PhD projects - Daniel Bearup - University of Kent

I am a mathematician with a focus on modelling and understanding biological and ecological systems. Particular interests include spatial population dynamics, integration with experimental data, and dynamics on networks. I suggest some specific projects below, but am open to other ideas. Contact: `d.bearup@kent.ac.uk`

Animal movement, random walks and boundary effects

It is common practice in mathematical biology and theoretical ecology to model movement through advection and diffusion processes [1]. The justification for these approximations is that these processes describe the average behaviour of populations of random walking individuals. However, flaws develop in these approximations for discrete random walks near boundaries [2] which can be characterized algebraically on short time scales.

Possible directions for this project include: extending this analysis for more complex, particularly concave, boundaries; investigating how these short time scale effects propagate into longer term behaviour; and considering how the behaviour of spatial population models changes due to these effects.

References

[1] Lewis, M. A., Petrovskii, S. V., & Potts, J. R. (2016). *The mathematics behind biological invasions* (Vol. 44). Berlin: Springer.

[2] Bearup, D., & Petrovskii, S. (2015). "On time scale invariance of random walks in confined space". *JTB*, 367, 230-245.

Functional response for a heterogeneous world

Functional response describes the rate at which a species consumes resources as a function of the density of the resource [1]. It is a fundamental building block of models of interacting populations and thus ecological communities. Apparently minor variations in the form of this response can significantly affect the dynamics of a community, in particular, determining whether a species is, or is not, at risk of extinction [2]. Consequently, it is important to understand the factors that change functional response. While there is a rich history of research on functional response, e.g. [3], there remain many open questions.

A natural starting point for this project would be the increasingly recognised issue of population variability, or demographic structure. Variation in resource requirements within a population could naturally be expected to affect the consumption rates, however such effects have yet to be incorporated into the classification of functional response types. Other streams of the project could include how demographic structure affects classical results in mathematical biology and effects of habitat variability and particularly environment change.

References

[1] Murray, James D. (2001) *Mathematical biology. I An Introduction.* New York: Springer-Verlag New York Inc.

[2] Adamson, M. W., and A. Yu Morozov (2013) "When can we trust our model predictions? Unearthing structural sensitivity in biological systems". *Proc. R. Soc. A*, 469.2149: 20120500.

[3] Jeschke, J. M., Kopp, M., and Tollrian, R. (2002). "Predator functional responses: discriminating between handling and digesting prey". *Ecological Monographs*, 72(1): 95-112.

Interacting species in space

Mathematical theory for non-spatial models of interacting species is relatively well developed. However, when these models are embedded in space, using partial differential equations or other frameworks, the dynamical properties of the resulting systems are rarely predictable see e.g. [1, 2]. This project could go in a variety of directions, from the classical reaction-diffusion frameworks to spatially discrete models [3] depending on what you are interested in.

One specific idea I have in mind is to look at mutualistic interactions between species in an invasion scenario. I have done some, unpublished, numerical work on the problem and there are several interesting patterns to explore.

References

[1] Turing, A. (1952) "The chemical basis for morphogenesis". *Phil. Trans. R. Soc. B*, 237(641):37-71.

[2] Manhart, A. (2019) "Counter-propagating wave patterns in a swarm model with memory." *J. Math. Biol.*, 78(3): 655-682.

[3] Zhang, H. *et al.* (2021) "Dispersal network heterogeneity promotes species coexistence in hierarchical competitive communities." *Ecol. Lett.*, 24(1):50-59.

Modelling the regulation processes responsible for polar cell growth

Cell growth is one of the central biological processes common to life. A regulatory protein network responsible for the localisation of cell growth machinery to the tips of the cell has recently been characterised [1]. This project will focus on developing a model of this system in order to identify typical behaviours and key processes within it. We will explore what information is needed to parameterise this model to allow it to be used to make experimentally testable predictions. In the later stages of the project we will consider how this network integrates with wider cell processes with input from experimentalists investigating this network.

References

[1] Johnson, M., & Mulvihill, D. P. (2018). "Dependency relationships within the fission yeast polarity network". *FEBS Letters*, 592(15), 2543-2549.