Dynamical systems and spatial models in ecology
Systèmes dynamiques et modèles spatiaux en écologie
(Org: **Amy Hurford** (memorial University))

ALI GHAROUNI, Population Ecology Division, Fisheries and Oceans Canada
Larval versus adult dispersal: implications of two modes of dispersal on the spread rate and population structure at an invasion

Marine species can spread by both adult movement and through dispersal of pelagic larval stages or propagules. Optimal methods to control the spread of the species depend on which mechanism is dominant. However, measuring the scale of stage-specific dispersal is usually difficult, if not impossible. By comparison, sampling the population at the leading edge of an invasion is much easier logistically. Hence, we are interested in the relationship between the population structure at the leading edge of an invasion and the relative scales of dispersal between stages. To address this problem, we considered a deterministic, stage-structured integrodifference equation (IDE) model with dispersal by both larval and adult stages. The fractions of the population by stages at the wave front are predicted by the eigenvector corresponding to the principal eigenvalue of the linearized IDE model. Analysis of this eigenvector leads to a relationship between the fractions of the population by stages at the invasion wave front and the demographic parameters, the dispersal parameters and the spread rate.

AMY HURFORD, Memorial University
Skewed temperature dependence affects range and abundance in a warming world

In response to climate warming, range shifts have occurred in almost all major taxa, but it remains poorly understood why some species respond positively, for example increasing their range sizes, while others respond negatively. We hypothesize that skewness in the relationship between temperature and fitness will affect species' responses to climate change. Asymmetric fitness curves arise due to the relative strength of temperature dependence in positive and negative components of fitness, and although empirical evidence suggests that cold-skewed fitness curves are common, the strength of the skew can vary dramatically between species. We formulate a moving habitat integrodifference model that combines net reproduction and dispersal to test if differences in fitness curve skewness may explain differences in range size, abundance, and lag arising due to climate warming. We find that climate warming will adversely affect populations with cold-skewed, positively affect populations with warm-skewed, and have relatively little or mixed effect on populations with symmetric fitness curves, and that the degree of the skew will further magnify each of these effects. These results are robust to different choices of growth and dispersal functions and parameters, and are a necessary step towards understanding species' responses to climate change more generally. This research is in collaboration with Christina Cobbold and Peter Molnar.

THEODORE KOLOKOLKINOV, Dalhousie University
Agent-based models exhibiting spatial aggregation

We discuss two agent-based models which exhibit spatial aggregation. The first example is a simple stochastic model of bacterial aggregation which leads to a novel fourth-order nonlinear PDE in its continuum limit. This PDE admits soliton-type solutions corresponding to bacterial aggregation patterns, which we explicitly construct.

The second example models complex predator-swarm interactions. Here, each prey within a swarm is represented by a point particle, with near repulsion and far-field attraction, in addition to the repulsion from the predator. The resulting system of ODE's can be approximated by a nonlocal PDE whose analysis yields insight about whether swarming behaviour helpful in avoiding a predator.

MARK LEWIS, University of Alberta
Generational spreading speeds for integrodifference equations

Some of the most fundamental quantities in population ecology describe the growth and spread of populations. Population dynamics are often characterized by the annual rate of increase, lambda or the generational increase, R_0. Analyses involving R_0 have deepened our understanding of disease dynamics and life-history complexities beyond that afforded by analysis of annual growth alone. While range expansion is quantified by the annual spreading speed, a spatial analog of lambda, an R_0-like expression for the rate of spread is missing. Using integrodifference models, we derive the appropriate generational spreading speed for populations with complex stage-structured life histories. The resulting measure, relevant to locations near the expanding edge of a (re)colonizing population, incorporates both local population growth and explicit spatial dispersal. The calculations for generational spreading speed are often simpler than those for annual spreading speed, and analytic or partial analytic solutions can yield insight into the processes that facilitate or slow a population's spatial spread. We analyze the spatial dynamics of teasel as an example to demonstrate the flexibility of our methods and the intuitive insights that they afford. This work is joint with Andrew Bateman, Marty Krkosek and Mike Neubert.

AO LI, University of Western Ontario

Modelling the fear effect on prey population in patchy environment

Empirical results and theoretical analyses reveal that fear alters the behaviours of prey then influences its population size. In most cases, animals are observed to reduce activities to avoid being captured by predators at the cost of growth, which also results in the reduction of movement. We formulate a two-patch model incorporated with dispersal. Survival of prey is possible in a poor environment if prey from both patches can move freely to the other at a low rate. Using methods of adaptive dynamics to study the evolution of anti-predation strategy, we show that in an isolated patch there may exist a non-zero optimal strategy which is both an evolutionary stable strategy (ESS) and a convergence stable strategy (CSS). Numerical simulations are given for the two-patch model, implying that anti-predation strategy plays an important role in the long-term population dynamics of prey and an optimal strategy may exist which is stable in evolutionary sense.

JOANY MARIÑO, Memorial University

Dynamic Energy Budget theory predicts smaller energy reserves in clams that harbour symbionts

Dynamic energy budget (DEB) theory describes the upktake and use of energy by individuals, and distinguishes between the biomass of an organism that function as an energy reserve and as a structure. Two related species of small-sized clams inhabit the same seasonal environment and have similar diets. However, one species harbours bacteria that are digested as an additional resource, and how this nutritional symbiosis affects the energy budget of the clam is unknown. We parameterized a DEB model for each species and we found that the symbiotic clam has a smaller fraction of its biomass as an energy reserve relative to the asymbiotic species. A smaller energy reserve, in turn, implies reduced energy assimilation and mobilization fluxes, lower structural maintenance costs and growth rate, and larger energy allocation to maturity and reproduction in the symbiotic clam. Together, these features may comprise an evolutionary strategy where the symbionts function as a partial energy reserve for the host, and are an adaptation to fluctuating food availability. Our results highlight how a nutritional symbiosis may alter the energy budget of a host clam.

This work is joint with Starrlight Augustine, Suzanne C. Dufour and Amy Hurford.

MICHAEL NEUBERT, Woods Hole Oceanographic Institution

Two-Sex Invasion Dynamics

A key descriptive statistic of an ecological invasion is the speed at which it spreads across the landscape—the invasion speed. In general, the invasion speed depends on the vital rates (growth, survival, fecundity, etc.) and dispersal rates of individuals. These rates vary from individual to individual and much of that variability can be attributed to the individual's life-history stage. Ecologists have incorporated these stage-specific differences into integrodifference matrix population models from which they can compute the invasion speed, and the sensitivity of the speed to changes in the vital and dispersal rates.

Vital rates and dispersal rates also vary according to an individual's sex, and for many animal species, fertility depends on the formation of breeding pairs, which in turn depends on the relative frequency of the sexes. We have developed an invasion model that accounts for both the age- and the sex-structure of the population, and includes the pair formation process and sex bias in the vital and dispersal rates.

We have derived, and will present, a formula for the invasion speed obtained from the model using low-population-density approximations. Our comparison of this formula with the results of numerical simulations suggests that the formula is correct for a class of reasonable nonlinear models and initial conditions as well. Using the formula, we will show that the invasion speed depends in complex ways upon the model parameters and on the nature of the pair-formation process that governs mating.

ERIC PEDERSEN, Fisheries and Oceans Canada
Statistical estimation of the moment dynamics of ecological communities to detect regime changes

As anthropogenic changes increasingly shape the global ecosystem, more are more ecological communities are undergoing regime shifts (abrupt changes from one persistent ecological state to another). Current statistical techniques for detecting regime shifts have focused on detecting abrupt changes in the abundances of single species, ignoring the possibility of more complex community dynamics during shifts such as transient responses, the existence of slow variables, or compositional re-arrangements. Here I argue that regime shifts are more readily detectable from among-species statistical moments of rates of change; i.e. means and variances of instantaneous rates of change among species. I show how it is possible to estimate these rates of change from noisy community data by using a novel penalized spline / Markov Random Field tensor product smoother that fits species-specific time series while simultaneously penalizing species towards a common trend, using long-term monitoring data from the collapse of the Newfoundland Atlantic Cod stocks as an example.

OLGA VASILYEVA, Memorial University of Newfoundland - Grenfell Campus
Nonlinear Population Dynamics in River Networks

We study the population dynamics of aquatic organisms in a river network. The habitat is viewed as a tree-like metric graph with the population density satisfying a reaction-diffusion-advection equation on each segment along with the appropriate junction and boundary conditions. In the case of a linear reaction term, the question of persistence in such models was studied by Sarhad, Carlson and Anderson. We focus on the case of a nonlinear (logistic) reaction term. We obtain necessary and sufficient conditions for the existence and uniqueness of a positive steady state solution for an arbitrary river network.

YANG WANG, University of Western Ontario
A predator-prey system with digest delay and anti-predation strategy

Predator-prey system is one of the most fundamental topics in ecology and evolutionary biology. Classic point of view focuses on direct predation only. With theoretical and experimental studies focusing on indirect effect such as cost of fear, researchers proposed that indirect effect may even have stronger impact than direct killing. Recent works by Wang, Zanette and Zou (2016,2017) have proposed some mathematical models to discuss the influence of such kind of effect. In this project, we consider indirect effect represented by anti-predation strategy. The anti-predation strategy such as group defense and avoiding detection can help prey survive from hunting by predator. Meanwhile, as a cost of these anti-predation strategies, the reproduction rate decreases due to the lack of time, space and energy. We adopt differential equation models to describe the dynamics between two species. At the same time, we take digest delay of predator into account. That is, after consuming the prey, predators need time τ to convert the biomass to their own. By applying stability analysis for delay differential equations, we find that for specialist predator, if the prey species use high level anti-predation strategy, the predator will become extinct and the prey will survive after suffering from the cost of this kind of strategy. A mild anti-predation strategy can guarantee coexistence of two species. Periodic change of population is possible for low level anti-predation strategy and sufficient large delay. Numerical simulations are given to verify our theoretical results.

RUIWEN WU, Memorial University of Newfoundland
Propagation Dynamics for a Spatially Periodic Integrodifference Competition Model

In this talk, I will report our recent research on the propagation dynamics for a class of integrodifference competition models in a periodic habitat. An interesting feature of such a system is that multiple spreading speeds can be observed, which biologically means different species may have different spreading speeds. We show that the model system admits a single spreading speed, and it coincides with the minimal wave speed of the spatially periodic traveling waves. A set of sufficient conditions for linear determinacy of the spreading speed is also given. This talk is based on a joint work with Dr. Xiaoqiang Zhao.

ALI BEYK ZADEH, University of New Brunswick
Dispersal Redistribution Approximation

Integrodifference equations (IDEs) are often used as discrete-time models for populations with distinct growth and dispersal stages. Most studies of these systems simplify the model by assuming either homogeneous dispersal, isolated single patches, or spatial or temporal periodicity. However, patchy landscape with bias at patch boundaries are often of interest and can lead to asymmetric and discontinuous dispersal kernels. In this case, the non-trivial solution of the IDE is a piecewise continuous function. Using a partial integral of the dispersal kernel known as the redistribution function, I derive an approximation of the non-trivial steady-state solution of the IDE model with a discontinuous, asymmetric kernel modeling dispersal and growth on a patchy landscape. The error of the this Dispersal Redistribution Approximation (DRA) is a decreasing function of the bias at patch boundaries. This work is joint with Dr. James Watmough.