protomont before encysting and converting into a tomont, which is the reproductive stage. The tomont matures and divides into various tomites. The span of the whole life cycle may differ, depending upon several factors including, strain of the parasite, temperature, salinity and fish host (Yambot et al. 2003; Rigos et al. 2013). An average duration of life cycle is recorded around 1 to 2 weeks; however, it may extend up to 11 weeks. This variation in the life cycle is attributed to the uncertainty of tomont maturation (Dickerson 2006). Time required and the size at different life cycle stages may vary due to the variety of strains of *C. irritans,* temperature and salinity level of water, or maybe due to different fish species acting as hosts. The temperature range for the ideal development of most of the strains of Cryptocaryon is 23–30℃ (Wang et al. 2018).

Infection with Cryptocaryon in most cases shows small white spots, nodules, or patches on the skin, fins, or gills of infected fish. Other symptoms include ragged fins, cloudy eyes, pale gills, increased mucus production, or changes in skin colour, and skin may also appear thin (Raga 2007; Yin et al. 2014). Behaviourally, fish may flash (scratch), swim unusually, hang at the surface or on the bottom, act lethargic or breathe more speedily in distress (Colorni and Burgess 1997).

The parasite can be diagnosed through microscopic examination (wet mount) of tissue taken from gill arch, tail fin or the body surface of the infested fish. Within a host population, Cryptocaryon may increase mortalities for several days. However, the degree of pathology may vary, depending upon the strain of parasite, the species of host (fish), previous exposure to the parasite and the water temperature. Affected fish can be transferred to freshwater for 1 hr for 2-3 days. The other method can be used as the addition of 0.5 ppm $CuSO_4$ in the treated water with strong aeration for 5-7 days. The water must be replaced daily during the treatment. The infected fish must be shifted to parasite-free water storage tanks 2-3 times at 3 days intervals (Martin 2015; Jiang et al. 2016).

Trichodinas

Trichodina is one of the common parasites of fishes (wild or cultured) that resides in the marine and freshwaters. These parasites are popularly known as ecto-commensals and ciliated protozoans (Martins and Ghiraldelli 2008). So far, approximately 300 species have been reported from different environments in the world (Tang and Zhao 2012). This ciliated parasite can infest the host in a very short time frame due to its direct transmission and mainly infests fish kept under sub substandard conditions (Lom 1995). It replicates by binary fission and has been the topic of great interest since the previous century (Kruger et al.

1995). Not all trichodinids are pathogenic, most of them are non-pathogenic, but when the relationship among host/parasite/environment is broken by any of the given factors, like nutritional deficiency, low water quality, infectious and/or parasitic diseases, trichodinids proliferate and become responsible for severe epidermal lesions and disease outbreaks, as reported by Huh et al. (2005). The lesions mostly seen due to the infestation of this parasite are hyperplasia and necrosis of the epidermal cells (Hassan 1999). Trichodina is the most dominant parasite in Nile tilapia. The disease caused by *Trichodina* sp., is termed as Trichidiniasis and its clinical signs are abnormal coloration, lethargic movement, loss of appetite, weight loss, skin lesions, fin erosion, elevated mucus production, and gill necrosis. Gills are the main targeted organ for infestation (Biagini et al. 2009); thus, the epithelial tissue of gills is an outstanding factor to assess the properties of environmental variables, toxins, and water quality (Mazon et al. 2002). Formalin and sodium chloride are used as chemotherapeutic agents and may harm branchial tissue because these are ingredients that have a toxic influence on the fish, as detected by Mert et al. (2014). Color changes also occur in fish exposed to different doses of sodium chloride and formaldehyde.

Ichthyophthirius multifiliis

Ichthyophthirius (I.) multifiliis is an obligate parasite, ciliated protozoan of freshwater fish present in warm and humid climates. The temperature range for its outbreaks is 15–25°C (Noga 2014). It causes high mortality and economic downfall towards various aquaculture food fish. It also affects several aquaculture species, including grass carp, rainbow trout, channel catfish, snow trout (Mallik et al. 2015), striped catfish (Kumar et al. 2018), ornamental fish, and hatcheries (Mohammadi et al. 2012). It is present in 3 progressive stages: (1) a reproductive tomont, (2) an infective theront and (3) a parasitic trophont (Nigrelli et al. 1976). The trophont is an obligate parasitic stage and depends upon vulnerable fish for its proliferation. The theront penetrates fish epithelium and causes infection. The trophont grows in fish epithelium for 5 to 6 days; after its development the adult trophont leaves the host. Infected fish show various clinical signs including, swimming promptly and rubbing their bodies against the sides of the tanks, gasping at surface water. They become more lethargic and eventually stop feeding. Infection may occur due to lower water temperature (Ling et al. 2013). Histo-pathologically, large trophont stuck in the gills can be seen. The parasite has a C-shaped, large-sized macronucleus. The outer layer of the infected gills appears as inflamed, clubbed, and deformed. The presence of multiple trophonts at the gill lamella might be because of their rapid multiplication inside host fish. Hyperplasic and hypertrophied secondary gill lamellae can be observed. Management of water temperature is another effective way to control the multiplication of the parasite. Salt is an effective treatment for Australian warm water fish against Ich. It is inexpensive, safe, and easy to handle. A solution of 2% salt in 250 ppm formalin has also proved very effective in lowering the burden of trophonts in Snow trout (Mallik et al. 2015). Many other chemicals like malachite green, malachite green in combination with salt or formalin, formalin, chloramine-T, potassium permanganate, and copper sulphate have been tested to prevent Ichthyophthiriasis (Kinnunen et al. 2005).

Brooklynella hostilis

Brooklynella (B.) hostilis is the causative agent for Brooklynellosis, which is also recognized as slime-blotch or clownfish disease. In the marine aquarium, *B. hostilis* infects most teleosts. It is a kidney shaped organism and has a length of about 60-80 μm, with bands of cilia. *B. hostilis* belongs to the order Hartmannulidae, and genus monotypic *Brooklynella*, which includes only one species. It replicates by binary fission, depends on dead skin, and causes severe damage to gills (Fioravanti and Florio 2017). Common symptoms are discoloration and abnormal breathing. It can also cause cast aside skin and congestion of gills. After its reproduction, the newly formed protozoa can swim freely by using their ciliates. The parasite spreads swiftly and can get transferred to a novel host effortlessly. These tiny protozoa can get entry into an advanced host or generally they become attached to the already existing host, on which their parents were residing (Anshary 2020). While feeding upon the fish, the parasite also releases toxins that can be fatal to the fish. Free swimming protozoa can survive without a host for a short time. To make the aquarium free of this parasite, it must remain fallow (fishless) for at least four weeks to kill the remaining free-swimming parasites that will not be able to find a host to feed upon. All fish within the aquarium must be put into a quarantine tank and kept out of the main aquarium during these four weeks (Hirazawa et al. 2016).

Trypanoplasma

The kinetoplast genera *Trypanosoma* and *Trypanoplasma* are common marine and fresh-water fish parasites. Similar blood flagellates are present in Europe, Asia, and North America in freshwater and occasionally marine fishes. *Trypanoplasma (T.) borreli* and *T. bullocki* are pathogenic blood parasites, affecting cyprinids in Europe and marine flatfish in the Atlantic United States, respectively (Carrington 2017). Leeches feed on infected fish and act as an intermediate host. Infected leeches then act as vectors to infect other fishes. *T. borreli* possesses an indirect life cycle in leeches, especially *Hemiclepis marginata*. Like other flagellates, *T. borreli* has a large variety of parasitic forms present within the blood. It infects the vascular system, kidneys, and other organs. Heavily infected hosts are lethargic, emaciated, and have sunken eyes. Infected fish are anemic with damage of the excretory part of the kidney, causing osmoregulatory problems (Lom and Dykova 1992). *Trypanosoma carassi* can induce far-reaching damage to hematopoietic tissues in goldfish, causing anemia, whilst Kamińska-Gibas et al. (2018) described a long-running decrease in hematocrit, hemoglobin, and protein levels in sculpins analytically

infected with *T. bullocki*. Removal of leeches is the best way to elucidate this problem.

Myxobolus cerebralis

Myxobolus (M.) cerebralis is a parasite of the Salmonidae family, including salmon and trout (Hedrick and El-Matbouli 2002). Myxosporean causes a disease known as whirling disease. It was first described in rainbow trout in Germany, and also appeared in Europe, United States, and South Africa. There is no zoonotic importance of this parasite. Skeletal deformation and neurological damage occur by myxosporean infection. Invertebrates and vertebrates are the definitive and intermediate hosts of this parasite, respectively; either host can be called alternate host for *M. cerebrali*s (El-Matbouli and Hoffmann 1998). Younger fish are more susceptible to the disease before ossification of cartilage and full development of the central nervous system (Ryce et al. 2005). Susceptibility depends upon the age of the fish. Parasites can attack fish within 2 days after hatching (Markiw 1991), this could be different for different fish species as in the case of rainbow trout. It infects until 9 weeks after hatching, while chinook salmon can become infected 3 weeks after hatch (Sollid et al. 2003). Several reports are unable to differentiate between entry of parasite and setting of the life cycle. So, in most situations, recognition is based on the transport of infected fish coming from Europe, but it may be due to the reason that the parasite does not easily inhabit the new area and it does not need further confirmation of its occurrence (South Africa, Lebanon, Morocco). In North America, its presence was first reported in 2006 in Alaska (Arsan 2007), while in Arizona, its presence was first reported in 2000 (Bartholomew and Reno 2002). Myxospore develops within the oligocheate host (*Tubifex (Tu.) tubifex)*. The *M. cerebralis* ingestion by *Tu. tubifex* occurs, which leads to protuberance of the polar filaments and their spores anchor into the gut lining. Shell valves get open, binucleate sporoplasm runs away and sticks in the middle of epithelial cells. Then, inter-epithelial schizogonic multiplication of binucleate sporoplasm takes place. The plasmogamy of 2 uninucleate cells occurs to develop 1 binucleate cell stage. Both nuclei divide mitotically to produce the 4-nuclei stage. The emergence of the 4-cell stage through plasmotomy; 2 cells enfold the other 2 cells which in turn leads to the generation of early pan-sporocyst with 2 somatic and 2 generative cells. As a result of 3 mitotic divisions of both generative cells and 2 mitotic divisions of the somatic cells, 16 gametocytes (8α and 8β) masked by 8 somatic cells emerge. Then the meiotic division of the 16 diploid gametocytes, 16 haploid gametocytes, and 16 polar bodies results, leading to the formation of 8 zygotes after copulation of each pair of α- and β-gametes. The sporoblast emergence occurs after 2 mitotic divisions of the zygote, 3 pyramidally arranged cells, and one inner cell are produced. As a result of the mitotic division of the 3 peripheral cells, 3 capsulogenic and 3 valvogenic cells are formed. The valvogenic cells outstretch the capsulogenic cells, while internal cleavage of the developing sporoplasm cell generates one generative cell enfolded by one somatic cell. The sporoplasm persists unfolded in the pansporocyst till its final number of germs by recurrent mitotic divisions. The inflated mature triactinomyxon spore is formed (El-Matbouli and Hoffmann 1998).

Whirling disease is identified predominantly by persistent inflammation of the cartilage, although other clinical signs are also present. Cartilage degradation occurs after the development of lesions. Although, in mature fish, parasites are present in isolated pockets in bone and are less likely to be associated with inflammatory lesions. Parasites digest the cartilage, destroying tissue structure, outcome of which is irregular bone formation and skeletal abnormalities (Hedrick et al. 1999). Any cartilage can get an infection and it differs among salmonid species, cranial regions develop lesions (Baldwin et al. 2000) and in Yellowstone cutthroat trout lower jaw (Murcia et al. 2011). Lesions originate as small foci then get developed with time into necrosis, destroying cartilage along with tissue damage and inflammation (Baldwin et al. 2000; MacConnell and Vincent 2002). Several stages of parasites are present at a single time-older stages locate themselves enclosed and younger stages at the leading edges (Baldwin et al. 2000). No drug treatment is specifically recommended for *M. cerebralis*, many drugs have been evaluated but no drug is found satisfactory. Several drugs reduced infection and suppressed disease, but none prevented or eliminated the infection. Most of the drugs cause toxicity and reduce growth.

Myxozoan parasites

Myxozoans are protozoan parasites that largely affect the gut region of various kinds of fish, living both in fresh and marine water. The most common of these parasites is *Enteromyxum (E.) leei*. It is a cause of disease in cultured sea bream and other species which commonly inhabit the Mediterranean region. Parasites affect the digestive tract, leading to severe enteritis which may in worse situations lead to emaciation and death. It also causes a similar type of disease in tiger pufferfish Rea. *E. leei* can get transferred between hosts without the need of an intermediate host, leading to the rapid spread of the disease in the fish population (Diamant 1997). Another important myxozan parasite is *E. scophthalmi* that causes similar intestinal conditions in the intestinal cavity of turbot fish species (Redondo et al. 2004) and is known to have direct transmission.

Neobenedenia girellae

Neobenedenia (N.) girellae is a monogenean, warm water ectoparasite of marine cultured fish species, which affects significantly greater amberjack, representing the main bottleneck for its production (Shirakashi et al. 2013). It causes high mortality and the range is 70-100% (Ogawa et al. 1995; Shinn et al. 2015). In early infection, the parasite gets attached to the fins and the cranial skin region, while for long-term infections it moves towards ventral and

dorsolateral skin regions (Hirayama et al. 2009; Hirazawa et al. 2011). The life cycle is shown in Figure 4. The adult parasites attach to the epithelial surface of the fish and deposit eggs into the environment. The ciliated larvae hatch from the embryonated eggs, which are called oncomiracidia. These oncomiracidia reinfect the fish and continue the life cycle. The symptoms of fish ectoparasites are host and parasite-specific. For instance, sea lice-infected Atlantic salmon skin shows an ulcerative process resulted from the second antennae and dermatitis characterized by varied epidermal thickness, detached cells, necrosis, and mobilized leucocytes (Jones et al. 1990). Other monogenean infection, as *N. amelleni,* shows surface epithelium denudation and interstitial oedema in red hybrid tilapia (Oreochromis spp.) (Robinson et al. 1992). Previously, it has been stated that *N. girellae* infection affects amberjack skin and alters epidermis thickness and density of goblet cells due to distorted osmoregulatory and respiratory skin functioning (Hirayama et al. 2009; Hirazawa et al. 2016). Additionally, it causes secondary bacterial infections to the skin, observed by the revamped fish conduct; scratching its skin with the tank, resulting in major skin injuries (Ogawa et al. 1995; Hirayama et al. 2009). Hydrogen peroxide solution, when used as bath treatment along with oral administration of praziquantel, has proved to be effective to control the parasite. Moreover, acquired protection against secondary infection with the parasite was demonstrated in primed Japanese flounder (Hirazawa et al. 2016).

Bolbophorus confuses

It is a digenetic fish trematode and affects skeletal muscles and viscera of the host fish, and therefore, adversely affects fish production. It affects channel catfish (Doffitt 2020) and has a complex life cycle, involving different hosts; white pelican being the definitive host, while snail, and catfish being the first and second intermediate hosts, respectively (Outa 2020). Metacercariae affect the skin and skeletal muscles of the host, but in severe cases, they penetrate the visceral organs, like the kidney and liver, and cause channel virus disease or enteric septicemia like condition. Visceral organ involvement increases mortality rates (Kahn 2010).

Posthodiplostomum cuticula

It is also a digenean that hosts freshwater fish and causes black spot disease in them. Like other digenean, it also possesses a complex life cycle, involving three hosts (Ritossa 2013). Adult parasite affects the bird (definitive host) and eggs are released in feces that contrive the miracidia which penetrate the snail (the first intermediate host). These give rise to sporocysts which evolve into Furco-cercariae, released from the snail, penetrate the skin of fish (second intermediate host) and develop into metacercaria. They infect the skin, fins, and muscles, producing visible black cysts (melanin surrounded meta-cercaria so-called as black spot disease) (Ondračková 2004).

Proteocephalus ambloplitis

It is a tapeworm, belonging to a large group of cestodes that infect a variety of species. It is of serious health concern (Scholz 2019). The larval stage inhabits the ovary of the host, while adult *Proteocephalus* worms reside in the inner wall of the gut and shed eggs (egg-filled proglottids: body segments) with the fish feces. Eggs hatch and get dispersed in water, then taken up by the crustaceans, where they develop into larvae, procercoid. This gets entry to fish gut when fish eat crustacean and develops to plerocercoid within the host.

Contracaecum rudolphii

Contracaecum rudolphii is a nematode parasite, affecting several fish species such as *Alburnoides bipunctatus*, *Anguilla anguilla*, *Barbatula barbatula*, *Cyprinus carpio*, *Gobio gobio*, *Perca fluviatilis*, *Phoxinus phoxinus*, *Poecilia reticulata* and *Tinca tinca* (Moravec 2009). It infects the fish directly or indirectly i.e., by infecting the copepods that are ingested by the fish. Its life cycle involves three larval stages, the third larval stage being the infective stage of the parasite. It penetrates the intestinal wall to get access to the body cavity and to encyst the visceral organs (Baruš 2001).

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