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Modelling livestock parasite risk under climate change

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Introduction

Parasitic worms present one of the most pervasive threats to grazing livestock, and climate change has been implicated as a driving force for recent increases in their intensity and range (van Dijk *et al*., 2008; Kenyon *et al*., 2009; Fox *et al*., 2011). Owing to the potential for climate driven disease outbreaks to have food security, animal welfare and economic implications (Moran *et al*., 2013), there is a need to predict future parasite risk. At the coarse scale parasite distribution will be dependent on the species' climate envelope, and the survival and development of free-living parasite stages are dependent on temperature and moisture levels (Armour, 1980). Consequently, our first model focuses on how changes in parasite development and survival affect nematode outbreaks in livestock. However, such predictions do not account for variations in transmission at the farm level, and impacts of climate change on host physiology and management should also be considered in development and parameterisation of parasite models. By applying a second mechanistic model which incorporates a number of additional elements of the system dynamics, we determine the robustness of our findings to the inclusion of a number of realistic farm-level processes.

Model development

A non-spatial, population level model is used to explore how parasite intensity is influenced by changing key temperature-sensitive parameters (development and survival of the parasite's free-living stages). This model also captures the basic processes in helminth infections including host immunity, and survival and development of the parasites in the host. All simulations model a directly transmitted gastrointestinal nematode of a managed ruminant population, in set stocking, over one grazing season.

The first model highlights fundamental trends in outbreak dynamics that result from changing larvae survival and development rates. Although governed by basic rules, transmission is a complex process, and it has been shown that host grazing behaviour and spatial effects are also important in outbreak dynamics (Fox *et al*., 2013). It is therefore imperative to consider climate-sensitive elements of transmission within the context of a wider system of interacting processes. Consequently, a spatially explicit, individual based, stochastic model was formulated to test the robustness of predicted parasite patterns within the context of farm-level processes. This model incorporates host grazing behaviour, and spatio-temporal variation in resources, perceived parasite risk and free-living parasite larvae.

Model predictions

Using parameter values representative of cattle grazing in a temperate system (Fox *et al*., 2012), the models successfully reproduces empirically observed parasite dynamics (Smith and Grenfell, 1985; Roberts and Grenfell, 1991; Hilderson *et al*., 1993). The outputs of the non-spatial, population level model show that changes in temperature-sensitive parameters can lead to non-linear responses in outbreak patterns, with distinct 'tipping-points' in nematode parasite burdens. The spatially explicit, individual-based model demonstrated that these non-linear responses are robust to the inclusion of a number of realistic processes present in livestock grazing systems. Although the qualitative patterns observed are independent of which model is used, it remains important to consider wider elements of the system. Our results show that spatial distribution of parasites, over-winter survival of free-living parasites, host grazing behaviour and host immunity all influence the non-linear responses to changing larval development rates and affect the magnitude of peak parasite burdens under different climate change scenarios.

Discussion

Our results indicate that climate change can lead to non-linear responses in infection dynamics, such that minor alterations in temperature around critical thresholds could cause dramatic shifts in outbreak intensity. This could lead to an increase in the frequency and geographic range of pathological cases for pathogens that are currently widespread but at low incidence levels. The relationship between survival and development of the parasites' free-living stages,

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over-winter larval survival, larval distribution on pasture and behavioural characteristics of the host are all pivotal determinants of outbreak intensity.

Although the indicative patterns observed are independent of model complexity, this work highlights the need for models which incorporate wider elements of the system as changes in livestock management will influence outbreaks in a changing climate. For example, our results show that availability of larvae at the start of the grazing season has a large impact on parasite burdens. The timing and magnitude of infective larvae availability will shift as rising temperatures and CO_2 levels, and a decrease in ground frosts will lead to changes in grass growth and an increased growing season (NFU, 2005; UKCP09, 2009).

Our results demonstrate that, within the parasite's climate envelope, peak parasite burdens remain heavily dependent on the host's immune response. Heat stress directly affects the immune response of sheep and cattle (Sevi and Caroprese, 2012), and has been identified as a threat to livestock production under climate change (Harle *et al*., 2007; Gale *et al*., 2009). These changes in host immune response could have substantial impacts on future parasite burdens. Livestock grazing behaviour also changes under heat stress (O'Brien *et al*., 2010), and our results demonstrate that temperature driven changes in host grazing will affect parasite dynamics. This highlights the need for predictive models to consider wider elements of the livestock systems that are also likely to be concurrently affected by climate change.

Livestock husbandry and management will be influenced by climate change as adaptation and mitigation strategies will be required to help negate the economic and welfare implications of climate change on livestock (e.g. heat stress). A range of adaptation approaches have already been proposed, for example provision of shade (Berman and Horovitz, 2012) and sprinklers (Avendaño-Reyes *et al*., 2006) to reduce heat stress. However, increased shade and moisture aid larval survival for temperate parasites, which can lead to non-linear increases in parasite risk. Hence, the consequences of adopting such adaptation approaches on parasite intensity should be considered.

There is a need for process based predictive models to incorporate changing livestock management, and the framework developed here will also allow the efficacy of potential control strategies to be explored. There is currently strong reliance on anthelmintics; however, their efficacy is diminishing and resistance is rife (Abbott *et al*., 2007). Strategies to lower the dependence on chemicals and manage the spread of resistance will consequently need to be adopted. Through incorporating wider elements of the transmission process, there is potential for models to predict which of the panoply of control strategies would be effective under specific climate change scenarios. For example, by understanding how climate change will affect availability of infective larvae and timings of host grazing seasons, optimal grazing strategies could be explored to ensure hosts encounter sufficient levels of larvae for trickle infection to initiate an immune response, but avoid deleteriously high challenges. Given the uncertain nature of climate change projections, the robustness of control strategies should be tested to identify those that are effective over the broadest range of potential climate scenarios. Novel areas for manipulation and control could also be explored in such models, potentially identifying leverage points where changing management could have substantial impacts on changing parasite risks.

Conclusions

Our work highlights that dramatic changes in parasite burdens can result from small changes in climatic conditions around critical thresholds. Our results are applicable to a wide range of significant host–parasite systems, as our models incorporate fundamental elements of parasite transmission that are common to a wide range of macroparasites in managed grazing systems. In addition to direct impacts of climate change on parasite transmission, climate will also drive changes in livestock management, and necessitate uptake of mitigation and adaptation strategies that will have a compounding effect on future parasite risk. By developing predictive models with a broader view of the livestock system, we can identify potential risks and highlight opportunities for control.

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Further information

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