Dynamics of Microbial Systems
Dynamique des systèmes microbiens
(Org: **Gail Wolkowicz** (McMaster University))

HERMANN EBERL, University of Guelph
Spatio-temporal modeling of cellulosic biofilms

Cellulosic ethanol is a transportation biofuel, primarily produced from non-edible, renewable plant material. An important step in its production is hydrolysis of cellulosic material by certain anaerobic bacteria. Whereas mathematical models of biofilms typically focus on microbial aggregates that form on non-reactive, impermeable surfaces, cellulosic biofilms grow in thin layers and degrade the substratum on which they grow. We present a highly nonlinear spatio-temporal model for their formation. It is able to reproduce important experimentally observed phenomena,including the formation of inverse colonies, crater-like colonies, degradation of paper chads at constant speed (which correspond to a traveling wave solution of the model), and temporal CO2 production patterns. This based on joint work with Eric Jalbert, Alexandru Dumitrache and Gideon Wolfaardt.

SCOTT GREENHALGH, Siena College
Fighting HIV with viruses: the benefit of GB virus C on the health burden of AIDS

Highly active antiretroviral therapy has revolutionized the battle against HIV/AIDS. From its current global rollout, HIV/AIDS morbidity and mortality has been greatly reduced, yet substantial interest exists in the development of new therapies to further mitigate the HIV/AIDS health burden, and to inhibit fallout from the development of antiretroviral drug resistance. One potential therapy under recent deliberation is GB virus C (GBV-C). GBV-C is a virus that does not cause disease, and most remarkably is clinically shown to delay the progression of HIV to AIDS.

In this talk, we illustrate the utility of GBV-C inoculation for mitigating the health burden of AIDS using mathematical models. Our results show that, even in the face of GBV-C virulence evolution, GBV-C inoculation can be an effective therapy for reducing AIDS morbidity and mortality.

TING-HAO HSU, McMaster University
Interaction of Phage-Sensitive and Phage-Resistant Bacteria with Acquisition of Phage Sensitivity

We study a delay system modeling the interaction of phage-sensitive and phage-resistant bacteria in a chemostat. Phage are viruses that attack bacteria. For a lytic phage, the typical infection cycle is initiated by attachment to the host receptor, followed by injection of DNA into the host, and replication of the phage genome. After a latent period, the membrane of the host breaks down, and then the host bursts and releases mature phage.

Most phages can only infect a limited set of strains within a bacterial species. Thus resistant bacteria may emerge. Bacterial resistance is generally due to loss of the receptor molecule to which a phage binds. Because this receptor is involved in bacterial metabolism, the phage-resistant bacteria are usually the weaker competitors than phage-sensitive bacteria for the limiting resource.

Recently Tzipilevich et al. discovered a phenomenon called "acquisition of sensitivity", in which bacteria lacking phage receptors can become transiently sensitive to phage and get infected. This is caused by transfer of phage receptors to the resistant cells, released from phage-sensitive cells, mediated by membrane vesicles. Acquisition of sensitivity implies that the resistant mutant loses more competitiveness than that expected in the literature, so the persistence of the mutant bacteria becomes even less possible. In our work, using persistence theory and the numerical solver DDE-BIFTOOL, we analyze a delay system involving the acquisition of sensitivity to confirm this prediction.

DANIEL KORYTOWSKI, Fields Institute / McMaster University
Permanence and Stability of a Kill the Winner Model in Marine Ecology

Focus on the long term dynamics of "Killing The Winner" Lotka-Volterra models of marine communities consisting of bacteria, virus, and zooplankton. Under suitable conditions, it is shown that there is a unique equilibrium with all populations present which is stable, the system is permanent, and the limiting behavior of its solutions is strongly constrained.

CHIU-JU LIN, McMaster University
An alternative formulation for a distributed delayed logistic equation

We study the alternative single species logistic distributed delay differential equation (DDE) with decay-consistent delay in growth. Population oscillation is rarely observed in nature, in contrast to the outcomes of the classical logistic DDE. In the alternative discrete delay model proposed by Arino et al. [J. Theor. Biol. 2006, pp109–119], oscillating behavior is excluded. This study adapts their idea of the decay-consistent delay and generalizes their model.

We establish a threshold for survival and extinction: in the former case, it is confirmed using Lyapunov functionals that the population approaches the delay modified carrying capacity; in the later case the extinction is proved by the fluctuation lemma. We further use the adaptive dynamics to conclude that the evolutionary trend is to make the mean delay in growth as short as possible. This confirms Hutchinson's conjecture and fits biological evidence.

TYLER MEADOWS, McMaster University
A simplified model of anaerobic digestion

Anaerobic digestion is a complex biologically mediated process which is used in the treatment of waste and wastewater to produce biogas and other bio-fuels. The Anaerobic Digestion Model No. 1 (ADM1) is the industry standard for modelling the anaerobic digestion process, and comprises of 32 state variables when implemented as a system of differential equations. We analyze a simplified model proposed by Bornhöft, Hanke-Rauschenback, and Sundmacher, that seems to capture the qualitative dynamics of ADM1. We show that their model simplifies further to a chemostat with non-monotone response. Using a novel Lyapunov function argument, we show there are no periodic orbits in the full system, an every solution converges to an equilibrium point. The absence of periodic orbits is a new result for single species growth in the chemostat with non-monotone response.

SHIGUI RUAN, University of Miami
Spatial and Temporal Dynamics of a Nonlocal Viral Infection Model

We study a spatial model of viral dynamics on a bounded domain in which virion movement is described by a nonlocal (convolution) diffusion operator. The model is a spatial generalization of a basic ODE viral infection model that has been extensively studied in the literature. We investigate the principal eigenvalue of a perturbation of the aforementioned nonlocal diffusion operator and show that the principal eigenvalue plays a key role similar to the basic reproduction number when it comes to determining the infection dynamics. Through analyzing the spectra of two matrix operators, it is shown that the model exhibits threshold dynamics. More precisely, if the principal eigenvalue is less or equal to zero, then the infection-free equilibrium is asymptotically stable while there is an infection equilibrium which is stable provided that the principal eigenvalue is greater than zero. (Based on a joint paper with Guangyu Zhao)

ZHISHENG SHUAI, University of Central Florida
Graph Design and Reduction to Global Lyapunov Functions in Population Dynamics

The graph-theoretic approach has become a standard method to construct global Lyapunov functions for large-scale differential equation systems. Appropriate graph/network design and reduction is the key in the successful application of the approach. We illustrate these graph/network techniques using various biological models in the literature.

ALEXANDRA TESLYA, York University
Dynamics of the threshold-delay model of the HIV infection of infants through breastfeeding: control implications.

It is known that the breast milk of HIV infected women contains HIV. And therefore, while breastfeeding contributes significantly to optimization of nutrition and protection against a number of childhood infections, it can also lead to HIV infection of infants. It is important to evaluate the threshold of breastfeeding duration, which can lead to an in-host HIV infection and, subsequently, affect an epidemic in a population. Authors extended a general immuno-epidemiological threshold-delay model given by Qesmi et al. (2015) which incorporated in-host virus dynamics and views the infection process as a series of exposures. The new model depicts an intrinsic virus growth rate as a function of the number of infected females in the population. This allows for a simpler modelling framework which operates in a population of susceptible, exposed and infected infants and infected breastfeeding women, without having to explicitely account for the dynamics of other healthy and infected individulas in the population. The model is reduced to an equivalent state-dependent delay equation model, which is analyzed using stability and numerical bifurcation analysis. One of the most biologically important features of the model is a backward bifurcation, as the result of which a bi-stability between an endemic and the disease-free equilibrium is possible, when the basic reproductive ratio R0 is less than one. Additionally, from the numerical simulations and bifurcation analysis, it is evident that the in-host dynamics parameters determine whether a backward bifurcation is possible.

MATTHEW WADE, Newcastle University and McMaster University
A model of a hybrid shortcut nitrification process

Nitrogen removal is a key process in the treatment of wastewater but, in systems with low carbon influent streams, complete denitrification is difficult without supplementary organic carbon. The discovery of microorganisms that can oxidise ammonium directly to nitrogen gas under anaerobic conditions using nitrite as the electron acceptor has led to a significant change in the design of nitrogen removal. This process, Anammox (AMX), has been coupled with partial nitritation (PN/A), the incomplete nitrification of ammonium to nitrite, for cost-effective treatment of ammonium rich waste streams. However, these systems are far from ideal, given the dynamics and characteristics of the functional groups involved in the process. To overcome the issues of substrate competition and imperfect control of the undesired Nitrite Oxidisers (NOB) under mainstream operation, hybrid systems have been developed that assume perfect segregation between the AMX, retained as a biofilm in the reactor, and the Ammonia Oxidisers (AOB) and NOB, which form flocs and are subject to selective washout. A mathematical model of the PN/A model developed previously as a series of ODEs with some gross assumptions is analysed as both a Sequencing Batch Reactor with impulsive differential equations, and as a conventional CSTR. The existence and stability of equilibria in the CSTR to describe the behaviour of r and K *strategists*, and some discussion on the analysis of the impulsive system are given.

MARION WEEDERMANN, Dominican University
Feedback control for cascading systems of chemostats

Cascading systems of chemostats can be used to describe a number of biochemical processes. In industrial applications of these processes, the goal is to maximize the end product under stable conditions. In this talk I give results for nonlinear adaptive feedback controls for a class of cascading systems of chemostats and outline the challenges that arise when one seeks to stabilize some systems at the optimum.

XIAOQIANG ZHAO, Memorial University of Newfoundland
A Reaction-Diffusion Model of Harmful Algae and Zooplankton in An Ecosystem

In this talk, I will report our recent research on an unstirred chemostat system modeling the interactions of two essential nutrients (i.e., nitrogen and phosphorus), harmful algae (i.e., P. parvum and cyanobacteria), and a small-bodied zooplankton in an ecosystem. To obtain a weakly repelling property of a compact and invariant set on the boundary, we introduce an associated elliptic eigenvalue problem. It turns out that the model system admits a coexistence steady state and is uniformly persistent provided that the trivial steady state, two semi-trivial steady states and a global attractor on the boundary are all weak repellers. This talk is based on a joint work with Drs. Sze-Bi Hsu and Feng-Bin Wang.

HUAIPING ZHU, York University

A temperature driven matrix model for Culex mosquitoes population

There have been a lot of models for single species population, including for mosquitoes. Usually, the available models ignore the effect of daily weather conditions on the reproduction and hatching process of the mosquitoes. In this talk, I will first introduce the mosquito surveillance program and data from five health regions of Greater Toronto Area, then present our modeling studies of mosquitoes abundance. To facilitate the modeling of the impact of temperature on different stages of Culex mosquitoes, we define the mosquito annual calendar by separating each year as summer season and mosquito winter. The two periods are determined by the weather conditions of the year. We then build a matrix population model to track the impact of temperature on different stages of the mosquitoes development in each period, in particular, the daily average temperature and heat accumulation are incorporated to model the aquatic stages of culex mosquitoes. The average winter temperature and length are used to model the survival of overwintering adult mosquitoes. The trap counts of adult Culex from the weekly surveillance program in the regions are used to estimate some of the parameters, and the model simulation and calibration show that our model can catch the trend of mosquito abundance well. This is a joint work with Longbin Chen, Beate Sander, Steven Wang, Wendy Pons, Nicholas Ogden.