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Review

Fishborne zoonotic parasites and aquaculture: A review

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ABSTRACT

A large number of parasites infect fish but only a few cause illnesses in humans. Due to their high incidence the following helminth families deserve particular attention: *Opisthorchiidae* and *Heterophyidae* (Class Trematodea, subclass *Digenea*), *Anisakidae* and *Gnathostomidae* (Phylum Nematoda), and *Diphyllobothridae* (Class Cestoda). Humans acquire these fishborne parasitic zoonoses through the consumption of infected raw, undercooked, or inadequately preserved fish. Though the transmission of these parasites through fish caught in the wild has been well documented, the association between cultured fish and human parasitic illness has for long been neglected and it is only recently, during the last 10–15 years, that this association has gained increased consideration. This review summarizes and considers this recent evidence linking fish farming to human pathogenic parasites, and discusses the need and opportunities for prevention and control of these zoonoses.

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Contents

1. Introduction

Foodborne diseases caused by helminth parasites transmitted by fish and shellfish products pose major public health problems, and worldwide the number of people at risk, including those in developed countries, is more than half a billion (WHO, 1995, 2004). Some of these parasites are highly pathogenic, and human infection is a result of the consumption of raw or undercooked fish infected by the parasites (WHO, 1995). The reported incidence of these ichthyozoonoses has increased significantly in recent years for several reasons: the development of new and improved diagnosis, by the increase in raw fish consumption in those countries in which such dishes have commonly been eaten, by the increased consumption elsewhere of regional fish dishes such as sushi, sashimi, ceviche, carpaccio based on raw or minimally processed fish, by the growth in the international market in fish and fish products, and by the spectacular development of aquaculture (Keiser and Utzinger, 2005; McCarthy and Moore, 2000; Nawa, et al., 2005; Robinson and Dalton, 2009).

The association between wild fish and the transmission of foodborne parasitic diseases is well documented, but until recently, few examples had been reported of the transmission of parasites to

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humans directly by the products of aquaculture. Some earlier reviews of fishborne parasites suggested that farmed fish could be vectors of diseases of concern for human health (Howgate, 1998; Kabata, 1985; Paperna, 1991; WHO, 1995), but there was almost no documented evidence for this before about the year 2000. Since then a considerable amount of information has been published concerning the role of aquacultured products in the epidemiology of fishborne zoonoses.

The objectives of this paper are to review recent information on fishborne parasites in farmed fish and to discuss measures for prevention and control of parasitic infections in them. The fishborne parasites come from three main groups: digenetic trematodes, especially species of the families *Opisthorchiidae* and *Heterophyidae*; nematodes, especially species of the families *Anisakidae* and *Gnathostomatidae*; and cestodes, especially species of the family *Diphyllobothriidae*. Of these, the trematodes are of most concern based on the morbidities of the associated diseases. Much of the new information comes from Asia and South East Asia and concerns fishborne trematode (FBT) infections, but new information concerning other parasites and regions will be reviewed. The emphasis is on the scientific evidence and epidemiological facts associating foodborne zoonoses with aquaculture.

Much of the information presented here was retrieved by searching the Internet electronic data banks PubMed, Scirrus, Science Direct and Scielo using the keywords fishborne parasites, foodborne trematodiasis, *Opisthorchis*, *Clonorchis*, Heterophyidae, anisakidosis, *Anisakis*, *Gnathostoma*, and *Diphyllobothrium* in combination with the words “aquaculture” and “fish farming”, and also by searching the Internet directly and by following up bibliographies in published papers.

2. Trematodiasis

Trematodiasis is the infection of humans by trematode parasites. Illnesses caused by the infections are a serious public health problem in Asia and Southeast Asia, but trematodiases occur, and cause ill health, in countries elsewhere. Of particular concern are infections by species of the family Opisthorchiidae, the liver flukes, especially *Clonorchis sinensis*, *Opisthorchis viverrini* and *Opisthorchis felineus*. The taxonomy of trematodes is summarized in Kaewkes (2003) and Keiser and Utzinger (2009). The life cycles of these trematode species are similar and are described in textbooks of parasitology and in several references cited in this review (Kaewipitoon et al., 2008; Kaewkes, 2003; Keiser and Utzinger, 2009; Lun et al., 2005; Sithithaworn et al., 2007). The definitive host is man or other piscivorous animals and there are two intermediate hosts, a snail and a fish. The parasite matures in the definitive host and eggs are shed with the feces of the host. If the eggs reach water they develop into miracidia which are ingested by a snail, the first intermediate host. There they develop and are ultimately shed into the water as motile cercariae which penetrate into the muscle tissue of a fish, the second intermediate host. Human infection takes place through the consumption of raw, undercooked or otherwise under-processed fish containing the infective stage of the parasite (Tran et al., 2009; WHO, 1995). A large number of freshwater fish species can transmit the infective trematode metacercariae with fish belonging to the Cyprinidae (carps) being the most common, but not only, family involved in transmission (Chen et al., 2010; Lun et al., 2005; Touch et al., 2009; WHO, 1995). Farmed fish of a variety of species have also been shown to be hosts of trematode parasites (Chi et al., 2008; Hop et al., 2007; Thanh et al., 2009; Thien et al., 2007, 2009; Thu et al., 2007; Thuy et al., 2010). There do not seem to be any new global surveys of numbers of persons infected or at risk from trematode infections since the WHO (1995) report, though there are some data for individual countries in WHO (2004). Keiser and Utzinger (2005) used the frequency of infections from the WHO (1995) report and updated the numbers at risk using the 2004 values of populations in the countries where the parasites are endemic to give revised estimates of 601.0, 293.8, and 79.8 million people at risk of infection with *Clonorchis sinensis*, *Paragonimus* spp., and *Opisthorchis* spp., respectively, a total of 975 million. Lun et al. (2005) estimated that 35 million persons globally could be infected by *C. sinensis* including 15 million in China (Zhou et al., 2008). Of the diseases due to liver flukes, clonorchiasis is endemic in South China, Taiwan, South Korea and North Vietnam (Cho et al., 2008; Dung et al., 2007; Rim, 2005; Zhang et al., 2007), opisthorchiasis caused by *O. viverrini* is endemic in Thailand, Lao, Cambodia and Central Vietnam (Andrews et al., 2008; Hortle, 2008; Sayasone et al., 2007; Senior, 2009; Sithithaworn and Haswell-Elkins, 2003; Touch et al., 2009), while that due to *O. felineus* is found in Russia and countries of Central Europe (Yossepowitch et al., 2004).

Generally, infections by liver flukes are asymptomatic, but high levels of infection and chronic infection cause damage to the bile duct epithelium, eliciting gastrointestinal problems, damage to the liver, and possibly cholangiocarcinoma (Choi et al., 2004; Kaewipitoon et al., 2008; Lun et al., 2005; Rim, 2005; Sripa, 2003). *C. sinensis* and *O. viverrini* have been rated as Class 1 carcinogens by the International Agency for Research on Cancer, (WHO, 2011).

Another group of foodborne trematodes that transmit parasitic diseases to man is that of the so-called ‘minute intestinal flukes’. There are approximately 70 species (14 families and 36 genera) within this group of pathogenic parasites with those belonging to the family Heterophyidae (the largest among them) being the more important due to their higher incidence. Among Heterophyidae noteworthy genera are *Heterophyes*, *Haplorchis*, *Metagonimus*, *Ascocotyle* (*Phagicola*) and *Centrocestus* (Chai, 2007; Chai et al., 2009; Fried et al., 2004; Toledo et al., 2006; Yu and Mott, 1994). Their life cycles are typical of those of trematode parasites with humans and other animal species as definitive hosts, a variety of snail species as first intermediate hosts, and a variety of freshwater, brackish water, and marine fishes as secondary hosts (Chai, 2007). Their epidemiology and pathogenicity are not well understood and the clinical aspects of the illnesses caused need further study. When compared with the illnesses caused by liver flukes, infection with intestinal trematodes do not generally present significant clinical symptoms, however, some heterophyidae species can cause significant pathology, often fatal, in the heart, brain and spinal cord of humans (Chai, 2007; Toledo et al., 2006). It is thought that approximately 18 million individuals could be infected globally by these trematodes (Fried et al., 2004).

Heterophyid eggs are difficult to differentiate from those of liver flukes in human fecal samples and this situation may result in inaccurate estimates of the prevalence of both trematode groups, inaccurate estimates of incidences and intensities of infection by the two groups, and misdiagnosis and inappropriate treatments of illnesses (Chai and Lee, 1990, 2002; Ditrich et al., 1992; Kaewkes et al., 1991; Lee et al., 1984). New diagnostic techniques are increasingly being used to improve specific diagnosis of these flukes (Johansen et al., 2010; Sato et al., 2009).

Several authors have observed that in certain areas where diseases caused by liver flukes have diminished, intestinal fish-borne trematodiases are now prevalent. This situation has been observed particularly in Taiwan (Ooi et al., 1997), Thailand (Radomyos et al., 1998; Sukontason et al., 1999), and Vietnam (Dung et al., 2007). The explanation for this apparent substitution could be due to improved diagnostic methods, but also other factors contributing to changing patterns in the epidemiology of fishborne trematodiasis, such as population growth, pollution, poverty, changing food habits, might contribute as well. These factors could affect the presence and prevalence of intermediate hosts (snails, fish) thereby influencing the life cycles of different trematode species.

2.1. Trematodes and aquaculture

Aquaculture is one of the most important of the world's food producing activities, and Asia is by far the world's chief aquaculture

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producer; approximately 90% of the world aquaculture production is in Asia (Bostock et al., 2010; FAO, 2010). Coincidently Asia is the region where foodborne trematodiasis transmitted by fish is the most prevalent.

Aquaculture practices are similar throughout all of Asia and in endemic areas these practices may directly impact on the prevalence and persistence of FBTs. Freshwater fish, especially cyprinids (carps), are commonly raised in small ponds in the region and these ponds generally provide excellent habitats for the snails which act as the first intermediate host for the parasite. Latrines are often placed over the ponds to allow human excreta to enter the system and fertilize the water. Excreta from domestic pigs and poultry is used directly as manures, or the pigs and poultry are penned alongside the ponds so that excreta enters ponds deliberately or adventitiously. Cattle, dogs, cats and other animals, not necessarily domestic, and which are definitive hosts for the parasites may live in the vicinity of fish farms and their excreta too can enter the ponds. All this human and animal fecal material contributes to the maintenance of high numbers of trematode eggs and miracidia in the water (Chi et al., 2008; Lan Anh, 2009; Lan Anh et al., 2009a,b; Lin et al., 2005; Mikolasek et al., 2006; Phan et al., 2010a; Pillay and Kutty, 2005; Vu et al., 2007). Such agricultural and aquacultural practices ensure the introduction of trematode eggs into the aqueous environment, and the presence of snails and cultivated cyprinids in the water combined with the traditional habit of consuming raw fish closes the FBT's life cycle so that humans are infected. Ignorance of the hazards associated with the use of untreated animal or human waste to increase production in aquaculture ponds has enormous health implications, and as freshwater aquaculture increases in those countries in which FBTs are endemic, the incidence of the disease may also increase if poor sanitation habits persist and no efficient control measures are put in practice (Chai et al., 2005; Chomel, 2008; Fried et al., 2004; Jongsuksuntigul, 2003; Keiser and Utzinger, 2005, 2009; Phan et al., 2011; Sohn et al., 2009; WHO, 2004).

However, when reviewing a large number of past studies on the epidemiology of fish borne trematodes, it is clear that there is disagreement on the relative importances in the epidemiology of human infection of cultured fish versus wild caught fish. Probably this lack of agreement arises from the general acceptance that FBT can be transmitted to humans by wild fish, while until recently, few examples have been reported of trematodes being transmitted to humans by the products of aquaculture. However, the picture has changed dramatically mainly due to the investigations of the FIBOZOPA (Fishborne zoonotic parasites in Vietnam) project that has been operating in Vietnam since 2005, (http://fibozopa2.ria1.org/_E#). FIBOZOPA is a project funded by Danish International Development Assistance (DANIDA) for building research capacity in the study of fishborne zoonotic parasites (FZP). The development objective of FIBOZOPA is to create general awareness nationally of the occurrence, risks and preventive measures for FZP infections of humans, as well as specialized knowledge of how to handle the problems at central government and provincial levels. Results obtained by FIBOZOPA undoubtedly link farmed fish with fish borne trematode infections in Vietnam and these results can be extrapolated to other countries in the region and to other parts of the globe.

Earlier findings on the association between aquaculture and clonorchiasis reported in Malaysia (Bisseru, 1970; Shekhar, 1997), Korea (Kim and Choi, 1981), China (Chen et al., 1994; Chen et al., 1997; Ling et al., 1993) and Vietnam (Kieu et al., 1990; Kino et al., 1998) have more recently been confirmed in China (Sohn et al., 2009; Zhang et al., 2007; Zhou et al., 2009), and in Vietnam (Chi et al., 2008; Phan et al., 2010a,b; Van et al., 2008). The association between aquaculture and *Opisthorchis viverrini* first raised in Malaysia (Bisseru and Chong, 1969) and Thailand (Khamboonruang et al., 1997) has more recently been confirmed in Vietnam (Cam et al., 2008; Chi et al., 2008; Hop et al., 2007). Similarly, early studies linking Heterophyidae and aquaculture in Kenya (Sommerville, 1982), Thailand (Khamboonruang et al., 1997; Poolphol, 1995 quoted by Namue et al., 1998) and Taiwan (Wang et al., 2002) were more recently confirmed in Vietnam (Chi et al., 2008; Hop et al., 2007; Lan Anh et al., 2009b; Phan et al., 2010a,b; Thanh et al., 2009; Thien et al., 2007, 2009; Thu et al., 2007; Thuy et al., 2010; Van et al., 2008; Vo et al., 2008). Despite this new evidence, a number of authors recommend that further research should be directed to the role of farmed fish in the transmission of FBT (Keiser and Utzinger, 2005, 2009; Rim et al., 1994; Senior, 2009; Sripa, 2008).

Tables 1 and 2 show summaries of published reports of the presence of fishborne zoonotic trematodes in aquacultured fish.

3. Cestodiasis

Human diphyllobothriasis is a fish borne parasitic illness caused by cestodes of the Family Diphyllobothridae. Several species of *Diphyllobothrium* are described as pathogenic to man with *Diphyllobothrium latum* being considered as the more prevalent. The parasite has a complex life cycle with piscivorous animals, including man, being the primary host. There are two intermediate hosts: a copepod as the first intermediate host and a predatory freshwater, anadromous, or marine fish as the second intermediate host. The biology and geographical distribution of *Diphyllobothrium,* and other cestodes infesting fish, are described in Dick (2007).

Diphyllobothriasis is considered a mild disease; persons infected with the tapeworm may often be symptomless, in others it may cause diarrhea, abdominal pain and anemia (Dick, 2007; Scholtz et al., 2009). The disease is associated with the habit of eating raw or inadequately cooked or otherwise inadequately heat processed fish. Diphyllobothriasis is known to occur widely in the world. Human infections with *Diphyllobothrium* tapeworms were generally associated with cold freshwater fish from North Europe and North America, but cases in Asia and in South America are also known. Recent estimates indicate that approximately 20 million individuals could be affected by the disease (Scholtz et al., 2009).

3.1. Cestodes and aquaculture

The incidence of diphyllobothriasis has markedly increased in recent years, the increase being closely linked with the consumption of raw fish in ethnic dishes such as sushi, sashimi, ceviche, carpaccio, and similar products. These products have long been prepared from fish caught in the wild, but there are suggestions that the marked increase in incidence of the disease in some regions in recent years can be attributed to the use of farmed salmon (Cabello, 2007; Dick,

Table 1
Presence of *Clonorchis sinensis* and *Opisthorchis viverrini* metacercariae in cultivated Cyprinidae fish (carps) in different countries.

Parasite	Country	References
O. viverrini	Malaysia	Bisseru and Chong (1969)
	Vietnam	Cam et al. (2008), Chi et al. (2008), Hop et al. (2007)
C. sinensis	China	Chen et al. (1997, 2010), Lin et al. (2005), Ling et al. (1993), Zhang et al. (2002, 2007), Zhou et al. (2009)
	Korea	Kim and Choi (1981)
	Malaysia	Bisseru (1970)
	Taiwan	Wang et al. (2002)
	Vietnam	Chi et al. (2008), Kieu et al. (1990), Kino et al. (1998), Lan Anh (2009), Lan Anh et al. (2009a), Phan et al. (2010a,b), Van et al. (2008)

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Table 2
Presence of Heterophyidae metacercariae in cultivated fish in different countries.

Parasites	Fish species	Country	References
Haplorchis pumilio	Tilapias (*Sarotherodon spp*)	Kenya	Sommerville (1982)
Haplorchis spp.	Carp (*Puntius gonionotus*)	Thailand	Khamboonruang et al. (1997)
H. pumilio *H. taichui*	Carps (Cyprinidae)	Taiwan	Wang et al. (2002)
H. pumilio *H. taichui* *Centrocestus formosanus*	Carps (Cyprinidae) Silver carp (*H. molitrix*), Tilapia (*Oreochromis niloticus*)	Vietnam	Hop et al. (2007)
H. pumilio	Catfish “Tra”(*Pangasius hypophthalmus*)	Vietnam	Thu et al. (2007)
H. pumilio *H. taichui* *C. formosanus*	Carps (Cyprinidae) Hybrid catfish (*Clarias*) Other species	Vietnam	Thien et al. (2007)
H. pumilio	Carps (Cyprinidae)	Vietnam	Van et al. (2008)
H. pumilio *H. taichui*	Carps (Cyprinidae), Silver carp (*H. molitrix*), tilapia	Vietnam	Chi et al. (2008)
Heterophyopsis *Procerovum sp*	Groupers (*Epinephelus coiodes*, *E. bleekeri*)	Vietnam	Vo et al. (2008), Thanh et al. (2009)
Heterophyidae	Carps (Cyprinidae)	Vietnam	Lan Anh et al. (2009b)
H. pumilio *H. taichui*	Carps, tilapia, pacu, catfishes (*Clarias*, Pangasius)	Vietnam	Thien et al. (2009)
H. pumilio *H. taichui* *C. formosanus*	Carps (Cyprinidae)	Vietnam	Phan et al. (2010b)
H. pumilio *H. taichui* *C. formosanus* *Procevorum sp*	Catfish “Sutchi” (*Pangasianodon hypophthalmus*)	Vietnam	Thuy et al. (2010)

2007). The presence of pleurocercoid larvae of *Diphyllobothrium* in cultivated fish, particularly salmonids, is reported in several countries (see Table 3).

Epidemiological studies carried out in Brazil during a recent (2004–2005) outbreak of diphyllobothriasis in the State of Sao Paulo pointed to the possibility of an association with farmed salmon (Eduardo et al., 2005). However, during the Brazilian outbreak it was not possible to demonstrate the presence of *Diphyllobothrium* larvae in imported salmon filets (Eduardo et al., 2005). Extensive studies carried out in Chile established the presence of *Diphyllobothrium* larvae in cultivated salmonids, but the parasite was reported in the fish viscerae, never in the musculature (Torres et al., 2002, 2010).

The cases of diphyllobothriasis in Sao Paulo during 2004–2005 were followed by new cases of the disease in other Brazilian states, always associated with the consumption of imported salmon from Chile. However, despite routine parasitological analysis of salmon filets in Chile and Brazil, larvae of Diphyllobothridae cestodes were not detected in the filets of cultivated salmon presumed exported to Brazil (Lima dos Santos, 2010). Nevertheless, in the specific case of salmonids, there seems no doubt that wild salmon is the main transmitter of human diphyllobothriasis (Scholtz et al., 2009).

Table 3
Reported presence of *Diphyllobothrium* pleurocercoid larvae in cultivated salmonids in different countries.

Parasites	Fish species	Country	References
D. sebago	Atlantic salmon (*Salmo salar*)	USA	Johnson (1975)
D. dentriticum *D. ditremum*	Rainbow trout (*Oncorhyncus mykiss*)	Scotland	Wootten and Smith (1979)
D. ditremum	Atlantic salmon (*S. salar*)	Ireland	Rodger (1990)
D. dentriticum	Trouts	Finland	Rahkonen and Valtonen (1997)
D. dentriticum	(*O. mykiss*) Rainbow trout	Russia	Karasev et al. (1997)
Diphyllobothrium spp	Rainbow trout (*O. mykiss*)	Chile	Torres et al. (2002, 2010)

4. Nematodiasis

4.1. Anisakiasis

Anisakiasis refers to infection with larval stages of nematodes belonging to the family Anisakidae, particularly from two genera: *Anisakis* and *Pseudoterranova*. *Anisakis simplex is* the most prevalent pathogenic species (Adams et al., 1997; Audicana et al., 2003; Butt et al., 2004; Chai et al., 2005; Lymbery and Cheah, 2007; Sakanari and McKerrow, 1989; Torres et al., 2007). *Contracaecum* and *Hysterothylacium*, are also considered able to infect man, but rarely (Deardorff and Overstreet, 1980; Yagi et al., 1996). The life cycle of Anisakidae is rather complex involving small crustaceans as the first intermediate host, fishes and cephalopods as the second host, and marine mammals as the definitive host. Humans are considered as accidental hosts of the parasite following consumption of the secondary hosts. A large number of marine fish and cephalopod species are associated with the transmission of the disease (Sakanari and McKerrow, 1989; Smith and Wootten, 1978).

Anisakiasis is a serious zoonotic disease caused by the consumption of raw or undercooked fish dishes containing the larvae of the parasite. *A. simplex* causes an acute or chronic infection that may lead to abdominal pain, nausea, vomiting, and/or diarrhea. Some patients develop syndromes exhibiting clinical manifestations of allergy following infection or following consumption of dead larvae (Audicana and Kenneddy, 2008; Miranda da Silva, 2008; Valero et al., 2003). The incidence of the disease differs widely among countries with Japan reported as having the highest incidence. Orphanet (2009) estimates the reported incidence of anisakiasis in Europe in 2009 was 3.8/100 000.

4.2. Gnathostomiasis

Gnathostomiasis is the fishborne illness caused by nematodes belonging to the genera *Gnathostoma*, with several species pathogenic to man. Its life cycle is complex involving intermediate (crustaceans and fishes), paratenic (piscivorous birds, reptilian and small

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mammals), and final hosts (wild and domestic animals). Man is considered an accidental host in whom the parasite can cause a wide clinical picture, internal or external, where the condition 'larva migrans' is one of the known symptoms (Waikagul and Diaz Camacho, 2007).

4.3. Nematodes and aquaculture

The literature on the presence of nematodes in aquacultured fish reveals a varied picture. Most published studies in the specialized literature report that *A. simplex* is not present in farmed salmonids fed with processed feeds (Angot and Brasseur, 1993; Deardorff and Kent, 1989; Inoue et al., 2000; Lunestad, 2003; Marty, 2008; Skov et al., 2009; Wootten et al., 2009), and also reported to be absent in other aquacultured species (Peñalver et al., 2010). However, it is possible that smaller invertebrates and fish can enter aquaculture net cages and if infected by Anisakidae – common in the marine environment – these potential transport hosts can present a risk of transferring parasites to the maricultured fish (Marty, 2008; Skov et al., 2009).

On the other hand, nematodes of the genera *Contracaecum*, *Hysterothylacium* and *Anisakis* have been reported in farmed fish (Abollo et al., 2001; Carvajal et al., 1995; Carvajal and Gonzalez, 1990; Chen et al., 2008; Dick et al., 1987; Gonzalez, 1998; Marty, 2008; McKenzie et al., 1976; Muzzall et al., 2006; Paperna, 1996; Rückert et al., 2009; Sepúlveda et al., 2004; Shih et al., 2010; Torres et al., 2010; Wootten and Smith, 1975). Nevertheless, it should be emphasized that the source of infection in the large majority of the positive cases resulted from feeding untreated, infected, marine raw fish to the aquacultured fish (Abollo et al., 2001; McKenzie et al., 1976; Shih et al., 2010; Wootten and Smith, 1975).

Table 4 shows reports of the presence of Anisakidae larvae in cultivated fish.

Despite the increasing incidence of Gnathostomiasis in several countries (Mexico, Ecuador, Peru, China, Japan, Myanmar, Thailand, Vietnam, Spain, and others), there are very few reports of the association of the disease with aquaculture. In Mexico where the disease is endemic in several areas of the country, there is evidence of *Gnathostoma binucleatum* being present in fish produced through aquaculture activities. Among these are several species of tilapia (*Oreochromis aureus*, *Oreochromis niloticus*, *Oreochromis mossambicus*), catfish (*Ictalurus furcatus*) as well as others (Almeyda-Artigas, 1991; Waikagul and Diaz Camacho, 2007). Nevertheless, in a recent study carried out in Vietnam comparing the incidence of parasitosis in wild and cultivated snake-head (*Monopterus alba*), *Gnathostoma spinegarum* larvae were not found in cultivated fish while during the rainy season the incidence in wild fish reached more than 20% (Sieu et al., 2009).

Table 4
Presence of Anisakidae larvae in cultivated fish in different countries.

Parasite	Fish	Country	References
Anisakis sp. *Contracaecum sp.*	Trout *Oncorhynchus mykiss*	Belgium	Bassleer et al. (1973)
Anisakis simplex	Trout *Oncorhynchus mykiss, Salmo trutta*)	Scotland	Wootten and Smith (1975)
Anisakis sp. *Contracaecum sp.*	Plaice (Pleuronectes platessa)	Scotland	McKenzie et al. (1976)
Contracaecum sp.	Salmon (Salmo salar)	USA	Dick et al. (1987)
Anisakis sp.	Cod (Gadus morrhua)	Norway	Hemmingsen et al. (1993)
Hysterothylacium aduncum	Salmonids	Chile	Gonzalez (1998), Carvajal and Gonzalez (1990), Carvajal et al. (1995), Sepúlveda et al. (2004), Torres et al. (2010)
Contracaecum sp.	Tilapia	Israel	Paperna (1996)
Contracaecum sp.	Walleye (*Sander vitreus*)	USA	Muzzall et al. (2006)
Anisakis spp. *Hysterothylacium*	Several marine species	China	Chen et al. (2008)
Anisakidae	Salmon (Salmo salar)	Canada	Marty (2008)
Anisakis simplex	Cobia (*Rachycentron canadum*)	Taiwan	Shih et al. (2010)

5. Prevention and control

Illnesses due to fishborne parasites derive from the consumption of raw fish or fish dishes or products that have not been cooked or have not been processed sufficiently to kill the parasites in them. Clearly the incidence of illness would be reduced or even eliminated if consumption of such products ceased, but in practice this goal is extremely difficult to achieve bearing in mind the popularity of a variety of traditional fish dishes, often with a regional character, which include raw or only lightly processed fish (Chai et al., 2005; WHO, 1995, 1999, 2004). Traditional methods for control of zoonotic fishborne parasitic diseases, especially where these diseases are endemic, are chiefly based on identification and treatment of sick individuals, on consumer education campaigns, and by preventative mass medication. Despite successful results achieved in certain countries such as Japan and Korea, these methods have not generally reached the expected results in most countries where the diseases are endemic and incidences of the diseases have not been reduced significantly. Undoubtedly, one reason is reinfection by the repeated consumption of risky products. Ideally the goal should be the production of parasite-free fish from which this popular raw or lightly processed dish could be prepared, and so breaking the cycle. We believe aquaculture can be a means for achieving this goal.

There is a precedence for this in the production of aquacultured fish free from nematode parasites. The literature on this has been reviewed in Section 4.3 but in summary some thousands of samples of farmed salmonids, *Salmo salar* and *Oncorhynchus* spp., cultivated in Europe, North America and Japan have been examined for nematode parasites and only one sample has been found to have the parasite in its viscera and none have been found to have the parasite in the musculature. This freedom from nematodes is recognized in the derogation of farmed Atlantic salmon from the requirement of food hygiene regulations in the EU, (Regulation (EC) no 853/2004), that fish to be used for the preparation of cold-smoked products or lightly processed products must previously be frozen to kill nematode parasites. It must be remembered that people can become sensitized to dead anisakid larvae and their absence from the flesh in the first place has the benefit of avoiding sensitisation. The present farmed salmon industry has not developed for the primary purpose of producing fish free from nematodes, but, nevertheless, it is a welcome corollary of the process. Fish acquire the nematode larvae in the food they consume and the freedom from nematode parasites in farmed salmonids in the reports cited in Section 4.3 is a consequence of their being fed with feeds that do not contain the parasites. However it must not be assumed that feeding pelleted food at just some stage or stages of production will guarantee this freedom. Hemmingsen et al. (1993) kept cod harvested from the wild for two years in cages feeding them throughout on uninfected food, (cod scraps frozen to kill larvae), and found that the fish at the end of this period were infected with nematode larvae to the same extent as they were at the beginning and as in comparable wild populations of cod sampled during this time. Other examples reviewed in Section 4.3 show that farmed fish cultivated in both fresh and marine waters can be infected with nematodes where they have access to natural food or are fed with infected feed. It is necessary for the production of nematode-free fish that feed at all stages of production, from hatching to harvesting, must be free of the larvae. A European risk assessment of public health aspects of parasites, essentially nematodes, in fishery products is given in a report of the European Food Safety Authority (EFSA, 2010).

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In the larger, worldwide, picture of fishborne parasitoses, nematodiasis is perhaps not all that an important disease, though, not neglectable — the illness is not severe and the incidence is low. Of much more concern are the fishborne trematodiases — the illnesses can be severe, and the incidences are high in endemic areas. Though we believe that aquaculture of species of fish transmitting the diseases has the potential to reduce the risks to humans it will certainly not be as straightforward or as easy as aquaculture of salmon has been for reducing the risk of anisakiasis. In the case of trematodes, cercariae are shed by the first intermediate host, a snail, and positively seek out the second intermediate host, a fish, working their way into the flesh of the fish where they develop into metacercariae which are infective in the definitive host. Control of the parasite then requires control over the environment in which the fish is cultured, which is more difficult to do than just controlling the feed as in the case of control of nematode parasites, especially in the context of the extensive culture of fish in those areas where trematode infections are endemic. There are several stages in the life cycle of trematodes where control could be applied, but it is unlikely that control of one single stage would be effective over the variety of cultural practices employed in the countries and regions where trematodiases are endemic. What is needed is a disciplined, systematic, appraisal of the complete production systems to identify where control can be applied to reduce the risk of infection. Such an approach is available in the Hazard Analysis Critical Control Point (HACCP) system.

HACCP was developed to control the safety, especially the microbiological safety, of processed foods. It is now a widely-used system in the food industry and is described in several texts of which that issued by the Codex Alimentarius (2009) is a succinct, but full, account. Though it is described for, and almost always practiced in, the closed environment of a food factory its principles are sound and can be applied in other situations. The development of an HACCP plan for an aquaculture facility requires the collaboration of a team of persons from several disciplines related to public health and aquaculture, for example, public health specialists, veterinarians, (food inspectors and ichthypathologists), aquaculturists, and fishery extension workers. The team examines the production system at a site and breaks down the whole process into stages to produce a flow chart of the process. Each stage is evaluated for the existence of hazards and of risks for public health. (Hazards are the presence of an agent with the potential to cause harm, and risk is the likelihood that the hazard will be realized to cause actual harm). The team then considers if there are ways to eliminate the hazard at that stage or at least reduce the risk. If this is possible, the stage becomes a control point and the team draws up procedures for measuring and monitoring the hazard, establishes control limits for it, and establishes procedures for correcting the process to bring the system under control if monitoring shows the product is outside the limits. As well as technical aspects, an HACCP plan establishes procedures for management of the plan by, for example, monitoring its effectiveness, periodical review and revision of the plan if necessary in the light of new developments, review of any lapses in control and corrective actions, and full documentation of activities for tracing failures in control. Khamboonruang et al. (1997), Lima dos Santos (1997, 2002) and WHO (1999) provide descriptions of model HACCP plans for control of trematode parasites in the production of farmed carp.

Experiments to control and/or prevent fish borne trematode infections employing the HACCP concept were carried out by FAO in Asia by a multidisciplinary team of experts in public health, parasitology, aquaculture, fisheries extension, and fish inspection (Son et al., 1997). During studies in Thailand and Vietnam, experimental activities were conducted simultaneously in two side-by-side carp ponds. In the experimental ponds, carp were cultured according to HACCP principles, while fish in the control pond were cultured according to conventional, local aquaculture practices. Preliminary results showed that no fish infected with the parasite metacercariae were observed in the experimental ponds where HACCP principles were implemented. These results indicate that application of HACCP-based principles to fish culture in both countries can be an effective way to prevent and/or control FBTs, when correctly implemented (Lima dos Santos, 2002). However, to use HACCP as a practical and efficient control weapon against fish parasites at farm level, it will be necessary to significantly improve our knowledge of the biology and epidemiology of zoonotic fishborne parasitic diseases under the conditions of aquaculture. As an example, a comprehensive study of risk factors for development of food-borne zoonotic trematodes in integrated small-scale fish farms was recently carried out in Northern Vietnam (Phan et al., 2010b).

Prevention activities are generally not currently employed at the primary fish production level, particularly at small scale fish farm level. The main reason for this is the lack of knowledge and of interest (Garrett et al., 1997; Lima dos Santos, 2002). Vietnam is an important exception with the training of fish inspectors in the practical recognition and identification of the presence of fishborne parasite infection in cultivated fish through the FIBOZOPA project. However, there are no indications that these methods are being routinely used by fish inspectors in Vietnam.

6. Conclusions

This review indicates that an association between aquaculture and human diseases caused by fish borne parasites has now been well documented and is no longer speculative. The risks should be considered real and there is a need for research in this area through multidisciplinary and multisectoral collaborations mainly directed to the prevention of infection of the fish by the parasites at fish farm level. Research is most needed in geographical areas where the diseases are endemic, and needs to include cultivated fish and not just wild fish. In practice the possibility that cultivated fish might transmit fishborne zoonotic parasitic diseases should always be considered when carrying out a public health risk analysis of products from aquaculture.

Aquaculture production systems offer unique opportunities for prevention and control of infection of fish by zoonotic parasitic vectors of diseases that are not available to capture fisheries from the wild, and in certain specific cases, such as infection by nematodes, it has been demonstrated that it is possible to produce farmed fish uninfected by *Anisakis* larvae. The HACCP system is a tool that has the potential to assure the safety of cultivated fish at risk of infection with zoonotic fishborne parasites. Implementation of HACCP systems is likely to be more feasible in the cases of medium and large size commercial fish farms, but the lessons learned in these larger establishments should be applicable to the small subsistence fish ponds commonly found in endemic areas affected by fishborne zoonotic parasitic diseases.

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