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Current and potential future impacts of food- and water-borne parasites in a changing world: A Norwegian perspective

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A B S T R A C T

In 2021, the Norwegian Scientific Committee for Food and Environment published a multi-criteria risk ranking of 20 potentially food-borne pathogens in Norway. The pathogens ranked included five parasite taxa (3 species, one genus, one family): *Toxoplasma gondii*, *Echinococcus multilocularis*, *Giardia duodenalis*, *Cryptosporidium* spp., and Anisakidae. Two of these, *T. gondii* and *E. multilocularis*, scored very highly (1st and 3rd place, respectively), *Cryptosporidium* was about midway (9th place), and *G. duodenalis* and Anisakidae ranked relatively low (15th and 20th place, respectively). Parasites were found, on average, more likely to present an increasing food-borne disease burden in the future than the other pathogens. Here, we review the current impact of these five potentially food-borne parasites in Norway, and factors of potential importance in increasing their future food-borne disease burden. Climate change may affect the contamination of water and fresh produce with transmission stages of the first four parasites, potentially leading to increased infection risk. Alterations in host distribution (potentially due to climate change, but also other factors) may affect the occurrence and distribution of *Toxoplasma*, *Echinococcus*, and Anisakidae, and these, coupled with changes in food consumption patterns, could also affect infection likelihood. Transmission of food-borne pathogens is complex, and the relative importance of different pathogens is affected by many factors and will not remain static. Further investigation in, for example, ten-years' time, could provide a different picture of the relative importance of different pathogens. Nevertheless, there is clearly the potential for parasites to exert a greater risk to public health in Norway than currently occurs.

1. Introduction

Compared with viruses and bacteria, (food-borne) parasites are relatively neglected by health and regulatory bodies (FAO, 2021). Among the 20 neglected tropical diseases listed by the World Health Organization (WHO) in their 2021–2030 roadmap (WHO, 2021), 12 are parasites (or groups thereof) and, of these, seven are associated with food-borne or waterborne transmission. One reason why parasites are neglected is due to their association with poverty (Robertson, 2018); exposure to parasitic infections (and other pathogens) is generally higher in populations living where basic infrastructure, such as good sanitation and a clean water supply, are lacking.

Against this background, it could seem unlikely that Norway and other Nordic countries should be concerned with food-borne parasites. The most recent Human Development Report of the United Nations Development Programme (UNDP, 2024), ranks the Human Development Index of Norway as the second highest globally (after Switzerland), based on indicators such as life expectancy at birth and gross national income per capita. Other Nordic countries also ranked highly: Iceland at #3, Denmark and Sweden both at #5, and Finland at #12. Furthermore, with a low population density (approximately 5.5 million citizens, around 14/km^2 - the European average being around 34/km^2), relative geographical isolation, and ample freshwater availability, food-borne parasites seem unlikely to be a Norwegian concern. Nevertheless, food-borne illness is a global issue and, in 2019, Norway's Food Safety Authority requested that the Norwegian Scientific Committee for Food and the Environment (VKM) undertake a ranking of infectious agents and food combinations potentially posing a risk to public health. In particular, VKM was asked to rank 20 agents: 12 bacteria, 5 parasites, and 3 viruses. Infectious agents covered by regulated food-control programmes (such as *Trichinella*, *Taenia saginata*, *Mycobacterium bovis*, etc.) were excluded. Ranking was based on expert knowledge elicitation on six criteria, concerned with prevalence, morbidity (acute and chronic) and mortality, along with likelihood of the burden of human disease increasing in the future.

The report from this exercise (VKM, 2021) ranked the five selected

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parasites at first (*Toxoplasma gondii*), third (*Echinococcus multilocularis*), 9th (*Cryptosporidium* spp.), 15th (*Giardia duodenalis*), and 20th/last (nematodes of the family Anisakidae) positions (Fig. 1). Four of the parasites (*T. gondii*, *E. multilocularis*, *Cryptosporidium* spp. and *G. duodenalis*) may enter the food chain as contaminants of fresh produce (or water), and *Toxoplasma* may also enter the food chain *via* meat from infected animals. Nematodes of the family Anisakidae enter the food chain solely through marine fish or cephalopods.

A previous Europe-wide ranking of food-borne parasites (Bouwknegt et al., 2018), reported a slightly different prioritization list for Northern Europe, with *E. multilocularis* heading the list, followed by *Cryptosporidium*, with *Toxoplasma* and Anisakidae ranked 4th and 5th, respectively. *Giardia* did not feature at all, probably reflecting that the European ranking did not include water as a transmission vehicle.

In the Norwegian ranking, all parasites obtained a relatively high score (mean of 1.98 of a maximum of 3) regarding the likelihood of increasing disease burden, ranging from 1.0 (Anisakidae) to 2.67 (*E. multilocularis*) (VKM, 2021). For the other 15 pathogens, scores for this criterion ranged from 0.56 (*Clostridium perfringens*) to 2.67 (*Vibrio* spp.), the mean score being 1.43. Thus, an increasing food-borne disease burden in Norway was considered more likely to be due to parasites than the other pathogens ranked. Here, we review each of these five parasites individually, regarding both their impacts in Norway now, and how and why we might expect their food-borne disease burden to increase in the future.

2. *Toxoplasma gondii* (food-borne pathogen species ranked as #1 in Norway)

Toxoplasma gondii is a highly successful apicomplexan protist. Although usually causing only benign symptoms in people, it may result in severe health problems, including abortion, in women first infected during pregnancy. A systematic review indicated a European seroprevalence of around 32%, but generally lower in northern Europe, particularly Norway (Calero-Bernal et al., 2023). Indeed, seropositivity in Norway among pregnant women has been low and stable for around three decades; the last published survey from Norway reported a seroprevalence of 9.3% among pregnant women from two regions (Findal et al., 2015). However, it is noted that this lack of seropositivity among fertile women leaves them vulnerable to infection during pregnancy (Findal et al., 2015), and thus with the potential for congenital transmission; this likely contributed to the high ranking for this parasite (VKM, 2021).

Despite the low human *Toxoplasma* seroprevalence in Norway, data from Norwegian livestock and some game animals show quite substantial seroprevalences. Although recent studies are lacking, Skjerve et al. (1998) reported around 44% of sheep flocks (and 16% of individual lambs) had antibodies against *Toxoplasma*. Among wild cervids, around 40% of roe deer, 13% of moose, 8% of red deer, and 1% of reindeer were found to be seropositive (Vikøren et al., 2004). Furthermore, over 40% of domestic cats in Norway were seropositive (Saevik et al., 2015). These animal data indicate that *Toxoplasma* is circulating among animal populations in Norway, with the potential, should triggers arise, for spill-over into a susceptible human population.

In Arctic regions, including Norway, notably the Svalbard archipelago, high seroprevalences have been reported from various Arctic species, such as polar bears and canids (Bouchard et al., 2022). Given the general absence of felids above the treeline, *Toxoplasma* has been postulated to enter Arctic environments in northern Norway with migrant birds (Sandström et al., 2013; Bouchard et al., 2022), thereafter being maintained by carnivorous cycling between intermediate hosts. Climate change, already a reality in Norway (Fig. 2), may, however, mean felid populations expanding their ranges, and the potential for oocysts entering the environment, contaminating otherwise pristine water sources. *Toxoplasma* has previously been detected in Norwegian waters (Harito et al., 2017), and climate change may result in such contamination becoming more widespread. It is also possible that movement of cervid populations may result in the spread of *Toxoplasma*, as has been reported for caribou in North America (Hernández-Ortiz et al., 2023).

Further studies to improve our knowledge of this parasite in the Norwegian environment in current conditions would be of value, and molecular markers should be employed to confirm the genotype(s) circulating in Norway. Although less-virulent genotypes (II and III) have previously been reported from Norwegian wildlife (Bouchard et al., 2022), globalization and substantial import of fresh fruit, especially from South America, may result in the introduction of more virulent genotypes. For example, among 820 berry samples from the Norwegian

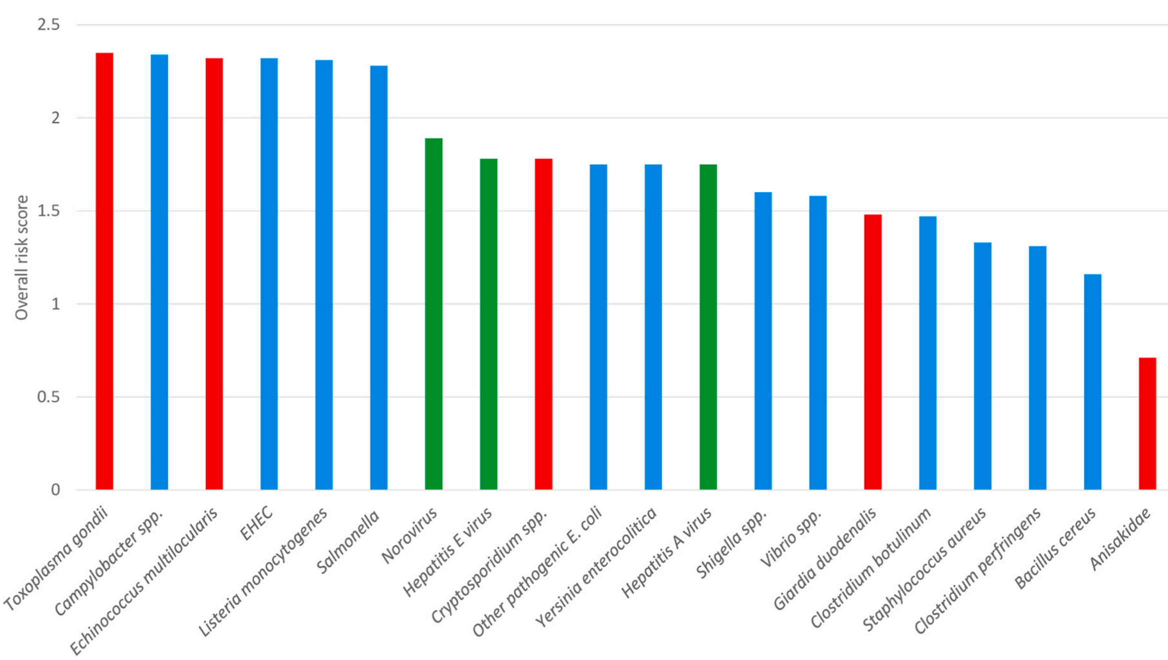

Fig. 1. Ranking of food-borne pathogens in Norway by expert knowledge elicitation (VKM, 2021). Bars in red represent parasites, bars in blue represent bacteria, and bars in green represent viruses.

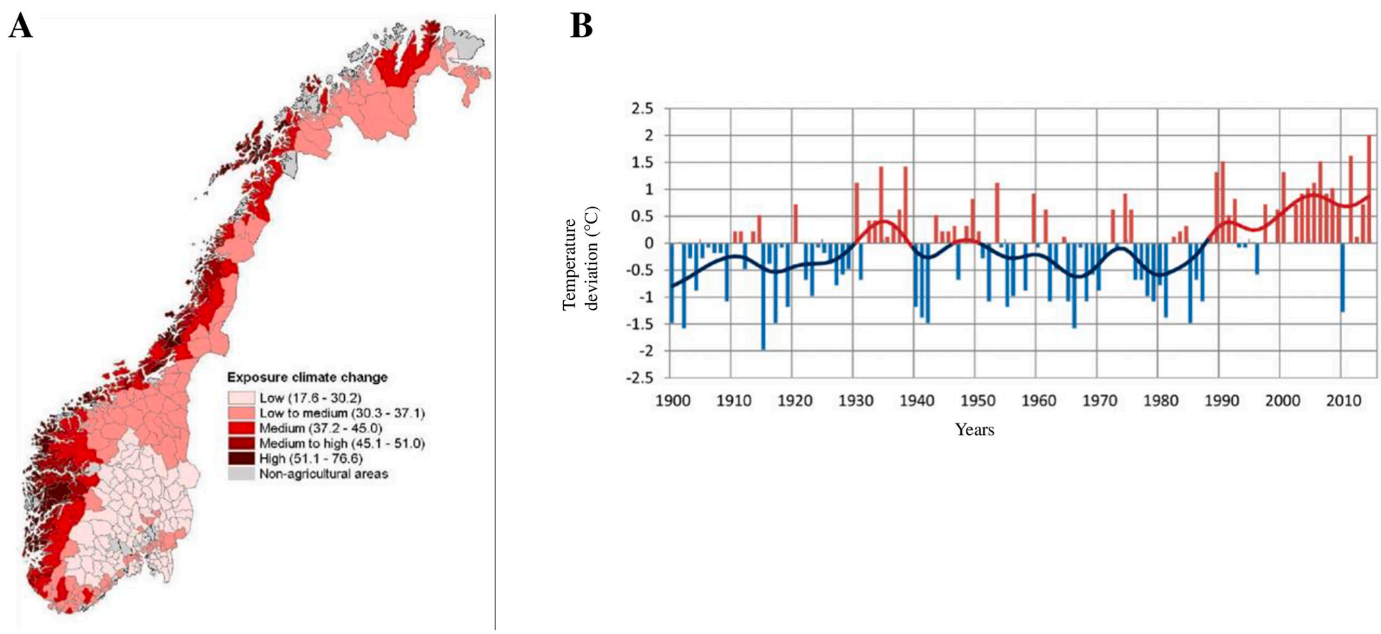

Fig. 2. Data from the Norwegian Centre for Climate Services (NCCS, 2015) showing areas in Norway according to their exposure to predicted effects of climate change (**A**) and deviations in annual temperatures from the mean temperature during 1917–2000 in mainland Norway, hinting at effects of climate change under the current scenario (**B**). Red bars illustrate positive deviations in temperature, blue bars are negative deviations in temperature, and the line shows the trend.

market analysed in Norway, around 3% were positive for *Toxoplasma* DNA, with many of the positive samples being imported, including berries from Chile and Peru (Temesgen et al., 2022).

3. *Echinococcus multilocularis* (food-borne pathogen species ranked as #3 in Norway)

The cestode, *Echinococcus multilocularis*, is widely distributed within, but restricted to, the Northern Hemisphere, covering much of the temperate and Arctic regions of Eurasia and North America (Romig and Wassermann, 2024). The parasite causes alveolar echinococcosis (AE) in humans following ingestion of eggs shed from the definitive canid hosts, predominantly red foxes (*Vulpes vulpes*). AE is responsible for 688,000 disability-adjusted life-years globally (Torgerson et al., 2015).

Unlike Sweden and Denmark, *E. multilocularis* is not endemic in the Norwegian mainland but is established on Norway's Svalbard archipelago, where the life-cycle seems to be maintained between the only rodents there (the sibling vole, *Microtus levis*) and Arctic foxes (Davidson et al., 2012). In northern regions of North America, the polar fox and the brown lemming seem important in maintaining the life-cycle (Massolo et al., 2014). A similar situation could occur in Fennoscandia, although *E. multilocularis* infection in the Norwegian lemming has not, to date, been reported.

Assuming similar distributions of rodent intermediate host species in Scandinavian countries and free flow of canid definitive hosts, particularly the red fox, it seems only a matter of time before this parasite establishes in Norway also (VKM, 2012), raising the possibility of human endemic infection.

The first detection of *E. multilocularis* in Sweden occurred in 2011 (Osterman Lind et al., 2011). Although only nine cases of alveolar echinococcosis were diagnosed in Sweden between the years 2012–2020, six of these were reported from 2018 (Bläckberg et al., 2020). Five of these had a Swedish background, with a mean age at diagnosis of 61 years, with the remaining patients having an immigrant background - but had not returned to their home countries for 30 years. As the establishment of *E. multilocularis* larvae is asymptomatic (Kern et al., 2017) and the parasite can grow undetected for 10–15 years in immunocompetent individuals (Ammann and Eckert, 1996), it is impossible to determine whether these infections were acquired in Sweden, as all patients had travelled to endemic countries (e.g. Central Europe) within this timeframe. The authors do not state that these infections occurred in Sweden, but they note the difficulty in localizing infections with long incubation periods; however, a Swedish public health press report states that it is no longer possible to exclude domestic infection (Bläckberg et al., 2020).

Patient survival is heavily influenced by country of diagnosis. In Switzerland, patient survival following diagnosis is reduced by only a few years compared to an AE-negative age-matched population; in Lithuania, the prognosis is worse; $>$ 30% of patients dying within 1 year of diagnosis. Key contributing factors include medical infrastructure, but also awareness of the parasite (VKM, 2021). This is of concern in Norway, where knowledge of this parasite is low.

The life-cycle of *E. multilocularis* can be maintained by various canids, but suitable species of intermediate hosts are less clear. Areas of high endemicity, where prevalence in foxes exceeds 50%, roughly coincide with the occurrence of the common vole (*Microtus arvalis*). This vole species is not currently found in Fennoscandia, and the life-cycle is presumably maintained in Sweden by the less-susceptible field vole (*Microtus agrestis*) and the water vole (*Arvicola amphibius*) (Romig and Wassermann, 2024). However, climate change could result in habitat compatibility for the common vole on the Scandinavian Peninsula. This could significantly increase transmission potential and thereby the likelihood of human infection here, including in Norway.

4. *Cryptosporidium* spp. (food-borne pathogen genus ranked as #9 in Norway)

Cryptosporidium spp. are protozoan intestinal parasites utilizing a direct faecal-oral life-cycle, and are often transmitted by oocyst-contaminated water or food (especially fresh produce), as well as directly from human or animal infections. *Cryptosporidium parvum*, a zoonotic species and the most common cause of cryptosporidiosis in Norway, as well as being an important public health problem, also causes livestock production losses. Symptoms include diarrhoea, abdominal pain, nausea, weight loss and dehydration (Thomson et al., 2017). In healthy, immunocompetent hosts, symptoms typically last for around two weeks before resolving. In immunocompromised hosts, however, chronic diarrhoea and infection in extra-intestinal locations can occur (Thomson et al., 2017). Around 20% of cryptosporidiosis cases diagnosed in Norway require hospitalisation (VKM, 2021).

Currently, only nitazoxanide is available for treating human infections, but is not appropriate for the most vulnerable groups, the very young and the immunocompromised. The damp, cool climate of Scandinavia facilitates transmission of *Cryptosporidium*, and it has been noted that Nordic countries may be particularly associated with food-borne cryptosporidiosis (Robertson and Chalmers, 2013). A European ranking of food-borne parasites identified *Cryptosporidium* spp. as more important in both northern and western Europe (2nd place) than in eastern and south-western Europe (8th place), and south-eastern Europe (below 10th place) (Bouwknegt et al., 2018). Although large outbreaks of waterborne cryptosporidiosis have been reported from Sweden (e.g. Rehn et al., 2015), as well as several substantial food-borne outbreaks (Bujila et al., 2024), Norwegian outbreaks have usually been associated with contact with infected young ruminants. The only recorded food-borne outbreak in Norway involved only a few cases (Robertson et al., 2019b). However, surveillance data indicate diagnosis of cryptosporidiosis in Norway is rising, and that most cases have been acquired endemically (e.g. Campbell et al., 2022).

Transmission of cryptosporidiosis is extremely sensitive to climate conditions, with temperature, rainfall, and relative humidity being particularly significant (Ikiroma and Pollock, 2021). A study from Canada reported that extreme precipitation following a dry period was associated with a rise in human cryptosporidiosis cases (Chhetri et al., 2017). Environmental contamination by *Cryptosporidium* oocysts is thus likely to increase due to climate change in Norway (Fig. 2). This, coupled with globalization and rising consumer tendencies for fresh produce, is likely to increase human cryptosporidiosis. Population shifts, with more immunosuppressed and/or elderly in the population, may also result in greater disease severity.

Species and genotypes of *Cryptosporidium* may also be of importance. Currently over 40 species of *Cryptosporidium* have been described, of which around 20 have been associated with human infection. Although zoonotic *C. parvum* predominates in human infections in Nordic countries, including Norway, an interesting recent trend in this region indicates the importance of a newly recognised species, *Cryptosporidium mortiferum* (previously *Cryptosporidium* chipmunk genotype I). This seems to be an emerging zoonotic threat in Scandinavia, with 20% of cryptosporidiosis cases in Finland caused by this species (Häkkänen et al., 2024) and an ongoing survey suggesting that over 5% of Norwegian cryptosporidiosis cases are caused by *C. mortiferum* (Hanevik and Tipu, pers. comm.).

5. *Giardia duodenalis* (food-borne pathogen species ranked as #15 in Norway)

As with *Cryptosporidium*, the enteric flagellate parasite *Giardia duodenalis* has frequently been associated with major waterborne outbreaks due to contamination of water supplies with *Giardia* cysts. One of these occurred in Bergen, Norway in 2004 resulting in several thousand cases of giardiasis (Robertson et al., 2006). This water-borne outbreak is probably one reason why the Norwegian ranking of food-borne pathogens (in which drinking water was included as a food) ranked at position number 14 among food-borne pathogens (VKM, 2021), despite giardiasis cases never having been associated with food in Norway. Although *Giardia* cysts have been detected on fresh produce during screening projects, there has not been any association with infection, and cyst numbers have been low. Contamination of drinking water sources with *Giardia* cysts is also routinely detected in Norway, although cyst concentrations are, again, low. We have already suggested that climate change may increase water contamination in Norway with *Cryptosporidium* oocysts (see *Section 4*), and the same is true of *Giardia* cysts. A discussion of two risk assessments conducted in Norway regarding contamination of water with parasites (Robertson et al., 2021), noted that run-off from the environment to surface waters, which are the primary sources of Norwegian drinking water, under increased precipitation events could increase contamination. Furthermore, climate change may affect water colour and quality (humic matter content), which may have a detrimental effect on the efficacy of some drinking-water treatment methods used in Norway (Robertson et al., 2021). The study from Canada that reported an association between extreme precipitation following a dry period and a rise in human cryptosporidiosis cases noted a similar pattern for cases of giardiasis (Chhetri et al., 2017). The authors suggest that this is likely due to greater run-off associated with soil compaction in dry periods (Chhetri et al., 2017). As higher turbidity was also noted, water disinfection systems may also be sub-optimal in such conditions.

Unlike cryptosporidiosis, it seems that the majority of cases of giardiasis diagnosed in Norway are acquired abroad (Campbell et al., 2022). However, the Bergen outbreak reminds us that endemic transmission can and does occur. It is possible that due to the less acute symptoms associated with giardiasis, fewer people who are infected seek medical assistance.

Zoonotic transmission of *Giardia* is currently considered to occur relatively rarely (Cai et al., 2021), and although *Giardia* infection occurs frequently in Norwegian domestic animals, molecular analysis indicates that host-specific assemblages predominate. However, genotypes that could be zoonotic (A and B) have been detected in wildlife species, such as foxes (Robertson et al., 2019a) and wild cervids (Robertson et al., 2007), in Scandinavia, including Norway. Given the potential for these relatively common animals to contaminate surface water sources, more extensive monitoring of these wildlife species and genetic characterisation of positive samples could be of value.

6. Anisakidae (food-borne pathogen family ranked as #20 in Norway)

Anisakiasis (clinical infection with an anisakid nematode, including members of the *Anisakis simplex* complex, the *Pseudoterranova decipiens* complex, and the *Contracecum osculatum* complex) results from ingestion of their third-stage larvae in inadequately cooked or processed seafood dishes. Although people are dead-end hosts, and larvae cannot progress to the adult stage in the human intestine, larval penetration can cause clinical disease, usually severe, acute epigastric pain, a few hours after ingestion (Adroher-Auroux and Benítez-Rodríguez, 2020). Additionally, parasite-specific antigens, which remain stable despite cooking or freezing, may cause “allergenic anisakiasis” in sensitized people. This is not an infection, but an allergic response, largely characterized by angioedema, urticaria, and anaphylaxis.

Anisakiasis (infection) has been particularly associated with countries where raw or lightly cooked marine fish are a substantial part of the diet, such as Spain and Japan. However, despite Norway being well-known as a marine fishing country, anisakiasis is uncommon, probably due to no tradition of eating raw fish. Thus, in the VKM ranking (VKM, 2021), Anisakidae scored lower than all other pathogens.

However, the occurrence of anisakid larvae in fish caught in Norwegian fishery areas (e.g. Norwegian coastal waters, the Barents Sea) is increasing. One study from 2022 showed that fish caught in Norwegian waters had a higher occurrence of anisakids than historical samples, cod and saithe being particularly highly infected (Kristiansen, 2022). Another study investigating fish from commercial fisheries in the Barents Sea in 2019 also noted abundant anisakid infections in cod and saithe (Levsen et al., 2022). Both studies postulate that rising populations of definitive hosts (marine mammals) in these fishery areas maybe relevant.

In addition to the rising occurrence of anisakid infections in commercially important fish, much of the world, including Norway, has simultaneously developed a taste for raw fish consumption (particularly sushi). This change in global eating habits has resulted in anisakiasis being considered an emerging infection (Robertson, 2018). Available data indicate that the number of sushi businesses in Norway rose from around 100 in 2006 to almost 350 in 2016 (STATISTA, 2017). Nevertheless, Norwegian regulations demand that fresh fish used in sushi should be frozen (−20 °C) for at least 24 h in order to kill anisakid worms (farmed salmon and trout are regarded as having negligible infection likelihood and are exempt; Roiha et al., 2017). Thus, most sushi/sashimi etc. in Norway probably do not represent an infection risk. However, although anisakiasis may not be expected to increase, exposure to anisakid antigens may be rising, with a consequent increase in allergenic anisakiasis. A systematic review from 2020, suggested that Portugal and Norway were two hot spots for allergenic anisakiasis, with allergy prevalences of over 20% (Rahmati et al., 2020). However, this has been strongly disputed (Daschner et al., 2021). Despite this topic being currently controversial, clearly anisakids in fish should remain of concern in Norwegian food safety.

7. Conclusion

Although food-borne infections probably do not occur more often in Norway than elsewhere in Europe, food-borne disease remains of concern. Recognition that parasites, traditionally neglected, are just as important as food-borne bacterial and viral pathogens is a positive advance. In Norway, *T. gondii* and *E. multilocularis* are of particular concern, *Cryptosporidium* spp. are of moderate concern, whereas *G. duodenalis* and anisakids remain of relatively minor concern. Nevertheless, changes in climate, eating habits, and food-chain globalisation may affect food-borne parasites in unexpected ways. We should be aware that a *status quo* should not be expected.

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Lucy J. Robertson: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Ian D. Woolsey:** Writing – original draft, Writing – review & editing. **Alejandro Jiménez-Meléndez:** Writing – original draft, Writing – review & editing.

Declaration of competing interests

Ian D. Woolsey and Alejandro Jiménez-Meléndez declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Lucy J. Robertson declares that she is a member of the Panel for Biological Hazards of the Norwegian Scientific Committee for Food and Environment (VKM) and participated in the risk ranking that provided the initial inspiration for this article.

Data availability

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