Estimation of the necessary vaccination coverage to protect cattle and sheep farms from bluetongue virus serotype 8 infection

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INTRODUCTION

Bluetongue virus serotype 8 (BTV8) appeared for the first time in Northwestern Europe in Summer 2006. 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.

OBJECTIVES

The objectives of this study are i) to determine the farm-level vaccination coverage needed to protect cattle and sheep farms from an infection with BTV8 and ii) to evaluate the effect of different vaccination strategies on the bluetongue disease dynamics for Switzerland.

Temperature dependent infection rate β(T)

$$\beta(T,t) = \psi\left[\frac{(T(t-\delta)-T_b)^2}{(T(t-\delta)-T_b)^2+D^2} - \exp\left(-\frac{T_m-(T(t-\delta)-T_b)}{\Delta T}\right)\right]$$

Based on the model by Hilbert & Logan, 1983

T: mean daily temperature in °C
T_b: base temperature (for temperatures below T_b the infection rate equals 0)
T_m: lethal maximum temperature threshold
ΔT: width of high-temperature boundary area (T_m – ΔT = temperature optimum)
δ: necessary time period in days for the vector population to develop a sufficient population density and infectivity
D: Form parameter; Ψ: infection rate at temperature optimum

MATERIAL & METHODS

An SIR model is set up which differs from other models by the introduction of a temperature dependent infection rate β(T). This dependency 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. Parameters of the SIR model are estimated using observed daily incidences from June 2006 until December 2007 of cattle and sheep farms in several districts (Kreise) of Germany where bluetongue infections were officially notified.

By the calculation of the basic reproduction number R_h, the minimum protection level necessary to prevent or stop the spread of BTV8 in a population of farms can be determined, as it equals to $1-1/R_h$. R_h can be estimated using the equation $R_h(T) = \beta(T)N/\lambda$, where N is the population at risk and λ is the transition rate I → R. Because β is temperature dependent, R_h also depends on temperature.

In order to model the effect of vaccination on the disease dynamics, the SIR model is extended by the states V (farms to be vaccinated) and P (protected farms). The vaccination model is used to simulate different vaccination strategies for Switzerland using the estimated temperature dependent infection rate β(T) together with Swiss population and temperature data.

PRELIMINARY RESULTS

The results of the parameter estimation show a very good fit of the model to local field data/outbreaks (Figure 1). Thus, the model seems to be adequate to describe the circumstances in the field.

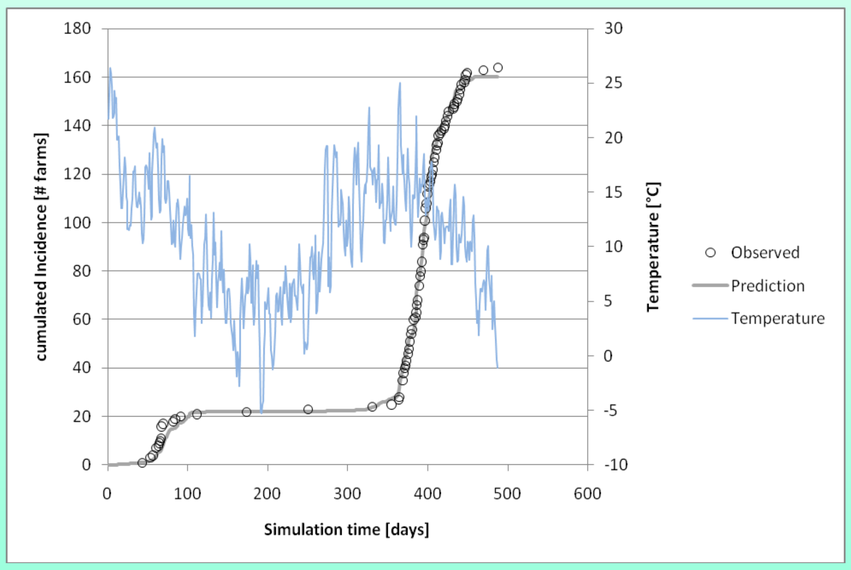
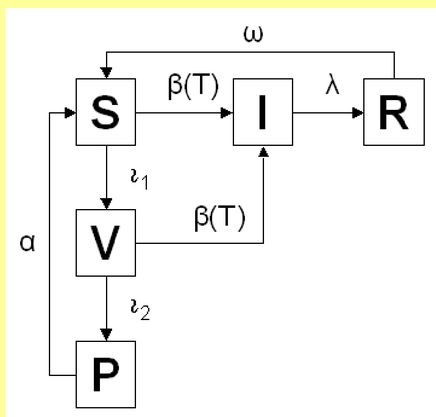


Figure 1: Observed and predicted cumulative bluetongue incidence of cattle farms (time frame June 2006 – December 2007).

Structure of the farm vaccination model



S: susceptible farms
I: infected and infectious farms
R: recovered (immune) farms
V: farms to be vaccinated
P: protected (immune) farms

β(T): temperature dependent infection rate
λ: transition rate from I → R
ω: transition rate from R → S
ι: transition rate from S → V (ι_1) and V → P (ι_2)
α: transition rate from P → S

DISCUSSION

- The knowledge about transmission of bluetongue virus is very limited, particularly the interaction between midges, virus and ruminants. In this model 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.
- Although the population dynamics of midges is not explicitly modeled, its temperature dependency is considered. Doing this, the spread of the disease between the population of farms will decelerate during periods with low, and accelerate during periods with high temperatures, respectively. In this study, we can relinquish to explicitly model the population dynamics of the vector population, because the measure to control the spread of BTV8 are implemented at the host farm and NOT the vector population level.
- By modeling a temperature dependent infection rate, the vaccination rate can also depend on temperature, so that areas with different temperature regimes will also require different vaccination regimes. Thus, the model can be used to analyse whether considerable vaccination doses can be saved with the application of different regimes.
- The evaluation of the effect of different vaccination strategies on the bluetongue disease dynamics will help to design a most effective vaccination strategy against BTV8 for Switzerland considering the optimal time point of vaccination and number of farms to be vaccinated.