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Review

Climate change and foodborne transmission of parasites: A consideration of possible interactions and impacts for selected parasites

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ABSTRACT

A changing climate alters the living conditions for almost every species on earth. We recognise that these changes may threaten our environment, our water and food supply, and our health; predicting the likely changes and impacts we try to prepare for different weather conditions. A complicated and perhaps underestimated threat is how climate change may affect foodborne parasites — a subject that tends to be neglected among infectious diseases under any climatic conditions. Here we review some selected examples of these pathogens, and how they may interact and alter with the changing environment: the complexity and variation in their lifecycles mean that different parasites will not necessarily be affected similarly by the same climate changes. To provide illustrative examples we have chosen a couple of parasites from each major group: trematodes, cestodes, nematodes, and protozoans. Even within these groups, different members utilize widely varying routes to complete their lifecycles, exploring new areas together with their hosts, floating from one place to another, or travelling along with their hosts to white spots on their maps. These parasites are very different from each other, but all are influenced by abiotic factors and have a common goal, to reach their next host. This review aims to open the readers mind to how exposure routes and transmission routes may be affected by climate change: realization of the possibilities is the first step towards closing the door to the parasites that are knocking at it.

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1. Introduction

Predicted climate changes will create impacts throughout the globe, and these will vary from region to region. Some areas will experience an overall temperature rise and polar ice is melting; in some countries or regions precipitation is expected to increase, while others are preparing for drier conditions. Overall, sea levels are rising and an increase in the frequency and intensity of extreme weather events is expected in many places. It is generally accepted that these ongoing and predicted climate changes will affect the distribution of infectious diseases (Altizer, Ostfeld, Johnson, Kutz, & Harvell, 2013). Some factors may result in the door opening to new geographical areas for pathogens to explore, while the same, or different, factors may result in other doors closing. The situation is complex and uncertain, and as climate change may affect environmental conditions, making predictions regarding spread of infection due to climate change events must be recognised to include these uncertainties.

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Although most research on climate change and infectious diseases has focused upon viral infections, bacterial infections, and those infections transmitted by vectors, another group of pathogens should also be considered: foodborne parasites. Although foodborne parasites encompass a vast diversity of species with different characteristics, transmission routes and clinical conditions, they are often neglected in comparison with other pathogens. The reasons for this lack of focus on this important pathogen group are diverse, but probably include:

1) many of the parasitic infections that may be transmitted by contaminated food may manifest as a chronic disease progression, rather than acute febrile or gastro-enteric infection; such infections tend to be considered as being of lesser importance or urgency;
2) the relatively lengthy incubation periods between infection and symptoms for several parasites – ranging (depending on the parasite) from a day or so up to months or even years – again reduce the human perception of importance and create problems in ascertaining source attribution;
3) problems in identification of the vehicle of infection and difficulties in diagnosis and detection; these diagnostic and identification challenges hamper both clinical studies and recognition of importance;
4) the range and complexity of foodborne parasites can be off-putting for those without expertise in this subject;
5) there is the mistaken perception in many Western or industrialised countries that parasites are uniquely associated with tropical areas or regions of acute poverty. Although it is true that when infrastructures such as sanitation and water supply are inadequate, then transmission can be exacerbated, outbreaks of foodborne parasitic disease occur globally, including in the wealthiest countries in the world.

Despite parasites being the "poor relation" in terms of perceived pathogen importance, it appears that foodborne parasites are gradually becoming recognised as being serious public health concerns. Not only has *Cryptosporidium* infection been demonstrated as one of the most important causes of moderate to severe paediatric diarrhoea in developing countries (Kotloff et al., 2013), but also in 2010, WHO/FAO were requested by the Codex Committee on Food Hygiene (CCFH) to 'review the current status of knowledge on parasites in food and their public health and trade impact in order to provide the CCFH with advice and guidance on the parasite-commodity combinations of particular concern, the issues that need to be addressed by risk managers and the options available to them'. Part of this review process involved experts evaluating the potential for increases in disease rates (Robertson, van der Giessen, Batz, Kojima, & Cahill, 2013; WHO/FAO, 2014), and thus must consider factors such as climate change that may affect the spread and emergence or re-emergence of these infections.

It should be noted that whereas climate may restrict the range of infectious diseases, it is weather, as a short-term manifestation of climate, which affects timing and intensity of outbreaks; this has been recognised for decades by many parasitologists, particularly those concerned with veterinary infections, and temperature and humidity have long been considered as major factors constraining the geographical range of many of these pathogens. Weather events such as El Niño and La Niña are of relatively short duration and have a greater magnitude and impact on the local environment than the more gradual character of other proposed climate changes. A higher frequency of extreme events will result in parasites that are more tolerant of highly diverse conditions, being able to survive, adapt to the new environments, and perhaps thrive. However, how the dynamics of parasite transmission may alter under conditions of climate change is also dependent on host characteristics (Martínez & Merino, 2011).

Thus, although some modelling has been conducted to provide useful data for some foodborne parasites (e.g. *Fasciola hepatica*; Valencia-López, Malone, Carmona, & Velásquez, 2012) precisely how the predicted climate changes (and also weather events such as El Niño and La Niña, floods etc.) will impact on the distribution and burden of the majority of foodborne parasites is uncertain, as it is for all pathogens. Nevertheless, it is possible to make some general comments based on our current state of knowledge. Although some assumptions may retrospectively be found to be flawed, by examining what the future may hold for us, it is possible that plans can be made to mitigate increased transmission.

In this review we focus on a few selected parasites from each of the major parasite groups: trematodes, cestodes, nematodes, and protozoa, their various and varied paths to our plates, and how these routes in different regions of the world may alter in the face of climate change. It is not possible to cover all foodborne parasites or include all scenarios, but we hope that this selection provides some insights and suggestions of what may occur.

Slowly the world is waking up to smell the coffee, but are we prepared to drink it?

2. Selected foodborne parasites

2.1. Trematodes

Most trematode parasites, also known as flukes, have relatively complicated lifecycles including one or more intermediate hosts, of which the first intermediate host is almost always a mollusc, usually, but not always, an amphibious snail. It is generally well-accepted that in parasite-host systems in which intermediate hosts or free-living stages are intrinsic to the lifecycle, weather conditions have a considerable impact on transmission (Marcogliese, 2008), and therefore climate change is likely to affect trematodes.

For trematode parasites in general, it has been suggested that a small increase in temperature will lead to a marked increase in cercarial emergence from the first intermediate host (snails), with little if any reduction in their transmission efficiency, and that this may also enhance the local impact of trematodes (Poulin, 2006). Under many climate change scenarios this may result in an increase in local burden in endemic areas, as well as increases or shifts in distribution. The number of generations per year may also increase.

A model trematode to consider in terms of potential effects of climate change on spread and transmission is *F. hepatica*. The final stage of the lifecycle of *F. hepatica* can occur in a range of different mammals, including humans, and is also a disease of veterinary concern, causing disease, sometimes severe or even fatal, in sheep and cattle. The zoonotic aspect also maintains the transmission cycle in the absence of human infection. As with other trematodes, the lifecycle of *F. hepatica* depends on amphibious snail intermediate hosts (infected by the miracidium stage, produced from the parasite eggs), from which the cercariae emerge after a stage of asexual multiplication. The resultant metacercariae (encysted cercariae in the environment) are robust, and final hosts, including humans, are infected by ingesting either plants or water contaminated with these metacercariae.

Climate change may affect transmission of *F. hepatica* not only by affecting the parasite directly, but also indirectly, by affecting the success and distribution of the intermediate host. Snails are cold-blooded animals, so their activity and metabolism are dependent on environmental temperature. In Europe the major intermediate host, *Lymnaea truncatula*, has its northern distribution limited by temperature, and is recognised as a rather stenoecious species (Caron, Martens, Lempereur, Saegerman, & Losson, 2014); higher temperatures may enable northward spread of this intermediate host, and hence northward spread of this parasite.

In the trematodes themselves, temperature has a direct and pronounced effect on crucial lifecycle stages, including the production of cercariae in the snail host, which is a key component of the parasite's success (Mas–Coma, Valero, & Bargues, 2009). An increase of only a few degrees in environmental temperatures may result in marked increases in cercarial emergence; within the range of temperatures in which the snails and parasites can live, an increase in temperature is almost invariably coupled with an increase in cercarial output. This