

Review Article

An overview of climate change and prevalence of bacterial diseases in salmonid aquaculture

A. Marandi¹, A. Fakhri Demeshghieh², P. Almasi³, M. Bashiri¹, M. Soltani^{1*4}

¹Department of Aquatic Animal Health, Faculty of Veterinary Medicine, University of Tehran, Tehran, Iran

²Department of Food Hygiene and Quality Control, Faculty of Veterinary Medicine, University of Tehran, Tehran, Iran

³Department of Clinical Pathology, Faculty of Veterinary Medicine, University of Tehran, Tehran, Iran

⁴Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University, Australia

Received: September 2022

Accepted: November 2022

Abstract

Food fish farming is regarded as one of the most important sectors of the aquaculture industry. Salmon farming is a major contributor to the growth of the aquaculture sector. Climate change is predicted to have a complex impact on aquatic ecosystems, including fisheries and aquaculture. Climate change can cause a fluctuation in water temperature of rivers, lakes, seas, and oceans. This can change the pattern of ocean currents and marine productivity to be redistributed, especially to higher latitudes, and reduce the global concentration of phytoplanktons, increasing ocean acidity, creating deoxygenated zones, and inducing episodic shocks to marine systems. However, the impact of climate change on fish health is not limited to the physical changes in the environment.

A change in climate can also influence the incidence of infectious diseases by shortening generation times and/or increasing the survival rates of the pathogenic agents, improving disease transmission, and enhancing the host's susceptibility to the pathogens. The actual impact of climate change on infectious diseases, particularly those caused by bacterial agents, is not fully understood in both wild and captured fish species. This review addressed the impact of climate change on outbreaks of salmonid bacterial diseases and discuss the present gaps.

Keywords: Climate change; Fish health; Temperature; Bacterial disease

Introduction

Food fish farming is regarded as one of the most important sectors of the aquaculture industry (Rahmati-Holasoo *et al.*, 2021, 2022; Ziafati Kafi *et al.*, 2022), with a significant portion of

*Corresponding author's email:
msoltani@ut.ac.ir

global aquaculture production dedicated to food products worldwide. Salmonids represent the third group of farmed fish species, following cyprinids and tilapines (FAO, 2019; Lulijwa *et al.*, 2022). Salmon farming is a major contributor to the growth of the aquaculture sector (FAO, 2014; Lulijwa *et al.*, 2022). As aquaculture spread, new categories emerged, including ecotoxicology (Chen *et al.*, 2020), temperature tolerance (Wade *et al.*, 2019; Cheung and Frölicher, 2020), and health and disease (Brosnahan *et al.*, 2019). Climate change, as a globally significant issue, is expected to have a significant impact on aquatic ecosystems, particularly on fisheries and aquaculture activities. The change in the global climate can significantly affect the patterns of ocean currents, causing a remarkable change in the sea's productivity, especially at higher latitudes. For instance, a decrease or increase in the phytoplankton concentration, an increase in the ocean acidity, and a fluctuation in the oxygen level are all consequences of climate changes in aquatic ecosystems (Butler, 2016; Cheung *et al.*, 2021; Galappaththi *et al.*, 2022). In addition to the physical changes in the environment, climate change can affect the health criteria of aquatic organisms via alterations in pathogen characteristics. Increasing in the temperature of freshwater can have a direct impact on fish pathogens by changing their biological processes or a secondary impact by modifying the distribution and quantity of the fish that are affected (Chiaramonte *et al.*, 2016). A higher fluctuation in water temperature can seriously affect the load of potentially harmful

indigenous and exogenous microbiota of aquatic organisms, including fish. This can facilitate the localization, multiplication, and penetration of these microbes into fish tissues, causing mass morbidity and mortality (Marcogliese, 2008).

In other words, increases in the ambient temperature speed up the proliferation of some pathogenic agents, such as bacteria and exacerbates disease outbreaks (Chiaramonte *et al.*, 2016). Although a vast range of bacteria are the most prevalent infectious agents in aquaculture (Palmeiro and Roberts, 2013; Marandi and Rahmati-Holasoo, 2021), the actual impact of climate change on bacterial diseases is not fully understood in both wild and captured fish species (Abirami *et al.*, 2021). This review addressed the impact of climate change on outbreaks of salmonid bacterial diseases and discussed the present gaps.

Climate change and disease outbreaks by Gram-negative bacteria

Yersinia ruckeri

Yersinia ruckeri is the causative agent of yersiniosis, a systemic disease primarily affecting farm-reared trout (*Oncorhynchus mykiss*) that is considered a significant disease in various fish species both in temperate and cold-water aquaculture of freshwater and marine environments. *Y. ruckeri* is known as one of the aquatic bacterial flora in aquatic ecosystems and is the cause of economic losses in many countries, including Canada, Switzerland, Denmark, Great Britain, and Iran

(Soltani *et al.*, 2014, 2016; Taheri-Mirghaedi *et al.*, 2018). Although the disease occurs in various fish species, rainbow trout is the most susceptible species to *Y. ruckeri*. With the exception of salmonid species, the bacterium can invade many other non-salmonid species from the families of Cyprinidae, Acipenseridae, Ictaluridae, and Anguillidae (Pajdak-Czaus *et al.*, 2019).

Y. ruckeri can grow at temperatures ranging from 9 to 37 °C, with an optimal growth occurring between 22 and 25 °C. In salmonids, the disease becomes more serious and causes higher morbidity and mortality when the water temperature is increased to above 15 °C, which is a stressful condition for the fish. Therefore, disease outbreaks can be increased in salmonid aquaculture by changes in the global climate, especially in the northern hemisphere, where nowadays the water temperature increases during the summer season (Kumar *et al.*, 2015). Although most bacterial isolates incubated at 37 °C are non-virulent to fish, biotype II strains can cause disease in both temperate and tropical fish species, thus making the disease as a re-emerging bacterial disease (Wrobel *et al.*, 2019). The severity of the outbreaks depends on some virulence factors of the bacterial strains and the degree of environmental stress. In the risk framework, which was developed to investigate the impact of climate change on disease emergence in freshwater fish in the United Kingdom, it was shown that fish yersiniosis was likely to be more prevalent and more difficult to control with a global warming condition (Marcos- López *et al.*, 2010).

Aeromonas salmonicida

Aeromonas salmonicida is the causative agent of furunculosis in fish (Soto-Dávila *et al.*, 2022) and so far five subspecies, *A. salmonicida salmonicida*, *A. salmonicida achromogenes*, *A. salmonicida masoucida*, *A. salmonicida smithia*, and *A. salmonicida pectinolytica*, have been detected as the cause of disease in both salmonid and non-salmonid species (Romstad *et al.*, 2012; Schwenteit *et al.*, 2013). Some new atypical strains causing severe mortality in farmed salmonids have also been reported (Vasquez *et al.*, 2022).

The optimum growth temperature for *A. salmonicida* is reported at 22-25 °C, and most strains are unable to grow at 37°C (Woo and Cipriano, 2017). However, recent reports have demonstrated the existence of some strains able to grow at 37°C and even cause infections in immune-compromised humans (Tewari *et al.*, 2014). Thus, by increasing water temperature, these new, higher-temperature-tolerated isolates can become more prevalent in aquatic ecosystems. This is especially true as reports regarding furunculosis in temperate and tropical fish species are becoming abundant. Thus, it is more likely that the disease is latent in cooler environments and turns into an active stage in warm environments, as the disease outbreaks are more common in summer months. In salmonids, the bacterial isolates prefer water temperatures of 16 °C or higher, which is a stressor factor for the cold-water fish family; thus, with global warming, disease outbreaks can become more serious in the spring and autumn.

Flavobacterium columnare

F. columnare as the causative agent of freshwater columnaris disease in many fish species in both tropical and temperate environments (Patra *et al.*, 2016) is categorised into five genomovars that are apparently geographically dependent (Kayansamruaj *et al.*, 2017), but with a worldwide distribution. The pathogen can infect a wide range of fish, including Salmonidae, Cyprinidae, Anguillidae, Ictaluridae, and Acipenseridae (Declercq *et al.*, 2015; Verma *et al.*, 2015; Lange *et al.*, 2021).

The disease outbreak is highly temperature-dependent, thus, more incidences of disease outbreaks are expected at higher water temperatures as the optimal temperature of *F. columnare* is varied from 25 °C (Cain and LaFrentz, 2007) to 37 °C (Bernardet, 1989), with the shortest generation times of 2 hours at 30 °C, 3.7 hours at 20 °C, 4.4 hours at 15 °C, and 34 hours at 4°C (Soltani and Burke, 1995). If fish are affected by the virulent strains of the bacterium at 20-35 °C, rapid mortality can occur without any clinical signs (Soltani *et al.*, 1996). Thus, the disease outbreaks and mortality by *F. cloumnare* are associated with seasons when water temperature rises (Evenhuis *et al.*, 2014), and temperatures above 18°C promote columnaris epidemics with high mortalities (Runtuvuori-Salmela *et al.*, 2022). The effect of higher temperatures on columnaris disease is due to the shortening of the bacterial generation time, increasing the adhesion capacity of the pathogen in fish tissues, increasing the host susceptibility to columnaris disease, and enhancing the chances of bacterial initiation and colonization

(Suomalainen *et al.*, 2006; Farmer *et al.*, 2021). It has been suggested that global warming has an impact on the increased prevalence of columnaris disease in countries such as Finland, where the water temperature has increased by approximately 2-3°C over a twenty-year period (Shoemaker *et al.*, 2012).

Flavobacterium johnsoniae

F. johnsoniae, formerly known as *Cytophaga johnsonae*, the causative agent of the false columnaris (Soltani *et al.*, 1994), is a suitable model organism for studying gliding motility function, gene regulation, and biochemistry (McBride *et al.*, 2009).

Although *F. johnsoniae* is generally regarded as an opportunistic fish pathogen, it has been able to induce disease in barramundi fish when the water temperature was lowered from 28°C to 20°C (Soltani *et al.*, 1994). During the five-year surveillance of fin-rot problems in Norwegian salmonid fish farms, the bacterium was the most dominant etiological agent. Therefore, with the increasing temperatures in aquatic ecosystems, the infection by this bacterium can become more prevalent in both freshwater and brackish environments.

Flavobacterium psychrophilum

F. psychrophilum, a filamentous Gram-negative bacterium, is the causative agent of the systemic disease called bacterial cold-water disease (also called rainbow trout fry syndrome) (Harrison *et al.*, 2022). The disease has been frequently reported in wild and cultured salmonids as well as non-salmonids.

Most of the recovered bacterial isolates can grow at temperatures ranging from 4-23°C,

with an optimum growth temperature of 12-15 °C. However, it cannot survive at 25 °C or higher (Oplinger and Wagner, 2013; Tenma *et al.*, 2021). The disease predominantly occurs at 16 °C but is generally more prevalent and severe at 10 °C (Starliper, 2011). Thus, bacterial cold-water disease can be prevalent in the northern or southern hemispheres where the iced mountains are thawing due to climate change.

Flavobacterium branchiophilum

F. branchiophilum, an ubiquitous bacterium in the freshwater environment, is the causative agent of bacterial gill disease (BGD) (Dar *et al.*, 2022). Many juvenile freshwater fish species are susceptible to BGD (Plumb and Hanson 2010), but cultured salmonids, mainly rainbow and brook trout, are the most severely affected species. BGD has been reported to have a worldwide distribution, ranging from North America and Europe to Japan, and water supply, sediments, and pathogen-carrying fish are thought to be the reservoirs of the bacteria.

The bacterium generally grows at 4 to 23 °C, depending on the bacterial strain. The optimum growth of the bacteria is also varied among different strains and has been reported to be in the range of 15-19 °C (Uddin *et al.*, 2008). Although the virulence of *F. branchiophilum* is not as severe as that of *F. columnare* or *F. psychrophilum*, it is still one of the important pathogens that affect salmonid aquaculture industries.

As a result of climate change, heavy rainfall may occur, causing disturbance in fine particle-size sediments in the water supply pipes or in the spring collection basin. These sediments

can enter holding tanks, and, as a result, BGD outbreaks may occur within 1-2 days. Also, seasonality may have an influence on BGD occurrence since the majority of outbreaks happen in the spring, which coincides with an increase and/or fluctuation in water temperatures. However, the relationship between the environment, in particular the effect of climate change, and the occurrence of the disease warrants further studies.

Tenacibaculum maritimum

T. maritimum, the cause of an ulcerative disease of marine fish, is an opportunistic bacterium that commonly invades the gills and skin of susceptible fish (Valdes *et al.*, 2021). Although an increase in the population of this agent has been observed with gill disease (Ruane *et al.*, 2013), the relationship between these two factors has not yet been discovered. The pathogen has been reported in many different marine fish species in Japan, Europe, Australia, the United States, Chile, and Canada (Frisch *et al.*, 2018; Bateman *et al.*, 2022). Other species of *Tenacibaculum* that have been implicated as salmonid pathogens and cause similar disease complications are *T. finnmarkense* (Småge *et al.*, 2016, 2017) and *T. dicentrarchi* (Wade & Weber, 2020). The significance and emergence of tenacibaculosis have been noted recently in a variety of cage-cultured marine fishes, including salmonids of different ages (Toranzo *et al.*, 2005).

The growth temperature of the pathogen is 15-35 °C with an optimum at 30 °C (Avendaño-Herrera *et al.*, 2006). Depending on the type of bacterial strain, environmental stressors such as high water temperature (> 15 °C) are usually a

risk factor for the disease occurrence (Downes *et al.*, 2018; Frisch *et al.*, 2018). Other risk factors, including high salinity (30 ppt), increased ammonia, and physical or toxic damage, can all be stimulated by the change in global climate making fish become more susceptible to such bacterial disease (Mitchell and Rodger, 2011).

Motile Aeromonads

Various species of motile *Aeromonas* species are the causative agents of motile *Aeromonas* septicaemia (Rahman *et al.*, 2022), among which *Aeromonas hydrophila*, *A. veroni*, *A. sobria*, and *A. dhakensis* are more prevalent as the cause of disease in finfish (Carriero *et al.*, 2016; Ninh *et al.*, 2021). However, *A. hydrophila* is the most serious pathogen, and it caused bacterial septicaemia in various fish species, including salmonids (Eftekharmanavi *et al.*, 2020). It is also a serious pathogen for amphibians, reptiles, and humans (Dias *et al.*, 2016; Woo *et al.*, 2022). The severity of the disease is often stress-dependent particularly under conditions of water temperature fluctuations leading to higher temperatures and poor water quality conditions (Kim *et al.*, 2021).

The pathogen can be isolated from various water sources, including brackish water, freshwater, estuaries, seawater, chlorinated water, sludge, sewage, and aquatic sediments, particularly during the warm months of the year.

Depending on the species, they prefer temperatures of 22-28 °C or 35-37 °C and salinity up to 6% NaCl for a better growth and

multiplication (Joseph and Carnahan, 1994). An increase in water temperature can influence the host's susceptibility and is linked with the production of bacterial virulent factors such as cytotoxins and haemolysins, hence, the virulence factors seem to be temperature-dependent. For instance, clinical strains of *A. hydrophila* can grow at temperatures higher than 28 °C, but when the temperature is raised to 37 °C, the protease activity of the bacterium decreases while the cytotoxin and haemolysin activities increase (Rasmussen-Ivey *et al.*, 2016). From a climate change point of view, outbreaks of motile *Aeromonas* septicaemia in salmon farms are notable, as with an increase in water temperature, more morbidity and mortality can be anticipated.

***Vibrio* spp.**

Vibriosis is caused by certain *Vibrio* and *Photobacterium* species, which are important pathogens in marine aquatic environments. These agents are pathogenic in wild and farmed aquatic animals, including fish, crustaceans, molluscs, corals, and rotifers (Gomez-Gil *et al.*, 2014). About 60% of heterotrophic bacteria are *vibrio* species and are predominant in seawater (Nagasawa and Cruz-Lacierda, 2004; Rivera, 2006). Many *Vibrio* species can cause disease in salmonids, but there are more reports of outbreaks by *Vibrio anguillarum*, *Vibrio salmonicida* (hitra disease; cold water vibriosis), *Moritella viscosa* (*Vibrio viscosus*) (Vintersår, winter ulcer), *Moritella logei*, and *Vibrio splendidus* (Noga, 2010).

Like motile *Aeromonas* sp., *Vibrio* can survive in aquatic environments, particularly in

water above 17 °C (Pridgeon and Klesius, 2012). Depending on the strain, the optimal temperature is between 15 and 30°C. At temperatures above 20°C, cryophilic vibrios like *V. logei*, *V. wodanis*, and *V. salmonicida* grow poorly (Thompson *et al.*, 2004). All species are sensitive to acid and grow best at neutral or alkaline pH levels up to 9 (Igbinosa and Okoh, 2008).

Stressors due to chemical (diet, water quality, and pollution), physical (salinity and temperature), and biological (population density, macro- or microorganisms) agents/substances are all risk factors for vibriosis outbreaks in marine farmed fish including salmonids (Huicab-Pech *et al.*, 2016). Climate change, like other diseases, affects the epidemiological patterns of vibriosis as the changes in water temperature in early to mid-summer provide an optimal growth condition for *Vibrio* spp., as do low water quality, salinity fluctuations, and inadequate nutrition (Gratacap, 2008; Albert and Ransangan, 2013).

According to studies by the US Environmental Protection Agency, there is scientific evidence that global warming is increasing sea temperatures, including evidence that the aquatic temperature has risen by about 1 °C over the past 100 years (NOAA, 2021). However, there is a possibility that the polar ice caps will melt, which could lead to a decrease in seawater salinity worldwide. Given that vibrios, except for a few species, prefer warmer waters, the conditions are likely to facilitate the increase of the bacterial population with a

consequent increase in the risk of vibriosis outbreaks (Roux *et al.*, 2015).

Rickettsiae

Piscirickettsia salmonis, the first pathogenic *Rickettsia* identified in fish, is a Gram-negative, immobile, aerobic, non-encapsulated, pleomorphic bacteria that is usually coccoid-shaped (Carrizo *et al.*, 2021). *Piscirickettsia*-like bacteria have been identified in freshwater and seawater fish species causing a significant impact on the aquaculture industry in different regions, including Chile, Scotland, Ireland, Norway, Croatia, Australia, New Zealand, and the Mediterranean Sea region (Cusack *et al.*, 2002; Mauel and Miller, 2002). The disease has been mostly reported in salmonids, but occasionally other species can also be infected (Zrnčić *et al.*, 2021).

The optimum temperature of *P. salmonis* is 15 to 18 °C, but it does not grow at 25 °C or more, which is the reason for its lack of growth in warm-blooded animals (Fryer *et al.*, 1990). Fluctuation in water temperature appears to be an important factor for disease outbreaks and the highest prevalence of the infection is observed in autumn and spring, which is probably due to the suitable temperature for bacterial multiplication in host tissues (Cvitanich *et al.*, 1990). Outside the host, the survival of *P. salmonis* is also affected by water temperature and salinity, as *P. salmonis* survives in seawater for a long time but is rapidly inactivated in freshwater. *P. salmonis* can tolerate seawater at 5 to 10 °C for 21 days, at 15 °C for 14 days, and at 20 °C for 7 days (Lannan and Fryer, 1994). Thus, the disease outbreak occurs after a period of extensive changes in the water

environment, including temperature fluctuations and an increase in concentration of non-toxic algae (Branson and Diaz-munoz, 1991). With an increase in global climate change, such pathogens may adapt to the new conditions.

Climate change and disease outbreaks by Gram-positive bacteria

Streptococcus spp. and *Lactococcus* spp.

Lactococcus garviae and *Streptococcus iniae* are two Gram-positive microorganisms that are more important bacterial species causing major health problems in many fish species of freshwater-, brackish-, and marine environments (Pekala-Safińska, 2018; A El-Noby *et al.*, 2021, Soltani *et al.*, 2021a; Van Doan *et al.*, 2022). Dependent on water temperature, streptococcal/lactococcal infections can be classified into warm-water infections caused by cocci species such as *L. garviae*, *S. iniae*, *S. agalactiae*, *S. dysgalactiae*, *S. parauberis*, and *S. uberis* and cold-water infections caused by cocci such as *Vagococcus salmoninarum* and *L. piscium* (Romalde *et al.*, 2008; Vendrell *et al.*, 2006).

However, almost all streptococcal/lactococcal agents are able to invade aquatic organisms, including salmonids, in both cold and temperate aquatic ecosystems (Soltani *et al.*, 2005; Haghighi Karsidani *et al.*, 2010; Soltani *et al.*, 2014; Soltani *et al.*, 2021a, b; Van Doan *et al.*, 2022). Disease outbreaks in some regions, such as the Middle East, are highly serious problem in farmed trout, especially during the warm seasons (Soltani *et al.*, 2015). Therefore, a rise in inland water temperature caused by global

warming is a significant predisposing factor in salmonid aquaculture (Soltani *et al.*, 2021b; Van Doan *et al.*, 2022).

Renibacterium salmoninarum

R. salmoninarum, as a Gram-positive bacterium, is the causative agent of bacterial kidney disease, one of the most serious bacterial infections in salmonid species (Delghandi *et al.*, 2020a; Fuentes *et al.*, 2022). It is a slow-growing organism with an optimal growth at temperature of 15 to 18°C, so with global warming, it could imply that a stress associated with rising water temperature contributes to the spread of disease in the northern and southern hemispheres (Delghandi *et al.*, 2020a). For instance, global warming can facilitate more disease outbreaks in farmed salmonids in regions such as North America, Europe, and Japan.

Mycobacterium spp.

The bacteria are acid-fast, non-motile, aerobic bacilli belonging to the family *Mycobacteriaceae* of the order Actinomycetales, with an optimal growth temperature of 25-35 °C (Delghandi *et al.*, 2020b). Mycobacteriosis is a granulomatous disease that primarily affects aquarium fish and farmed food fish, particularly those raised in harsh conditions (Kumari *et al.*, 2020).

Fish mycobacteriosis is a chronic, progressive disease caused by nontuberculous mycobacteria, including *M. marinum*, *M. fortuitum*, and *M. chelonae* (Hashish *et al.*, 2018). Piscine mycobacteriosis is a common disease of marine, brackish, and freshwater fish that affects over 200 freshwater and marine fish species. Warmer temperatures can affect both

the spread and the progression of fish mycobacteriosis worldwide (Collins *et al.*, 2020). Thus, fluctuations in water temperature are stressful to fish, making the host more vulnerable to the pathogens, as the ideal temperature for disease development is 25 °C-27 °C (Delghandi *et al.*, 2020b; Dar *et al.*, 2022).

Conclusion

Regarding the physiological features of bacterial fish pathogens, it is clearly understood that climate change, particularly global warming, can seriously affect the spread of disease in the aquaculture sector, including farmed salmonids. This is because global warming can reduce the generation time of the pathogenic mesophilic bacteria. However, the effects of climate change on the development of infectious diseases in aquaculture are complex and multifactorial and thus require more attention in detail.

Acknowledgment

This work was partial funded by University of Tehran.

Conflict of interest

The authors have no conflict of interest in this work.

References

A El-Noby, G., Hassanin, M., El-Hady, M. and Aboshabana, S., 2021. Streptococcus: A review article on an emerging pathogen of farmed fishes. *Egyptian Journal of Aquatic Biology*

and Fisheries, 25(1), 123-139. <https://doi.org/10.21608/ejabf.2021.138469>

Abirami, B., Radhakrishnan, M., Kumaran, S. and Wilson, A., 2021. Impacts of global warming on marine microbial communities. *Science of The Total Environment*, 791, 147905. <https://doi.org/10.1016/j.scitotenv.2021.147905>

Albert, V. and Ransangan, J., 2013. Effect of water temperature on susceptibility of culture marine fish species to vibriosis. *International Journal of Research in Pure and Applied Microbiology*, 3(3), 48-52.

Avendaño-Herrera, R., Toranzo, A. E. and Magariños, B., 2006. Tenacibaculosis infection in marine fish caused by *Tenacibaculum maritimum*: a review. *Diseases of aquatic organisms*, 71(3), 255-266. <https://doi.org/10.3354/dao071255>

Bateman, A. W., Teffer, A. K., Bass, A., Ming, T., Kaukinen, K., Hunt, B. P., Krkošek, M. and Miller, K. M., 2022. Atlantic salmon farms are a likely source of *Tenacibaculum maritimum* infection in migratory Fraser River sockeye salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, 99(999), 1-16. <https://doi.org/10.1139/cjfas-2021-0164>

Bernardet, J. F., 1989. France and comparison with bacterial strains from other origins. *Diseases of Aquatic Organisms*, 6, 37-44. <https://doi.org/10.3354/dao006037>

Branson, E. and Diaz-munoz, D. N., 1991. Description of a new disease condition

occurring in farmed coho salmon, *Oncorhynchus kisutch* (Walbaum), in South America. *Journal of fish diseases*, 14(2), 147-156. <https://doi.org/10.1111/j.1365-2761.1991.tb00585.x>

Brosnahan, C. L., Munday, J. S., Ha, H. J., Preece, M. and Jones, J. B., 2019. New Zealand rickettsia-like organism (NZ-RLO) and *Tenacibaculum maritimum*: distribution and phylogeny in farmed Chinook salmon (*Oncorhynchus tshawytscha*). *Journal of fish diseases*, 42(1), 85-95. <https://doi.org/10.1111/jfd.12909>

Butler, C., (Ed.) 2016. Climate change and global health. CABI.

Cain, K. D. and LaFrentz, B. R., 2007. Laboratory maintenance of *Flavobacterium psychrophilum* and *Flavobacterium columnare*. *Current protocols in microbiology*, 6(1), 13B-1. <https://doi.org/10.1002/9780471729259.mc13b01s6>

Carriero, M., Mendes Maia, A., Moro Sousa, R. and Henrique-Silva, F., 2016. Characterization of a new strain of *Aeromonas dhakensis* isolated from diseased pacu fish (*Piaractus mesopotamicus*) in Brazil. *Journal of fish diseases*, 39(11), 1285-1295. <https://doi.org/10.1111/jfd.12457>

Carrizo, V., Valenzuela, C.A., Aros, C., Dettliff, P., Valenzuela-Muñoz, V., Gallardo-Escarate, C., Altamirano, C., Molina, A. and Valdés, J.A., 2021. Transcriptomic analysis reveals a *Piscirickettsia salmonis*-induced early inflammatory response in rainbow trout skeletal

muscle. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, 39, p.100859. <https://doi.org/10.1016/j.cbd.2021.100859>

Chen, C., Zou, W., Cui, G., Tian, J., Wang, Y. and Ma, L., 2020. Ecological risk assessment of current-use pesticides in an aquatic system of Shanghai, China. *Chemosphere*, 257, 127222. <https://doi.org/10.1016/j.chemosphere.2020.127222>

Cheung, W. W. and Frölicher, T. L., 2020. Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific. *Scientific reports*, 10(1), 1-10. <https://doi.org/10.1038/s41598-020-63650-z>

Cheung, W. W., Frölicher, T. L., Lam, V. W., Oyinlola, M. A., Reygondeau, G., Sumaila, U. R., Tai, T.C., Teh, L.C. and Wabnitz, C. C., 2021. Marine high temperature extremes amplify the impacts of climate change on fish and fisheries. *Science Advances*, 7(40), eabh0895. <https://doi.org/10.1126/sciadv.abh0895>

Chiaramonte, L., Munson, D. and Trushenski, J., 2016. Climate change and considerations for fish health and fish health professionals. *Fisheries*, 41(7), 396-399. <https://doi.org/10.1080/03632415.2016.1182508>

Collins, C., Bresnan, E., Brown, L., Falconer, L., Guilder, J., Jones, L., Kennerley, A., Malham, S., Murray A. and Stanley, M., 2020. Impacts of climate change on aquaculture.

MCCIP Science Review 2020, 482–520.
<https://doi.org/10.14465/2020.arc21.aqu>

Cusack, R. R., Groman, D. B. and Jones, S. R., 2002. Rickettsial infection in farmed Atlantic salmon in eastern Canada. *The Canadian Veterinary Journal*, 43(6), 435.

Cvitanich, J., Garate, O., and Smith, C., 1990. Etiological agent in a Chilean coho disease isolated and confirmed by Koch's postulates. *FHS/AFS Newsletter*, 18, 1-2.

Dar, G. H., Bhat, R. A., Qadri, H., Al-Ghamdi, K. M. and Hakeem, K., 2022. *Bacterial Fish Diseases*. Elsevier.

Declercq, A. M., Chiers, K., Haesebrouck, F., Van Den Broeck, W., Dewulf, J., Cornelissen, M. and Decostere, A., 2015. Gill infection model for columnaris disease in common carp and rainbow trout. *Journal of aquatic animal health*, 27(1), 1-11.
<https://doi.org/10.1080/08997659.2014.953265>

Delghandi, M. R., El-Matbouli, M. and Menanteau-Ledouble, S., 2020a. *Renibacterium salmoninarum*—The causative agent of bacterial kidney disease in salmonid fish. *Pathogens*, 9(10), 845.

Delghandi, M. R., Menanteau-Ledouble, S., Waldner, K. and El-Matbouli, M., 2020b. *Renibacterium salmoninarum* and *Mycobacterium* spp.: Two bacterial pathogens present at low levels in wild brown trout (*Salmo trutta fario*) populations in Austrian rivers. *BMC veterinary research*, 16(1), 1-12.

Dias, M. K., Sampaio, L. S., Proietti-Junior, A. A., Yoshioka, E. T., Rodrigues, D. P., Rodriguez, A. F., Ribeiro, R. A., Faria, F. S., Ozório, R. O. and Tavares-Dias, M., 2016. Lethal dose and clinical signs of *Aeromonas hydrophila* in *Arapaima gigas* (Arapaimidae), the giant fish from Amazon. *Veterinary microbiology*, 188, 12-15.
<https://doi.org/10.1016/j.vetmic.2016.04.001>

Downes, J., Yatabe, T., Marcos-Lopez, M., Rodger, H., MacCarthy, E., O'Connor, I., Collins, E. and Ruane, N., 2018. Investigation of co-infections with pathogens associated with gill disease in Atlantic salmon during an amoebic gill disease outbreak. *Journal of fish diseases*, 41(8), 1217-1227.
<https://doi.org/10.1111/jfd.12814>

Eftekharmanavi, S., Peyghan, R., Soltani, M., & Ghorbanpoor najafabadi, M., 2020. Investigation on protective effect of recombinant protein (OmpTS) of *Aeromonas hydrophila* in Common carp (*Cyprinus carpio*). *Aquaculture Research*, 51(9), 3479-3487.
<https://doi.org/10.1111/are.14682>

Evenhuis, J. P., LaPatra, S. E. and Marancik, D., 2014. Early life stage rainbow trout (*Oncorhynchus mykiss*) mortalities due to *Flavobacterium columnare* in Idaho, USA. *Aquaculture*, 418, 126-131.
<https://doi.org/10.1016/j.aquaculture.2013.09.044>

FAO. 2014. The State of World Fisheries and Aquaculture (Sofia) 2014. Available:

<http://www.fao.org/documents/card/en/c/097d8007-49a4-4d65-88cd-fcaf6a969776/>.

FAO. 2019. Fishery and Aquaculture Statistics. Global aquaculture production 1950-2017 (FishstatJ). Available: <http://www.fao.org/fishery/statistics/software/fishstatj/en>.

Farmer, B. D., Fuller, S. A., Beck, B. H., Abernathy, J. W., Lange, M. D. and Webster, C. D., 2021. Differential susceptibility of white bass (*Morone chrysops*), striped bass (*Morone saxatilis*) and hybrid striped bass (*M. chrysops* × *M. saxatilis*) to *Flavobacterium columnare* and effects of mucus on bacterial growth and biofilm development. *Journal of Fish Diseases*, 44(2), 161-169. <https://doi.org/10.1111/jfd.13272>

Frisch, K., Småge, S. B., Brevik, Ø. J., Duesund, H. and Nylund, A., 2018. Genotyping of *Tenacibaculum maritimum* isolates from farmed Atlantic salmon in Western Canada. *Journal of fish diseases*, 41(1), 131-137. <https://doi.org/10.1111/jfd.12687>

Fryer, J., Lannan, C., Garces, L., Larenas, J. and Smith, P., 1990. Isolation of a rickettsiales-like organism from diseased coho salmon (*Oncorhynchus kisutch*) in Chile. *Fish Pathology*, 25(2), 107-114. <https://doi.org/10.3147/jsfp.25.107>

Fuentes, D. E., Acuña, L. G. and Calderón, I. L., 2022. Stress response and virulence factors in bacterial pathogens relevant for

Chilean aquaculture: current status and outlook of our knowledge. *Biological Research*, 55(1), 1-9.

Galappaththi, E. K., Susarla, V. B., Loutet, S. J., Ichien, S. T., Hyman, A. A. and Ford, J. D., 2022. Climate change adaptation in fisheries. *Fish and Fisheries*, 23(1), 4-21. <https://doi.org/10.1111/faf.12595>

Gomez-Gil, B., Thompson, C. C., Matsumura, Y., Sawabe, T., Iida, T., Christen, R., Thompson, F. and Sawabe, T., 2014. The Family Vibrionaceae. In: The Prokaryotes: Gammaproteobacteria, in: Rosenberg, E., DeLong, E. F., Lory, S., Stackebrandt, E. and Thompson, F. (Eds.), Springer Berlin Heidelberg, pp. 659-747. https://doi.org/10.1007/978-3-642-38922-1_225

Gratacap, R. M., 2008. Characterisation of *Vibrio anguillarum* for the development of vaccine in cod (*Gadus morhua*).

Haghighi Karsidani, S., Soltani, M., Nikbakhat-Brojeni, G., Ghasemi, M., & Skall, H. F., 2010. Molecular epidemiology of zoonotic streptococcosis/lactococcosis in rainbow trout (*Oncorhynchus mykiss*) aquaculture in Iran. *Iranian journal of microbiology*, 2(4), 198.

Harrison, C. E., Knupp, C. K., Brenden, T. O., Ebener, M. P. and Loch, T. P., 2022. First isolation of *Flavobacterium psychrophilum* from wild adult great lake whitefish (*Coregonus clupeaformis*). *Journal of Fish Diseases*. <https://doi.org/10.1111/jfd.13626>

- Hashish, E., Merwad, A., Elgaml, S., Amer, A., Kamal, H., Elsadek, A., Marei, A. and Sitohy, M., 2018. *Mycobacterium marinum* infection in fish and man: epidemiology, pathophysiology and management; a review. *Veterinary Quarterly*, 38(1), 35-46. <https://doi.org/10.1080/01652176.2018.1447171>
- Huicab-Pech, Z., Landeros-Sánchez, C., Castañeda-Chávez, M., Lango-Reynoso, F., López-Collado, C. and Platas Rosado, D., 2016. Current state of bacteria pathogenicity and their relationship with host and environment in tilapia *Oreochromis niloticus*. *Journal of aquaculture research and development*, 7(5), 1-10.
- Igbiosa, E. O. and Okoh, A. I., 2008. Emerging *Vibrio* species: an unending threat to public health in developing countries. *Research in microbiology*, 159(7-8), 495-506. <https://doi.org/10.1016/j.resmic.2008.07.001>
- Joseph, S. W. and Carnahan, A., 1994. The isolation, identification, and systematics of the motile *Aeromonas* species. *Annual Review of Fish Diseases*, 4, 315-343. [https://doi.org/10.1016/0959-8030\(94\)90033-7](https://doi.org/10.1016/0959-8030(94)90033-7)
- Kayansamruaj, P., Dong, H. T., Hirono, I., Kondo, H., Senapin, S. and Rodkhum, C., 2017. Comparative genome analysis of fish pathogen *Flavobacterium columnare* reveals extensive sequence diversity within the species. *Infection, Genetics and Evolution*, 54, 7-17. <https://doi.org/10.1016/j.meegid.2017.06.012>
- Kim, K. T., Lee, S. H., Lee, K. K., Han, J. E. and Kwak, D., 2021. Enhanced Virulence of *Aeromonas hydrophila* Is Induced by Stress and Serial Passaging in Mice. *Animals*, 11(2), 508. <https://doi.org/10.3390/ani11020508>
- Kumar, G., Menanteau-Ledouble, S., Saleh, M. and El-Matbouli, M., 2015. *Yersinia ruckeri*, the causative agent of enteric redmouth disease in fish. *Veterinary research*, 46(1), 1-10. <https://doi.org/10.1186/s13567-015-0238-4>
- Kumari, K., 2020. Pathogens of major concern in fish: A review. *Journal of Advances in Microbiology Research*, 1(1), 15-18.
- Lange, M. D., Abernathy, J., Farmer, B. D. and Beck, B. H., 2021. Use of an immersion adjuvant with a *Flavobacterium columnare* recombinant protein vaccine in channel catfish. *Fish & Shellfish Immunology*, 117, 136-139. <https://doi.org/10.1016/j.fsi.2021.07.025>
- Lannan, C. and Fryer, J., 1994. Extracellular survival of *Piscirickettsia salmonis*. *Journal of fish diseases*, 17(5), 545-548. <https://doi.org/10.1111/j.1365-2761.1994.tb00251.x>
- Lulijwa, R., Alfaro, A. C. and Young, T., 2022. Metabolomics in salmonid aquaculture research: Applications and future perspectives. *Reviews in Aquaculture*, 14(2), 547-577. <https://doi.org/10.1111/raq.12612>
- Marandi, A. and Rahmati-Holasoo, H., 2021. A comprehensive overview of Mycobacteriosis; zoonosis and transmissible disease between fish and humans. *Journal of Fisheries*, 74(4), 511-523. <https://doi.org/10.22059/jfisheries.2021.319834.1235>

- Marcogliese, D. J., 2008. The impact of climate change on the parasites and infectious diseases of aquatic animals. *Review Science Technology*, 27(2), 467-484.
- Marcos-López, M., Gale, P., Oidtmann, B. C. and Peeler, E. J., 2010. Assessing the impact of climate change on disease emergence in freshwater fish in the United Kingdom. *Transboundary and emerging diseases*, 57(5), 293-304. <https://doi.org/10.1111/j.1865-1682.2010.01150.x>
- Mauel, M. J. and Miller, D. L., 2002. Piscirickettsiosis and piscirickettsiosis-like infections in fish: a review. *Veterinary microbiology*, 87(4), 279-289. [https://doi.org/10.1016/S0378-1135\(02\)00085-8](https://doi.org/10.1016/S0378-1135(02)00085-8)
- McBride, M. J., Xie, G., Martens, E. C., Lapidus, A., Henrissat, B., Rhodes, R. G., Goltsman, E., Wang, W., Xu, J., Hunnicutt, D.W. and Staroscik, A.M., 2009. Novel features of the polysaccharide-digesting gliding bacterium *Flavobacterium johnsoniae* as revealed by genome sequence analysis. *Applied and environmental microbiology*, 75(21), 6864-6875. <https://doi.org/10.1128/AEM.01495-09>
- Mitchell, S. and Rodger, H. 2011. A review of infectious gill disease in marine salmonid fish. *Journal of fish diseases*, 34(6), 411-432. <https://doi.org/10.1111/j.1365-2761.2011.01251.x>
- Nagasawa, K. and Cruz-Lacierda, E. R., 2004. Diseases of cultured groupers. Aquaculture Department, Southeast Asian Fisheries Development Center.
- Nhinh, D. T., Le, D. V., Van, K. V., Huong Giang, N. T., Dang, L. T. and Hoai, T. D., 2021. Prevalence, virulence gene distribution and alarming the multidrug resistance of *Aeromonas hydrophila* associated with disease outbreaks in freshwater aquaculture. *Antibiotics*, 10(5), 532. <https://doi.org/10.3390/antibiotics10050532>
- NOAA., 2021. Climate Change Indicators: Sea Surface Temperature. Available: <https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature>
- Noga, E. J., 2010. Fish Disease: Diagnosis and Treatment. 2nd ed. USA: Wiley-Blackwell.
- Oplinger, R. W. and Wagner, E. J., 2013. Control of *Flavobacterium psychrophilum*: tests of erythromycin, streptomycin, osmotic and thermal shocks, and rapid pH change. *Journal of Aquatic Animal Health*, 25(1), 1-8. <https://doi.org/10.1080/08997659.2012.720636>
- Pajdak-Czaus, J., Platt-Samoraj, A., Szweda, W., Siwicki, A. K. and Terech-Majewska, E., 2019. *Yersinia ruckeri*—A threat not only to rainbow trout. *Aquaculture Research*, 50(11), 3083-3096. <https://doi.org/10.1111/are.14274>
- Palmeiro, B. and Roberts, H., 2013. Bacterial disease in fish. In: Clinical Veterinary Advisor: Birds and exotic pets, in: Mayer, J., Donnelly, T. M., Elsevier/Saunders, pp. 17-20.

- Patra, A., Sarker, S., Banerjee, S., Adikesavalu, H., Biswas, D. and Abraham, T. J., 2016. Rapid detection of *Flavobacterium columnare* infection in fish by species-specific polymerase chain reaction. *Journal of Aquaculture Research & Development*, 7, 445.
- Pękala-Safińska, A., 2018. Contemporary threats of bacterial infections in freshwater fish. *Journal of veterinary research*, 62(3), 261-267.
- Plumb, J. A. and Hanson, L. A., 2010. Health maintenance and principal microbial diseases of cultured fishes. John Wiley & Sons.
- Pridgeon, J. W. and Klesius, P. H., 2012. Major bacterial diseases in aquaculture and their vaccine development. *CABI Reviews*, 7, 1-16. <https://doi.org/10.1079/PAVSNNR20127048>
- Rahman, M. M., Rahman, M. A., Hossain, M. T., Siddique, M. P., Haque, M. E., Khasruzzaman, A. K. M. and Islam, M. A., 2022. Efficacy of bi-valent whole cell inactivated bacterial vaccine against Motile Aeromonas Septicemia (MAS) in cultured catfishes (*Heteropneustes fossilis*, *Clarias batrachus* and *pangasius pangasius*) in Bangladesh. *Saudi Journal of Biological Sciences*, 29(5), 3881-3889. <https://doi.org/10.1016/j.sjbs.2022.03.012>
- Rahmati-Holasoo, H., Marandi, A., Ebrahimzadeh Mousavi, H., & Azizi, A., 2021. Study of the losses of Siberian sturgeon (*Acipenser baerii*) due to gill infection with *Diclybothrium armatum* in sturgeon farms of Qom and Mazandaran provinces. *Journal of Animal Environment*, 13(4), 193-200. <https://doi.org/10.22034/AEJ.2021.165929>
- Rahmati-Holasoo, H., Marandi, A., Ebrahimzadeh Mousavi, H. and Taheri Mirghaed, A., 2022. Parasitic fauna of farmed freshwater ornamental fish in the northwest of Iran. *Aquaculture International*, 30(2), 633-652. <https://doi.org/10.1007/s10499-021-00832-0>
- Rasmussen-Ivey, C. R., Figueras, M. J., McGarey, D. and Liles, M. R., 2016. Virulence factors of *Aeromonas hydrophila*: in the wake of reclassification. *Frontiers in microbiology*, 7, 1337. <https://doi.org/10.3389/fmicb.2016.01337>
- Rivera, H. U. a. I. N. G., 2006. Aquatic Environment. In: The biology of vibrios. Washington, D.C., ASM Press, pp. 175-189.
- Romalde, J. L., Ravelo, C., Valdés, I., Magariños, B., de la Fuente, E., San Martín, C., Avendaño-Herrera, R. and Toranzo, A. E., 2008. *Streptococcus phocae*, an emerging pathogen for salmonid culture. *Veterinary Microbiology*, 130(1-2), 198-207. <https://doi.org/10.1016/j.vetmic.2007.12.021>
- Romstad, A. B., Reitan, L. J., Midtlyng, P., Gravningen, K., & Evensen, Ø., 2012. Development of an antibody ELISA for potency testing of furunculosis (*Aeromonas salmonicida* subsp *salmonicida*) vaccines in Atlantic salmon (*Salmo salar* L). *Biologicals*, 40(1), 67-71.

<https://doi.org/10.1016/j.biologicals.2011.09.011>

Roux, F. L., Wegner, K. M., Baker-Austin, C., Vezzulli, L., Osorio, C. R., Amaro, C., Ritchie, J. M., Defoirdt, T., Destoumieux-Garzón, D. and Blokesch, M., 2015. The emergence of *Vibrio* pathogens in Europe: ecology, evolution, and pathogenesis (Paris, 11–12th March 2015). *Frontiers in microbiology*, 6, 830. <https://doi.org/10.3389>

Ruane, N., Rodger, H., Mitchell, S., Doyle, T., Baxter, E. and Fringuelli, E., 2013. GILPAT: An Investigation into Gill Pathologies in Marine Reared Finfish.

Runtuvuori-Salmela, A., Kunttu, H. M., Laanto, E., Almeida, G. M., Mäkelä, K., Middelboe, M. and Sundberg, L. R., 2022. Prevalence of genetically similar *Flavobacterium columnare* phages across aquaculture environments reveals a strong potential for pathogen control. *Environmental Microbiology*, 24(5), 2404-2420. <https://doi.org/10.1111/1462-2920.15901>

Schwenteit, J., Bogdanović, X., Fridjonsson, O. H., Aevansson, A., Bornscheuer, U. T., Hinrichs, W., & Gudmundsdottir, B. K., 2013. Toxoid construction of AsaP1, a lethal toxic aspzincin metalloendopeptidase of *Aeromonas salmonicida* subsp. *achromogenes*, and studies of its activity and processing. *Veterinary microbiology*, 162(2-4), 687-694. <https://doi.org/10.1016/j.vetmic.2012.09.015>

Shoemaker, C. A., LaFrentz, B. R. and Klesius, P. H., 2012. The *Flavobacterium columnare* challenge: Host, Genomovar and Virulence. In: *Flavobacterium Meeting*. *Flavobacterium*, pp. 41.

Småge, S. B., Brevik, Ø. J., Duesund, H., Ottem, K. F., Watanabe, K. and Nylund, A., 2016. *Tenacibaculum finnmarkense* sp. nov., a fish pathogenic bacterium of the family Flavobacteriaceae isolated from Atlantic salmon. *Antonie Van Leeuwenhoek*, 109(2), 273-285. <https://doi.org/10.1007/s10482-015-0630-0>

Småge, S. B., Brevik, Ø. J., Frisch, K., Watanabe, K., Duesund, H. and Nylund, A., 2017. Concurrent jellyfish blooms and tenacibaculosis outbreaks in Northern Norwegian Atlantic salmon (*Salmo salar*) farms. *PloS one*, 12(11), e0187476.

Soltani, M. and Burke, C. M., 1995. Responses of fish-pathogenic Cytophaga/Flexibacter-like bacteria (CFLB) to environmental conditions. *Bulletin of the European Association of Fish Pathologists*.

Soltani, M., Baldisserotto, B., Hosseini Shekarabi, S. P., Shafiei, S. and Bashiri, M., 2021a. Lactococcosis a Re-Emerging Disease in Aquaculture: Disease Significant and Phytotherapy. *Veterinary Sciences*, 8(9), 181.

Soltani, M., Jamshidi, S. and Sharifpour, I., 2005. Streptococcosis caused by *Streptococcus iniae* in farmed rainbow trout (*Oncorhynchus mykiss*) in Iran: biophysical characteristics and

pathogenesis. *Bulletin of the European Association of Fish Pathologists*, 25(3), 95-106.

Soltani, M., Mohamadian, S., Rouholahi, S., Soltani, E., & Rezvani, S., 2015. Shirazi thyme (*Zataria multiflora*) essential oil suppresses the expression of PavA and Hly genes in *Lactococcus garvieae*, the causative agent of lactococcosis in farmed fish. *Aquaculture*, 442, 74-77. doi.org/10.1016/j.aquaculture.2015.03.001

Soltani, M., Mokhtari, A., Mirzargar, S. S., Taherimirghaed, A., Zargar, A., Shafiei, S., & Hosseini-Shekarabi, S. P., 2016. Efficacy and immune response of intraperitoneal vaccination of rainbow trout (*Oncorhynchus mykiss*) with a *Yersinia ruckeri* bacterin formulated with Montanide™ ISA 763 AVG adjuvant. *Bulletin of European Association of Fish Pathologists*, 36(6), 225-236.

Soltani, M., Munday, B. and Carson, J., 1994. Susceptibility of some freshwater species of fish to infection by *Cytophaga johnsonae*. *Bulletin of the European Association of Fish Pathologists*.

Soltani, M., Munday, B. L. and Burke, C. M., 1996. The relative susceptibility of fish to infections by *Flexibacter columnaris* and *Flexibacter maritimus*. *Aquaculture*, 140(3), 259-264. [https://doi.org/10.1016/0044-8486\(95\)01157-9](https://doi.org/10.1016/0044-8486(95)01157-9)

Soltani, M., Naeiji, N., Zagar, A., Shohreh, P. and Taherimirghaed, A., 2021b. Biotyping and

serotyping of *Lactococcus garvieae* isolates in affected farmed rainbow trout (*Oncorhynchus mykiss*) in north Iran. *Iranian Journal of Fisheries Sciences*, 20(6), 1542-1559.

Soltani, M., Shafiei, S., Yosefi, P., Mosavi, S. H., & Mokhtari, A., 2014. Effect of Montanide™ IMS 1312 VG adjuvant on efficacy of *Yersinia ruckeri* vaccine in rainbow trout (*Oncorhynchus mykiss*). *Fish & shellfish immunology*, 37(1), 60-65. <https://doi.org/10.1016/j.fsi.2013.12.027>

Soto-Dávila, M., Chakraborty, S. and Santander, J., 2022. Relative expression and validation of *Aeromonas salmonicida* subsp. *salmonicida* reference genes during ex vivo and in vivo fish infection. *Infection, Genetics and Evolution*, 105320. <https://doi.org/10.1016/j.meegid.2022.105320>

Starliper, C. E., 2011. Bacterial coldwater disease of fishes caused by *Flavobacterium psychrophilum*. *Journal of Advanced Research*, 2(2), 97-108. <https://doi.org/10.1016/j.jare.2010.04.001>

Suomalainen, L. R., Kunttu, H., Valtonen, E. T., Hirvelä-Koski, V. and Tiirola, M., 2006. Molecular diversity and growth features of *Flavobacterium columnare* strains isolated in Finland. *Diseases of aquatic organisms*, 70(1-2), 55-61. <https://doi.org/10.3354/dao070055>

Taheri-Mirghaed, A., Soltani, M., Shafiei, S., Mirzargar, S., & Shokrpur, S., 2018. Pathogenicity of *Yersinia ruckeri* in Rainbow trout (*Oncorhynchus mykiss*). *Journal of*

Veterinary Research, 73(1). 1-8.
<https://doi.org/10.22059/jvr.2017.118638.2252>

Tenma, H., Tsunekawa, K., Fujiyoshi, R., Takai, H., Hirose, M., Masai, N., Sumi, K., Takihana, Y., Yanagisawa, S., Tsuchida, K. and Ohara, K., 2021. Spatiotemporal distribution of *Flavobacterium psychrophilum* and ayu *Plecoglossus altivelis* in rivers revealed by environmental DNA analysis. *Fisheries science*, 87(3), 321-330.
<https://doi.org/10.1007/s12562-021-01510-z>

Tewari, R., Dudeja, M., Nandy, S. and Das, A.K., 2014. Isolation of *Aeromonas salmonicida* from human blood sample: a case report. *Journal of clinical and diagnostic research: JCDR*, 8(2), p.139.
<https://doi.org/10.7860/JCDR/2014/6883.4032>

Thompson, F. L., Iida, T. and Swings, J., 2004. Biodiversity of vibrios. *Microbiology and molecular biology reviews*, 68(3), 403-431.
<https://doi.org/10.1128/MMBR.68.3.403-431.2004>

Toranzo, A. E., Magariños, B. and Romalde, J. L., 2005. A review of the main bacterial fish diseases in mariculture systems. *Aquaculture*, 246(1-4), 37-61.
<https://doi.org/10.1016/j.aquaculture.2005.01.002>

Uddin, M. N., Al-Harbi, A. H. and Wakabayashi, H., 2008. Optimum temperatures for the peak growth of some selected bacterial fish pathogens. *Asian Fisheries Science*, 21, 205-214.

Valdes, S., Irgang, R., Barros, M. C., Ilardi, P., Saldarriaga-Córdoba, M., Rivera-Bohle, J., Madrid, E., Gajardo-Córdova, J. and Avendaño-Herrera, R., 2021. First report and characterization of *Tenacibaculum maritimum* isolates recovered from rainbow trout (*Oncorhynchus mykiss*) farmed in Chile. *Journal of Fish Diseases*, 44(10), 1481-1490.
<https://doi.org/10.1111/jfd.13466>

Van Doan, H., Soltani, M., Leitão, A., Shafiei, S., Asadi, S., Lymbery, A. J., & Ringø, E., 2022. Streptococcosis a Re-Emerging Disease in Aquaculture: Significance and Phytotherapy. *Animals*, 12, 2443.
<https://doi.org/10.3390/ani12182443>

Vasquez, I., Hossain, A., Gnanagobal, H., Valderrama, K., Campbell, B., Ness, M., Charette, S.J., Gamperl, A.K., Cipriano, R., Segovia, C., and Santander, J., 2022. Comparative Genomics of Typical and Atypical *Aeromonas salmonicida* Complete Genomes Revealed New Insights into Pathogenesis Evolution. *Microorganisms*, 10(1), 189.
<https://doi.org/10.3390/microorganisms10010189>

Vendrell, D., Balcázar, J. L., Ruiz-Zarzuela, I., De Blas, I., Gironés, O. and Múzquiz, J. L., 2006. *Lactococcus garvieae* in fish: a review. *Comparative immunology, microbiology and infectious diseases*, 29(4), 177-198.
<https://doi.org/10.1016/j.cimid.2006.06.003>

Verma, D. K., Rathore, G., Pradhan, P. K., Sood, N. and Punia, P., 2015. Isolation and characterization of *Flavobacterium columnare* from freshwater

ornamental goldfish *Carassius auratus*. *Journal of Environmental Biology*, 36(2), 433.

Wade, J. and Weber, L., 2020. Characterization of *Tenacibaculum maritimum* and mouth rot to inform pathogen transfer risk assessments in British Columbia. *DFO Canadian Science Advisory Secretariat*. Research document, 61.

Wade, N. M., Clark, T. D., Maynard, B. T., Atherton, S., Wilkinson, R. J., Smullen, R. P. and Taylor, R. S., 2019. Effects of an unprecedented summer heatwave on the growth performance, flesh colour and plasma biochemistry of marine cage-farmed Atlantic salmon (*Salmo salar*). *Journal of thermal biology*, 80, 64-74. <https://doi.org/10.1016/j.jtherbio.2018.12.021>

Woo, P. T., and Cipriano, R. C., (Eds.) 2017. Fish viruses and bacteria: pathobiology and protection. CABI.

Woo, S. J., Kim, M. S., Jeong, M. G., Do, M. Y., Hwang, S. D. and Kim, W. J., 2022. Establishment of Epidemiological Cut-Off Values and the Distribution of Resistance Genes in *Aeromonas hydrophila* and *Aeromonas veronii* Isolated from Aquatic Animals. *Antibiotics*, 11(3), 343. <https://doi.org/10.3390/antibiotics11030343>

Wrobel, A., Leo, J. C. and Linke, D., 2019. Overcoming fish defences: the virulence factors of *Yersinia ruckeri*. *Genes*, 10(9), 700. <https://doi.org/10.3390/genes10090700>

Ziafati Kafi, Z., Ghalyanchilangeroudi, A., Nikaein, D., Marandi, A., Rahmati-Holasoo,

H., Sadri, N., Erfanmanesh, A. and Enayati, A., 2022. Phylogenetic analysis and genotyping of Iranian infectious haematopoietic necrosis virus (IHNV) of rainbow trout (*Oncorhynchus mykiss*) based on the glycoprotein gene. *Veterinary Medicine and Science*. <https://doi.org/10.1002/vms3.931>

Zrnčić, S., Vendramin, N., Boutrup, T. S., Boye, M., Madsen, L., Nonneman, B., Brnić, D. and Oraić, D., 2021. First description and diagnostics of disease caused by *Piscirickettsia salmonis* in farmed European sea bass (*Dicentrarchus labrax* Linnaeus) from Croatia. *Journal of Fish Diseases*, 44(7), 1033-1042. <https://doi.org/10.1111/jfd.13366>