Simulation Model to Estimate the Necessary Vaccination Coverage to Protect Herds from Bluetongue Virus Serotype 8 Infection

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ABSTRACT

Since August 2006, bluetongue virus serotype 8 (BTV8) has caused a severe epidemic of bluetongue disease (BT) in north-western Europe. In order to control the disease, several European countries started vaccination campaigns for cattle, sheep and goats in 2008. To be able to eradicate a disease by vaccination, it is important to evaluate the minimal necessary level of vaccination coverage in the susceptible population that must be attained. The objectives of this study are i) to determine the farm-level vaccination coverage needed to protect cattle and sheep herds from BTV8 infection and ii) to evaluate the effect of different vaccination strategies on the BT disease dynamics for Switzerland.
An SIR model was set up to predict the BT incidence dynamics of farms. Instead of explicitly modeling the temperature dependent population dynamics of the vector, a temperature dependent infection rate is introduced which captures the temperature effect on the vector population dynamics and on the whole infection dynamics. The model parameters were estimated using observed daily incidences from June 2006 until December 2007 of cattle and sheep farms in several districts of Germany where BT infections were officially notified. The results of the parameter estimation show a very good fit of the model to local field data. The estimated parameters are used in a vaccination model to simulate the effect of vaccination on the BT disease dynamics in Switzerland. The results of the simulations will serve as a decision-making basis for the choice of the BT vaccination strategy 2010 in Switzerland.

KEYWORDS

Bluetongue, SIR model, parameter estimation, vaccination coverage, vaccination strategy

INTRODUCTION

Bluetongue disease (BT) is a non-contagious, viral disease of ruminants transmitted by *Culicoides* spp. biting midges. It can cause severe clinical symptoms in farmed ruminants, particularly in sheep, including death (Elbers et al. 2008). Because of its big economic impact, BT is listed as a notifiable disease by the World Organization for Animal Health (OIE). Before summer 2006, BT had never been reported in Europe north of the Alps. In August 2006, bluetongue virus serotype 8 (BTV8) appeared for the first time in the Netherlands as well as in Belgium, France and Germany (Schwartz-Cornil et al. 2008). In the following year, the disease spread rapidly in north-western Europe and reached Switzerland in late October 2007 (Hofmann et al., 2008). In several European countries, the huge scale of the BTV8 epidemic in 2007 led to the decision to launch an either voluntary or compulsory vaccination campaign for cattle, sheep and goats, in order to control the disease and to avoid further economic losses. In Switzerland, a compulsory mass vaccination of cattle, sheep and goats started in June 2008 in which a vaccination coverage of 70-90% was reached. During the second vaccination campaign, carried out from February 2009 until May 2009, compulsory vaccination was restricted to cattle and sheep. Since the start of vaccination until May 2009, 58 BT cases have been reported in Switzerland (http://www.infosm.bvet.admin.ch/public/awzeit/auswertung).
From the beginning of the vaccination it has been obvious that several subsequent annual vaccination campaigns would be necessary in order to control the BTV8 epidemic in north-western Europe. To be able to eradicate a disease by vaccination, it is important to evaluate the minimal necessary level of vaccination coverage in the susceptible population that must be attained. The objectives of this study are i) to determine the farm-level vaccination coverage needed to protect cattle and sheep herds from an infection with BTV8 and ii) to evaluate the effect of different vaccination strategies on the BT disease dynamics for Switzerland. The results will serve as a decision-making basis to design an effective vaccination strategy for 2010 to prevent herds from infection with BTV8 in Switzerland.

MATERIAL & METHODS

An SIR model was set up to predict the BT incidence dynamics of herds. In the model, the population of herds is subdivided into three exclusive states: Susceptible (S), Infected and infectious (I) and Recovered (R). Transition rates between states are constant except the transition between state S and state I which

depends on the temperature. This temperature dependent infection rate β(T) captures the temperature effect on the population dynamics of the vector and on the whole infection dynamics. With this simplification, it is not necessary to model the temperature dependent population dynamics of the vector. The model parameters were estimated using observed daily incidences from June 2006 until December 2007 of cattle and sheep farms in several districts of Germany where BT infections were officially notified. The estimation of β(T) is based on a model proposed by Hilbert and Logan (1983) to predict the temperature dependent development rate of poikilotherm individuals. Temperature data (daily mean temperature) was obtained from the nearest weather station of the respective district. A time lag of 48 days was included in the model to consider the time needed for the vector population to develop a sufficient population density and infectivity to transmit BT as well as the time between infection of the host and case notification. The SIR model was programmed and run in Java.
In order to model the effect of vaccination on the BT disease dynamics, the model is extended by the states V (herds to be vaccinated) and P (protected herds) (Figure 1).

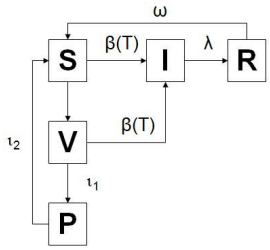

Figure 1 Structure of the vaccination model
S: susceptible herds, I: infected and infectious herds, R: recovered (immune) herds, V: herds to be vaccinated, P: protected (immune) herds, β(T): temperature dependent infection rate, λ: transition rate from I to R, ω: transition rate from R to S, ι: transition rate from V to P (ι_1) and from P to S (ι_2)

The vaccination model is used to simulate different vaccination strategies for Switzerland using Swiss population and temperature data and the parameters estimated by the SIR model. Parameters not estimated by the SIR model are based on literature and expert information. Three altitude strata for Switzerland were defined: 1) < 800 meters above sea level (m.a.s.l.), 2) 800-1499 m.a.s.l. and 3) 1500-2000 m.a.s.l. with a population at risk (S(t=0)) of 2000, 700 and 400 herds, respectively. For each day of the year, the mean of the daily mean temperature of all weather stations in the respective altitude stratum was taken and the mean value for each day over the last 10 years was calculated. The following vaccination strategies will be simulated for each altitude stratum: 1) no vaccination, 2) voluntary vaccination with 35% vaccination coverage, 3) compulsory vaccination with 80% vaccination coverage and 4) with 95% vaccination coverage. Running time of the model is five years with the simulation starting on January 1st. The annually repeated vaccination starts at time point t=32. At time point t=110, one infected farm is introduced into the population which is thereafter considered to be a closed population. The vaccination model is built and run in the modeling software Vensim© Professional Version 5.5c (Ventana Systems, Inc., Harvard, USA).

PRELIMINARY RESULTS

The results of the parameter estimation show a very good fit of the SIR model to local field data/outbreaks (Figure 2). Thus, the model seems to be adequate to describe the circumstances in the field.

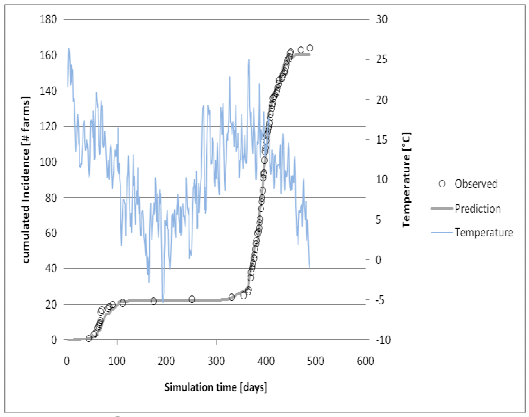

Figure 2 Observed and predicted cumulative BT incidence of cattle farms (time frame June 2006 – December 2007).

DISCUSSION AND CONCLUSIONS

The model approach in this study offers divers advantages. The knowledge about the transmission of BTV is very limited, particularly the interaction between midges, virus and ruminants. In this approach, the proposed simplification to a temperature dependent infection rate has the advantage to estimate the (few) required parameters from field data instead of requiring a large number of parameters based on expert opinions. Moreover, it has the advantage that the estimation of the model parameters from field observations directly links the model to the real situation of the BTV8 outbreak in north-western Europe. With the help of the parameters obtained, expert opinion about the disease dynamics can be validated. However, as the available field data is based on notification data, it reflects the daily reporting of cases rather than the actual time of infection. Thus, observer bias is included. This has partly been taken in account by the introduction of a time lag which considers the time between the actual infection of the host and the case notification. As the measure to control the spread of BTV8 is implemented at the host herd and not the vector population level, it can be relinquished to explicitly model the population dynamics of the vector population to answer the question of the study. Because the population dynamics of the midges is not explicitly modeled, a lean, clear and communicable model is obtained. Switzerland and Germany are bordering countries with overlapping climate conditions. Therefore, it is likely that parameters estimated on the basis of German field data can be adopted and used as input parameters for a vaccination model used to simulate the effect of different vaccination strategies on the BT disease dynamics in Switzerland. However, some circumstances in the field might not be quite the same in both countries. The modeling results have therefore to be interpreted with care.

So far, very good results with the parameter estimation model have been obtained in this study showing the SIR model to be adequate to describe the circumstances in the field. First simulations with the vaccination model for Switzerland are being done at the moment showing interesting and plausible results. A sensitivity analysis is performed to see whether other parameters besides temperature have a strong influence on the model output. With the vaccination model, an easy tool to evaluate the effect of different vaccination strategies on the BT disease dynamics is provided which can help decision makers to design an effective vaccination strategy to prevent herds from infection with BTV8.

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