DIRECT AND INDIRECT EFFECTS OF TEMPERATURE ON THE DYNAMICS OF LAKE PLANKTON

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Prediction implies the estimation of future states of dynamical systems on the basis of time series. Unavoidable uncertainty in making predictions stems from errors and fluctuations associated with making measurements, and also from the complexity of the dynamics themselves. To be predicted, the time series have to contain some kind of repeatability, which can be exploited in the course of forecasting. In particular, even irregular time series are often characterized by the repeatability that implies fuzzy recurrences of the states of the system under study. Recently, the recurrence quantification analysis was used in order to assess numerically the horizon of predictability of chaotic fluctuations of the phytoplankton abundance in the Naroch Lakes system consisting of three reservoirs, Lake Naroch, Lake Myastro and Lake Batorino (Medvinsky et al., 2015. Chaos far away from the edge of chaos: A recurrence quantification analysis of plankton time series. Ecol. Complex., 23, 61–67). Here, we present the results of the analysis of the dynamics of bacterioplankton populations, which inhabit the Naroch Lakes. We demonstrate that the dynamics are chaotic. The horizons of predictability of the bacterioplankton dynamics are shown to be equal to 4.8 months for Small Stretch of Lake Naroch, 4.6 months for Large Stretch of Lake Naroch, 4.7 months for Lake Myastro, and 3.4 months for Lake Batorino. Chaoticity of fluctuations in population abundance can be either an immanent feature of the dynamics or be related to environmental influences. In order to evaluate the action of changes in the environment on plankton dynamics, we assessed numerically the extent to which chaotic fluctuations of bacterioplankton and phytoplankton abundances in the Naroch Lakes were synchronized with temperature oscillations. With the use of the analysis of phase relations between

bacterioplankton and temperature time series we show that the chaotic bacterioplankton oscillations are synchronized with water temperature oscillations, while chaotic fluctuations of the phytoplankton abundance are not synchronized with the temperature oscillations in Lake Naroch and Lake Myastro in contrast to the phytoplankton fluctuations in Lake Batorino, the smallest of the Naroch Lakes, where phytoplankton fluctuations are phase-locked by the temperature oscillations. We conclude that temperature is the factor that has significant impact on predictability of the bacterioplankton fluctuations, while dynamics and predictability of phytoplankton dynamics can apparently be controlled not only by the temperature but also by trophic interactions and nutrient supply. Hence, temperature is apparently the factor, which does not directly impact the temperature-phytoplankton phase synchronizations in the Naroch Lakes, but is indicative of coupling/uncoupling of bacterioplankton and phytoplankton oscillations.

Ecology II

SECONDARY SEED DISPERSAL IN THE KLAUSMEIER VEGETATION MODEL FOR SLOPED SEMI-ARID ENVIRONMENTS

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Keywords: Banded vegetation, Pattern formation, Klausmeier model, Parabolic and hyperbolic reaction-diffusion model.

Highly organized vegetation patterns are typical of arid and semi-arid environments and manifest themselves as bounded vegetated regions separated by bare ground areas. They arise from positive feedback between vegetation and infiltration of rainwater and play a fundamental role as indicators of climate changes and imminent regime shifts. Among the mathematical models widely used to describe the complex competition between vegetation for the limited availability of water, here we consider an extension of the one proposed by Klausmeier [1] to describe the formation of vegetation patterns along sloped semi-arid environments. In such a model, the plant dispersal is treated as a two-stage process: (i) isotropic primary dispersal from plant to ground (modeled via a diffusion term) and (ii) directional secondary seed dispersal by overland flow (modeled via an advection term) [2]. On the other hand, water dispersal along the sloped terrain is mainly due to its downhill flow.

In dimensionless form, the 1D evolution of plant biomass $u(x,t)$ and surface water with $w(x,t)$ at time t and distance x (measured in the uphill direction) is described by the following model equations: $u_t - u_{xx} - \psi u_x = wu^2 - Bu$, $w_t - \upsilon w_x = A - w - wu^2$ where A and B are parameters proportional to rainfall and plant loss, respectively, whereas ψ and υ represent the advection velocities describing the down-slope transport of seeds and water, respectively. In the absence of secondary seed dispersal, the striped patterns predicted by the original Klausmeier model are non-stationary (an intriguing natural phenomenon which is still under debate) and, in particular, the moist soil on the uphill side of a stripe is believed to create the tendency for the stripes to migrate uphill. However, some studies pointed out that the introduction of an advection term, accounting for the down-slope flux of vegetation biomass, may lead to stationary patterns or may even reverse the direction of band migration [2]-[4]. In the present work, we investigate this phenomenon analytically and numerically. By using linear stability analysis arguments, we point out how the presence of secondary seed dispersal affects the Turing-like instability threshold and we show how it reduces the region of the phase plane in which patterns can be observed. Moreover, under

realistic assumptions on the model coefficients, we deduce an analytical expression for the locus of no-migrating (stationary) bands as well as for the excited wavelength. At the same time, we evaluate their dependencies on the key parameters. In particular, our results reveal that, even for relatively small values of seeds-to-water advection ratio (about 10^{-2}), down-slope migration of vegetation bands takes place. As expected from linear stability analysis, our analytical results are in satisfying agreement with numerical ones close to the instability threshold. When the distance from the threshold is progressively increased, the no-migration locus requires some corrections that are identified through numerical simulations. Finally, we develop an *hyperbolic* extension of the parabolic equation governing the evolution of vegetation biomass and discuss the role of hyperbolicity in the resulting patterned dynamics.

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A NOVEL ADVECTION-DIFFUSION-REACTION MODEL OF THE SPATIO-TEMPORAL MERCURY DYNAMICS IN WATER AND SEDIMENTS

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Keywords: Spatial-temporal model, Advection-diffusion-reaction model, Mercury concentration.

Mercury (Hg) is a chronic pollutant of global concern known to be transported long distances in the atmosphere into remote ecosystems. Although a part of the Hg emitted naturally comes from geological and geothermal sources, much of it is recycled Hg previously emitted from primary or anthropogenic sources, and subsequently re-deposited to terrestrial and ocean surfaces. As a consequence, a large part of the 2000 t of yearly emissions from natural sources is actually reemission of previously deposited mercury, much of which has an anthropogenic origin. In some instances, it has been discovered that marine sediments contaminated by industrial effluents may be secondary sources of Hg to aquatic ecosystems even though discharge has been strongly reduced or has even ceased. The exchange of Hg between oceanic surfaces and the atmosphere represents an important process for the atmospheric cycling and environmental turnover of this element. According to [1], the ocean releases about 1/3 of the total global Hg emissions to the atmosphere (about 30% of the total budget of atmospheric mercury on a global scale) and receives about 30–70% of the global atmospheric deposition. Re-emissions from the ocean of previously deposited Hg are dominated by gaseous elemental mercury. Its low solubility and high Henry's Law constant induce high evasion fluxes from fresh water systems. In this framework, theoretical studies were able to reproduce the spatial-temporal dynamics of mercury concentration in marine ecosystems by using biogeochemical models. Specifically, in recent works, for biogeochemical models an WASP (Water Analysis Simulation Program) approach has been used to discretize a water body in one, two or three dimensions, by means of interconnected zero dimensional boxes, which represent water or sediment compartments. However, this approach does not allow to localize the zones within the zero dimensional boxes where the mercury concentration takes on the maximum value. Moreover, the effects of the seasonal variations of most environmental variables on mercury concentration are not usually taken into account in this kind of model. Finally, the previous analyses include neither the study of the spatio-temporal dynamics of phytoplankton distributions nor one of the mechanism responsible for absorption of mercury within the phytoplankton cell in real aquatic ecosystems.

In this context, we introduce an advection-diffusion-reaction model which allows to reproduce the temporal and spatial behaviour of the concentrations of three mercury species (inorganic, organic, elemental) observed in water, pore water and sediments. Moreover, we also consider the partition of methyl-mercury and inorganic mercury into the dissolved phases (water and pore water) and the particulate phases (Suspended Particulate Matter and Sediment particles). The former include both the ionic form and the fraction complexed by the DOC (Dissolved Organic Carbon), while the latter consider the mercury fractions adsorbed by both inorganic and organic matter.

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Title of your talk. Do not use capital letters along the title, only when needed

COLLECTIVE MOVEMENT OF MARINE ANIMALS: THE EFFECT OF ANTHROPOGENIC NOISE ON PATTERN FORMATION

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Keywords: Fish, Velocity and position order parameters, Aggregation patterns.

Moving as a part of a collective group is a phenomenon required by many different species to carry out typical biological processes such as reproduction, migration and foraging. Here, we present a simple agent-based model describing the collective motion of marine animals whereby individuals update their position and velocity through three key behavioural rules: repulsion, orientation and attraction. To investigate the impact that varying the strength of each of these rules has on the group, we introduce weighted terms to each of the rules in the equation. To identify different types of aggregations with clear phase transitions from varied behavioural strengths, we combine numerical simulations with the calculation of order parameter values for both the velocity and the position. We then consider the disruption caused when anthropogenic noise is present in the environment, and how this subsequently leads to changes in the group behaviour. We find that a high noise term leads to a significant reduction in the level of alignment in the group which ultimately disrupts the schooling behaviour. We investigate the cause of this change in behaviour by introducing noise solely to the respective behavioural rules. We find that when the interactions individuals have with their nearest neighbours is disrupted (i.e. those affected by the repulsion rule) the group can no longer maintain typical shoaling behaviour. Thus, we suggest that noise prevents the function of the lateral lines in fish which ultimately prevents the group from moving as part of a school.

HOMING OF GREEN SEA TURTLES ACROSS VARIOUS GEOGRAPHICAL LOCATIONS

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Keywords: Ecology, Animal navigation.

Many adult green sea turtles cover hundreds of kilometres during nesting journeys. While largely mysterious, a number of studies have suggested navigation is aided through following magnetic information and chemical plumes. In this talk we investigate the homing capacity of green sea turtles according to various combinations of navigating strategies. This work builds on the results discussed in [1] which investigated the homing of turtles to Ascension Island. Here we focus on a wider study of popular turtle nesting sites; including Ascension Island, the Galapagos islands, Hawaii and locations on the coasts of Madagascar and Thailand. We use aspects of many modelling techniques: individual-based models, scaling to a continuous PDE and steady state analysis following the method of characteristics. We investigate the key properties of various navigating cues and their impact on turtle homing, and discuss how the geographical location impacts on successful homing.

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<u>Parallel Session</u>
Ecology II

FORAGING UNDER PREDATION RISK: A MARGINAL VALUE APPROACH

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Keywords: Behavior, Boldness, Ecology of fear, Movement, Optimization.

Foragers exploiting heterogeneous habitats must make strategic movement decisions in order to maximize their fitness. Foraging theory has produced very successful and general formalizations of the optimal patch-leaving decisions rational individuals should make. One is the Marginal Value Theorem (MVT; [1,2]), modeling the sequential visit of habitat patches distributed in space. The MVT has a simple intuitive graphical interpretation in terms of gain functions and travel times, but considers only energy gains: the effect of predation risk on the time allocation strategy is notoriously lacking. Economic treatments of optimal patch leaving decisions under predation risk have been proposed, but are quite disconnected from the MVT. Here we formally introduce predation risk into the original MVT, and show that this yields generalized MVT equations. Much of the graphical simplicity of the MVT can be retained, provided one introduces risk-relative time units, similar to the micromorts used in decision analysis. We then establish a formal connection between the MVT and the risk-oriented foraging theories. By reconciling the two, we hope to help behavioral ecologists take the best of two worlds.

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