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WORKSHOP REPORT

One Health in Fish and Shellfish

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One Health is a term increasingly in focus on a global scale. The *One Health* concept grew from a centuries-old understanding of the connectedness of human and animal health and the need to consider them together. This is not only the case in the interaction between humans and warm-blooded animals but also related to contact with cold-blooded animals like fish and shellfish, produced for food, or as pet or laboratory animals. During this three hour virtual workshop held during the 21st EAFP Conference, at Aberdeen, Scotland, we aimed at highlighting a *One Health* approach regarding the interactions of cultured and ornamental fish, shellfish, their environment, pathogens, human health, and human sociological and economic activity, contact- and food-zoonoses by bacteria and parasites, and AMR issues. In total, more than 65 participants from various countries from all over the world participated in this workshop. This paper provides a summary of each presentation and some of the discussions arising from them, giving a snapshot of different *One Health* perspectives being pursued by the participants.

What is *One Health* and how can it be implemented? (David Bass)

The *One Health* concept was created in 2005 (Zinsstag et al. 2011) deriving from the "One Medicine" concept ambitioning to combine human and veterinary medicines to understand zoonoses (Schwabe 1984). The novelty in this *One Health* concept was the incorporation of the ecosystem health, including that of wildlife. *One Health* provides a framework for looking at complex systems and requires an approach that is holistic and transdisciplinary (Hristovski et al. 2010). More recently, a *One Health* perspective has been developed for managing aquatic animal health and successful industry outcomes, particularly in respect to aquaculture (Stentiford et al. 2020). *One Health* is an integrated systems approach that aims to sustainably balance and optimize the health of humans, animals, plants and ecosystems, which are closely linked and interdependent.

One Health is a framework/concept, not a protocol or workflow. With respect to aquaculture the most recent model (Stentiford et al. 2020) proposes a set of success metrics (SM) relating to organisms (i.e., healthy stock, minimal chemical hazards, biosecure farms, safe farms, optimized farm systems), environment (optimal water usage, optimal water quality, protected biodiversity and natural capital, low-energy production, low spatial footprint), and people (nutritious and safe food, equitable income generation, gender equalization, quality employment, knowledge and skills generation). Thus the *One Health* scope has been widened here to work towards the success of a sector, and provides the basis for measuring that success (Figure 1).

Fulfilment of the 15 success metrics listed above is underpinned by the availability and application of relevant research, evidence, policy, and legislation. These can be measured according to a scale of one to five: (1) no research, evidence, policy, or legislation is in place to allow delivery of SM; (2) basic research outputs are available but have not been applied to policy formation and legislation to allow delivery of SM consistently; (3) applied research has been conducted and used for policy formation and legislation to deliver SM, but not yet applied; (4) policy and legislation is in place, is continually refined by further research and evidence but SM has not been consistently achieved; and (5) policy and legislation is in place and applied consistently, research and evidence contribute to further refinement, or SM being consistently achieved (Stentiford et al. 2020). The overarching target outcomes are aquaculture sustainability, benefitting producers and consumers, whilst minimising negative impacts on stock, farms, and the surrounding environment.

A 'seafood risk tool' (SRT) has also been devised to assess and mitigate chemical and pathogen hazards in the aquaculture supply chain; this is one way in which the *One Health* approach can be operationalized (Stentiford et al. 2022). The SRT can be applied to any aquatic food production scenario - for example bivalve mollusc aquaculture in which live animals are destined for an export market for consumption in raw form. The SRT would then determine a customised hazard list specific to this scenario from a 'menu' of hazards in three categories: 1) chemicals, 2) animal pathogens, and 3) human pathogens. This 'uncontrolled' collection of risks is then moderated using a risk mitigation matrix, which considers each risk at different production and supply stages. For example, the animal pathogen risk 'bacterial pathogens' can be mitigated at early-life, grow-out, and harvest stages of the production cycle by application of measures in the World Organisation for Animal Health (WOAH) Code for listed pathogens, and generic chapters (surveillance and biosecurity) for other pathogens, application of Progressive Management Pathways supported by national biosecurity tools, and application of best aquaculture practices (BAP). In the trade phase, application of WOAH standards for international trade, as recognised by the World Trade Organisation, or other regional/national controls, can be applied. Mitigation measures identified and applied for all of the relevant risks inherent in a particular scenario result in a 'controlled' SRT, which can form the basis of developing biosecurity and food safety plans for that scenario. An alternative outcome is the recognition that sufficient risk control is not possible, and an alternative scenario may be preferable (e.g. alternative species, farm location, market, etc.).

Another potential framework enabling the operationalization of the *One Health* approach is syndemic theory. Hazards must be considered not in isolation but in order of their impact and considering the additional impacts of their combined action (Stentiford et al. 2023). A good illustration of syndemic theory (and one which prompted further development of the theory) is the COVID-19 pandemic, where the outcomes of population-level infection by this emerging novel virus varied according to differing political, environmental, and demographic landscapes. The syndemic concept can also be applied to aquaculture, for example to animal health outcomes. The impact of pathogens in an aquaculture system may be influenced (amplified or reduced) by the wider symbiome of the animals they infect, the nature of the host (e.g. its immunological competence) and (fluctuations in) the surrounding environment (e.g. water quality, climate change), and farmer behaviours. Even factors that are not directly in contact with the system itself can have profound influences on the nature and direction of pathogen impacts, for example alignment (or not) with trade legislation, capacity of Responsible Authorities for disease surveillance and management, societal knowledge of the importance of biosecurity and BAP, and the academic capability to support research on aquaculture systems and health. As all of these stages in the syndemic pathways differ between countries and regions, health outcomes associated with a particular host-pathogen system can differ profoundly, with widely varying impacts on yield, income, livelihoods, and wellbeing. Therefore policies relating to aquaculture should extend well beyond attempts to manage or exclude individual pathogens, to ones that drive investment in more resilient aquaculture systems, enabling people working in and relying on those systems to avoid or to disable syndemic pathways.

AMR in aquaculture: evidence from the *One Health* approach – a trout farming case study

(**Sandrine Baron,** Eric Jouy, Laëtitia Le Devendec, Sophie Le Bouquin, Claire Chauvin)

Antimicrobial resistance (AMR) is now recognized as among the top ten threats to global health, with currently increasing trends in resistant infections in humans and livestock pointing toward a potential post-antibiotic era (WHO 2019). To understand and mitigate the dissemination of AMR, a *One Health* (OH) approach can be applied.

Among farming sectors, aquaculture is especially concerned/impacted by AMR dissemination due to its direct contact with the aquatic environment, without real barriers of transmission of antimicrobial resistance genes (ARG)

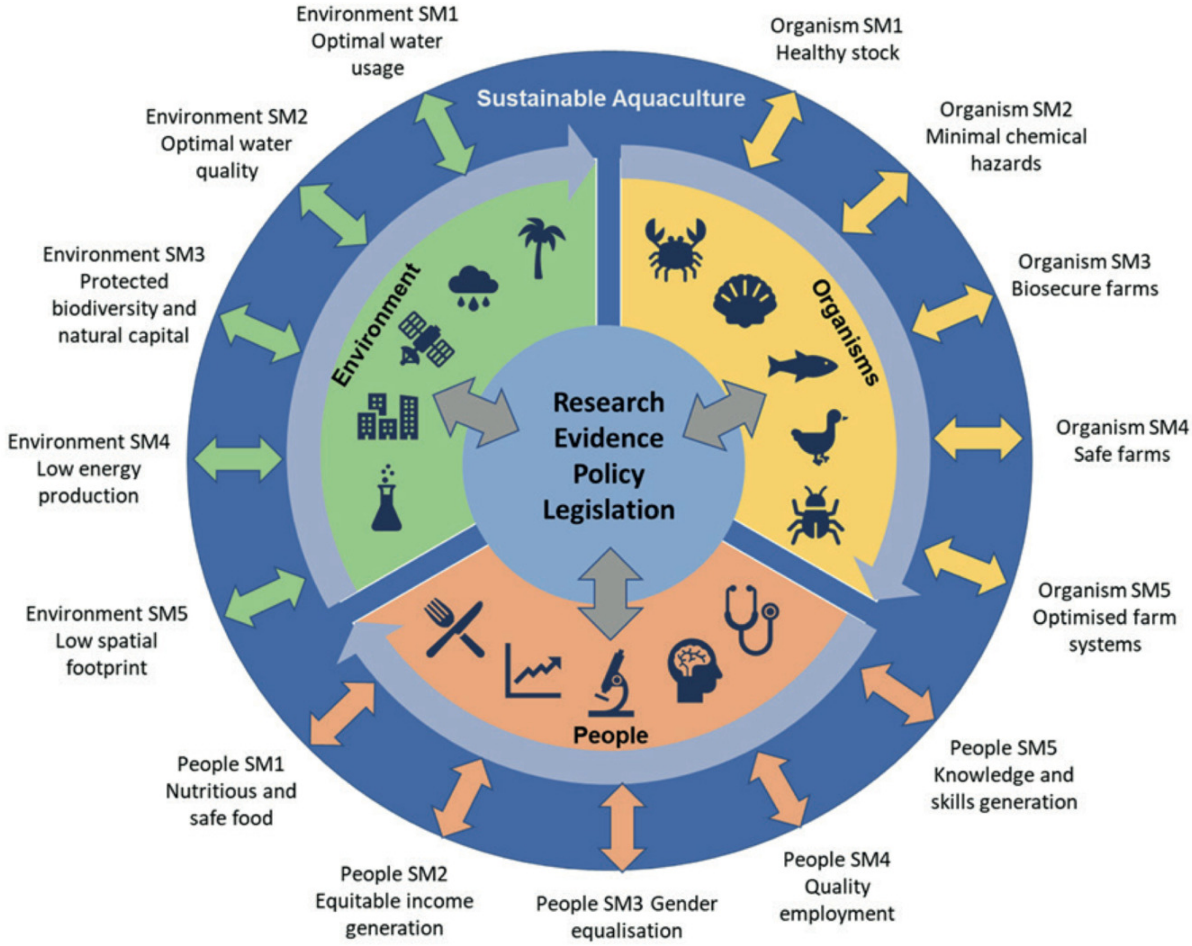

Figure 1. The One Health Aquaculture approach to design of a sustainable aquaculture sector. The approach proposes 15 success metrics spanning environment, organism and human-health; fulfilment of which are underpinned by the availability and application of research, evidence, policy, and legislation.

Figure reproduced with permission from Stentiford et al. (2020) (Nature Food)

and/or resistant bacteria (ARB). In aquaculture, antibiotic treatments are mainly performed through medicated feed and there is no specific compound dedicated to aquaculture (Smith 2008). In Europe, the therapeutic arsenal is limited. For example in France, there are only five antibiotics licensed for use in aquaculture: flumequine, oxolinic acid, oxytetracycline, florfenicol and trimethoprim-sulphamethoxazole.

At the global level, regulations are very heterogeneous and until now, limited information has been available about the usages of antibiotics in aquaculture (Tuševljak et al. 2013). Nevertheless, a better knowledge of the usages (quantity and molecules) is currently being developed. WOAH is preparing guidelines and, at the European level, new regulations on veterinarian use and data collection in all sectors including aquaculture are being progressively implemented. From 2026, all EU member states will be required to automatically collect data on the use of medicines containing antimicrobials, based on prescriptions made by veterinarians.

Freshwater is of particular interest, as it receives the runoff from agricultural activities, effluents from wastewater treatment plants, and because of its natural microflora. Freshwater can serve both as a natural reservoir of antibiotic resistance and as a vehicle for the spread of clinical resistance traits (Hernando-Amado et al. 2019). In France, 65% of studied trout fish farms use river water (Le Bouquin et al. 2021) and are thus affected by the water quality.

Neither ARG nor ARB are included in the parameters considered in water quality monitoring frameworks, and there are very few ARG/ARB studies focusing on freshwater fish farming. As reported by Liguori et al. (2022) standardized methods for monitoring AMR in the water environment are crucial to produce comparable data sets. The first question to be answered is which antibiotic resistance indicator to choose? Over the last decade, *Aeromonas* has been proposed by several authors as a good candidate to monitor AMR in the aquatic environment. Jones et al. (2023) used *Aeromonas* not only to monitor but also as a model to improve our understanding of the factors influencing AMR from Global and *One Health* perspectives.

As reported in an oral presentation at the 13th International Symposium of *Aeromonas* and *Plesiomonas* (Wroclaw, Poland, June 2023) project Resist3A (part of the EMFF-funded EcoAntibio Program) aimed to investigate the AMR dissemination upstream and downstream of two trout fish farms, located respectively at the source and at the mouth of a French river impacted by agricultural farming and a wastewater treatment plant. As part of this project, every two weeks for 17 months water samples were collected upstream and downstream of these two fish farms. Enumeration of *E. coli*, *Aeromona*s spp. and *Pseudomonas aeruginosa* was performed using culture methods on the 144 water samples collected. Antimicrobial susceptibility testing of a selection of *E. coli* (n=142), *Aeromonas* (n=355), and *Pseudomonas aeruginosa* (n=123) isolates was performed using agar diffusion method. The so far unpublished results of this work demonstrated variations of wild type aeromonads in the water samples collected along the source to the mouth of the river, indicating that *Aeromonas* is a valuable indicator of AMR spread in aquatic environments.

A *One Health* approach to identify potential sources of antimicrobial resistance genes in European coastal areas used for oyster culture

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Coastal areas are home to dense human populations as well as rich marine biodiversity. They are of high economic importance for the development of activities such as tourism or aquaculture. However, the combination of a growing population and economic development increases threats to marine ecosystems, due to inputs of nutrients and pollutants from anthropogenic activities on the coast. Aquaculture, fishing, shipping, recreational water sports, etc. might constitute a substantial source for contamination of coastal waters. In addition, terrestrial activities including agriculture and animal farming contribute to coastal water contamination through anthropogenic runoff (e.g. rainwater, wastewater). This creates a melting pot of chemicals such as antibiotics and heavy metals, as well as microorganisms from marine sources but also from human and animal origin. This can affect aquaculture management by increasing fish mortality, epidemics or contamination of fish and shellfish products (McLean et al. 2001). As coastal areas concentrate human populations, coastal water contamination can also threaten human health.

For more than 50 years, as a result of the abuse and/or inappropriate use of antibiotics, increasing amounts of antibiotic resistant bacteria (ARB) have been observed not only in hospitals but also from environmental sources (Aarestrup, Wegener, and Collignon 2008). Aquatic environments subjected to strong anthropogenic pressures have been identified as long-term reservoirs. Antibiotic resistant genes (ARGs) play a central role in the transmission, spread, and evolution of antibiotic resistance of anthropogenic origin (Manaia et al. 2016; Chen et al. 2017; Eckert et al. 2019). The spread of antibiotic resistance in wild and exploited ecosystems can have numerous consequences on environmental health, animal health (wild and cultivated fauna) and human health.

As our reliance on aquaculture grows, it is essential to identify the factors that influence sources, sinks, and transfer routes of antimicrobial resistance within and between microbial communities (Watts et al. 2017) to accurately gauge the risk for the environment, aquaculture (i.e. animal health) as well as its connection to human health (Seiler and Berendonk 2012). This explicit connection of environmental, animal and human health shows a prime example of the applicability of the "One Health" concept to intensively-used coastal areas that can accelerate antibiotic resistance transfer (Destoumieux-Garzon et al. 2018).

Aquaculture has been identified as a main gateway for spread of antibiotic resistance of clinical concern (e.g. beta-lactamases) (Cabello et al. 2016). Several species of bivalves including oysters are cultured in highly human-impacted coastal environments, and as filter-feeders they can act as bio-reactors that concentrate contaminants and microorganisms, thereby potentially accelerating horizontal gene transfer and the spread of ARGs among microbial communities. Indeed, genes related to mobile genetic elements, particularly those involved in conjugative transfer, are highly induced in vibrios during oyster colonization (Rubio et al. 2019). Similarly, biofilms in mixed bed biofilters are a reservoir for antibiotic resistance genes (Li et al. 2017). Due to the accelerated transfer of resistance genes, the genetic characterization of an environmental metagenome is a better proxy for estimating the spread of ARGs (the "resistome") through coastal ecosystems.

In the SPARE-SEA and ANTIBIOTHAU projects, we adopted a 'from the source to the mouth' approach to investigate the distribution and spread of ARGs in bacterial communities including emerging pathogens connected to oyster culture. We monitored ARBs and ARGs in oysters with controlled life history traits and in their near environment. Using a culture-based approach, we found a high proportion of marine bacteria resistant to colistin and β-lactams in the four European coastal systems studied, supporting oyster farming (Ebro delta, Spain; Thau lagoon, France; Bay of Brest, France; Sylt reserve, Germany). By pool-sequencing and metagenomics of bacterial and oyster DNA, we found a broad diversity of ARGs circulating in these coastal areas. Their ability to confer resistance to colistin and β-lactams was demonstrated experimentally (Saad et al. 2024). Our results support earlier observation by Aminov (2009) that "the environmental microbiota, even in apparently antibiotic-free environments, possess an enormous number and diversity of ARGs, some of which are very similar to the genes circulating in pathogenic microbiota". Whether pesticides and metals accumulating in marine coastal systems participate in the co-selection of these ARGs is currently under investigation.

Zoonotic parasites

Matt Longshaw

It is recognised that parasites can be transmitted to humans from a number of sources, including via food and through contact with infectious stages; most of these are accidental or unintentional with little evidence of deliberate infections in humans. Furthermore, it is generally accepted that risk of infections is greater in geographical regions with poor infrastructure, or where traditional foods are eaten raw or undercooked. However, with increased globalisation, including travel and trying new and exotic foods, the risk of being infected with parasites through contact or ingestion increases more widely. As with other disease agents, infections occur through ingestion of infected fish or shellfish or via contact with water containing infectious stages. As the probability of infection via fomites (inanimate objects that harbour infectious stages) is extremely low to negligible, it is not considered further here.

Around 40 species of fish and shellfish zoonotic parasite taxa have been recorded in humans globally. The majority of the infections reported are helminths and nematodes, possibly due to their larger size making diagnosis in the aquatic and human hosts easier. As a result of visual inspections of fish and shellfish containing these larger parasite stages infected food can be avoided or cleaned up by removal of infectious stages. In contrast, the presence of small larval stages in asymptomatic fish can go unnoticed, meaning that accidental ingestion occurs. However, limited awareness of diagnostic methods, symptoms and risks associated with zoonotic parasites by farmers, processors, retailers, the general public, and medical practitioners further increases risks of infection. The main parasite groups reported as zoonotics are protists, myxozoans, trematodes, cestodes, and nematodes.

The three main protist zoonotic parasites reported from aquatic systems are *Cryptosporidium* spp., *Giardia duodenalis*, and *Toxoplasma gondii* which are included here for completeness. However, they bioaccumulate in shellfish via feeding rather than being true infections and no evidence exists to suggest transmission from fish to humans. Using molecular methods, (Hayes et al. 2023) reported the presence of *C. hominis* in freshwater salmonids in the UK that had a low risk of transmission to humans.

Myxozoans are metazoans with a typical two-host lifecycle that alternates between a vertebrate (normally a fish) and invertebrate host, including oligochaetes, polychaetes, and bryozoans; exceptionally a small number of species are known to have direct life cycles in marine fish. Although infections were previously considered to be restricted to poikilothermic aquatic hosts, recent surveys have identified myxozoans in terrestrial shrews and waterfowl (Bartholomew et al. 2008; Székely et al. 2016). Myxozoans have been detected in stool samples of humans experiencing abdominal pain and / or diarrhoea (Boreham et al. 1998; Lebbad and Wilcox 1998; McClelland, Murphy, and Cone 1997; Moncada et al. 2001), which have been considered as incidental findings rather than true infections. However, a more recent outbreak of food poisoning in Japan was linked to *Kudoa septempunctata* present in the raw olive flounder (Harada, Kawai, Jinnai, et al. 2012; Harada, Kawai, Sato, et al. 2012; Iwashita et al. 2013; Kawai et al. 2012). Following ingestion, patients present with diarrhoea and vomiting within a day. Additionally, myxozoans have been associated with allergic reactions in a small number of patents following ingestion of *Kudoa* spores present in marine fish muscle (Martínez de Velasco et al. 2008; Martínez De Velasco et al. 2007). It follows that humans are not natural hosts for myxozoans with no evidence that humans are involved in the propagation and development of these parasites.

Trematodes (also known as flukes) have complex lifecycles that generally involve three hosts – larval stages occur in an invertebrate such as a snail or crustacean, followed by a secondary larval stage in a vertebrate such as a fish, and an adult stage in a final vertebrate host. A number of trematodes have been reported as problematic to humans and zoonotic species include *Clonorchis sinensis*, *Opisthorchis viverrini*, *O. felineus, Paragonimus westermani*, and *P. heterotremus*. *Centrocestus formosanus*, *Haplorchis pumilio*, and *H. yokokawi*. Infections in humans can be chronic with damage usually to bile ducts, liver and the gastrointestinal tract; deaths have been attributed to untreated infections with an estimated 45 million people infected with freshwater liver flukes. Treatment with a variety of anthelmintics is possible and diagnosis of infection is achieved through a combination of classical taxonomy and use of multiplex PCR which has been designed to detect opisthorchiid and heterophyid metacercaria in fish and fish products. Cestodes (or tapeworms) also have complex lifecycles, involving a number of hosts, including fish and higher vertebrates. Around 20 million people globally are infected with tapeworms derived via ingestion of fish with around 14 out of the 50 recognised species of *Diphyllobothrium* / *Dibothriocephalus* being reported in humans. Disease is usually asymptomatic or mild with patients presenting with diarrhoea, abdominal pain, anaemia and / or weight loss.

Arguably, the most well known group of zoonotic parasites reported in humans are nematodes. These serious pathogens have complex lifecycles that involve invertebrate, fish and mammalian hosts. Zoonotic nematode infections are a global issue and are particularly associated with the ingestion of sushi / sashimi. One major issue is that larval stages typically show low host specificity which can increase the number of infected fish hosts and, upon fish death, can migrate form the intestine to the muscle, thus increasing the risk of transmission. Well-recognised genera include *Anisakis*, and *Pseudoterranova* with infections often mimicking food poisoning and can last from days to months depending on underlying health conditions as well as clinical interventions. Of growing concern are reports of hypersensitivity in humans following ingestion of small doses of dead (cooked) *Anisakis simplex* that can cause lethal and rapid-onset anaphylactic shock (Baptista-Fernandes et al. 2017; Heffler et al. 2011; Kirstein et al. 2010). These cases have been reported worldwide with a focus in Japan and Europe and it is probable that a lack of understanding has led to underreporting and/or misdiagnosis of this issue. Similarly, infections with Gnathostomatidae (*Gnathostoma spinigerum*, *G. doloresi*, *G. hispidum*, *G. binucleatum*, *G. nipponicum* and *G. malaysiae*), found in Japan, Southeast Asia, South America, China, and India, have been reported to cause a hypo-allergic response. Clinical symptoms are similar to those reported for *A. simplex* infections in humans but are more severe and include nausea, abdominal pain within 24–48 hours post infection (Diaz Camacho et al. 2003; Jiménez and Alava 2009; Shamsi, Steller, and Zhu 2021). Larval stages are known to migrate within the human host leading to inflammatory migratory swellings that may result in brain haemorrhage if they are allowed to infect the brain. Infections of the nervous system are generally considered to be fatal.

The use of processed feeds manufactured to high hygiene standards, including quality controls will limit the risk of transmission of infective stages via this route. However, with open water farming such as cages, ponds, etc., there is always a probability that infections in intermediate hosts within the farm or water-borne stages are able to infect farmed fish. These events are generally rare and measures to exclude intermediate hosts and/ or final hosts such as birds that may provide a source of eggs, should be considered as a way to reduce infections. It is recognised that detection can be difficult with a lack of appropriate and cost-effective diagnostic tools being readily available. Furthermore, given the relatively low risk associated with aquaculture species, there is perhaps a reluctance to invest in these tools at the farm or processing stage due to prohibitive time and costs. Good hygiene at all stages of production and processing are critical to ensure that zoonotic infections from aquaculture species are kept to a minimum. However, despite knowledge of types and risks associated with these zoonotics, humans continue to be infected by fish-borne parasites with consequent effects of health and mortality.

Zoonotic bacterial infections in and from fish

Olga Haenen

When we talk about zoonosis related to fish, it is important to define whether we mean a single direction of infection of agents (bacteria, viruses, parasites or prions), from fish to humans (Merriam-Webster Dictionary, n.d.), or a bilateral direction, *i.e.* from fish to humans, and from humans to fish (CDC, n.d.). Here, we refer to the first definition, and focus on bacteria. Bacterial zoonosis from fish may be food-born (food zoonosis), or topically acquired (contact zoonosis).

Food zoonosis may be acquired via ingestion of infected fish, fish products or zoonotic bacteria-contaminated water. Contact zoonosis may be acquired through direct contact with infected fish by especially the fish farmer and fish processor, the sport fisher, the ornamental fish keeper, and the laboratory fish keeper, especially when with they have a reduced immune status and have an injured skin in hands, arms or legs (O. L. Haenen, Evans, and Berthe 2013). This means that food zoonosis occurs mainly in finfish and shellfish consumers, and contact-zoonosis occurs predominantly in fish professionals and tropical fish hobbyists. The risk of acquiring these zoonosis is low, dependent for food zoonosis on the way of preparing fish and shellfish, and for contact zoonosis on the hygiene, but the risk to acquire a zoonosis from fish and shellfish is present.

The most important bacterial species causing zoonosis in and from fish are listed in O. L. Haenen, Evans, and Berthe (2013; O. L. M. Haenen et al. 2020). Food zoonotic bacteria mostly are in fact contaminants in (spoiled) fish, tested for via the HACCP system (Reilly and Käferstein 2008), like *Listeria monocytogenes, Campylobacter* spp., and *Vibrio* spp. However, contact zoonotic bacteria are real fish pathogens, which occur especially in fish kept at water temperatures of above 24°C. Some of these may cause acute fish disease, like *Vibrio vulnificus* and *Edwardsiella tarda*, some are causing chronic fish disease, like *Mycobacterium marinum*, and some may cause acute or chronic disease, like *Streptococcus agalactiae* (O. L. M. Haenen et al. 2023). The main contact zoonotic bacteria, of which some may also be food zoonotic are listed in Table 1.

When a zoonosis from fish is suspected, the advice is to contact a medical doctor immediately, reporting that you have worked with (diseased) warmwater fish and possibly suffered a spine/puncture issue. Also important to seek information online, i.e. from specialized literature (as given in reviews of DeCostere, Gauthier, Lehane, Haenen *et al*., referred to in this paper). Specialized and fast diagnosis is crucial and can be life-saving, in case of the fast developing zoonotic Ser E of *Vibrio vulnificus* pathovar *piscis* infection, which occurs in rare cases, in immunocompromised patients: Then, laboratories using the protein-based diagnostic method MALDI-TOF, like hospitals, should be contacted, and use Boonstra et al. (2023). Where possible, a zoonotic bacterium should be isolated from the wound or blood, and an antibiogram against a panel of antibiotics should be determined by a medical laboratory. We need to realize, that, sometimes, months of treatment with antibiotics might be needed, like in the case of human fish tuberculosis by *Mycobacterium marinum*, treated for with antibiotic combinations during sometimes even 8 months (Lewis, Marsh, and Von Reyn 2003).

In conclusion, various warm water fish bacteria may be food- or contact-zoonotic, and some even life threatening in rare cases, especially in severely immunocompromised patients which may have also skin injuries, like with *V.vulnificus* pv *piscis* Ser E. Therefore, good hygiene is essential. Fast and accurate diagnosis, for instance with MALDI-TOF may save lives. Prevention against contact zoonosis from fish can be done through hygiene, record keeping, and possibly through fish vaccines.

Conclusions

A *One Health* perspective has been developed for managing aquatic animal health and successful industry outcomes, particularly in respect to aquaculture (Stentiford et al. 2020). *One Health* approaches can be operationalized for aquaculture by using the Seafood Risk Tool, and considering the Syndemic Pathway.

However, specific aspects of the *One Health* framework, such as AMR and transfer of pathogens between animals and humans, are important perspectives in *One Health*, and featured significantly in this symposium. Transfer of pathogens and parasites of poikilothermic aquatic animals to humans is sometimes considered relatively insignificant, but two contributions to the symposium (Olga Haenen and Matt Longshaw), and many subsequent questions, highlighted the human relevance of aquatic pathogens, which, like AMR, are likely to become more prominent risks

Table 1. Main contact zoonotic bacterial species from warmwater fish, some of which are also potential food zoonotics

Bacterial species	Fish species	Food (F) or Contact (C) zoonosis?	Clinics / Disease in Fish	Clinics / Disease in Humans	References
Streptococcus agalactiae	Tilapia a.o.	F & C	Exophthalmos, cataract, surfacing, anorexia swimming turn-wise “C-shaped” body faeces hanging out of anus	ST283: food zoonosis. In general: Superficial & invasive infections in immune-compromised non-pregnant adults; Main cause of neonatal sepsis.	Fish: Evans et al. 2008. Man: Evans et al. 2008; O. L. M. Haenen et al. 2020, 2023.
Streptococcus iniae	Tilapia, and other various freshwater and marine warmwater fish species	C	Haemorrhagic meningoencephalitis often accompanied by blindness. Pale and/or haemorrhagic liver and kidney, swollen spleen, and ascites.	Cellulitis of soft tissue injuries after handling/ spine puncture from fresh fish. Arthritis, meningitis, endocarditis and osteomyelitis.	Fish: Soltani, Jamshidi, and Sharifpour 2005; Salati 2011 Man: Evans et al. 2009; O. L. M. Haenen et al. 2020.
Edwardsiella tarda	eel, cichlids, ornamental fish in fresh, brackish and marine waters	C	Deep skin ulcers, cataract/blindness, systemic infection, granuloma in or between organs, anorhexia, mortality	Extra-intestinal infections through puncture wounds in adults with underlying disorders such as hepatobiliary disease, diabetes, malignance.	Fish: O. L. M. Haenen et al. 2020. Man: Lehane and Rawlin 2000.
Vibrio vulnificus	Eel, tilapia	F & C	Redness of the flanks of the body and tail. Open ulcers (non-zoonotic ST 140 strain), and muscle boils that burst open (zoonotic strain ST 112, Ser E of pathovar *piscis*)	Wound infections after skin injury, may develop into fasciitis necroticans, in exceptional cases, even full sepsis and death.	Fish: Austin and Austin 1999; O. L. M. Haenen et al. 2014; Amaro et al. 2015; Carmona-Salido et al. 2021. Man: Oliver 2005; Ralph and Currie 2007: Boonstra et al. 2023.
Mycobacterium marinum	Ornamental fish, eel, African catfish, tilapia, and many other freshwater to marine fish species	C	Lethargy, loss of appetite, exophthalmos, ulcers, eroded fins, loss of scales, granuloma in/ between organs, and mortality	Granulomatous inflammation, Nodular or diffuse granulomas of the skin, subcutaneous tissues and tendon sheaths of fingers and hands, Invasive septic arthritis and osteomyelitis in immuno-compromised hosts causing chronic skin lesions, congestion of the whole finger and hand, and tenosynovitis	Fish: DeCostere, Hermans, and Haesebrouck 2004; Gauthier and Rhodes 2009 Man: Lawler 1994; Lewis, Marsh, and Von Reyn 2003

under emerging climate change scenarios, and/or as aquaculture expands in scale and scope (e.g., number of species farmed, in indoor warmwater culture, geographic/ecological distribution both within countries and on a global scale).

Information about appropriate hygiene measures and other *One Health* risks is needed to prevent zoonoses and AMR transfer from fish and shellfish. This could be achieved through teaching future vets and aquaculture professionals about the *One Health* concept, and how it can be operationalised. We recommend that medical doctors should in future be similarly educated, particularly in the light of aquaculture expansion and intensification, climate change, and environmental degradation, which will likely expand the ranges of these risks, and amplify their effects and impacts.

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