Impact of climate change on amoeba and the bacteria they host

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Global temperature has risen faster from 1970 to 2020 than in any other 50-year period over that past 2000 years of human history (1). Climate change impacts many aspects of the environment, human society, and human health, including the distribution and activity of infectious disease. Out of 375 diseases considered to have a measurable impact on humanity, 58% showed evidence of an increase in severity that can be linked back to climate change (2). Additionally, climate change could potentially increase the risk of disease emergence (3). As the global temperature continues to rise, we are likely to see further effects on infectious disease trends.

This topic was previously discussed in a 2019 note by Carignan and colleagues (4), focusing on mosquito-borne, tick-borne, and fungal disease. We are revisiting this critical topic in the wake of the warmest July on record and with a focus on lesser known and investigated pathogens, specifically free-living amoeba and water-borne pathogens. When infectious diseases are discussed in the context of climate change, vector-borne diseases have received more focus. We aim to examine some of the less explored pathogens, as well as highlight the gaps in our current knowledge of these diseases and their relation to climate change.

FREE-LIVING AMOEBA

Free-living amoebae are widely distributed across the environment, found in water, air, and soil environments. *Naegleria fowleri, Acanthamoeba* spp, and *Balamuthia mandrillaris* are most commonly associated with human disease (5). However, cases are rare, difficult to diagnose, and have varied presentations including cutaneous, mucosal and sinus infections, keratitis, and disease of the central nervous system (5,6).

The free-living amoeba with the most evidence of the effects of climate change is *N. fowleri*. *N. fowleri* is known for causing primary amebic meningoencephalitis (PAM), which is predominantly associated with recreational water exposure (6–8) and has a mortality of 96% in laboratory confirmed cases (7). *N. fowleri* is thermophilic (6,8,9) and one of its food sources is cyanobacteria, which flourishes in warmer waters (8). Climate change raising the water

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temperature and the heat driving more people to recreational water use are likely to increase encounters with this pathogen (8,9).

Furthermore, warming temperatures may be expanding the geographical range of *Naegleria* species. In 2023, four *Naegleria* species were identified in recreational lakes in Alberta, the first reported evidence of this genus in Canada (10). While *N. fowleri* was not found, the identification of other species indicates the environment could support its growth. Human cases of PAM have been found as close to the Canadian border as Minnesota (11). Additionally, an analysis of PAM cases in the United State has indicated a northward expansion of the disease (12). These cases occurred in the weeks after an increase in air temperature (12), once again indicating a potential relation to climate change.

Disease caused by other species of free-living amoeba has not been associated directly with climate change. However, the absence of a link cannot be confirmed as there is little research into these amoebas. Another angle to approach the effect of climate change on free-living amoeba is through the bacterial pathogens they host. Free-living amoeba (particularly *Acanthamoeba* spp) are hosts for a variety of species of pathogenic bacteria, often being an essential part of their life cycle. There is evidence of these intracellular bacteria being impacted by climate change, which implies an effect on the amoeba as well.

INTRACELLULAR BACTERIA OF AMOEBA

Legionella spp

Legionella is an intracellular pathogen that causes a severe pneumonia known as Legionnaires' disease. Canada does not have a surveillance system for *Legionella*, but incidence in the United States has risen 6.5-fold from 2000 to 2019 (13). *Legionella* has a wide range of amoeba hosts, and the infection of these hosts enhances the pathogenicity of the bacteria, as well as enabling *Legionella* to persist in the environment (14). *Legionella* that is unable to be grown on rich media can even be resuscitated by infection of amoeba (14), emphasizing the relation between *Legionella* and its hosts.

Two significant climate change indicators are rising temperatures and increasing amounts of heavy precipitation (15), both of which enhance the growth of *Legionella*. Increased *Legionella* cases in the United States have been correlated with warming temperatures and high levels of precipitation attributed to climate change (16). Cases in Switzerland were associated with warm temperatures, heavy rainfall, and high humidity (17). Additionally, *Legionella* cases across Denmark, Germany, Italy, and the Netherlands have been associated with increased temperature, rainfall, and atmospheric pressure, with the highest risk seen when temperature and rainfall increased together (18).

Rising temperature may also indirectly increase *Legionella* cases. In response, the use of air conditioning systems is increasing over time (19), and these systems are associated with *Legionella*. In particular, one review examining *Legionella* outbreaks showed that cooling towers were associated with 50% of outbreak-related cases and 60% of outbreak-related deaths (20).

In addition, *Legionella* rates have been shown to rise after storms (21–23). In the United States, tropical cyclones, which often cause widespread destruction and extreme flooding events, resulted in an increase in *Legionella* case rates (21). Infection rates were shown to consistently increase in relation to the amount of rainfall, with cases peaking 2–3 weeks after the storm in question (21).

The observed trend is significant because floods and storms are the most common climate-related disasters, and they are occurring more frequently as global temperature rises (22). From 1980 to 1999, the United Nations reported 3656 climate-related disasters. From 2000 to 2019, this number had risen to 6681 climate related disasters (24).

Overall, *Legionella* infections have been increasing over time and several key factors to this prevalence can be associated with climate change. The current progression of climate change is likely to continue the trend of increasing *Legionella* cases.

Non-tuberculosis mycobacteria

Many species of non-tuberculous mycobacteria (NTM) can be found within amoeba hosts, especially the species belonging to the mycobacterium avium complex (MAC) (25). NTM become more virulent and resistant to antibiotics when cultured in amoeba (26), which is concerning for the treatment of this disease. The MAC species are responsible for the majority of human infections, and case rates have been increasing worldwide (26,27). A recent systematic review calculated the global growth rate of NTM disease as 4.0% per 100,000 persons per year (27).

NTM has been associated with natural disasters (28), such as hurricanes (29), which as discussed above, are increasing due to climate change. Climate variables such as temperature, rainfall, flooding, and drought have also been shown to affect environmental NTM populations, but this varies by region making the exact relation to changes in climate unclear (30), though it indicates that environmental NTM are climate sensitive. This is key because at least some NTM infections likely come from environmental exposure. The evidence for this is that NTM isolated from the lungs of infected persons has been shown to be genetically match environmental NTM isolates (25). Finally, NTM infection occurs most frequently in the tropics, and this range is expanding due to the global rise in temperature (26).

Chlamydophila pneumoniae

Chlamydophila pneumoniae is a frequent cause of pneumonia and an obligate intracellular pathogen of amoeba such as *Acanthamoeba* spp (31). While *C. pneumoniae* has not been specifically linked to climate change, there is some evidence for pneumonia cases being impacted by climate change. Emergency visits for childhood pneumonia have been observed to increase after significant temperature changes on 2 consecutive days, and this impact was observed to increase between the two time periods analyzed (32). Unstable temperatures and weather patterns are considered signs of climate change (32,33).

Other evidence includes higher pneumonia prevalence in the rainy season of tropical and subtropical areas (33) and after natural disasters such at typhoons and tsunamis (34). However, the effects of climate on pneumonia cases vary significantly between different geographical areas (33). More research is required to define the relation between climate change and pneumonia, particularly the similarities and differences between various pneumonia-causing agents, such as *C. pneumoniae*.

CONCLUSION

Climate change is proceeding at a rapid pace. The effects on infectious disease rates are not limited to vector borne diseases and are likely to continue. Climate change could potentially increase the risk of disease emergence, as well as expanding the range of current climate sensitive diseases. Adding diseases harboured by free living amoeba to surveillance systems will be important as the rise in extreme weather events and rising temperatures are expected to continue. As climate change continues, we will have to be mindful of water-borne and amoeba carried pathogens, considered uncommon in our geographical region, as that may not stay true in the future.

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