Incorporating behavioural feedback effects into animal disease surveillance: a proposed framework

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Introduction

Effective surveillance of endemic disease prevalence and monitoring for exotic disease incursion can be extremely resource intensive. The financial support to such systems is also often limited, so it is crucial that the resources available be allocated in the most efficient manner possible. Modelling of animal disease surveillance systems allows the effectiveness of different surveillance systems to be quantified, and therefore facilitates the optimisation of resource allocation. While heterogeneity between farms, for example in terms of animal numbers, is known to affect prevalence estimates and therefore is frequently incorporated into these models, it is much more difficult to incorporate behavioural effects which modulate the responses of individual farms to the perceived state of other farms around them. One solution is to utilize an agent-based approach, where the agents are further subdivided into actors representing farms of various types, and regulators such as media, government and veterinary interventions which have a feedback effect onto these actors. Each agent class is associated with a set of rules based on behavioural phenomena such as the perceived threat of disease incursion, and impacting on the probability that actors will look for disease. A major advantage of this approach is the ability to encapsulate different aspects of the system (for example an on-farm disease model, a between-farm movements model, and a behavioural feedback model) with only a few well defined interactions between actors and regulators. The internal functionality of each class can therefore be extensively re-written without the requirement to modify any other classes, or the code used to run the model.

Model Framework

We present an object-oriented programming framework for an agent-based, stochastic model written in the C++ programming language. At the core of this model are objects representing a population of actors, and one or more objects representing regulators with feedback effects onto their behaviour. At each time step, actors pass information about their observed state to regulators (incorporating the sensitivity and specificity of the diagnostic tests), and receive information about the wider population in return. The generic actor and regulator classes derive to more specific classes, which add functionality relevant to specific actor or regulator sub-types (Figure 1).

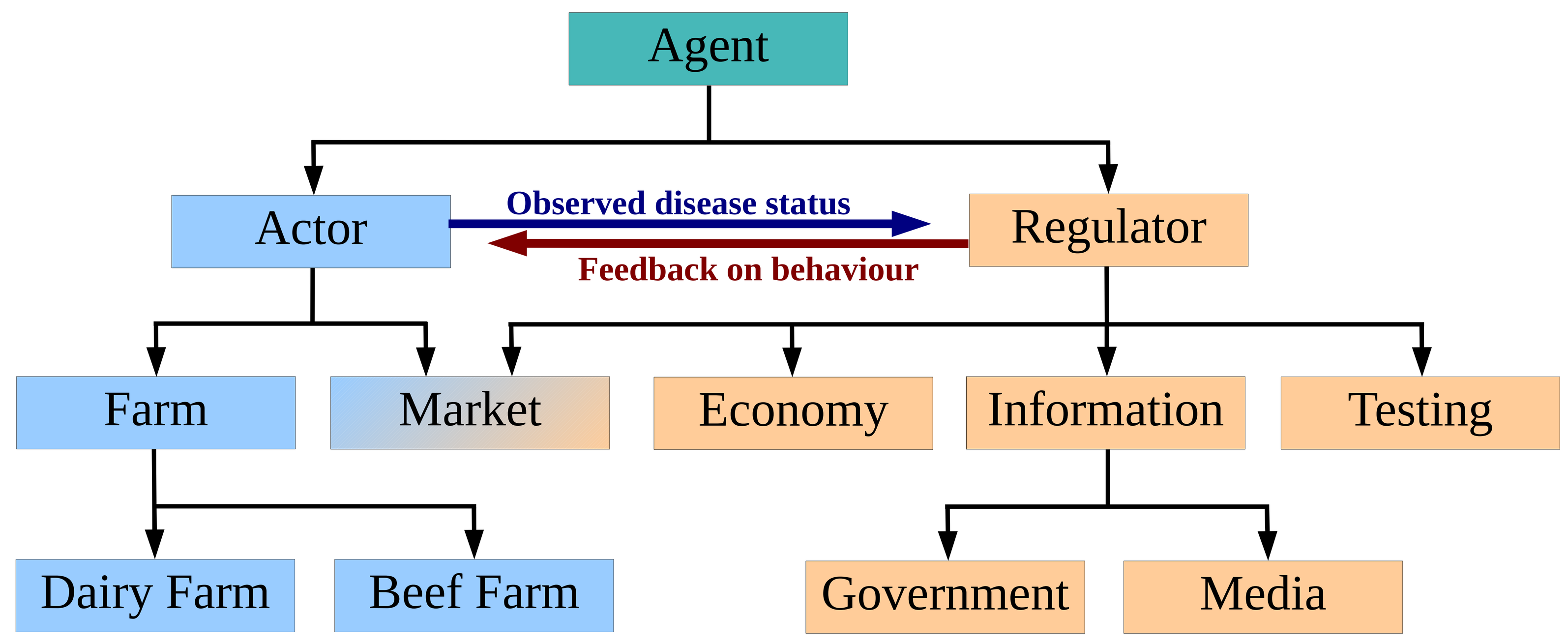

Figure 1. Diagram showing inheritance relationships, and interactions between actors and regulators, within a proposed object oriented animal disease surveillance modelling framework.

Exemplar Methods and Results

The model described was used to assess the effect of farm heterogeneity and behavioural feedback effects on the observed prevalence of infected premises following a sudden disease incursion event. A population of 1000 farms was set up each with 100 animals, a 10% probability of testing for disease at each time step, a 10% proportion of animals tested conditional on this, and test sensitivity and specificity of 50% and 99.9%. Initially, 10 of these actors were infected (1% infected farms), with a 20% on-farm prevalence of disease, and part-way through the simulation an additional 90 farms were infected at a single time step (total 100 = 10% infected farms). This simulation was repeated 1000 times, recording the observed proportion of infected farms at each time step. The exercise was repeated using heterogeneity between farms in the parameter values for number of animals and propensity to test for disease, again using feedback effects on the propensity to test for disease based on the observed proportion of infected farms, and finally using both farm heterogeneity and feedback mechanisms.

The results obtained are shown in Figure 2. Incorporating behavioural feedback effects into the model greatly increased the time between disease incursion (time 100) and the observed increase in disease prevalence. Including heterogeneity in the model reduced the mean observed prevalence.

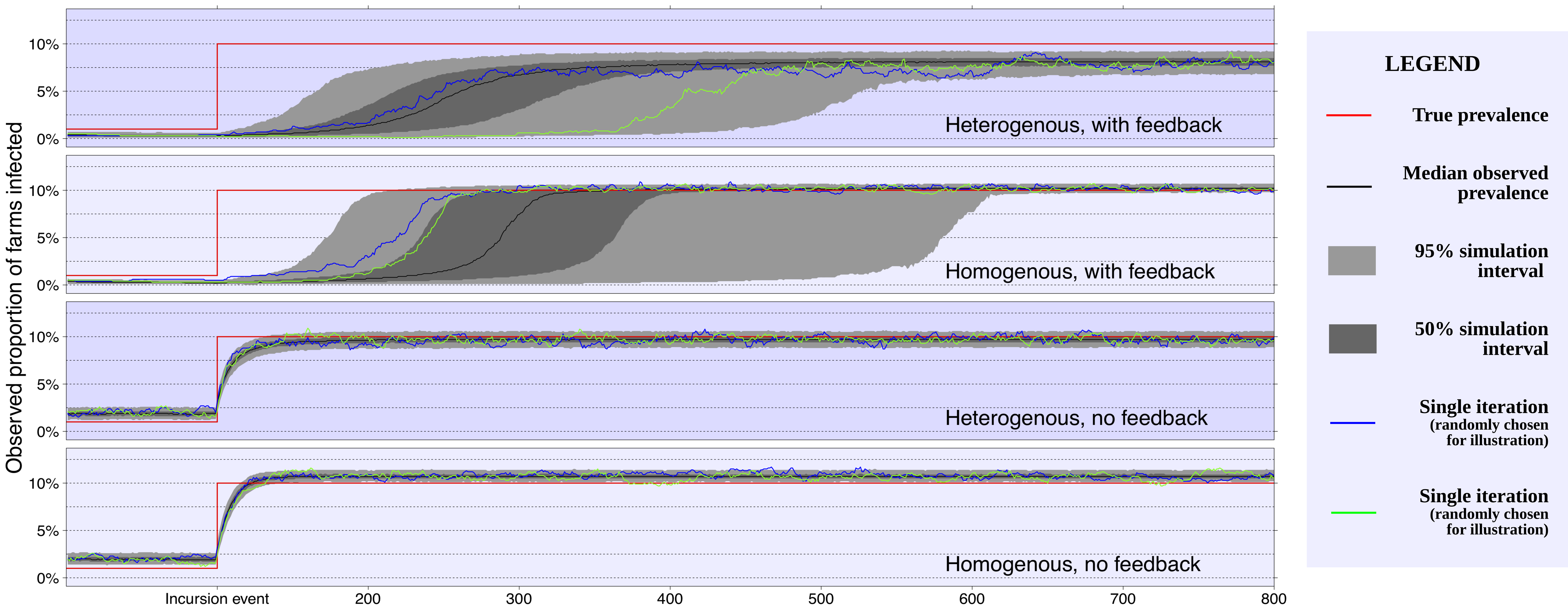

Figure 2. The effect of incorporating farm heterogeneity or behavioural feedback mechanisms on the observed prevalence of infected farms after a disease incursion. Obtained from 1000 simulation iterations based on a population of 1000 farms, with an increase in prevalence from 1% to 10% of infected farms at time point 100. Median, 50% and 95% simulation interval shown alongside two individual iterations.

Discussion

The generic model results presented are focussed on the effects of behavioural feedback mechanisms, and as such are deliberately presented without reference to a specific disease, and with no disease transmission model. Further work is clearly required to adapt the model to any given disease and surveillance system before more focussed recommendations can be made. Nevertheless, it can be seen that incorporating behavioural feedback mechanisms has a profound impact on the observed disease prevalence, especially when also modelling heterogeneity between farms. These effects appear to be non-random, and unpredictable in that this bias changes with heterogeneity and true prevalence. Sequential prevalence estimates are also highly autocorrelated, which introduces a random-walk-like effect in the observed prevalence, when the true prevalence is in fact static. This potential for observed disease prevalence estimates to be inconsistently and unpredictably biased clearly has the potential to effect the performance of disease surveillance strategies. Any possible behavioural feedback mechanisms should consequently be considered and evaluated for future disease surveillance programmes.

The framework presented has a variety of potential uses in disease surveillance scenarios, as well as other applications in which behavioural influences may be important. In the hope that the model might be used and developed in the wider community, we have set up a shared development environment for the model framework, using freely available and open source revision control software. Any researchers interested in collaborating on this project are invited to contact the corresponding author.

Conclusions

- Behavioural feedback mechanisms can have a dramatic effect on the observed disease prevalence, and compound the difficulties caused by heterogeneity between farms.
- Our agent-based approach is able to account explicitly for feedback mechanisms, as well as farm heterogeneity and imperfect diagnostic tests.
- Application of this method to specific population and disease parameters will provide more accurate evaluation of disease surveillance strategies.

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