gastrointestinal disorders

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Review

Climate Change and Enteric Infections in the Canadian Arctic: Do We Know What's on the Horizon?

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Abstract: The Canadian Arctic has a long history with diarrheal disease, including outbreaks of campylobacteriosis, giardiasis, and salmonellosis. Due to climate change, the Canadian Arctic is experiencing rapid environmental transformation, which not only threatens the livelihood of local Indigenous Peoples, but also supports the spread, frequency, and intensity of enteric pathogen outbreaks. Advances in diagnostic testing and detection have brought to attention the current burden of disease due to *Cryptosporidium*, *Campylobacter*, and *Helicobacter pylori*. As climate change is known to influence pathogen transmission (e.g., food and water), Arctic communities need support in developing prevention and surveillance strategies that are culturally appropriate. This review aims to provide an overview of how climate change is currently and is expected to impact enteric pathogens in the Canadian Arctic.

Keywords: climate change; enteric pathogens; gastrointestinal infections; Canadian arctic

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1. Introduction

Gastrointestinal (GI) infections are a major contributor to global morbidity and mortality [1]. While GI infections can occur at any age, individuals vulnerable to dehydration (i.e., young children and the elderly) are at an increased risk of experiencing severe complications. Notably, dehydration due to diarrheal disease is one of the leading causes of death in children under the age of five [2]. Other symptoms of infection include nausea, vomiting, abdominal pain, and fatigue. Diagnosis is often clinical, but can involve culture dependent and independent methods [3]. Most infections are self-limiting and therefore do not require treatment; however, oral rehydration solution, antibiotics, and zinc may be provided if indicated [3].

Viruses, bacteria, and parasites are the most common pathogens involved in GI infections. These pathogens can spread through food-borne, water-borne, mechanical vector-borne, and/or person-to-person transmission. The seasonality of diarrheal disease is in part attributed to climate, which can influence pathogen growth and dissemination [4–6]. In a recent three year retrospective study, Chao et al. (2019) assessed the seasonal prevalence of enteric pathogens in children with mild-to-severe diarrhea in seven study sites in Africa and South Asia [7]. They observed that the incidence of certain enteric pathogens consistently peaked each year, although not necessarily at all study sites. In general, rotavirus was most prevalent during the dry winter months, whereas many bacterial pathogens were more prevalent during the hotter and wetter months. With regards to bacterial pathogens, other studies have similarly found that *Salmonella* and *Campylobacter* infections peak in the summer and spring, respectively [8,9]. It is important to note that viral-induced diarrhea has distinct peaks in temperate climates (e.g., norovirus in winter) and year-round peaks in tropical climates [8,10]. In addition to temperature, humidity also effects GI pathogen replication and transmission. Decreased humidity has been found to increase GI illness due to rotavirus infection in the tropics, Japan, and Peru [11–13]. Seasons also influence human behaviour (e.g., social interaction and water and food consumption), which may help facilitate the spread of enteric pathogens [14].

As climate changes, so too does the pattern of diarrheal disease. For example, flooding is associated with increases in cholera, cryptosporidiosis, rotavirus, typhoid, and paratyphoid [15–20]. In the United States [20], New Zealand [21], the Solomon Islands [22], and Canada [23,24], the occurrence of diarrhea correlates with increases in temperature, and changes in precipitation. Similarly, there has been a correlation established between flooding and increased bacterial and parasitic populations found in potable, drinking water [25,26]. Flooding is thought to increase GI illness through the contamination of water supplies (either with human or animal pathogens) that increase turbidity, which hinders adequate disinfection [27]. In comparison, drought is associated with increases in salmonellosis, shigellosis, and leptospirosis [28]. Drought is thought to concentrate pathogens in remaining water sources [29]. Climate patterns like El Niño events have been linked to increased diarrheal disease in Peru [30], Bangladesh [31], China [32], and Japan [33]. Understanding how climate change impacts enteric pathogens will facilitate disease forecasting, diagnostic ability, and outbreak preparedness. It is for these reasons that Ledin and Macrae (2020), in a recent clinical review, urged the gastroenterology community to become more involved in the climate change movement through educating, advocating, and supporting others in their efforts [34].

While climate change is already having significant impacts globally, the Arctic is experiencing some of the fastest rates of environmental change with warming occurring at two to three times the global average [35–37]. The Arctic in Canada is inhabited by over 100,000 people, who primarily live in small, remote communities outside of city centers (Figure 1) [38]. Much of Northern Canada is Inuit Nunangat, the homeland of approximately 65,000 Inuit in Canada. The cold predictable northern climate is important to Inuit health and well-being as ice and snow offer opportunities to travel between communities, harvest and prepare foods, and for other cultural activities [39,40]. Climate change has not only impacted the livelihoods of Indigenous Peoples living in the Arctic [37], but also supports the spread, frequency, and intensity of infectious diseases [41]. Consequently, the purpose of this review is to summarize what is known about the relationship between enteric pathogens and climate change in Northern Canada. We begin by characterizing the extent of enteric infection in the Arctic, with further exploration into the connection between diarrheal disease and water and food safety practices. In the next section, we focus on three pathogens prevalent in the Arctic to explore the impact of infection on gastrointestinal health and disease. Finally, looking at what is to come, we review how the burden of disease will be impacted by climate change and we identify areas in need of continued research.

Figure 1. Map of Canada highlighting key locations discussed in this review (map outline from Creative Commons).

2. The Current State of Enteric Infections in the Arctic

Arctic communities across North America have a well-documented history of diarrheal diseases [42–45]. Between 1991 and 2008, campylobacteriosis, giardiasis, and salmonellosis were the most commonly identified GI pathogens in 33 communities found in the Northwest Territories [46]. All three pathogens seasonally peaked in late summer to autumn. In the last decade, surveys in Arctic Canada have shown higher rates of acute gastrointestinal illness (AGI) compared to communities in southern Canada and other high-resource countries [10,47–50]. In September 2012, Iqaluit and Rigolet each had an estimated annual incidence rate of 3.8 episodes/person per year, which was roughly three times as high as the rates in Ontario and British Columbia [50]. Research by Harper et al. (2015) found that while Inuit communities had higher rates of self-reported AGI than non-Inuit communities, they had lower rates of AGI-related healthcare use [51]. It is therefore important to consider that traditional passive surveillance of health care utilization may not accurately reflect the burden of AGI disease in these communities. Beyond the obvious costs for AGI, there are also several indirect costs including loss of pay, altered diet, poorer mental health, and decreased social welfare [52]. The higher incidence of AGI in the Arctic has been associated with factors including animal exposure, overcrowding, and water and food safety practices.

Despite Canada being a water wealthy country, water quality is a persistent concern for many northern communities [53]. In some communities, homes are built with a drinking water storage tank that is filled by municipal tanker trucks. The water is drawn from local bodies of water, treated with chlorine, and then delivered by truck. While treated tap water is available in many households, people also collect their own water (e.g., brooks, lakes, icebergs, etc.) or purchase bottled water. In Rigolet, 77.6% of surveyed households consumed alternative sources of water stored in containers [54]. When these containers were sampled for pathogens, 25.2% were found to have coliform concentrations above acceptable levels. Furthermore, use of dippers and transfer devices was associated with an increase in total coliforms. In their study in Iqaluit, Masina et al. (2019) examined untreated drinking water between June and September 2016 for *E. coli* (indicator coliform) as well as two select pathogens: *Giardia* and *Cryptosporidium* [55]. Using standard methods for detection in environmental samples, 20% of samples tested positive for *Giardia*, 1.8% tested positive for *Cryptosporidium*, and 30.9% tested positive for *E. coli*.

These rates of *Giardia* and *Cryptosporidium* contamination appeared lower than previously recorded in other parts of Canada [55]. Similarly, in a study by Daley et al. (2016) that sampled other sites in the Arctic (Coral Harbour, Pond Inlet, and Pangnirtung), there were low levels of fecal coliforms and none of the specific pathogens were detected (e.g., *Campylobacter jejuni*, *Cryptosporidium parvum*, *Giardia lamblia*, etc.) [56]. However, the occurrence of enteric pathogens in surface water is notoriously variable over time and conditions. In order to fully characterize vulnerabilities in the Arctic water system, additional research needs to occur during environmentally stressful periods (e.g., snowmelt). In a study by Harper et al. (2011) based in Nain, there was a positive association between water volume (e.g., heavy rainfall, rapid snowmelt) and total coliform counts in untreated water, as well as clinic visits for AGI [57]. While water volume peaked in spring and summer, the number of AGI-related visits to the healthcare facility increased in summer and fall. These studies illustrate how microbial contamination varies throughout the Arctic. As microbial indicators, fecal coliforms, specifically *E. coli*, are often used to assess water quality. In recent years, however, this practice has been called into question as outbreaks of waterborne illnesses resulted from sources deemed safe by coliform concentration standards. Furthermore, the presence or absence of fecal coliforms does not always correlate to other enteric pathogens [58]. It will be important to continue monitoring the development of microbial indicators to assess their application in water quality evaluation in northern communities.

Throughout the Arctic, gastrointestinal health is not only impacted by access to clean drinking water, but also to safe wastewater disposal. Due to climate, population size, and remoteness, many Arctic communities use basic treatment systems for wastewater management [59]. Treatment systems involve the natural environment and typically occur in lagoons, wetlands, lakes, and ponds. In wastewater stabilization ponds (WSPs), for example, there is no discharge during the winter months as the pond is frozen. In the summer when the pond thaws, the elevated water temperature “treats” the pond contents, which can then be discharged into the surrounding environment (either land or water). These systems are only capable of low-level pathogen removal, meaning that potentially hazardous microorganisms can be released into the surrounding environment. In their study of WSPs in Nunavut at two separate sites over three consecutive summer treatment seasons, Huang et al. (2017) observed that the WSPs provided a 2–3 Log removal of the indicator organism, *E. coli* [60]. Nevertheless, not all bacteria were reliably removed as *Salmonella* spp., pathogenic *E. coli*, and *Listeria monocytogenes* were still detected. The extent to which gastrointestinal disease can be attributed to wastewater contamination remains unclear, but there are several models being used to generate estimates [61]. Water contamination not only poses a direct risk for AGI, but also can pose an indirect risk through the contamination of food.

Many communities in the Arctic rely on country foods, which are foods that are gathered, trapped, and hunted from the surrounding lands and waters. Country foods are not only an excellent source of nutrition, but also are a way to support cultural continuity [62]. Several studies have suggested that the preparation and consumption of country foods may increase the risk of enteric pathogens (e.g., walrus, seal, caribou, and whale linked to botulism and trichinosis were the most common country foods tied to GI illness) [63–65]. Strategies to reduce water- and food-related AGI must be culturally appropriate and done in consultation with Arctic communities [66]. The Government of Nunavut, for example, developed safety guidelines for the preparation and consumption of country food in government-funded facilities [65]. Furthermore, Rigolet youth, in collaboration with a research team and community members, developed a whiteboard video tool to share recommendations aimed at reducing the risk of AGI [67]. As shown above, different parts of the Arctic face different challenges in regard to water and food safety; therefore, strategies have to be tailored to fit each community.

3. In-Depth Review of Three Prevalent Enteric Arctic Pathogens

While the Canadian Arctic is home to a large number of enteric pathogens, it would not be feasible to provide a thorough analysis for each one in this review. As such, we have selected three pathogens that offer different insights into how Arctic communities are affected and adapting to enteric pathogens.

3.1. Cryptosporidium

Since the first documented case in humans in 1976 [68], *Cryptosporidium*, a microscopic intestinal parasite, has become one of the most common global causes of water-borne disease [69]. Additionally, in the recent 2017 Qanuilirpitaa? Nunavik Inuit Health Survey, *Cryptosporidium* seroprevalence was positively associated with the consumption of certain country foods, such as seal meat, sea trout, brook trout, salmon, and shellfish (mostly raw) [70]. There are many species of *Cryptosporidium*, but most human infections involve *C. hominis* (which can only infect humans) and *C. parvum* (an important zoonotic species) [71].

While cryptosporidiosis has been a reportable disease in Canada since 2000, *Cryptosporidium* went largely undetected in the Arctic until 2013 when more specific techniques were implemented [72]. In the Qikiqtani region of Nunavut, multiple-target molecular testing conducted over an 18 month period identified *Cryptosporidium* in 20% of all stool samples, making it the most commonly identified pathogen [73]. Importantly, during this study period, Nunavut's territorial enteric surveillance program did not detect any cases of cryptosporidiosis, therefore passive surveillance is believed to vastly underestimate the true number of cases [73,74]. Around the same time, the Nunavik region of Québec, Canada, began using modified acid-fast staining to detect *Cryptosporidium* in stool samples [75]. Then, using molecular subtyping, all study specimens were determined to be *C. hominis*, suggesting an important role for human-to-human transmission [75]. As an aside, a subsequent Québec-based study between 2016 and 2017 found that 74% of fecal samples—predominantly from Southern Quebec—were infected with *C. parvum* (in comparison to 23% with *C. hominis*), demonstrating the geographical predominance of certain species [76]. More information on the history of *Cryptosporidum* in the Arctic can be found in the recently published document by Ducrocq et al. (2021) [70].

Previous studies have found the highest incidence of *Cryptosporidium* to be amongst children under 5 years of age [75]. Of the *Cryptosporidium* species, *C. hominis* is the main cause of childhood diarrheal disease [77]. This finding is particularly worrying seeing that *Cryptosporidium* infection (with or without diarrhea) has been associated with reduced linear growth, lower adult height, impaired cognitive development, poor performance in school, and less economic productivity [78–80]. Furthermore, food insecurity, which is a concern for 24%–46% of surveyed Canadian Arctic households, exacerbates the effects of *Cryptosporidium* infection on growth and brain development [81]. Important to the context of water treatment in the north, *Cryptosporidium* is relatively resistant to chlorination; however, boiling, filtration, and UV treatment is effective [77]. Following the 2013–2015 *Cryptosporidium* outbreak in Nunavik, UV filters were increasingly installed across northern Canada [75].

3.2. Campylobacter

Able to persist both on land and in water, *Campylobacter* is one of the leading causes of gastroenteritis worldwide [82]. *C. jejuni* is responsible for 95% of *Campylobacter*-induced diarrheal disease [83]. As mentioned previously, *Campylobacter* was one of the most commonly reported infections in the Northwest Territories between 1991 and 2008 (this article was not able to address any possible geographical reporting biases and did not mention the separation of Nunavut in 1999) [46]. In the Canadian Arctic, *Campylobacter* is typically thought to cause infection through the contamination of food, but person-to-person and zoonotic transmission is also possible. In a study of domestic dogs in northern Canada, Himsworth et al. (2010) identified *Campylobacter* using PCR in 75% of fecal samples [84]. In many northern communities there are large populations of free-roaming domestic dogs, which may serve as a source of infection for humans. Climate change, due to warmer and wetter seasons, has the potential to increase risk and frequency of campylobacteriosis through the various routes of transmission [85]. The article by Huang et al. (2015) provides a full review of the animal, food, and environmental sources of *Campylobacter* in Canada [86].

Campylobacter, similar to *Cryptosporidium,* has a history of being underreported in the north due to challenges with current standard testing methods. A study by Goldfarb et al. (2013) observed that PCR detected *Campylobacter* spp. more often than the standard culture approach in diarrheal stool samples from Qikiqtani General Hospital in Nunavut [73]. The diagnostic superiority of PCR over culture for the identification of *Campylobacter* has been reported by others [87]. Furthermore, Rothrock et al. (2009) showed that PCR was also the preferred method for identifying *Campylobacter* in aqueous and solid environmental samples [82]. While the effect of transportation time has been hypothesized to impair culturing of *Campylobacter*, Bullman et al. (2011) noted that 46.8% of PCR-positive specimens did not grow in culture even when transport time was not a factor [88]. As such, the role for molecular-based diagnostics over culture should be considered, especially as *Campylobacter* cases are expected to increase due to climate change. Qikiqtani General Hospital, for instance, has now implemented molecular testing on site. Since implementing enteric pathogen PCR testing on the Ungava coast of Nunavik, *Campylobacter* is the leading pathogen identified in stool [89]. Furthermore, the number of such reportable infections has doubled compared to the use of on-site culture [89]. While campylobacteriosis is usually self-limiting, it will continue to represent a significant public health burden if surveillance and diagnostics are not improved [86].

3.3. *Helicobacter Pylori*

Considered one of the most prevalent global human pathogens, *H. pylori* is a Gram-negative bacterium known to cause several gastropathies including inflammation of the gastric mucosa (gastritis), peptic ulcer disease, and gastric cancer [90]. Arctic residents, in comparison to those in southern Canada, have an elevated prevalence of *H. pylori* infection [91]. In an Arctic study by Fagan-Garcia et al. (2019), the estimated prevalence of *H. pylori* amongst Indigenous Peoples was 66% and amongst non-Indigenous Peoples was 22% [92]. Despite seroprevalence not being an ideal measure (as *H. pylori* serological testing does not distinguish between previous and current infection), 66% of gastric biopsies (n = 194) were positive for *H. pylori* on histology in a study conducted in the Northwest Territories by Cheung et al. (2014) [93]. Using a multivariable model for analysis, the prevalence of *H. pylori* was positively associated with alcohol consumption and inversely associated with previous gastroscopy and *H. pylori* therapy. Conversely, in a more recent 2017 medical file review, the Nunavik Inuit Health Survey observed no cases of gastric cancer or MALT lymphoma despite the high prevalence of *H. pylori* in Nunavik [70]. In that same survey, *H. pylori* infection was positively associated with several factors including drinking from natural water sources in winter and household overcrowding.

H. pylori has several routes of transmission, including between people and through contaminated food and water. In Nunavut, *H. pylori* has been detected in community water supplies [60]. As climate change in the north is expected to increase the transmission of water-borne pathogens, due to increased water volume, it is crucial that water treatment systems are prepared to limit *H. pylori* transmission [94].

Current guidelines recommend using non-invasive techniques to test individuals with dyspeptic symptoms for *H. pylori*, but this test-and-treat strategy has been shown in low-endemic areas to only have a modest benefit in relief of symptoms. Consequently, many are discussing the applicability of these current guidelines to areas like the Canadian Arctic that have higher prevalence levels [95]. Worryingly, there have been reports about treatment-resistant and anti-microbial resistant *H. pylori* infections from several parts of the Arctic [96,97]. Individuals with treatment-resistant *H. pylori* describe several GI symptoms including abdominal pain, indigestion, diarrhea, reflux, and constipation [97].

In comparison to Southern Canada, Arctic communities appear to have higher antibiotic dispensation rates, especially with beta-lactam and macrolide antibiotics [98]. This is particularly worrying seeing as work by Gromala (2020) identified both macrolide and beta-lactam antibiotic resistance genes in WSPs in the Arctic [99]. People in the Northwest Territories and Yukon are disproportionately impacted by gastric cancer when compared to the rest of Canada [100]. While Fagan-Garcia et al. (2019) found no cases of dysplasia or carcinoma (due to small sample size), the disease burden certainly increased the risk of stomach cancer within the study population [92,101].

Despite the number of epidemiological studies conducted in the Arctic surrounding *H. pylori* infection, there is limited understanding of how the pathogen is impacting communities on a broader level. In recent work, Cromarty (2020) examined how deprivation indicators (estimated from the Canadian Deprivation Index, a validated predictor of health status) could be related to *H. pylori* disease burden [102]. Cromarty observed that higher *H. pylori* prevalence was associated with higher deprivation levels, following adjustment for confounding variables. Further analysis suggested that disease burden due to *H. pylori* could be related to social and gender inequities within Indigenous Arctic communities. In addition, in order to comprehend the perception of *H. pylori* in the Arctic, Highet et al. (2019) analyzed drawings made by Indigenous children from Fort McPherson, an Arctic hamlet [103]. The authors noted that many children drew bacterium that were "overtly menacing," which emphasized how concerning *H. pylori* was to the community. Due to the serious harm that can come from chronic *H. pylori* infections, many Northern communities and health officials are attempting to improve public awareness and are seeking more research dedicated to preventing and reducing transmission [93].

4. The Future of Enteric Infections in the North

Arctic communities are already experiencing a wide-range of health concerns due to climate change [37]. While this review has focused on enteric pathogens, other areas of health that are expected to be impacted include, but are not limited to, mental health, obesity, and cancer [104–108]. Climate change influences infectious disease transmission in four major ways: (1) by affecting the development, reproduction, and mortality of the microbe, (2) by affecting the development, reproduction, and mortality of vectors and the host, (3) by affecting host/microbial/vector behaviour, and (4) altering host susceptibility [109]. In this final section, we will review how climate change is expected to continue impacting the gastrointestinal health of Arctic communities.

4.1. Routes of Infection

Climate change has already begun to threaten Indigenous food systems by impacting how people interact with the land, water, and animals. Due to increasing temperatures and changing climate, more country foods in the Arctic are becoming home to microbial pathogens [110–113]. One such pathogen is the bacterium, *Vibrio*, that can cause AGI through the ingestion of untreated water or raw/undercooked fish and shellfish. Increasing water temperatures have extended the summer season for non-cholera *Vibrio* spp. and have extended their geographical distribution to several locations around the subarctic [114–118]. As an example, *V. parahaemolyticus*, known for residing in oysters in more temperate waters, has more recently been found in Alaskan oysters, causing one of America's largest outbreaks of vibriosis [119]. Alongside oysters, mussel populations have been found to be affected by warmer waters [120]. Relatively small increases in ambient temperatures have been shown to be associated with dramatic increases in the filtration rate of mussels, therefore increasing exposure risk to pathogens [121]. In a study conducted in six communities in Nunavik, *Cryptosporidium* was detected in 73% of blue mussel samples [122]. Finally, in a recent study based in Iqaluit, *Giardia* DNA was detected in clams for the first time [62]. Other foodborne pathogens that will be important to consider in the context of climate change include Norovirus, *Clostridium perfringens, Campylobacter* spp., nontyphoidal *Salmonella* spp., *Bacillus cereus*, *E. coli*, and *Listeria* [123].

While environmental contamination is not the focus of this review, it is important to recognize that these contaminants also pose a risk to GI health in the Arctic. For example, fish and whale contaminated with methylmercury have been shown to increase the risk of gastric cancer in Arctic communities. In a study by Walker et al. (2021), analysis of 80 gastric biopsies found evidence of intestinal metaplasia, atrophy, and severe chronic gastritis in 17%, 29%, and 38% of cases, respectively [124]. Interestingly, selenium intake appeared to counter the harmful effects of methylmercury contamination. The review by Gibson et al. (2016) offers a more extensive review of chemical trends in the Arctic [125]. Many households in the Arctic are reporting food insecurity, reflecting challenges related to accessing country foods and purchasing retail foods. In comparison to country foods, store-bought food offers a very different nutritional profile.

Diet is known to impact the composition of bacteria in the gut, with traditional diets leading to more diverse and distinct microbial communities than western diets [126]. The traditional Inuit diet is low in carbohydrates and rich in animal fats and proteins. Due to climate change impacting the ability to access and consume certain country foods as well as other factors, some Inuit communities are shifting towards store-bought foods that have lower micronutrient intake [127]. To assess the impact of diet on gut bacterial composition, Girard et al. (2017) used 16S rRNA gene sequencing to compare Montrealers who consumed a Western diet and Inuit who consumed a range of Western and traditional diets [128]. Overall, microbial community was indistinguishable between the Montrealers and Inuit; however, following oligo-typing, there were significant differences in the relative abundance of certain bacterial subgenera. Those who consumed a more Western diet had enriched *Prevotella* spp., which are associated with high-fiber diets. In a follow-up study by Dubois et al. (2017) that collected monthly fecal samples from Montrealers and Inuit participants, it was clear that the traditional Inuit diet impacted gut microbial composition, diversity, and stability [129]. Nevertheless, Dubois et al. (2017) noted there were no clear seasonal shifts in the gut microbiomes of either study group, which might suggest the role of the western diet in acting like a buffer. The long term health implications of Western diet in Inuit populations remains unclear, but represents an active area of research.

Waterborne disease is also a mounting challenge due to climate change, with important and disproportionate impacts anticipated in the Arctic [57]. Several pathogens are expected to thrive including *Cryptosporidium* spp., *Brucella* spp., and *Giardia* spp. [41,55]. As described previously, many consume untreated water from the environment, primarily from moving bodies of water like rivers [53]. Environmental change, however, is making this practice riskier due to increased turbidity and microbial and chemical contaminants [57,130,131]. As such, communities may need to begin exploring other treatment options such as filtration, UV-treatment, or sedimentation. This recommendation, however, only impacts those who drink treated tap water, neglecting many who drink raw water because it tastes better. Furthermore, Harper et al. (2020) proposed in their review, additional Arctic adaptions including community-based monitoring and the development of health metrics that are locally and culturally appropriate [132].

4.2. Prevention and Detection

Currently, the Arctic is faced with inadequate surveillance systems and several challenges related to outbreak preparedness, such as low rates of healthcare-seeking behavior, overcrowding, and poor diagnostic ability [41,73,133,134]. Medical and public health systems have to be prepared for the expected increase in GI illness in the coming years. This will require clinicians to stay alert to enteric pathogen trends and learn to recognize the signs and symptoms of both common and emerging pathogens. Furthermore, clinicians will need to stay informed on anti-microbial trends when determining best treatment options. Public health will have to develop practices that keep the public informed. Laboratories will not only need to increase in capacity, but also create/modify techniques to identify emerging pathogens. Finally, surveillance will need to be strengthened to monitor trends and inform best practices.

5. Conclusions

It is clear that climate change is an irreversible process that is well underway. Arctic communities are vulnerable to the changing environment due to their close relationship with the land and water. Over the last few decades as temperature increases in the north, there has been a similar increase in GI infections and AGI. Further research is needed to fully understand the extent to which climate change will affect the health of northern Arctic populations, and which pathogens will be the most prevalent.

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