Simulation of the seasonal cycles of bird, equine and human West Nile virus cases

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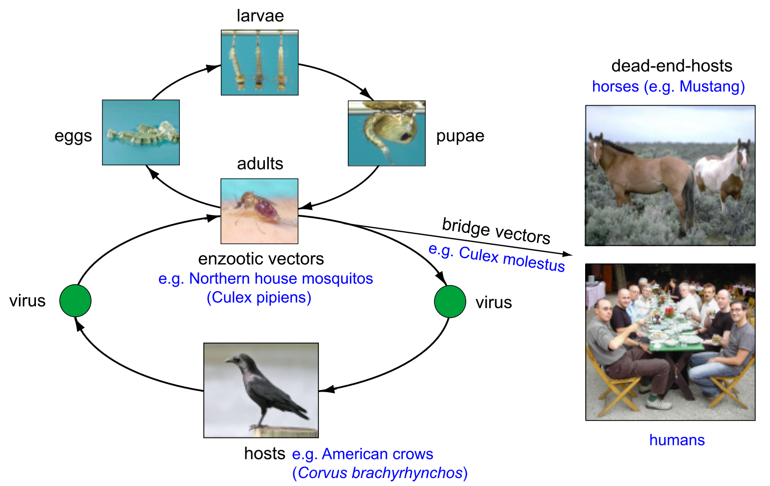
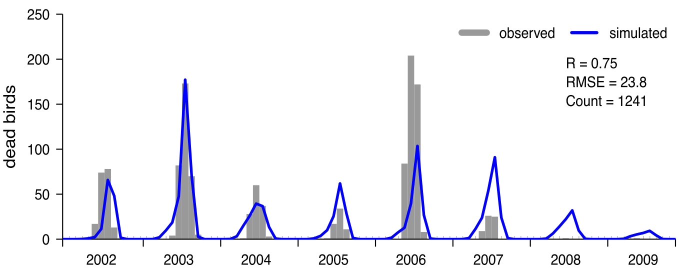
Motivation

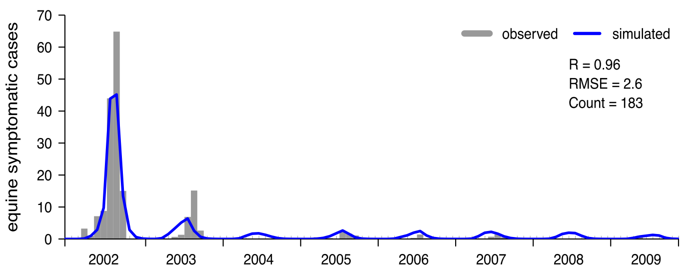
The West Nile virus (WNV) is an arbovirus circulating in a natural transmission cycle between mosquitoes (enzootic vectors) and birds (amplifying hosts). Additionally, mainly horses and humans (dead-end hosts) may be infected by blood-feeding mosquitoes (bridge vectors). We developed an epidemic model for the simulation of the WNV dynamics of birds, horses and humans in the U.S., which we apply to the Minneapolis metropolitan area (Minnesota).



Method

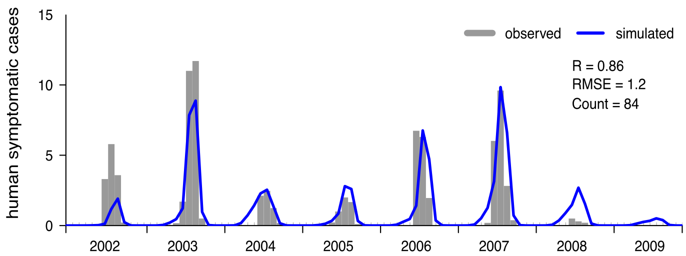
Our SEIR-type model comprises a total of 19 compartments, that are 4 compartments for mosquitoes and 5 compartments or health states for each of the 3 host species. It is the first WNV model that simulates the seasonal cycle by explicitly considering the environmental temperature (see the theoretical background at the bottom of the poster were temperature dependent parameters are marked in red). Generally, all parameters were estimated from literature or census. Special features of the epidemic model are: (1) density dependent population dynamics of wild birds and mosquito larvae, (2) temperature dependent mosquito parameters, including biting rate, hibernation and extrinsic incubation period, (4) population dynamics of horses and humans following national census, and (5) frequency dependent virus transmission (Laperriere *et al.*, 2011).





Results

We adjusted our WNV model to fit monthly totals of reported bird, equine and human cases. From this process we estimated that the proportion of actually WNV-induced dead birds reported by the Centers for Disease Control and Prevention is about 0.8%, whereas 7.3% of equine and 10.7% of human cases were reported. This is consistent with referenced expert opinions whereby about 10% of equine and human cases are symptomatic (the other 90% of asymptomatic cases are usually not reported). Despite the restricted completeness of surveillance data, all major peaks in the observed time series were caught by the simulations. Correlations between observed and simulated time series were R = 0.75 for dead birds, R = 0.96 for symptomatic equine cases and R = 0.86 for human neuroinvasive cases. Our WNV model may also be applied to other arbovirus epidemics. For example, Rubel *et al.* (2008) and Rubel and Brugger (2009) applied it to explain the Usutu virus epidemics in Vienna, Austria.



References

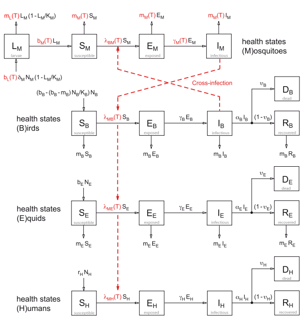
Laperriere, V., K. Brugger, and F. Rubel, 2011: Simulation of the seasonal cycles of bird, equine and human West Nile virus cases. *Prev. Vet. Med.*, **98**, 99-110.

Brugger, K., and F. Rubel, 2009: Simulation of climate-change scenarios to explain Usutu-virus dynamics in Austria. *Prev. Vet. Med.*, **88**, 24-31.

Rubel, F., *et al.*, 2008: Explaining Usutu virus dynamics in Austria: Model development and calib ration, *Prev. Vet. Med.*, **85**, 166-186.

Theoretical background

Epidemic Model



Equations

$$\frac{dL_M}{dt} = (b_L(T)\,\delta_M N_M - m_L(T) L_M)\left(1 - \frac{L_M}{K_M}\right) - b_M(T)\,L_M$$

$$\frac{dS_M}{dt} = -\lambda_{BM}(T)\,S_M + b_M(T)\,L_M - m_M(T)\,S_M$$

$$\frac{dE_M}{dt} = \lambda_{BM}(T)\,S_M - \gamma_M(T)\,E_M - m_M(T)\,E_M$$

$$\frac{dI_M}{dt} = \gamma_M(T)\,E_M - m_M(T)\,I_M$$

$$\frac{dS_B}{dt} = \left(b_B - (b_B - m_B)\frac{N_B}{K_B}\right) N_B - \lambda_{MB}(T)\,S_B - m_B\,S_B$$

$$\frac{dE_B}{dt} = \lambda_{MB}(T)\,S_B - \gamma_B\,E_B - m_B\,E_B$$

$$\frac{dI_B}{dt} = \gamma_B\,E_B - \alpha_B\,I_B - m_B\,I_B$$

$$\frac{dR_B}{dt} = (1-\nu_B)\,\alpha_B\,I_B - m_B\,R_B$$

$$\frac{dD_B}{dt} = \nu_B\,\alpha_B\,I_B$$

$$\frac{dS_E}{dt} = b_E\,N_E - \lambda_{ME}(T)\,S_E - m_E\,S_E$$

$$\frac{dE_E}{dt} = \lambda_{ME}(T)\,S_E - \gamma_E\,E_E - m_E\,E_E$$

$$\frac{dI_E}{dt} = \gamma_E\,E_E - \alpha_E\,I_E - m_E\,I_E$$

$$\frac{dR_E}{dt} = (1-\nu_E)\,\alpha_E\,I_E - m_E\,R_E$$

$$\frac{dD_E}{dt} = \nu_E\,\alpha_E\,I_E$$

$$\frac{dS_H}{dt} = r_H\,N_H - \lambda_{MH}(T)\,S_H$$

$$\frac{dE_H}{dt} = \lambda_{MH}(T)\,S_H - \gamma_H\,E_H$$

$$\frac{dI_H}{dt} = \gamma_H\,E_H - \alpha_H\,I_H$$

$$\frac{dR_H}{dt} = (1-\nu_H)\,\alpha_H\,I_H$$

$$\frac{dD_H}{dt} = \nu_H\,\alpha_H\,I_H$$

Parameters

Param.	Value	Interpretation	Param.	Value	Interpretation
b_L	f(T)	Birth rate, larvae			
m_L	f(T)	Mortality rate, larvae			
b_M	f(T)	Birth rate, mosquitoes	b_B	f(d)	Birth rate, birds
m_M	f(T)	Mortality rate, mosquitoes	m_B	0.00034	Mortality rate, birds
p_M	1.0	Transmission probability by infectious mosquitoes	p_B	0.125	Transmission probability by infectious birds
			α_B	0.4	Removal rate, birds
γ_M	f(T)	Rate with $1/\gamma_M$ extrinsic-incubation period	γ_B	1.0	Rate with $1/\gamma_B$ intrinsic-incubation period
δ_M	f(D)	Faction mosquitoes non-hibernating	ν_B	0.7	Fraction birds dying due to infection
k	f(T)	Mosquito biting rate	ϕ_B	30	Mosquito-to-bird ratio
b_E	0.00016	Birth rate, equids	b_H	0.000055	Birth rate, humans
m_E	0.00011	Mortality rate, equids	m_H	0.000034	Mortality rate, humans
α_E	0.2	Removal rate, equids	α_H	0.5	Removal rate, humans
γ_E	0.05	Rate with $1/\gamma_E$ equid incubation period	γ_H	0.25	Rate with $1/\gamma_H$ human incubation period
ν_E	0.04	Fraction equids dying due to infection	ν_H	0.004	Fraction humans dying due to infection
ϕ_E	300	Mosquito-to-equid ratio	ϕ_H	0.03	Mosquito-to-human ratio

Forces of Infection $\lambda_{BM}(T) = \delta_M\,k(T)\,p_B\,\frac{I_B}{K_B}\,,\ \ \lambda_{MB}(T) = \delta_M\,k(T)\,p_M\,\phi_B\,\frac{I_M}{K_M}\,,\ \ldots$