HSPI Inc. The Open Access Publisher

INSIGHTS IN VETERINARY SCIENCE
ISSN 2576-9510

Review Article

Fish-borne parasites proficient in zoonotic diseases: a mini review

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Abstract

Fish-borne parasitic zoonoses are primarily found in people living in developing and underdeveloped countries. The parasites that cause such zoonoses like *Trichinella* and *Taenia* are well-known in developed nations, but few people are familiar with fish-borne parasitic zoonoses, which are largely caused by helminths and protozoans. In general, parasitic zoonoses transmitted by fish are rarely life-threatening, although cases and reports of such infestations have increased over the world. The list of parasitic organisms is extensive. This article attempts to provide a complete overview of the many fish-borne parasites that can cause zoonosis among humans and animals alike.

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Submitted: February 21, 2022
Approved: March 14, 2022
Published: March 15, 2022

How to cite this article: Bardhan A. Fish-borne parasites proficient in zoonotic diseases: a mini review. Insights Vet Sci. 2022; 6: 005-012.

DOI: 10.29328/journal.ivs.1001035

Keywords: Zoonoses; Parasite; Fish; Trematode; Cestode; Nematode; Protozoans

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Introduction

Humans and animals have both been known to be infected with food-borne zoonotic parasites. They are the cause of a variety of pathological disorders, some of which are fatal. With the rapid advancement of globalization and mechanization, there have been changes not only in international markets but also in domestic markets. Previously, food-borne zoonoses were limited to developing countries due to poor hygiene, sanitation processes, and mishandling of food products and by-products. Aquaculture is the fastest increasing food production sector, according to an FAO report (FAO, 2019). The risk of contracting fish-borne zoonoses has risen in tandem with the rise in fish production. The World Health Organisation had estimated that around half a billion of the global population is infected with fish-borne trematodes [1]. The public health significance of these zoonoses needs to be chalked out for a better understanding of parasitic zoonoses and their linkage to several factors viz., poverty, intensification of aquaculture and waste disposal [2]. Such tasks are difficult and necessitate manpower (trained employees) as well as systems related to the public health system. The study on fish-borne parasitic zoonoses is generally meager primarily due to the lack of proper data on health and economic impacts [3]. This chapter aimed at listing out the fish-borne parasitic zoonoses that are prevalent along with efforts to summarize the global health data available on them. Fish-borne parasitic zoonoses are quite new to the food-borne zoonoses arsenal and demand extensive research and proper funding. It is noteworthy, that these fish-borne parasitic zoonoses are quite complex and whose transmission is often dependent on well-entrenched human behaviors. The complications of diagnosis, the intricacies of human cultural activities, and the poor understanding of latent economic impacts have made this field daunting, scientifically questionable, and therefore, somewhat unappealing to investigators, especially in developed countries [3]. Basic biological and epidemiological elements should be highlighted, as well as knowledge gaps that require further inquiry and investment, and, ultimately, effective preventative and control techniques.

Trematodiases

Trematode comes from the Greek word trematos, which means “pierced with holes.” Trematoda is a class of the Platyhelminthes phylum. The parasitic flatworms known as “flukes” with metacercariae as their infective stage make up the majority of it. The liver flukes and intestinal flukes are the most common trematodes associated with fish-borne zoonoses.

The liver flukes: The liver flukes are a group of trematodes that belong to the Ophisthorchiidae family and share a similar life cycle. Cholangitis, choledocholithiasis, pancreatitis, and cholangiocarcinoma are the most common clinical issues associated with such parasitic infections. The extent of such infections is more prominent in Southeast Asia due to the consumption of raw or improperly cooked fish facilitated partly by population migrations [2]. The popular liver flukes that are zoonotic to humans and documented worldwide [3-6] are enlisted in Table 1.

Clonorchis Sinensis, the Chinese liver fluke, is the most important species of the fish-borne zoonotic parasite in East Asia and is endemic to Asia and Russia [4]. Global infections by this fish-borne parasite stretched between 7-10 million [3]. Japan has shown more prevalence of this infection due to the consumer preference for raw uncooked fish [4]. Clonorchiasis is currently endemic in South Korea, China (excluding the northwestern provinces), Taiwan, northern Vietnam, and Russia's far-east. The prevalence of *C. Sinensis* was 0.4% in a countrywide sample of nearly 1.5 million persons [7]. Because the parasite feeds on bile, clonorchiasis is linked to the bile duct and gall bladder. Jaundice, indigestion, biliary inflammation, bile duct obstruction (cholangitis), liver cirrhosis, cholangiocarcinoma, and hepatic carcinoma are the most common symptoms [8].

Opisthorchis viverrini, a pathogenic liver fluke [5] is widespread in Southeast Asia including Thailand, Laos, Cambodia, and South Vietnam; about 9 million people are estimated to be infected globally [9]. *Opisthorchis felineus* was first described from a naturally infected cat and subsequently from a man in 1892 [5]. The estimated number of infected people is currently about 6 million [10]. *Opisthorchis infections in the bile duct and gall bladder are most commonly caused by raw or undercooked fish, crabs, or crayfish. Infections can last for 25–30 years if left untreated, which is the parasite's lifecycle. Indigestion, stomach pain, diarrhea, and constipation are common symptoms. Abdominal pain, nausea, and diarrhea might develop in severe cases. Fever, facial puffiness, enlarged lymph glands, aching joints, and rash are also symptoms of O. viverrini infections. Infections with O. felineus might cause difficulties in the pancreatic ducts. Opisthorchis infection is diagnosed by identifying their eggs in feces samples under a microscope. To treat Opisthorchis infections, safe and effective medication is available, as well as proper freezing/cooking of the fish before ingestion.*

Metorchis conjunctus, the Canadian liver fluke, is a parasite for carnivorous mammals in Canada and USA [6] and is known to cause metorchiasis by the ingestion of infected fish. The first intermediate host is *Amnicola limosus* (freshwater snail) followed by the fishes as the secondary host. Metacercariae was also found in northern pike [11]. Humans had eggs of *M. conjunctus* in their stools, but they were asymptomatic. Sashimi from raw *Catastomus commersonii* was identified as a source for an outbreak in Montreal [6] in 1993. The acute phase consists of upper abdominal pain and low-grade fever. High concentrations of eosinophil granulocytes and liver enzymes were detected [6]. Although chronic infections have not yet been observed, symptoms can continue anywhere from 3 to 4 weeks. Serologic testing should be followed by praziquantel treatment (75 mg/kg, 3 dosages per day) [5].

The intestinal flukes: Intestinal flukes of family *Heterophyidae* comprise a good chunk of fish-borne zoonotic trematodes (35 species) apart from liver flukes [3]. Molluscs (snails of freshwater and brackish water) are the primary hosts of such parasites followed by fishes. The parasites of concern that are zoonotic from fish [3, 12] are enlisted in Table 2.

The genus *Metagonimus* is characterized by a laterally deviated ventral sucker and absence of genital sucker [12]. The species has a broad fish host specificity, but the chief fish host in the Republic of Korea and Japan is sweetfish *Plecoglossus altivelis* [3] which is consumed quite vastly. Adult flukes attach to the mucosa of the small intestine, causing villous atrophy and hyperplasia (Metagonimiasis). Fatigue and moderate gastrointestinal problems (epigastric discomfort, diarrhea, and anorexia) are common in small cases. Abdominal pains, malabsorption, and weight loss are common with severe infections. Infections can affect people of any age range. These flukes occasionally infiltrate the mucosa, depositing eggs on tissues. Granulomas may develop around such eggs, resulting in convulsions or neurologic impairments [12,13]. The drug of choice is praziquantel (10 – 20 mg/kg body weight). Infections can be prevented by eating properly cooked seafood. Irradiation of sweetfish [3] is also practiced in popular restaurants for controlling the infectivity of these intestinal flukes (metacercariae).

The genus *Heterophyes* is notable by the presence of a ventral sucker placed in the middle with a genital sucker

Table 1: Details of zoonotic fish liver flukes.

Species	Piscine hosts	Other hosts	Geographic distribution
Clonorchis Sinensis	*Pseudorasbora parva*[a], *Abbottina rivularis*[a], *Ctenopharyngodon Idella* (grass carp), *Carassius carassius* (crucian carp), *Carassius auratus* (goldfish), *Cyprinus carpio* (common carp), *Cyprinus carpio nudus* (leather carp), *Zacco temminckii*[a]	Dog, cat, rat, pig, buffaloes	Korea, China, Taiwan, Vietnam, Russia
Opisthorchis viverrini	*Hampala dispar, Labio barbus lineatus, Puntius spp.*[a], *Osteochilus spp.*[a]	Dog, cat, rat, pig	Thailand, Laos, Cambodia, Vietnam
Opisthorchis felineus	*Tinca tinca* (tench/doctor fish), *Tinca Vulgaris, C. carpio, Barbus barbus*[a], *Abramis brama* (freshwater bream)	Dog, cat, rat, pig, fox, seal, lions	Europe, Russia
Metorchis conjunctus	*Perca flavescens* (yellow perch), *Catostomus catostomus, Salvelinus fontinalis (brook trout)*	Dog, cat, fox, raccoons, coyotes	Canada, USA

([a]species of ornamental trade and importance. Although some species in *Puntius sp.* are also food fish and consumed in Asia).

Table 2: Details of zoonotic intestinal flukes isolated from fishes and their animal hosts.

Species	Piscine hosts	Other hosts	Geographic distribution
Metagonimus yokogawai	*Plecoglossus altivelis* (Ayu), *Tribolodon sp., Lateolabrax japonicas*	Dog, cat, rat	Korea, China, Taiwan, Japan, Russia, Indonesia, Israel, Spain
M. takahashii	*Carassius carassius, Cyprinus carpio, Tribolodontac zanowskii*	Dog	Korea, Japan
M. miyatai	*Zacco platypus, Z. temmincki, P. altivelis, Tribolodon sp., Morocco steindachneri*	Dog, rat, hamsters	Korea, Japan
Heterophyes heterophyes	*Mugil cephalus* (mullet), *Oreochromis niloticus* (Nile tilapia), *Aphanius fasciatus, Acanthogobius sp.*(Gobies)	Dog, cat, fox, wolves, pelicans	Egypt, Sudan, Palestine, Brazil, Spain, Turkey, Iran, India, Russia
H. nocens	*M. cephalus, Acanthogobius sp.*	Cat	Korea, Japan, China
Haplorchis taichui	*C. carpio, C. auratus, Z. platypus, Pseudo rasbora parva, Rodeus ocellatus, Gambusia affinis, Ctenopharyngodon idella, Puntius* spp.	Cat, dog, fox, egret	Taiwan, Philippines, Bangladesh, India, Palestine, Egypt, Malaysia, Thailand, Laos, Vietnam, China
Haplorchis pumilio	*M. cephalus, Channa striata, Glossogobius giurus, Leiopotherapon plumbeus* (silver perch), *Gerris filamentosus, Teuthis javus, Ambassis buruensis, Astatotilapia desfontainesi, Acanthogobius sp., Anabas sp., Carrasius sp., Cyprinus* spp., *Oreochromis* **spp.**, *Barbus canis, Barbus longiceps, P. binotatus*	Cat, dog, fox, wolves, pelicans	Thailand, Laos, China
Haplorchisyo kogawai	*Mugil spp., Puntius spp., Misgurnus sp., Gerris kapas, A. buruensis, Amphacanthus javus, Hemiramphus georgii, O. striatus*	Cat, dog, egret	Taiwan, Philippines, China, Malaysia, Indonesia, Thailand, Laos, India, Australia, Egypt
Pygidiopsis summa	*M. cephalus* and *A. flavimanus*	Cat	Korea, Japan

surrounded by gonotyl and multidigitate spines [12]. Among this genus, *H. heterophyes* is more popular as a fish-borne zoonotic parasite as it is known to cause infections among the inhabitants of the Nile delta [12]. Particularly, the consumption of mullets (*M. cephalus*) proved to be the main source of heterophyidiasis [3]. Although reports of these parasites' eggs migrating to the heart and causing severe cardiac damage are recorded from the Philippines, the minor symptoms include diarrhea and colicky abdomen discomfort [3,5]. Being such a minute fluke they may enter the circulatory system and travel to various organs around the body making this a harmful pathogen.

The genus *Haplorchis* is categorized by the presence of a singular testis and a ventrogenital sucker complex armed with gonotyl and chitinous spines [13]. Five species, namely *H. taichui, H. pumilio, H. yokogawai, H. pleurolophocerca*, and *H. vanissimus*, are responsible for human infections with the first three being the most infectious [3]. Consumption of raw or pickled brackish water/freshwater fish infected with metacercaria is the main source of infection. The signs and symptoms are similar to those of heterophyidiasis. Although *Haplorchis* infections seldom result in death, they can result in considerable morbidity. *Haplorchis* received increased public health attention due to their high frequency and vast spread in Asia and Africa.

Pygidiopsis summa is a very small intestinal trematode. In Japan, experimentally, the flukes were found when the canines were fed the metacercariae from mullets, *M. cephalus* [14]. Brackishwater fish, namely, *M. cephalus*, *Liza haematocheila*, and *Acanthogobius flavimanus*, are known to be the secondary hosts and also the sources of human infections [14]. Symptoms are similar to heterophyidiasis and they do not pose any serious damage. However, reports on extreme gastric pains and diarrhea have been documented [3].

Echinostoma genus is a similar intestinal fluke and is characterized by an elongated body with a head collar surrounded by a crown of spines, hence the name [14]. A list of all the infective *Echinostoma* species which are fish-borne [3,5,14] and zoonotic are noted in Table 3. It is noteworthy that among these *E. hortense* infections are quite well known.

Echinostomiasis is a parasitic infection that occurs in people after eating fish or other foods (uncooked or infected with metacercaria). Smelts and loaches are popular in the Arctic regions of the continent, however, infections have been observed, showing a link between raw undercooked fish and parasitic influence [15,16]. Along with abdominal pain, diarrhea, and anorexia, duodenum mucosal bleeding and ulceration are the main clinical findings due to the mechanical damage (spines) caused by these flukes [15,16]. Drugs of choice are praziquantel and albendazole.

Paragonimiasis: Known by the name "lung fluke disease", it is caused by a number of species of the genus *Paragonimus.* The species of zoonotic importance include *P. westermani, P. Africanus, P. mexicanus, P. heterotremus,* and *P. philippinensis.* Paragonimiasis is widespread in Southeast Asia, Africa, and America [15,17]. Cercariae released into water swim to metacercariae by penetrating suitable kinds of crabs, crayfish, fish, and encyst. Humans contract paragonimiasis after consuming contaminated species (raw, salted, pickled, smoked, marinated, dried, or partially cooked) fish [15]. Because they are asymptotic, many go overlooked. When these metacercariae enter the lungs, they cause symptoms similar to tuberculosis, such as coughing up sputum or blood, chest pain, dyspnoea, fever, pleural effusion, and pneumothorax. Paragonimiasis is a recent re-emergent fish-borne disease [15] and quite devastating too. The role of sushi (marinated or partially cooked) with Paragonimiasis has been vastly studied [15].

Table 3: Details of zoonotic *Echinostoma* species isolated from fish and its predominant animal hosts.

Species	Piscine hosts	Other hosts	Geographical prevalence
Echinostoma hortense	*Misgurnus spp.* (loaches), *Coreoperca kawamebari* (Japanese perch)	Rat, dog, cat, mice	Korea, Japan, China
E. japonicas	*Pseudorasbora Parva, Hypomesusolidus* (smelt), *Gnathopogon strigatus*	Chicken, duck	Korea, Japan, China
E. perfoliatus	*Carassius* spp.	Fox, rat, wild boar, dog	Japan, China, Taiwan, Hungary, Italy, Romania, Russia
E. liliputanus	*P. Parva*	Dog, cat, badger, fox, raccoon	Egypt, Syria, Palestine, China
E. fujianensis	*P. parva, Cyprinus carpio*	Dog, cat, pig, rat	China

Diphyllobothriasis and Ligulosis

This is the most significant fish-borne zoonosis caused by a cestode (tapeworm). Species of the genus *Diphyllobothrium* and *Ligula intestinalis* (Order: Pseudophyllidae, Family: Diphyllobothriidae) are accountable for most of the reported cestode human infections [16]. Zoonosis occurs commonly in places where raw or marinated fish are consumed daily [16]. Both freshwater and marine fish, particularly anadromous species, serve as intermediate hosts. There have been reports that its prevalence and distribution are growing in some areas, most likely as a result of social and economic developments [5,18]. Although *L. intestinalis* infestations are quite common in fishes, *D. latum* is the most reported species from humans. Recent reports have identified *Bothriocephalus acheilognathi* (Asian tapeworm) from the fish gut which was also found in human stool samples with symptoms similar to Diphyllobothriasis suggesting a zoonotic threat [17]. Table 4 describes in detail all the cestodes that have been isolated from piscine hosts [18,19].

Diphyllobothriasis and *Ligulosis* are considered mild illnesses and hence the understanding of its global distribution is less due to lack of reports and studies. Although, the Scandinavian countries were considered as the 'hot-spot' of these infections [17] recent reports suggested that it has now spread all over the world [18] accounting for around 20 million global infections. The most problematic, *D. latum* (fish tapeworm), causes infections worldwide in children and adults alike. Few reports of human *Ligulosis* have been reported [3]. Freshwater fish is considered to be the epidemiological reservoir of *D. latum* whereas other species originate from marine fishes. Diphyllobothriasis causes gastrointestinal manifestations which include acute abdominal pain, diarrhea, constipation, intestinal obstruction, sub-acute appendicitis, cholecystitis, as well as cholangitis [17]. Hematological manifestations include megaloblastic anemia, vitamin B12 deficiency, pancytopenia, eosinophilia, and pernicious anemia. These symptoms are the most reported while severe infestations can affect the nervous system, eyes, and skin showing symptoms like paresthesia, optic neuritis, dyspnea, and other allergies [17]. Environmental changes, translocation of human and animal populations, tourism, changes in marketing (export and distribution) systems, and changes in eating habits are effective strategies in controlling this disease [18]. The medicine of choice for such infections is praziquantel.

Nematode infestations

Anisakiasis: Also known by the name anisakidosis, it refers to the infection caused by the larval stages of nematodes belonging to two families, *Anisakidae* and *Raphidascarididae* [3]. The two genera often concomitant with anisakiasis are *Anisakis sp.* and *Pseudoterranova sp* [3]. When people eat third-stage larvae (L3) found in the viscera or muscle of a variety of fish and cephalopod mollusk species, they get anisakiasis. Humans are unlucky hosts, and the parasites

Table 4: Details of cestodes isolated from the piscine body and the geographical regions they thrive in.

Species	Piscine hosts	Geographic distribution
Diphyllobothrium alascense	Burbot, Smelt	Alaska
D. cameroni	Marine fishes	Japan
D. cordatum	Marine fishes	Northern Seas, Greenland, Iceland
D. dalliae	Freshwater fish (*Dallia pectoralis*)	Alaska, Siberia
D. dendriticum	Salmonids, Coregonids, Burbot, Grayling	Circumpolar;
D. hians	Marine fishes	North Atlantic; North Sea
D. klebanovski	Salmonids	Eastern Eurasia, Japan, Alaska
D. lanceolatum	Coregonus	North Pacific, Bearing Sea
D. latum (fish tapeworm)	Pike, Burbots, Percids, Salmon	Fennoscandia, western Russia, North and South America, Korea
D. nihonkaiense	Salmon	Japan
D. pacificum	Marine fishes	Peru, Chile, Japan
D. Ursi	Red salmon	Alaska, British Columbia
D. yonagoensis	Salmon	Japan, eastern Siberia
L. intestinalis	Cyprinids, *Rutilus rutilus* (roach), *Albramis* spp. (bream), minnow, trench, silver bream, yellow perch,	Europe, America, Middle East, China
Bothriocephalus spp.	Cyprinids, freshwater fishes, breams, trench, perch	Asia and Central America

rarely progress further in the human gastrointestinal tract. Nonetheless, anisakiasis is a major zoonotic disease, and its frequency has increased dramatically over the world in the last two decades [19]. Two fish worms of cosmopolitan influence include *A. simplex* complex (herring worms) and *Pseudoterranova* complex (cod worms) [19]. Three species have been defined within the *A. simplex* complex: *A. simplex*, dominant in northern Atlantic, *A. simplex* C, established in the northern Pacific and southern waters below 30°N; and *A. pegreffi*, found in the Mediterranean Sea [21,22]. Also, three species within the *Pseudoterranova* complex are *P. decipiens* A (northeast Atlantic and the Norwegian Sea), *P. decipiens* C (northwest Atlantic and the Barents Sea), and *P. decipiens* B (northern waters); where the ranges of these species overlap, they appeared to preferentially utilize different definitive host species [21,22]. A very large number of fish species act as paratenic hosts for species of *Anisakis* and *Pseudoterranova* differences among which are based on their host ranges. Table 5 enlists the piscine hosts of the *Anisakis* and their geographical prevalence [20].

Every year, approximately 20,000 anisakiasis cases are reported worldwide [3,21,22]. Over 90% of these cases are from Japan, Spain, the Netherlands, and Germany, depending on the habits of raw fish consumption. Anisakiasis is contracted when inadequately cooked fish containing these nematode larvae (L3) are eaten [19]. Pickled herring from Scandinavia, sushi or sashimi from Japan, and cod, flounder, and tuna from the east coast of the United States are all popular meals that include living larvae. Marine animals (whales, dolphins) are the definitive hosts of nematodes that cause anisakiasis. The stomach pains start a few hours after you consume the fish. Larvae penetrate the gastric or intestinal mucosa or cling to the epithelium after being liberated from the ingested fish meat. Anisakiasis is characterized as either a luminal (small) or invasive infection based on the extent of intestinal wall invasion; the latter causes harm and accounts for over 90% of global Anisakis infestations. After surgical intervention for intestinal blockage or peritonitis, which is characterized by necrotizing, eosinophilic, granulomatous disease, infection is discovered. Worms in the throat or stomach are vomited or coughed up (wriggling sensation in the throat), with larvae appearing in the mouth of a patient. Intestinal anisakiasis clinically resembles appendicitis, with right lower quadrant pain, nausea, and vomiting [3]. The identification of larvae provides the diagnosis. Infections in the small intestine, caecum, or colon are usually not diagnosed before conducting laparotomy. Removal of worms relieves the symptoms. Patients with these symptoms should be cross-checked with any history of raw marine fish consumption [3]. Molecular genetics analyses will also provide an essential tool for basic ecological studies of anisakids.

Gnathostomiasis: *Gnathostoma,* an emerging fish-borne zoonosis, is being documented quite vastly in areas where it is not endemic and thus poses a risk as a significant imported food-borne zoonosis [3]. Previously, it was focused on Southeast Asia and South America but its geographical boundaries appear to be increasing with recent tourist reports showing infestations of this nematode. This genus belongs to the order *Spirurida*, one of the largest groups of nematodes. The species of importance and concern include *G. spinigerum*, *G. hispidum, G. doloresi,* and *G. nipponicum*, all geographically prevalent in China, India, Thailand, Vietnam (Southeast Asia), Europe, and parts of Mexico [21]. Humans are the accidental hosts while piscivorous animals are the definitive hosts [3]. Symptoms of Gnathostomiasis include cutaneous (edema, hemorrhages, nodular migratory panniculitis), pulmonary manifestations, gastro-intestinal infections (pain and obstruction), genitourinary infections, and ocular problems. It can also affect the CNS (eosinophilic encephalomyelitis and meningitis) [21]. Treatment and drugs of choice include albendazole and praziquantel.

Protozoans

Amoebiasis: Amoebic dysentery caused by the intestinal protozoan parasite *Entamoeba histolytica* has an estimated worldwide prevalence of 500 million people killing over 55,000 people every year [24,26]. It is a significant public health issue, particularly in poorer nations with insufficient sanitation and hygiene. Entamoeba has been classified as a developing fish-borne parasitic zoonose due to recent outbreaks in Southeast Asian nations such as Thailand and Vietnam [3,24]. Although humans get infected mainly by contaminated food and water (cysts and trophozoites), the consumption of raw fish from sewage-fed culture or waste-water culture and traditional cooking styles may be the main reason behind its outbreaks. Symptoms include dysentery, bloody diarrhea, vomiting, dehydration accompanied by abdominal pain.

Table 5: List of nematodes from piscine hosts responsible for several zoonotic ailments.

Species	Piscine hosts	Geographical prevalence
Anisakis simplex	*Merluccius Merluccius* (European Hake), *Trachurus trachurus* (Atlantic horse mackerel), breams, *Scomber japonicus* (Chub Mackerel), *Saurida tumbil* (greater lizardfish) *Nemipterus japonicus* (Japanese threadfin bream) *Carangoides armatus* (longfin trevally) *Thannus tonggol* (Long tail tuna fish) *Scomberomorus commerson* (Narrow-barred Spanish Mackerel), *Oncorhynchus* spp (Salmon), Herrings, Anchovies, Cod, Pike, Cuttlefish	Africa, China, Indonesia, Iran, Japan, Korea, Taiwan, America, Ecuador, Chile, Pacific Coast,
A. pegreffi	*Merluccius gayi* (Hake Merluza), *Salvelinus alpinus* (Arctic char), Salmon. Cod, Herrings, Anchovies, Tuna, *Merluccius merluccius* (European hake) *Scomber japonicus* (Chub Mackerel), *Sillago flindersi* (Eastern School Whiting), *Pseudocaranx dentex* (White trevally), *Neoplatycephalus richardsoni* (Flathead Tiger Fish), Conger, Croakers, *Seriola* spp. (Yellowtail)	

Balantidiasis: Balantidiasis, although rare, is another emerging fish-borne zoonosis. The aetiological agent responsible for this infection among humans is *Balantidium* spp. (Phylum: Ciliophora Family: Balantidiidae). Several *Balantidium* spp. have been recorded throughout the world in various species [22,27] of crustacea, fish, amphibians, and mammals (including humans). Infections caused by *B. coli* are prevalent particularly in pigs, monkeys, and humans, especially in the tropics, with zoonotic spread frequently occupied by epidemiological studies [22,27]. Individuals infected with *B. coli* often remain asymptotic as these parasites produce a proteolytic enzyme that digests the epithelium forming ulcers [22,27] stimulating secondary bacterial infections. Chronic infections may show dysentery-like symptoms. Colonic ulceration involves mucosal sloughing, necrosis, abscess formation, and perforation of the bowel. Antibiotics may be prescribed to control, although medical supervision may be needed for recovery.

Giardiasis: Giardiasis is the most prevalent waterborne disease in the United States and the most common cause of diarrhea in humans worldwide. The species of zoonotic importance from fish is *G. duodenalis* which has been isolated from wild tilapia, mullets [23] and the aquatic environment. They resemble a "tear-drop" shape and contain twin nuclei. It is a common water parasite and is often found among wild captured fishes than cultured fishes. The World Health Organisation has considered *G. duodenalis* as a zoonosis [23,29] since 1979. The most common host for *Giardia* is wild fishes and consumption of such from polluted or contaminated waters always poses a risk. Symptoms include diarrhea with foul smell, fatigue, abdominal cramps accompanied by bloating, and nausea. Signs and symptoms may persist for 2 - 6 weeks leading to a weight loss of the patient.

Cryptosporidiosis: Cryptosporidium is a ubiquitous enteric protozoan pathogen and has been quite popular for causing gastrointestinal problems. In fishes, they are often isolated from the gut and can be attested by histological analyses [24]. Two species have been isolated from fishes, namely, *C. parvum* and *C. hominis* [24]. These parasites are popular in farmed and aquarium fish [24]. Consumption of such infected raw uncooked fish is a cause for cryptosporidiosis. Also, fish handlers play a vital role in these infestations. Documentation of Cryptosporidian from fish fillets points out the risk of infections from fish or contaminated handling [24,31]. Cryptosporidium is an opportunistic infection that makes persons with weakened immune systems more vulnerable. Isolated oocytes (infectious stage) from stool samples also point to a resurgence of zoonotic parasites in fish [25]. Symptoms of cryptosporidiosis are similar to diarrhea and pregnant women are vulnerable [25].

Microsporidians

Microsporidia are a remarkably diverse group of organisms, embracing more than 1,200 species that parasitize a wide range of invertebrate and vertebrate hosts. These organisms have long been known to be the causative agents of economically important diseases in fish [22]. However, microsporidians are considered emergent pathogens in the global food industry [26] from aquatic biomass. Since fish is the most common host of such spore-forming parasites, consumption of uncooked, raw, and contaminated fish are the leading sources for zoonotic infestations. Previously considered as a protozoan, recent classifications suggest microsporidians as fungus [26]. Species of zoonotic importance include *Enterocytozoon* sp., *Encephalitozoon cuniculi, Mitosporidium* sp., and *Glugea* spp. which are common inhabitants of fish gut microbiota. Similar to *Cryptosporidian,* these spore-forming parasites target immunocompetent patients. With recent outbreaks of *Enterocytozoon hepatopenaeii* (Early mortality syndrome or acute hepato-pancreatic necrosis disease) in shrimps, zoonotic infestations must be considered, as shrimps make up a significant part of the export market [28]. Microsporidiosis symptoms include chronic diarrhea, malabsorption, gall bladder disease, *keratoconjunctivitis*, kidney failure, and lung infections. In the case of immune-compromised patients (HIV/AIDS), significant mortality/death risk remains [27]. Albendazole is the drug of choice.

Organizations overlooking the spread of fish zoonoses and success stories

Several organizations have been formed for the prevention and control of fish zoonoses across the globe. Although fish zoonoses pose minor threats to the anthropogenic community, WHO has not overlooked this [29]. The Kenyan Zoonotic Disease Unit (ZDU) is a secretariat of Zoonoses Technical Working Group (ZTWG) established in 2011, under the WHO One Health program. The Kenyan ZDU is chaired on a rotational basis by the Director of Veterinary Services and the Director of Medical Services, Government of Kenya, with the mandate to provide technical advice regarding the prevention and control of fish zoonoses in the country. Examples of successful control programs, utilizing currently available tools, were given for fish-borne trematodiases in Thailand and *Taenia solium* cysticercosis in Peru. It is now imperative to adapt and scale up possible control strategies in endemic geographical areas. During the period 2008–2014, the liver fluke infection rate in the program villages has declined to less than one-third from the baseline, and all nine schools were classified as 'liver fluke-free'. In 2012, the prevalence in Cyprinoid fish species, which are the second intermediate host, was found to be less than 1% compared with a maximum of 70% during the baseline survey. The 'Lawa project' is working with a transdisciplinary team in the north-eastern Lawa Lake region of Thailand, a fish-borne trematodiasis hotspot with a community prevalence of 67% before the initiation of control activities. Recent findings from an investigation in northern Vietnam [29] revealed high rates of FZT (fish zoonotic trematodes) transmission, especially in fish nurseries, where FZT prevalence among stocked FZT-free fish fry increased to 14.1%, 48.6%, and 57.8% after 1 week, 4 weeks, and when overwintered in ponds, respectively. The juvenile fish raised in nurseries are eventually transferred to grow-out farms, thereby potentially seeding a large number of grow-out farms with FZTs. The prevalence in fish declined from 70% to 1% over 10 years after a successful campaign. Although every country has set up ministries under the One Health program, works and projects are still on hold. Since problems like antibiotic resistance, treamtodiasis, and several human parasitic infestations are on the rise, fish zoonoses have suffered a backstage dim light. On the contrary, fish-borne zoonoses pose little threat to humans and animals thus propagating the lack of success stories.

Conclusion

Fish-borne zoonotic infestations in humans result from ingestion of contaminated edible tissues or products of aquaculture or, to a lesser extent, from physical contact with contaminated production. Globally, over 50 species of helminth parasites from fishes, crabs, crayfishes, snails, and bivalves are known to produce human infections and some pose serious health hazards [29]. Most of the fish-borne zoonoses across the world occur along with coastal provinces. Persistent improvements in transportation, technology, and food handling, increase the chances for the acquisition of parasitic infections. The increasing exploitation of the aquatic environment, changing dietary habits combining "natural" seafood dishes (e.g., sushi and sashimi), and tendency to lessen cooking time–all are the major factors that increase the chances of becoming infected with these parasites. Also, an influx in international trade of food items, particularly of the crustaceans and fishes, which may be contaminated with the infective stages of the trematodes, nematodes, or protozoans (fish-borne zoonotic) from the endemic countries to distant continents may contribute to a potential health hazard. Immigrants also play a vital and decisive role in the emergence and re-emergence of fish-borne parasitic zoonoses as recent research suggested the development of zoonosis in many tourists across the globe. Substantial evidence indicates that migratory birds and animals can contribute to the global spread of infectious agents in a spatial manner analogous to immigration and emigration. Water fowls frequently occur in large groups, can migrate extensive distances, habitually graze and defecate in water, and are in fact protected by environmental laws in many regions where they have unlimited access to the surface waters (potable water). Zoonotic diseases, in general, are diseases of poverty and are associated with poor sanitation and hygiene (developing or under-developed countries). These infections tend to drop with increased economic development. Any approach towards effective control measures against meat/fish-borne zoonotic parasites should be focused on the knowledge of numerous factors accountable for transmission and occurrence. Control of zoonotic fish parasites is a multifaceted task due to the intricate nature of the interactions between hosts, pathogen, and environment in the aquatic environment. A central point towards the control of fish-borne zoonoses is complete hygiene and sustained awareness among people (consumers/producers/handlers). Appropriate education, hygienic living circumstances, adoption of firm self-hygiene, the practice of eating properly cooked food, use of clean water for drinking and bath can control the worldwide fish-borne zoonoses graph. Culture, trading, and processing activities are also important. There is no robust and updated database on fish-borne parasitic zoonosis in India. Hence the endemic areas of zoonotic infections of fish origin should be revisited and surveyed thoroughly to update the present status of each disease in both fish as well as humans. Changes in human ecology and the impact of climatic changes on parasitic systems have raised a solemn voice of concern. Added to that, the fish-borne parasitic zoonoses have emerged as a major public health problem, posing a grave threat to human and animal health. Increased plunge is required to control parasitic infections both in slaughter animals and in aquatic animals/seafood. Further, there is also a need for the establishment of a national and international network of aquatic parasitologists and a surveillance system for parasite zoonoses of fish origin and their distribution. The establishment of a national surveillance system for parasitic zoonoses of fish origin could be considered for addressing food safety issues and augmenting the research agenda in this direction.

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