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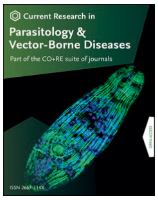

Is it possible to eliminate or eradicate human fish-borne parasitic diseases? A sweet dream or a nightmare?

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ABSTRACT

Human fish-borne parasitic diseases may be caused by at least 111 taxa of both freshwater and marine fish parasites. It is estimated that they occur in many hundreds of millions of people all over the world, and many more are at risk, sometimes with serious consequences including the death of the host. Therefore, all efforts must be made to minimize and prevent the infection. In this paper we present an overview detailing the several types of parasites infecting humans, the reasons for the occurrence of the disease, the ways of infection, the preventive measures and difficulties encountered when combating such infections. Finally, we discuss the possibility of eliminating or eradicating fish-borne diseases. It is concluded that elimination is difficult to achieve but it is possible in some places under favourable circumstances, and that eradication will probably never be fully achieved.

1. Introduction

The ultimate objective of medicine is to eradicate diseases. In this paper, we define eradication as “Permanent reduction to zero of the worldwide incidence of infection caused by a specific agent as a result of deliberate efforts: intervention measures are no longer needed” (Dowdle, 1998). If the disease is ruled out in a defined geographical area, then we consider it was eliminated, i.e. “Reduction to zero of the incidence of a specified disease in a defined geographical area as a result of deliberate efforts. Continued intervention measures are required.” (Dowdle, 1998; Hopkins, 2013).

Until now, only smallpox and rinderpest were declared eradicated respectively on the 8th of May 1980, by the World Health Assembly, and on the 25th of May 2011 by the United Nations Food and Agriculture Organization (FAO) and the World Organization for Animal Health (OIE). These are considered the most important human achievements concerning health and resulted from the hard work of thousands of people, huge investments, and strong efforts in international cooperation (Hopkins, 2013).

Other diseases have been targeted for eradication (poliomyelitis, Guinea-worm disease, measles, mumps and rubella) which will hopefully result in their eradication in the future. However, the difficulties in reaching eradication are almost insurmountable, and positive results depend on many unwieldy different factors, requiring active cooperation and coordinated actions of all countries. The measures that need to be taken must be “tailor-made”, adequate to the particularities of each disease, and are frequently impeded by human behaviour. Therefore, disease eradication remains an outcome that is only likely to be reached for a very small number of diseases under very specific conditions.

Elimination is apparently easier to reach than often thought despite a great number of difficulties which must be overcome. Once there is no global objective, implementation of the necessary measures to succeed is easier and may eventually be attained depending on the targeted parasite (Zhou et al., 2013).

There is a large amount of human infectious diseases caused by a great number of different fish parasites, spread all over the world. Hopefully, some may be eliminated or eradicated, at least theoretically and without the use of any medication. However, it must be stressed that massive chemotherapy with adequate drugs (either monotherapy or combining different drugs) is an important measure contributing to decreasing the infection in some cases (Prichard et al., 2012).

A number of researchers published reviews and general information about several aspects of these diseases (Adams et al., 1997; Chai et al., 2005; Macpherson, 2005; Nawa et al., 2005; Dorny et al., 2009; EFSA, 2010; Broglia and Kapel, 2011; Amer, 2014; Hussain et al., 2018; Zhu et al., 2019; Shamsi, 2019, 2020; Ziarati et al., 2022; Cong and Elsheikha, 2021; Hung et al., 2013; Chai et al., 2009, 2015, 2017, 2022;

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Toledo and Esteban, 2016; Yahata et al., 2015. Other researchers produced papers related specifically to some major parasite groups such as trematodes (Mas-Coma and Bargues, 1997; Clausen et al., 2012; Hung et al., 2013; Chai and Jung, 2020; Chai et al., 2009, 2015, 2017, 2022; Toledo and Esteban, 2016), nematodes (Buchmann and Mehrdana, 2016; Eiras et al., 2016, 2018a, 2018b, 2021; Bao et al., 2019; Mladineo, 2019), cestodes (Scholz and Kuchta, 2016; Scholz et al., 2009, 2019), acanthocephalans (Mathison et al., 2016, 2021; Lofty, 2020), and *Kudoa* sp. (Yahata et al., 2015). It is important to state that human infections are primarily due to the consumption of wild fish. However, farmed fish may also have an essential role as transmitters of pathogens to humans. This important aspect was reviewed by Lima dos Santos and Howgate (2011) and Hung et al. (2013).

In this review, we consider the different kinds of fish parasites involved in human infection, their geographical distribution, the mechanism of infection and the consequences of the disease. In particular, we discuss the possible ways and difficulties of eliminating and eradicating these diseases.

2. Fish parasites infecting humans

To produce this paper, an extensive bibliographical search was performed using the appropriate keywords, for instance, fish parasites, human infection, geographical distribution, diagnosis, One Health, disease elimination and eradication, the keywords being combined with the name of different parasite taxa. The Internet search engines Medline, PubMed, Science Direct, Redalyc, Google and Google Scholar were used, and the references of the papers were checked to identify useful publications. The checklist by Mathison and Sapp (2021) published recently was an important source of information used for this paper. The data collected are summarized in Table 1 which contains the species of fish parasites detected so far as human pathogens.

As shown in Table 1, there are at least 111 taxa including 106 named species of fish parasites detected as human pathogens, some of them causing very serious health hazards. These include Myxozoa (2 spp.), Digenea (61 spp.), Cestoda (17 spp.), Nematoda (19 spp.), and Acanthocephala (7 spp.). It can be stated that all fish species that were examined for the presence of zoonotic parasites were found to be infected all over the world (Hung et al., 2015; Scholz and Kuchta, 2016), with digeneans, cestodes and nematodes being the most common (Ziarati et al., 2022).

The location of the parasites within the human host is variable. However, the great majority of parasites locates within the intestine (mostly the small intestine) while a small number are found in the liver, pancreas or spleen. *Gnathostoma* spp. have a cutaneous or visceral *larva migrans*, and therefore may locate in several organs of the host. *Dioctophyme renale* is an exception as it locates only inside the kidney where it matures and destroys the parenchyma of the organ.

The life-cycles of most of these parasites are complicated and involve several hosts. Despite humans being possible definitive (final) hosts, they are not essential for the completion of the parasite life-cycle. The most important and fundamental characteristic of the infections is that they cannot occur unless there is some “cooperation” by humans, i.e. by ingesting raw or improperly cooked or preserved infected fish. This point shall be discussed later in this paper.

Moratal et al. (2020), provided a detailed review of the protozoans *Cryptosporidium* spp., *Giardia duodenalis* and *Toxoplasma gondii* concerning their potential presence in fishes. These water-borne parasites have been reported in both freshwater and marine fishes. However, the reviewed evidence did not allow a conclusion of whether fishes can be naturally infected with these protozoans or fishes act only as potential mechanical carriers; furthermore, there is no evidence for fish to human transmission (Moratal et al., 2020).

Regarding the Myxozoa, there are at least two species of the genus *Kudoa*, *Kudoa hexapunctata* and *Kudoa septempunctata*, causing food poisoning (Kawai et al., 2012; Kim et al., 2018; Tachibana and Watari, 2021) observed several times in Japan and South Korea. Martínez de Velasco et al. (2007) showed specific anti-*Kudoa* antibody levels in sera from patients with several digestive pathologies. The finding of spores of other species within the Myxozoa (*Myxobolus* sp. and *Henneguya* sp.) in human stool (McClelland et al., 1997; Lebbad and Willcox, 1998; Bradbury et al., 2015) suggests that these were simply fish parasites present in the gut content after being ingested with fish infected tissues, without any evidence of pathological effects to the hosts (Boreham et al., 1998). In fact, it was never demonstrated they were pathogenic to humans.

Members of the subclass Digenea are probably the most common, diverse and important human parasites, mainly in Asiatic countries. The number of people infected is not easy to estimate but it likely reaches many millions of people. Thus, about 35 million are infected with *Clonorchis sinensis*, *Opisthorchis viverrini* and *Opisthorchis felineus* in China, Japan, Korea, Taiwan and Vietnam (Macpherson, 2005), while Dung et al. (2007) estimated the infection of more than 17 million of people in Vietnam alone. The intestinal flukes frequently cause mechanical and chemical irritation in the mucosa of the small intestine, and sometimes erratic intestinal flukes cause mortal infections due to lesions in the heart and brain (Yamada et al., 2008), with some species leading to major clinical infections such as cholangitis, choledocholithiasis, pancreatitis, and cholangiocarcinoma (Choi et al., 2004; Sripa et al., 2011; Boerlage et al., 2013). The strong association of chronic infection with *C. sinensis* and *O. viverrini* with cholangiocarcinoma justified that both parasites were considered carcinogenic to humans by the International Agency for Research on Cancer (WHO, 2012). The data for some Digenea may be more impressive: for *C. sinensis* about 20 million people were infected (Hong and Fang, 2012) and about 601 million were at risk (Garcia, 2016), while for *O. viverrini* over 10 million were infected in Thailand and Laos alone (Liau et al., 2023), with about 80 million at risk of infection with *Opisthorchis* spp. (Sripa et al., 2011). Dung et al. (2007), Chai and Jung (2017, 2022), Clausen et al. (2012), and Hung et al. (2013) provided reviews about fish-borne zoonotic trematodes in humans.

There are 17 zoonotic species belonging to the class Cestoda, *Dibothriocephalus* spp. (6 spp.) and *Diphyllobothrium* spp. (9 spp.) being the most important and reported species, most of them occurring more frequently in cold climates. Humans are the definitive hosts, and *Dibothriocephalus latus* is the most important species, infecting 10–20 million people worldwide (Scholz and Kuchta, 2016). Additionally, a single adult *D. latus* can produce up to 1,000,000 eggs per day (Shamsi, 2019) which means a single specimen may play a crucial role in the dissemination of the infection. The occurrence of diphyllobothriasis (and other parasitic diseases) may be favoured by poverty or poor socio-economic conditions. However, infection may occur even in regions with good medical care and appropriate hygienic standards (Scholz and Kuchta, 2016). This demonstrates the importance of human behaviour in the control of parasitic infections. According to Scholz et al. (2019) only six species (*Adenocephalus pacificus*, *Dibothriocephalus latus*, *Dibothriocephalus dendriticus*, *Dibothriocephalus nihonkaiensis*, *Diphyllobothrium balaenoptera* and *Diphyllobothrium stemmacephalum*) can be considered genuine human parasites (all confirmed with molecular techniques). Scholz et al. (2019) and Waeschenbach et al. (2017) suggested that the remaining species of *Dibothriocephalus* and *Diphyllobothrium* listed in Table 1 should not be considered typical human parasites because they have only sporadically been reported from humans and their identification in these reports was based on morphological characters alone.

The nematodes (phylum Nematoda) are frequent in freshwater and marine fishes, and several species have zoonotic importance. *Anisakis* spp., *Pseudoterranova* spp., and *Gnathostoma* spp. comprise the more important species due to the extended geographical distribution and number of fish species infected. *Anisakis* spp. are probably the most intensively studied zoonotic nematodes. They migrate into the muscles of the fish after the death of the host which favours the transmission to

Table 1
Fish parasites infecting humans.

Taxon	Genus	Species	Reference
Myxozoa	*Kudoa*	*K. septempunctata*	Kawai et al. (2012)
		K. hexapunctata	Takashima et al. (2021)
		Kudoa sp.	Martínez de Velasco et al. (2007, 2008)
Digenea	*Acanthotrema*	*A. felis*	Chai and Jung (2020); Mathison and Sapp (2021)
	Amphimerus	*A. novocerca*	Chai and Jung (2022)
		A. pseudofelineus	Mas-Coma and Bargues (1997)
		Amphimerus sp.	Chai and Jung (2022)
	Apophallus	*A. donicus*	Chai and Jung (2020); Mathison and Sapp (2021)
	Ascocotyle	*A. longa*	Chai and Jung (2020); Mathison and Sapp (2021)
	Centrocestus	*C. armatus*	Hung et al. (2013); Chai and Jung (2020)
		C. caninus (syn. *C. longus*)	Waikagul et al. (1997); Hung et al. (2013)
		C. cuspidatus	Hung et al. (2013); Chai and Jung (2020)
		C. formosanus	Hung et al. (2013); Chai and Jung (2020)
		C. kurokawai	Chai and Jung (2020); Mathison and Sapp (2021)
	Clinostomum	*C. complanatum*	Kim et al. (2023)
	Clonorchis	*C. sinensis*	Qian et al. (2012); Chai and Jung (2022)
	Cryptocotyle	*C. lingua*	Chai et al. (2009); Chai and Jung (2020)
	Echinochasmus	*E. caninus*	Toledo and Esteban (2016); Chai and Jung (2020); Mathison and Sapp (2021)
		E. fujianensis	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
		E. japonicus	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
		E. jiufoensis	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
		E. liliputanus	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
		E. perfoliatus	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
	Echinostoma	*E. angustitestis*	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
		E. cinetorchis	Chai et al. (2009); Toledo and Esteban (2016); Chai and Jung (2020)
		E. paraulum	Hung et al. (2013)
	Haplorchis	*H. pleurolophocerca*	Hung et al. (2013)
		H. pumilio	Chai et al. (2009); Chai and Jung (2020)
		H. taichui (syn. *H. microrchis*)	Chai and Jung (2020); Mathison and Sapp (2021)
		H. yokagawai	Dung et al. (2007)
		H. vanissimus	Chai et al. (2009); Chai and Jung (2020)
	Heterophyes	*H. aequalis*	Taraschewski (1984)
		H. dispar	Hung et al. (2013)
		H. heterophyes	Taraschewski (1984); Hung et al. (2013); Chai and Jung (2020)
		H. nocens	Chai et al. (2009); Chai and Jung (2020)
	Heterophyopsis	*H. continua*	Chai et al. (2009); Chai and Jung (2020)
	Isoparorchis	*I. hypselobagri*	Mathison and Sapp (2021); Chai and Jung (2020)
	Isthmiophora	*I. hortensis*	Toledo and Esteban (2016); Chai and Jung (2020); Mathison and Sapp (2021)
		I. melis	Toledo and Esteban (2016); Mathison and Sapp (2021); Chai and Jung (2020)
	Metagonimus	*M. katsuradai*	Chai and Jung (2017, 2020)
		M. minutus	Chai and Jung (2017, 2020)
		M. miyatai	Chai and Jung (2017, 2020)
		M. takahashii	Chai and Jung (2017, 2020)
		M. yokagawai	Chai and Jung (2017, 2020)
	Metorchis	*M. bilis* (syn. *M. albidus*)	Mordvinov et al. (2012); Mathison and Sapp (2021)
		M. taiwanensis	Zhan et al. (2017); Mathison and Sapp (2021)
		M. conjunctus	MacLean et al. (1996); Behr et al. (1998); Chai and Jung (2022)
		M. orientalis	Na et al. (2016); Chai and Jung (2022)
	Nanophyetus	*N. salmincola*	Hung et al. (2013); Chai and Jung (2020)
		N. schikhobalowi	Voronova et al. (2017); Voronova and Chelomina (2018); Mathison and Sapp (2021)
	Opisthorchis	*O. felineus*	Pakharukova and Mordvinov (2016); Chai and Jung (2022)
		O. tenuicolis	Hung et al. (2013)
		O. viverrini	Kaewpitoon et al. (2008); Mathison and Sapp (2021)
	Plagiorchis	*P. muris*	Hong et al. (1996)
	Procerovum	*P. calderoni*	Chai and Jung (2020); Mathison and Sapp (2021)
		P. varium	Chai and Jung (2020); Mathison and Sapp (2021)
	Prohemistomum	*P. vivax*	Chai and Jung (2020)
	Pseudamphistomum	*P. aethiopicum*	Chai and Jung (2022)
		P. truncatum	Chai and Jung (2022)
	Pygidiopsis	*P. genata*	Hegazy et al. (2019); Chai and Jung (2020)
		P. summa	Chai et al. (2009); Chai and Jung (2020)
	Stellantchasmus	*S. falcatus*	Dung et al. (2007); Chai and Jung (2020)
		S. pseudocirratus	Chai et al. (2009)
	Stictodora	*S. fuscata*	Chai et al. (2009); Chai and Jung (2020)
		S. lari	Chai et al. (2009); Chai and Jung (2020)
Cestoda	*Adenocephalus*	*A. pacificus*	Amer (2014); Mathison and Sapp (2021)
	Dibothriocephalus	*D. alaskensis*	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. daliae	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. dendriticus	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. latus	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. nihonkaiensis	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. ursi	Kuchta et al. (2013); Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
	Diphyllobothrium	*D. balaenopterae* (syn. *D. fukuokaensis*)	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)

(*continued on next page*)

Table 1 (*continued*)

Taxon	Genus	Species	Reference
		D. cameroni	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. cordatum	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. elegans	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. hians	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. lanceolatum	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. orcini	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. scoticum	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
		D. stemmacephalum[a]	Scholz and Kuchta (2016); Waeschenbach et al. (2017); Scholz et al. (2019)
	Schistocephalus	*S. solidus*[b]	Rausch et al. (1967); Scholz and Kuchta (2016)
Nematoda	*Angiostrongylus*	*A. cantonensis*	Thobois et al. (1996)
	Anisakis	*A. pegreffii*	Amer (2014)
		A. physeteris	Shamsi and Barton (2023)
		A. simplex (*sensu lato*)	Baptista-Fernandes et al. (2017)
		Anisakis sp. larva Type I and II *sensu* Berland (1961)	Berland (1961)
	Capillaria	*C. philippinensis*	Amer (2014)
	Contracaecum	*C. osculatum*	Shamsi and Butcher (2011)
		Contracaecum sp.	Shamsi and Butcher (2011)
	Dioctophyme	*D. renale*	Orihel and Ash (1995); Eiras et al. (2021)
	Eustrongylides	*Eustrongylides* spp.	Orihel and Ash (1995); Eberhard and Ruiz-Tiben (2014)
	Gnathostoma	*G. binucleatum*	Cornaglia et al. (2016); Liu et al. (2020)
		G. doloresi	Herman and Chiodini (2009); Liu et al. (2020)
		G. hispidum	Myers (1970); Herman and Chiodini (2009)
		G. malaysiae	Nomura et al. (2000)
		G. nipponicum	Herman and Chiodini (2009); Liu et al. (2020)
		G. spinigerum	Myers (1970); Herman and Chiodini (2009)
		G. turgidum	Almeyda-Artigas et al. (2000)
	Hysterothylacium	*H. aduncum*	Yagi et al. (1996)
	Paracapillaria	*P. philippinensis*	Cross (1992); Mathison et al. (2021)
	Phocanema	*P. azarasi*	Arizono et al. (2011)
		P. cattani	Menghi et al. (2020)
		P. decipiens	Skírnisson (2006)
Acanthocephala	*Pseudoacanthocephalus*	*P. bufonis*	Schmidt (1971)
	Acanthocephalus	*A. rauschi*[c]	Schmidt (1971); Mathison et al. (2021)
	Bolbosoma	*Bolbosoma* cf. *capitatum*	Arizono et al. (2012); Mathison and Sapp (2021)
		B. nipponicum	Yamamoto et al. (2018); Mathison et al. (2021)
		Bolbosoma sp.	Tada et al. (1983)
	Corynosoma	*C. strumosum*	Schmidt (1971)
		C. cf. *validum*	Takahashi et al. (2016); Mathison et al. (2021)
		C. villosum	Fujita et al. (2016)
		Corynosoma sp.	Fujita et al. (2016)

[a] Presumed second intermediate hosts: marine fishes.
[b] Human infection is considered accidental by Scholz and Kuchta (2016).
[c] The source of human infection is unknown.

humans and may cause potential lethal anaphylaxis (Audicana et al., 1995).

Recently, based on phylogenetical analysis Bao et al. (2023) resurrected the genus *Phocanema* and transferred to it *Pseudoterranova azarasi*, *Pseudoterranova cattani* and *Pseudoterranova decipiens*. The existence of two morphotypes of larval *Anisakis* was identified: Type I including *Anisakis simplex* (*s.s.*), *Anisakis pegreffii*, *Anisakis berlandi*, *Anisakis typica* and *Anisakis ziphidarum*; and Type II including *Anisakis pagiae* and *Skrjabinanisakis brevispiculata* (Mattiucci et al., 2008).

Human infection with nematodes is not easy to detect due to non-specific symptoms. Even in Japan, where the infection is quite common, a significant number of cases are not properly diagnosed, being described as acute abdomen infection, appendicitis, ileitis, cholecystitis, and gastric and pancreatic cancer, among others (Nieuwenhuizen, 2016). Apparently, *Anisakis simplex* is the only fish nematode causing a strong allergic reaction in humans (EFSA, 2010). Once sensitisation occurs, a strong, sometimes very severe, reaction to the nematode allergens may also occur. *Dioctophyme renale*, the giant kidney worm, is the largest known parasitic nematode infecting humans (females may reach more than 1 m long and about 1 cm thick), and its biology was reviewed in detail by Eiras et al. (2021). Human infection is uncommon, and the parasite develops inside the kidney destroying the kidney cortex. Obviously, a bilateral infection implicates the death of the host if measures to extract the parasite are not taken (Eiras et al., 2021).

Acanthocephalans and clinical symptomatology are rarely observed, and the number of species infecting humans is low (Schmidt, 1971; Tada et al., 1983; Arizono et al., 2012; Fujita et al., 2016). In some cases, a route of infection to humans involving fish is strongly probable, but a definite conclusion has not been obtained.

3. World distribution of zoonotic fish parasites and routes of infection

First, it is important to take into consideration that since 1961, the global consumption of fish as food has been twice as high as population growth and, surprisingly, exceeds the consumption of meat from all terrestrial animals combined (FAO, 2018; Shamsi, 2020).

The literature shows that every time a fish is examined for the presence of zoonotic parasites, it is almost certain that at least one species (if not several) can be easily found in any host in any part of the world. This means that fish must always be considered a “suspicious” kind of food and special care must be taken to avoid human infection because “All wild-caught seawater and freshwater fish must be considered at risk of containing any viable parasites of human health concern if these products are to be eaten raw or almost raw”, and “for wild-caught fish, no sea fishing grounds can be considered free of *A. simplex*” (EFSA, 2010). It is important to mention that farmed fishes are also a source of human infection by fish parasites, as demonstrated by several genera of tilapia and other fish species all over the world (Broglia and Kapel, 2011; Lima dos Santos and Howgate, 2011; Boerlage, 2013; Madsen et al., 2015; Acosta-Pérez et al., 2022). According to the WHO (1999), it is necessary to raise awareness among fish farmers, especially small-scale rural subsistence farmers, about fish food issues associated with farmed fish and its impact on human health. We would add the importance of informing customers that small-scale fish farms may be as "dangerous" as larger ones, and the proximate presence of owners with farms is not a guarantee of healthier fish conditions (Hung et al., 2013).

Invasive alien species (IAS) are non-native species introduced deliberately or unintentionally outside their natural habitats where they become established, proliferate and spread (Zhu et al., 2019). Some fish IAS were introduced intentionally in many regions of the world, many times for aquaculture purposes, and reports of fish IAS in China showed that some species were heavily infected with a considerable number of digeneans and nematodes (Zhu et al., 2019). If some of these parasites did not occur in the places of introduction, it is probably not impossible that they may adapt to other hosts and become zoonotic species in new hosts in new countries.

Ingesting live, raw, smoked, salted, slightly cooked, marinated or insufficiently preserved fish is by far the most important factor in promoting infection, and it is absolutely crucial from an epidemiological point of view. It is well known that there are plenty of recipes including raw, or slightly cooked/preserved fish. An internet search easily allows us to identify recipes like Sushi and Sashimi (Japan), Carpaccio (Italy), Ceviche (Peru), Crudo (Italy), E'ia Ota (Tahiti), Esqueixada (Catalonia, Spain), Boquerones in vinegar (Spain), Gravlax (Nordic countries), Gohu Ikan (Maluku, Indonesia), Hinava (Malaysia), Hoe (Korea), Kelaguen (Mariana Islands), Kinilaw (Philippines), Koi pla (Thailand), Kokoda (Fiji), Kuai (China), Lakerda (Turkey), Lapa pla, Larb (Lao and Thailand), Matjes (Netherlands), Ota Ika (Tonga), Poke (Hawai), Sashimi (Japan), Stroganina (Siberia), Tiradito (Peru), Tuna tartare (USA), Umai (Malaysia), Xato (Catalonia, Spain), Yusheng (Singapore), and many more.

These dishes are strongly traditional and widespread, especially in most Asian countries. However, in recent years, this kind of food has spread all over the world, and today it is almost impossible to find a big western city without a considerable (sometimes vast) number of restaurants specializing in raw fish dishes, sometimes surpassing the number of traditional dishes not containing fish. For example, in some South American countries, the traditional meat restaurants were surpassed by the ethnic/Asian restaurants which became "fashionable" mostly with younger generations (Eiras et al., 2016. This resulted in a huge increase of zoonotic infections which are sometimes difficult to diagnose because physicians may not be prepared to identify properly the symptoms of the infection or the procedures adequate to treat it. Some authors provided reviews and general information about the importance and particularities of transmission through fish ingestion, and emphasize the contamination by different species of parasites, namely nematodes, in fish restaurants (Nawa et al., 2005; Broglia and Kapel, 2011; Torres-Frenzel and Torres, 2014; Eiras et al., 2016, 2018a, b; Shamsi, 2019; Acosta-Pérez et al., 2022).

Therefore, it is not surprising that some parasites infecting humans have an increasingly wide distribution and prevalence due principally to the feeding habits of the population. For instance, trematodes are much more prevalent in Asian developing countries because of poor hygiene, sanitation processes, and careless handling of food products or by-products (Bardhan, 2022) and, in particular, the very strong tradition of ingestion of raw fish (Cong and Elsheikha, 2021). However, even in developed countries like the USA, about 260,000 people get sick from infected fish per year (Ziarati et al., 2022). Interestingly, Corrêa et al. (2021), showed that despite the high prevalence and intensity of infection with potential zoonotic larvae of several nematode species in fishes of the Brazilian Amazon, human infection has never been reported in the region. This is attributed to the fact that local populations do not eat raw fish, thus demonstrating the fundamental importance of human behaviour for avoiding infection.

Another aspect that may be relevant is the infection occurring in travellers and their eventual potential role in spreading some of the diseases. Travelling abroad is very frequent and hundreds of millions of tourists travel every year to many diverse destinations. Contact with new ethnic dishes and the novelty of several types of food, mostly in "exotic" locations, may be a cause of infection with different kinds of fish parasites (Ziarati et al., 2022). Eiras et al. (2018b) provided an overview of fish-borne nematodoses among returning travellers over a 25-year period, showing that some acquired infection with *Angyostrongylus cantonensis*, *Anisakis simplex*, "Anisakidae", *Capillaria phillipinensis* and several species of *Gnathostoma.* This study concerned only nematodes, but most probably the travellers were also infected with trematodes and cestodes at a minimum. It is important to emphasize that travellers, acting as transporters, may introduce parasites into new locations.

Besides this transmission mechanism, occupational activities are suspected to be responsible for several infections without ingesting fish. That can occur during the handling of fish causing contact with wounds and skin scratch abrasions, and when processing fish for canning. This may provide conditions allowing the penetration of parasites into the operator. Using gloves is strongly suggested to avoid infection in those cases (Ziarati et al., 2022). Uña-Gorospe et al. (2018) described three cases of occupational disease in Spain due to a type I hypersensitivity to *A. simplex* in individuals who handle fish (one fishmonger, one supermarket employee, and one chef). Nieuwenhuizen et al. (2006) demonstrated *Anisakis* sensitization in fish-processing workers, and Scala et al. (2001) studied occupational generalised urticaria and allergic air-borne asthma due to *A. simplex*.

Evisceration of fish immediately after capture is recommended to avoid the ingestion of *Anisakis* spp., which migrate to the muscle after the fish death as observed in some species by several authors (Smith, 1984; Silva and Eiras, 2003; Broglia and Kapel, 2011; Cipriani et al., 2016; Bao et al., 2019). However, this procedure may be of little value in preventing infection as most fishes have larvae in the muscles as well as in the viscera (Verhamme and Ramboer, 1988). On the other hand, this procedure is easy to adopt when the number of fish needing to be treated is small but absolutely impossible to implement when dealing simultaneously with thousands of fish specimens.

Processing of fish after capture may reduce the risk of infection. Candling, i.e. the examination of filets (preferentially not thick and without skin) on a light table allows detection of the parasites and their removal manually (Adams et al., 1997). Attention must be paid to consumers at home using pickling solutions and marinades when taking care of the salt level to ensure the process is effective and parasites are eliminated (Adams et al., 1997).

The easiest and definitive ways of avoiding infection are the procedures advised by the US Food and Drug Administration (FDA): to freeze fish at a temperature of −20 °C or lower for 7 days (total time) or −35 °C or lower for 15 h (FDA, 2022). It may be necessary to adapt these procedures to fish species, the size of the fish, and the type of parasites, among other factors. In domestic freezers, it is essential to know the exact capability of the appliance's reducing temperature. If the fish are not eaten raw, a cooking temperature of 60 °C for 10 min is enough to prevent the infection. Similarly, according to the European Union Hazard Analysis and Critical Control Points (HACCP), marine fish for raw consumption should be frozen at less than −20 °C for more than 24 h (Nawa et al., 2005). This aspect has been more intensively studied considering the nematode genus *Anisakis*. Probably the same happens with other fish parasites but experimental support is lacking as far as we are aware.

4. One Health approach

The One Health concept, considering the integration of human medicine, veterinary medicine and environmental science has been advocated by several authors relating to fish-borne zoonotic diseases

(Torgerson, 2013; Shamsi, 2019; Ziarati et al., 2022). Shamsi (2019) stated that "for an effective seafood safety plan, extensive engagement between producers (fishermen and fish farmers), chefs, aquatic veterinarians, public health experts, clinicians, diagnostic laboratory staff, general and at-risk communities, and jurisdictional and federal agencies is crucial". Health authorities must provide the necessary conditions and facilities to ensure the effectiveness of this One Health approach. Of course, there are several difficulties in reaching this objective, mainly the integration of the great number of measures necessary to become "One Health effective". According to the World Health Organization (WHO), the One Health system may be less effective because of difficulties in organizational systems, control, interruption of transmission and diagnosis/detection. Therefore, effective cooperation between human and animal health officials, promotion of infection management, and improving early detection of diseases and controlling vectors are necessary (Ziarati et al., 2022) and multidisciplinary research is needed. Combining and managing all these variables efficiently on a global basis seems a difficult objective to reach. Moreover, it is important to stress that the correct identification of parasites is of paramount importance to identify the measures which should be taken. Frequently the identification is not performed by a specialist, and often the diagnosis is based on the observation of eggs present in stool, which may not be enough to identify the parasites and to define the necessary procedures to be adopted.

Eco-Health is "an emerging field that examines the complex relationships among humans, animals, and the environment, and how these relationships affect the health of each of these domains" (Lisitza and Wolbring, 2018). It may be combined with the One Health approach, as it happened concerning the "Lawa model" to fight against the transmission of *O. viverrini* around Lake Lawa, Thailand (Sripa et al., 2017). This was a complex task, involving many people and considerable resources to target every aspect related to the transmission of the parasite through ingesting raw fish: intensive education of the population, introduction of appropriate information into the school's science curriculum, training of the hospital staff and studying the environmental factors which promote the infection. Ten years later, the prevalence of infection fell from 60% to less than 10% in all villages near the lake, and infection of cyprinid fishes with metacercariae fell from 70% to less than 1% (Liau et al., 2023). This was no doubt an extremely important outcome, recognized as the most successful control programme for the digenean *O. viverrini* (Liau et al., 2023) which may be implemented relating to other parasites with the necessary adaptations. However, elimination was not fully achieved.

5. Elimination and eradication of diseases

Now the question arises: is it possible to eliminate or eradicate human diseases caused by fish parasites?

Several attempts to eliminate parasitic fish-borne human diseases were made in different parts of the world. Opisthorchiasis, caused by *O. viverrini*, was a major disease in northeastern Thailand for some decades, reaching a prevalence of 34.6% in 1981. The health authorities tried to eliminate the disease in four provinces. In 1984, and later, in 1988, the programme was expanded to cover all 19 north-eastern provinces, by intensive actions upon the population showing the importance of desired health behaviour such as not eating raw fish. The results after a 10-year period showed a decrease from 14% to 7% in consumption of raw fish (occasional consumption as high as 42%), and the prevalence of the infection was 18.5%, with a large prevalence rate range (5.2–56.2%). Consequently, elimination was not reached (Jongsuksuntigul and Imsomboon, 1997). This case illustrates the difficulties of eliminating infection and the great efforts necessary to get positive results.

Apparently, only one successful case is known, i.e. the elimination of infection with the nematode *A. simplex* in the Netherlands in 1968 due to the compulsory freezing to −20 °C of all fish before marketing (Verhamme and Ramboer, 1988). After reaching this objective, public health measures should have been taken to prevent the re-emergence of the infection. As of the writing of this article, an internet search on the follow-up of the situation, and the actual result of this procedure failed to identify new information about this matter.

Taking into account all the characteristics of these diseases, especially the way the parasites are transmitted to humans, it is likely that elimination of some of them would hopefully be possible in defined geographical areas where there is a high degree of literacy, an effective and aggressive information campaign targeted towards people at risk of certain feeding behaviours, the knowledge of the life-cycle of the target parasite and ways it can reach humans, the possibility of knowing the exact epidemiological situation regarding the starting time of the measures to be undertaken, the cooperation of stakeholders and, most importantly, the clear and convincing demonstration to people of the benefits of eliminating the disease with no more than a simple modification of feeding behaviour without using any medication. Reaching these objectives is difficult, and the resistance of people to change dietary habits may be strong, and probably impossible to overcome, especially for older people with low levels of literacy. However, we are convinced that an agenda carefully conceived, introduced step by step and targeting young and middle-aged people in particular, will contribute decisively to the success of the elimination of fish-borne human diseases in defined areas. Taking all of this into account, reaching this goal may be easier in some parts of the world than in others, and in this regard, the index of literacy will be of capital importance. Nevertheless, the example of the elimination of anisakiasis in the Netherlands (Verhamme and Ramboer, 1988) demonstrates elimination can be reached under favourable socio-economic circumstances.

Eradication is a much more complex and difficult problem to handle. Firstly, because eradication is a global action not limited to a fairly small region or country. Secondly, because socio-economic circumstances and literacy are extremely variable, and naturally, perception of the importance of the problem and acceptance of changing very old and strong traditions by hundreds of millions of people is an objective that will most probably never be reached. Furthermore, managing all the factors involved in the abundance and transmission to humans of many parasites cannot reasonably be expected. Moreover, there are no appropriate and reliable methods of observation regarding whether the infections were effectively stopped because of the difficulties involved in dealing with hundreds of millions of people infected worldwide with a huge diversity of fish parasites.

6. Conclusions

Taking into account all the considerations above, it is likely that eliminating human diseases caused by fish parasites is a sweet dream that may hopefully become a reality in particular conditions in some parts of the world. On the other hand, it is not likely that eradicating human diseases caused by fish parasites will be reached and shall remain a nightmare forever.

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Data availability

The data supporting the conclusions of this article are included within the article.

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