Introduction

Species interactions in population models may lead to complex dynamics. Also in coupled individual-based models (IBMs) such complexity may emerge. To understand emerging complex behaviour and to be able to predict it, it will be useful to study simpler models containing essentially the same processes. It might be that some of the tools for analysis of simple (ordinary differential equation) models can be adapted to work for IBMs as well.

We used a simple competition model to help explain the behaviour and stability properties of a 2-species IBM, and to predict the consequences of chronic stress and of a pulsed stress event (both affecting survival) on this behaviour. The coupled IBMs are not only an example of 2-species models with (simple) competitive interactions, but also of model systems with potentially alternative stable states (ASS). The impact of stress in the presence of ASS is an issue that deserves further attention in the context of chemical risk assessment, in particular when the ambition is to move beyond the single-species approach.

Material & Methods

General approach

- Find and use a simple, deterministic, non-spatial model to obtain a search image of the potential 'complex' dynamics and stability properties of the IBM
- Apply analysis methods available for deterministic ODE-based models, e.g. graphical analysis, bifurcation analysis.
- Where possible adjust and apply these methods also for IBM
- Predict from the simple models the possible impact of chronic stress and of a pulsed stress event, on dynamics and stability
- Test predictions in IBMs

Individual-based Model (IBM)

Relatively simple, stochastic, IBMs for Asellus and Gammarus [1]

\[
\begin{align*}
\frac{dN_1}{dt} &= \alpha_11 * N_1 \quad (\text{species 1}) \\
\frac{dN_2}{dt} &= \alpha_21 * N_1 + \alpha_22 * N_2 \quad (\text{species 2})
\end{align*}
\]

Movement within a simple 1D or 2D system (edge-of-field scale)

\[
\text{Life-history coefficients}
\]

\[
\begin{align*}
\text{Asellus} & \quad \alpha_11 = 0.001 \quad 70 \quad 20 \quad 1 \quad 0.001 \\
\text{Gammarus} & \quad \alpha_12 = 0.01 \quad 130 \quad 16 \quad 20 \quad 5 \quad 0.001
\end{align*}
\]

Simple model

Deterministic, mean-field (non-spatial), ordinary differential equation model (ODE) counterpart

\[
\begin{align*}
\frac{dN_1}{dt} &= r_1 * N_1 - \alpha_{11} * N_1 * N_2 \\
\frac{dN_2}{dt} &= r_2 * N_2 - \alpha_{22} * N_2 * N_1 + \alpha_{21} * N_2
\end{align*}
\]

Spatially-extended system

- Mobility of the species is low, relative to the spatial dimensions
- In systems with ASS, the transition to alternate state may take the form of a traveling front of one state taking over [3]
- In systems in a transient state (with a traveling front), stress may reverse the direction of a traveling front
- Another cause of ‘unpredictability’ in stochastic IBMs: even in homogeneous systems the distribution pattern in terms of local dominance, at the onset of the stress, may vary between runs and determine whether the system ends up in one or the alternate state

Well-mixed system

- For strong interaction ($\alpha_{12}, \alpha_{21} > 1$) the system may have alternative stable states (bi-stability) [Fig. 1]
- (chronic) stress may move the system into another stability region (Fig. 1)
- Deterministic ODE model predicts the impact of a stress event quite well, even when in the bi-stability region
- Stochastic IBM has for the same setting a probabilistic outcome: some runs ending up in one equilibrium state, others in the alternate state (Fig. 3). This is caused by random variation in the state of the population and the impact of stress (mortality)

Implications Risk Assessment

Small for systems that do not have ASS. It should be taken into account that stress may very easily change the outcome of competition. But this can be predicted quite well from competition models. Impacts on both species have to be considered, even if the stress affects only one. Large for systems with ASS. Random variation in population state, impact of the stressor and spatial distribution (even in homogeneous systems), that inevitably arises in stochastic models and experimental systems, make that under seemingly the same conditions the system may develop to more than one of the equilibrium states. Methods dealing with this possibility as yet need to be developed.

References


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