Mathematical modeling of the spatio-temporal dynamics of aphid-parasitoid-plant-virus interactions

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Aims

To model and analyse the spatio-temporal dynamics of a plant-aphid-natural enemy-plant virus system and explore whether aphid endosymbionts affect trophic dynamics in these systems.

'The potato aphid, *Macrosiphum euphorbiae*'

Background

Aphids are agricultural pests that damage crops by transmitting plant diseases. Some aphids harbour facultative endosymbionts that increase their resistance to parasitoid wasps and might influence their capacity to transmit disease. *Macrosiphum euphorbiae* (the potato aphid) feeds on and transmits diseases to potato plants.

As part of my research, I aim to develop a spatial individual based model (IBM) of the interactions between *M. euphorbiae* on potato plants and its natural enemy, the parasitoid wasp *Aphidius ervi*. This will be used to understand the processes that control the dynamics of a plant-aphid-natural enemy-plant virus system and assess the impact of aphid facultative endosymbionts on trophic interactions.

Model

The IBM that I am developing is based on partial differential equations that have been discretized:

$$\frac{\partial A}{\partial t} = D_A \nabla^2 A$$

$$\frac{\partial W}{\partial t} = D_W \nabla^2 W$$

Equation notation: A and W represent populations of aphids and parasitoid wasps respectively; D_A and D_W are diffusion coefficients for aphids and parasitoid wasps respectively.

These equations are used to generate the movement probabilities for individual hosts and parasitoids. Birth and death terms are handled elsewhere in the model.

Focus will be on the evolution of population dynamics and disease transmission during the summer, when aphid populations reach peak densities. Individuals will move randomly or via chemotaxis on a 2-dimensional domain representing one or more plants. Aphids are assumed to have constant birth and natural mortality rates and can also suffer mortality from being parasitized. Each aphid will have a probability of transmitting disease to plants and will either be winged or wingless.

Parasitoid wasps are assumed to attack aphids given a probability of successfully discovering the aphid and a probability of successful attack. Parasitoid population growth is limited by availability of the host and by the search efficiency of the parasitoid. If there are no available hosts in a patch of area, the parasitoid moves to a random location on the domain after a certain amount of time has passed, called the 'giving up time'.

Results from model

Simulating the model with aphids and parasitoids gives rise to a range of dynamics that include stable coexistence, instability (Figure 1a) and quasi-periodic oscillations (Figure 1b). These dynamics have been observed in other host-parasitoid models.

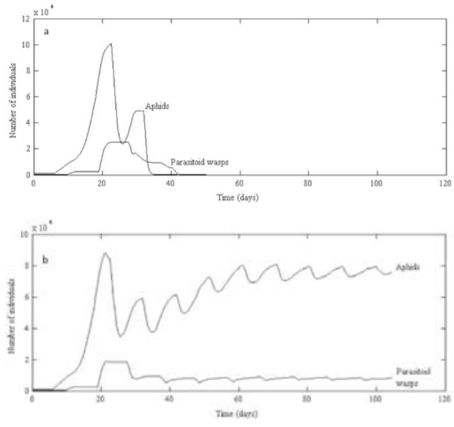

Figure 1. Aphid and parasitoid wasp population dynamics generated by varying the giving up time. Initial aphid population and parasitoid population sizes were 1000 and 100 respectively,nondimensionalised diffusion coefficients for wasps and aphids were α_W = 0.005, α_A = 0.0005 respectively, aphid fecundity was 2 nymphs day^{-1}. a. Giving up time was 3 days. b. Giving up time was 1 day.

Experimental Work

I collected *Macrosiphum euphorbiae* from various locations in Tayside and Perthshire in 2009, from which I have started clonal cultures. These clonal lines have been tested using diagnostic PCR for the presence of the facultative endosymbionts *Hamiltonella defensa, Serratia symbiotica* and *Regiella insecticola* (Douglas et al, 2006). These facultative endosymbionts are commonly detected in the pea aphid and can influence aphid performance. Secondary endosymbiont presence was detected in two of the six aphid clones shown (Figure 2)

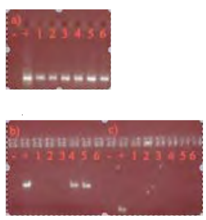

Figure 3. Diagnostic PCR performed on collected samples of *M. euphorbiae.* (a) A 1.4-1.5 kb product obtained with bacterial 16S rRNA primers indicated that bacteria were present in all samples; this would be expected due to presence of the primary symbiont *B.uchnera aphidicola.* (b) A 1.4 kb product (approx.) obtained with primers for *H. defensa* indicated the presence of this symbiont in samples 4 and 5. (c) *S. symbiotica* was not detected in any of the tested samples; *R. insecticola* was also absent from samples tested here (data not shown).

Future Work

Future work will include incorporating plants and disease transmission dynamics into my simulations. Environmental stochasticity will also be incorporated into the model by varying patch quality, temperature and light intensity and its effect on the system will be analysed.

Although the spatial dynamics of the system have not been fully explored, further work will incorporate an analysis of the spatial dynamics generated when parameters are varied and when different initial spatial distributions of species are used.

I am planning lab experimental work to obtain parameter estimates for my model and to assess the effect of facultative endosymbionts on aphid fitness. This information will be used in the model to analyse whether endosymbionts affect trophic dynamics.

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References:
Douglas, A.E., Francois, M.J., Minto, L.B. (2006) Facultative 'secondary' bacterial symbionts and the nutrition of the pea aphid, *Acyrthosiphon pisum. Physiological Entomology* **31,** 262-269.