Mathematical Ecology: Theory and Applications (META)

Joint Research Group in the UK - LMS Scheme 3

META WORKSHOP

`Mathematics of Ecological Complexity'

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ABSTRACTS

Daniel Bearup
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Population dispersal is well described by diffusion even when some individuals may perform Lévy walks

The dispersal of populations in space is known to have an important influence in a variety of ecological contexts. As such identifying the most appropriate model with which to describe the underlying patterns of movement is a subject of intense ongoing research. A common approach is to track the movement of individuals either in the field or in an experimental setting. Characteristics of the resulting tracks, such as the step length distribution, are then compared to the predictions of random walk models.

In this talk, I will present an alternative approach which instead focuses on the movement of a population as a whole. We use solutions of the diffusion equation to estimate the size and dispersal rate of a population of walking beetles from counts of the number of individuals leaving an experimental arena. The resulting estimates are found to be in good agreement with independent estimates of these quantities. We then simulate boundary counts for Lévy-type walks for an identical experimental setup and find that, for the majority of exponents, they are easily distinguishable from the boundary count trajectories observed experimentally. We conclude that the dispersal of these insects, as a population, is well described by Brownian motion (and the diffusion equation) rather than Lévy-type dispersal.

Jack Choules
University of Leicester

Ways to compare random walks resulting from different distributions: do we always have to focus on mean equal or variance?

When random movement is modelled, there are many different distributions that can be chosen from for the step length. Different distributions can appear to lead to the same result, i.e. equal mean and variance. What I will attempt to demonstrate is how different methods for comparing distributions can give very different answers for which is “best” or "fastest". I will then show another, broader, method for comparing distributions, one that can compare fat-tailed distributions to more common distributions.

Edward Codling
University of Essex

Optimal navigation strategies for animal movement: copycat dynamics revisited

Many animals have the ability to navigate towards targets in space: from foraging animals locating food items over small temporal and spatial scales, to annual long-range migration events over distances of thousands of kilometers. At the individual level, an animal may try to balance persistence (moving in the same direction as previously) with information about the target gained from external navigational cues (such as visual, auditory, or odour cues). In animal groups where all individuals are equally poor at navigating and there are no leaders, navigational benefits may also be gained through individuals directly copying the movements of neighbours and through group cohesion restricting individual navigation errors. I will demonstrate how in most realistic navigation scenarios, the optimal navigation strategy is to give a high weighting to indirect rather than direct navigational sources of information. This counter-intuitive result is related to the 'many wrongs principle' where errors are suppressed through information gained from the past history of an individual's movement trajectory or from copying the movement of group neighbours. The results are illustrated using an analytical approximation for the individual movement case and numerical individual-based simulations for the group movement case.

Stephen Cornell
University of Liverpool

Invasions, heterogeneity, and the evolution of dispersal

TBA

Emily Forbes
Harper Adams University

Why does agricultural research need mathematical modelling?

Deroceras reticulatum (grey field slug) is the most economically important mollusc in UK crop production, laying eggs whenever conditions are favourable and active at a wider range of temperatures than other slug species. The sustainability of the main control agent, metaldehyde is of significant current concern due to heavy usage pressure and contamination detected in water courses. Alternative control methods are not as effective or are too expensive to be commercially viable. New approaches that reduce metaldehyde applications in commercial fields are therefore urgently required.

Slugs are known to have a discontinuous distribution in the field but the environmental and biological factors determining this distribution are poorly understood. This project investigates the proposal that if the higher density patches of slugs are sufficiently stable in time and space then efficient control of the pest may be achieved by targeting metaldehyde application solely at higher density patches. Recent advances in application technology allow such precision targeting in the commercial environment. Focussing on patch rather than field scale slug management has two potential consequences, reduced risk of diffuse pollution and non-target effects from existing chemistry, arguably allowing use to be retained, and improved cost effectiveness of alternatives such as biocontrol agents.

This multi-disciplinary project combines mathematical modelling techniques with detailed biological and behavioural studies of slug populations in the field to improve our knowledge of patch dynamics, thus their temporal and spatial stability within and between cropping seasons in three important commercial crops; winter wheat, winter oilseed rape and ware potatoes. The output will be used to determine whether it is possible to reduce environmental impacts and the cost effectiveness of slug control through precision targeting of inputs providing a new scientific basis for rational pest management decisions.

Valerie Livina
National Physical Laboratory

Tipping point analysis of dynamical systems, with applications in geophysics and environmental sciences

We study time series using the tipping point analysis techniques for anticipation, detection, and forecast of tipping points in a dynamical system. The methodology combines degenerate fingerprinting and potential analysis. Degenerate fingerprinting indicator is a dynamically derived lag-1 autocorrelation, ACF (or, alternatively, short-range scaling exponent of Detrended Fluctuation Analysis, DFA [1]), which monitors short-term memory in a series. When such values rise monotonically, this indicates an upcoming transition or bifurcation in a series and can be used for early warning signals analysis. The potential analysis detects a transition or bifurcation in a series at the time when it happens, which is illustrated in a special contour plot mapping the potential dynamics of the system [2-6]. Potential analysis is also used in forecasting time series by extrapolation of Chebyshev approximation coefficients of the kernel distribution, with reconstruction of correlations in the data [6]. The methodology has been extensively tested on artificial data and on various geophysical, ecological and industrial sensor datasets [2-10], and proved to be applicable to trajectories of dynamical systems of arbitrary origin [11].

References: [1] Livina and Lenton, GRL 2007; [2] Livina et al, Climate of the Past 2010; [3] Livina et al, Climate Dynamics 2011; [4] Livina et al, Physica A 2012; [5] Livina and Lenton, Cryosphere 2012; [6] Livina et al, Physica A 2013; [7] Livina et al, Journal of Civil Structural Health Monitoring, 2014; [8] Kefi et al, PLoS ONE 2014; [9] Livina et al, Chaos 2015; [10] Perry et al, Smart Materials and Structures, 2016; [11] Vaz Martins et al, PRE 2010.

Andrew Morozov
University of Leicester

Environmental heterogeneity and density-dependent animals' dispersal as key regulators of top-down control in ecosystems with eutrophication

Classical models describing predator-prey (host-parasite) interactions generally predict large-amplitude oscillations under eutrophic conditions, i.e. when the resource supply for the prey (parasite) is high. This should potentially result in collapse and extinction of species since their densities would eventually drop to extremely low values. Such theoretical predictions, however, are often at odds with empirical data. Indeed, there exist a large number of examples of ecosystems in which the species densities remain low despite a high resource supply. Various mechanisms have been proposed to explain such stability (e.g. considering food selectivity of predators, introducing structuring within prey population, etc). However, physical heterogeneity of the habitat as well as complexity of animal dispersal patterns has been largely overlooked so far in the literature. In this talk, I will discuss a novel generic mechanism of stabilisation in predator-prey systems due to interplay between heterogeneity of physical environment and fast food-dependent dispersal of the predator. I will show that stabilisation in the ecosystem occurs even in the case where the resource supply for prey is unlimited. This mechanism seems to be robust to the choice of a specific model and it holds for both discrete and continuous modelling settings. Interestingly, available empirical data on vertical distribution of plankton in the water column in the ocean support the suggested mechanism of stabilisation of top-down control in eutrophic environment.

Wenxin Zhang
University of Birmingham

Spatial patterns of interacting stage-structured species with short-distance dispersal

Spatio-temporal dynamics of interacting species can be conveniently modelled with a system of integro-difference equations. In a stage-structured species model, it is assumed that the species have separate maturation stage and dispersal stage and they interact during the maturation stage only and this requirement should be reflected in the model. In my talk I will discuss various spatial patterns arising when the Gaussian dispersal kernel is used in the model.