LARGE LAKE ECOSYSTEMS: MODELING INTERACTIONS AMONG HUMAN, BIOLOGICAL, AND PHYSICAL PROCESSES

PROJECT SUMMARY

Goals and Objectives: Improvements in water quality in Lake Erie since 1970 have induced human responses in recreational and residential development that have substantially increased external loadings. Nutrient recycling by dreissenids, unintentionally introduced in 1986 by humans, have altered the Lake's biological structure. Both processes are hypothesized to have led to recent increases in phosphorus concentrations and harmful algal blooms. While both are likely to play a role, the relative magnitudes of these impacts are important as they have different implications for underlying biophysical and human processes and future human-lake outcomes. The project goals are to **(1) develop a coarse-scale, "simple" model of a generic large lake ecosystem with coupled human-lake linkages** in just sufficient detail to explore the role of coupled linkages in generating complex dynamics at a systems level; **(2) develop a more detailed, fine-scale model,** specified with Lake Erie data, and test its ability to explain observed human-lake outcomes; and **(3) contribute to the general knowledge of complex systems** by investigating the role of human-biophysical couplings in complex dynamics and by aggregating fine-scale models of component processes to coarse-scale models of the coupled system. We will first develop a simple, aggregate-level model that captures key linkages and the most basic components of a generic coupled system and examine the dynamical behavior under a range of plausible parameter values (**Objective 1**). We will further examine the complex dynamics of this generic coupled system by investigating how different specifications of aggregate and fine-scale processes, time lengths, and stochastic processes embedded in the couplings impact the stability of the system (**Objective 2**). A fine-scale model will be developed to elaborate the complexities of scale and interactions contained in the couplings and will be parameterized using Lake Erie data to test the model's ability to explain observed human-lake outcomes (**Objectives 3 and 4**). This will allow us to study the impacts of management policies on human and biophysical processes (**Objective 6**). We will use the fine-scale model to guide improvements to the simple model by aggregating the fine-scale results and comparing model outcomes (**Objective 5**).

Methods: A purposefully simple, aggregate-level model of a generic large lake ecosystem will be developed and analyzed using a mix of analytical and numerical simulation methods. Although the independent human and biophysical models within this model are very simple, the presence of coupled linkages—in the form of endogenous lake services that influence humans and endogenous human impacts that influence lake functioning—is likely to introduce complex dynamics. The role of coupled linkages will be examined by altering key parameters and by introducing a variety of perturbations to the system to examine how these changes alter the system's stability and robustness, e.g. changes in the average quantities of aggregate variables, fine-scale variations in spatial and temporal distributions of variables, time delayed feedbacks, and stochastic fluctuations. The simple model will be used as a guide to develop a fine-scale model that represents the couplings in greater detail and at much finer spatial and temporal resolutions. This detailed model will be comprised of two- and three-dimensional, fine-scale, cell-based models of the watershed and lake respectively. A spatially-explicit, agent-based model will overlay the watershed model to describe human actions. These models will be developed using computer simulation and the underlying processes specified using Lake Erie data on nutrient incomes, algal abundance, fish stocks, economic lake-based activities, population/land use changes, and water levels. Different aggregation methods will be explored to relate the fine-scale predictions to the coarse-scale model dynamics and guide improvements to the simple model.

Intellectual Merit: The project will make an original contribution to scientific understanding by testing hypotheses on the coupled linkages between human and biophysical large lake processes and by advancing methods used to study the stability and multiscale properties of complex, coupled systems.

Broader Impacts: We will integrate research and education by developing a new graduate-level biocomplexity course, integrating biocomplexity topics into existing courses, and training a new generation of interdisciplinary biocomplexity researchers. The research will be integrated with K-12 education programs by developing learning modules and hosting student workshops. We will build upon existing successful education programs to make special efforts in achieving science literacy among secondary school students from underrepresented groups. We will work with policymakers to perform policy analyses and identify implications regarding the management of the Lake Erie watershed, which is of economic, social and aesthetic importance to the 14 million American and Canadian stakeholders living within its watershed. These efforts will strengthen collaboration in international research and policy formulation regarding large lakes.