Biocomplexity: A Definition Under Development

Robin McC. Greenler
John M. Greenler
Beloit College and BioQUEST Curriculum Consortium

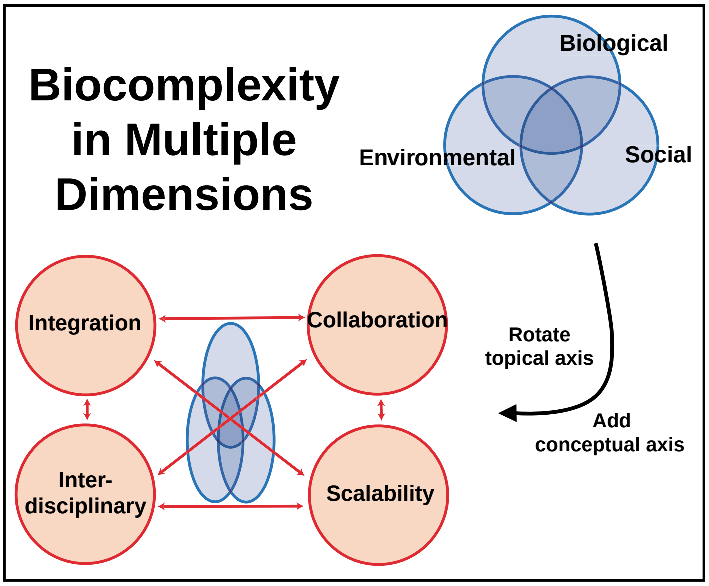
There is a lot of buzz about biocomplexity. The National Science Foundation (NSF) has identified biocomplexity as a priority area for research and education. The theme of the 2001 Annual Meeting of the American Institute of Biological Sciences (AIBS) was *From Biodiversity to Biocomplexity*. However, despite the attention, researchers in this nascent field are still struggling to articulate a concise and complete definition.

The fact that creating a robust definition of this new field has proven to be challenging does not come as a surprise. At its heart, biocomplexity represents the interplay of systems so intricate and dynamic that one individual may frequently comprehend only a part. If the sheer magnitude and complexity creates challenges in our perception, the translation of the concept to tight definition will, likewise, be difficult.

Nonetheless, the concept of biocomplexity has been and is continually being developed, refined, and clarified. Dr. Rita Colwell, director of the NSF and champion of the increased attention and funding to the area, defines the goals of biocomplexity as "understanding how components of the global ecosystem interact—biological, physical, chemical, and the human dimension—in order to gain knowledge of the complexity of the system and to derive fundamental principles from it" (Emmett, 2000). Dr. Colwell maintains that biocomplexity requires taking an integrative perspective across scales and disciplines that will allow us to tackle the intricacies of interactions among diverse disciplines (Colwell, 2001). Alan Covich, president of AIBS, underscores the need for such a biocomplex approach when he notes that, "examining the self-organization, hierarchical structure, and dynamics of communities and ecosystems over time and space requires new approaches and a new generation of nonlinear modeling, designed by collaborators in the natural, social, and computational sciences" (Covich, 2000).

The Ecological Society of America has produced a fact sheet on biocomplexity (http://esa.sdsc.edu/factsheetbiocomplexity.htm) wherein they further the discussion by listing common characteristics of biocomplexity that include:

- nonlinear or chaotic behavior
- interactions that span multiple levels or spatial and temporal scales
- hard to predict (unpredictable behavior)
- must be studied as a whole, as well as piece by piece
- relevant for all kinds of organisms — from microbes to human beings
- relevant for environments that range from frozen polar regions and volcanic vents to temperate forests and agricultural lands as well as the neighborhoods and industries of urban centers.



The multidisciplinary content areas of biocomplexity contain common characteristics that align well with goals in educational reform.

A research team enters the biocomplexity arena through many different doors. Some teams, responding to a call to address an urgent and complex environmental situation, assemble a broad-based, multidisciplinary team of scientists with the express goal of producing a clearer understanding of the system to decision makers. (And here "scientists" is used in its broadest sense and includes social scientists, engineers and mathematicians.) Other biocomplexity teams form through the linkage of several research programs that are examining common fundamental questions with vastly different systems, organisms, or temporal and spatial scales. Still other researchers find the contemporary label "biocomplexity" is being placed retroactively onto decades of prior ecological, environmental, policy or basic biological research. And indeed, several have pointed out that biocomplexity may be a term for "old wine in new bottles" (Maienschein, 2000).

Biocomplexity in Education

- Addresses significant contemporary issues
- Requires collaboration, integration and an interdisciplinary approach
- Employs multiple modes of understanding and learning
- Engages students in a diversity of techniques and hands-on inquiry
- Allows for participation in contemporary scientific research (questions and results)

As the field of biocomplexity emerges, it is becoming clear that it holds rich opportunities for education. Many biocomplexity research programs in the lab or field have education derivatives for the classroom. The nature of biocomplexity lends itself to rich pedagogical approaches and the nature of many of the research tools used are readily accessible in undergraduate classrooms. A productive route to deepening one's grasp of biocomplexity and its opportunities for education lies in the examination of case studies of active biocomplexity research. The following projects represent a few of the biocomplexity research areas within which BioQUEST sees great education potential and with which BioQUEST is beginning to collaborate.

University of Minnesota Biocomplexity Project

The University of Minnesota Biocomplexity Project is a collaboration of researchers who are analyzing and modeling the consequences of massive perturbation in biological communities. Tied together by this broad focus, they are bringing many areas of expertise to bear on the examination of the interactions of ecological, genetic and historical factors on spatially explicit, non-equilibrial systems. Four specific systems that they are currently examining include: Corn borer and Bt and non-Bt corn; prairie fragmentation and mating structure of native populations; Corn smut and corn; and Rhizobia associated with common bean.

The corn borer and Bt-corn team is examining the evolution of resistance to genetically engineered Bt-corn. In part they are investigating the dynamics of the policy-driven planting of non-Bt resistant corn refugia areas within Bt resistant corn fields. It is clear that the size and spacing of these refugia are important factors, and that natural predators of the corn borer can also play a critical role. The prairie fragmentation research group is examining the role of spatial habitat structure in the pollination and genetic transfer of certain plants native to North America's tallgrass prairies. The researchers are asking questions about the correlation between spatial characteristics of isolated populations and patterns of mating and progeny fitness. The corn smut team is exploring how the biogeographic history and spatial dynamics of corn (Zea mays) affects the population dynamics and evolution of corn smut (Ustilago maydis). The Rhizobia team is exploring the ecology and coevolution of host-Rhizobia relationships.

University of Minnesota Biocomplexity Project: ***http://www.entomology.umn.edu/biocomplexity/**,* *Corn Borer Lifecycle,* ***George Heimpel, University of Minnesota, Dept. of Entomology***

The scope of their research covers both cultivated and wild native legume hosts and therefore looks at disturbances associated with agricultural cultivation as well as fragmented native ecosystems.

From the outside, each of these projects looks like a traditional, robust research program at a large university. What makes these different is that they are all linked with common questions. They can examine how issues of time and spatial scale may affect underlying ecological principles. They can look for small or large universalities between very different environmental systems or between strongly disparate organisms. The distinctions between the "pieces" and the "whole" become blurred as one collaborator's "whole" (corm smut) may be another's "piece." (Bt and non-Bt corn plants). This kind of research collaboration, knit together with a broad focus, is a prime example of one way that biocomplexity research can proceed.

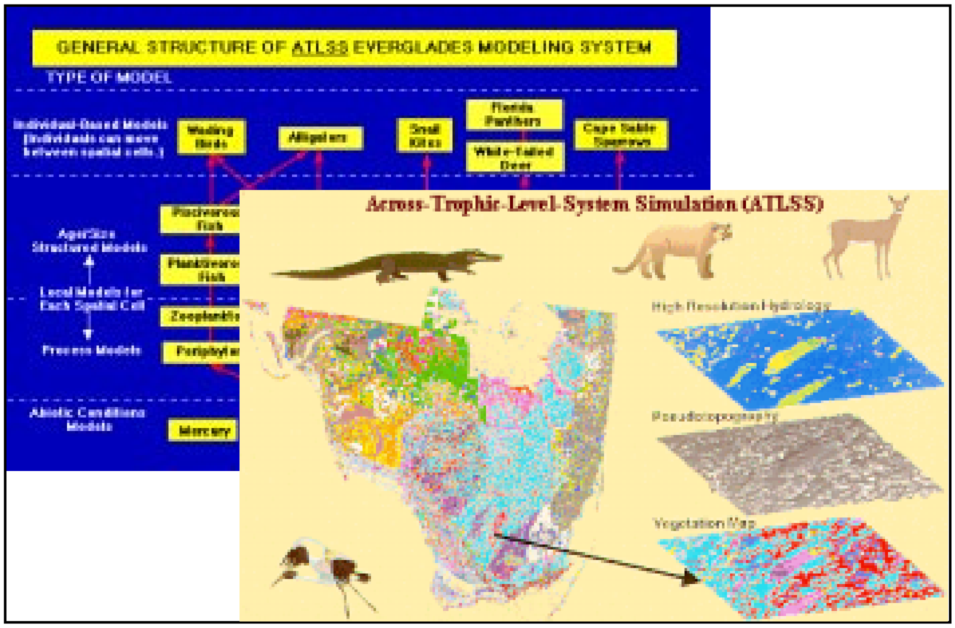
ATLSS Project

The ATLSS Project (Across Tropic Level System Simulation) is asking some similar questions but in a wholly different context. The project, involving Dr. Louis J. Gross of the University of Tennessee is concerned about how to effectively create models of community-level ecological interactions that include individual variation in both organisms and local habitat.

The project is exploring how to best model the effects of various hydrologic regimes on the plant and animal life in the Everglades and Big Cypress Swamp of South Florida. While water flow controls the trophic dynamics of the system, there are complex patterns of spatial heterogeneity and temporal variability within the system. As the trophic interactions occur at varying spatial and temporal scales, the use of a single modeling approach to predict impacts of hydrological change is inappropriate.

At higher trophic levels individual-based models that account for individual variation in factors such as sex, size, age, health, and social status and spatial variation such as habitat, roads, and topography are necessary in order to predict accurately the effects of various hydrologic scenarios. Lower trophic levels such as benthic insects, periphyton and zooplankton and functional groups of fish and macroinvertebrates need different modeling systems structured to their populations and life history characteristics. All these models are then integrated across the Everglades and Big Cypress Swamp landscape and coupled to GIS maps for cover type. With this data, one can more effectively assess the effects of alternative proposed hydrologic restoration scenarios on trophic structures.

The ATLSS team is driven by a concrete policy need. More accurate modeling regimes will provide policy makers the critical scientific information they need in order to make recommendations about scope, type and nature of the restoration efforts for the region. These recommendations will define the legal, economic and social implications of a large-scale land-use initiative. The research team is trying to characterize phenomena that are not consistent across spatial or temporal scales. The system must be studied from both a reductionist and integrationist perspective. This scenario would challenge the most traditional research approaches. The ALTAS program is responding to a policy need that <u>will</u> utilize whatever best research information is currently available. The task therefore is to integrate the information that has been gained from traditional research into the best contemporary understanding. This is often the challenge of biocomplexity—while the problem is too big to understand fully yet, the legal, economic, or environmental actions demand a synthesis of current best understanding.



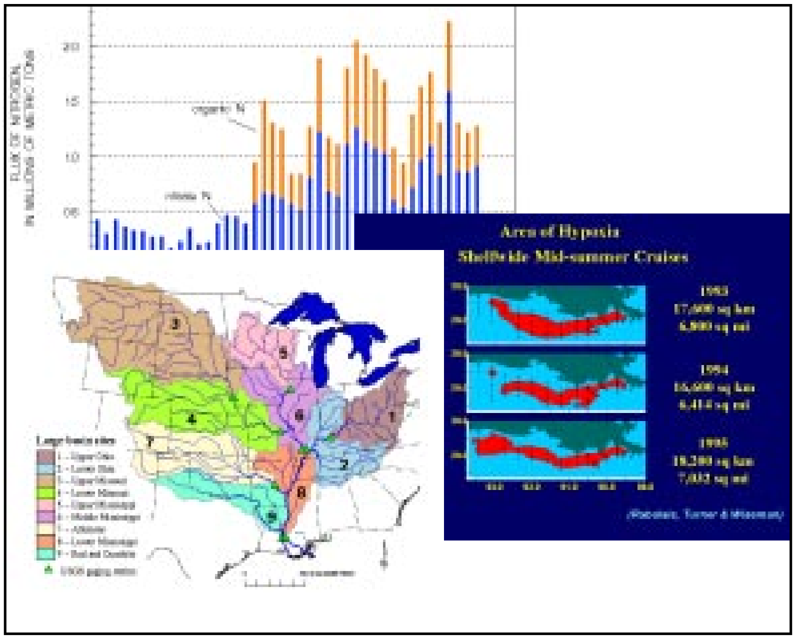
ATLSS Everglades Modeling System: ***www.atlss.org****, ATLSS Mutli-level Geographic Information System Model:* ***www.fcsc.usgs.gov/Ecosystem_Modeling***

<u>The Gulf of Mexico and the Hypoxia Zone</u>

Biocomplexity work by Dr. Nancy Rabalais of the Louisiana Universities Marine Consortium and Dr. R. Eugene Turner of Louisiana State University looks explicitly at the interactions of science and policy in the context of the Mississippi River and hypoxia zone in the Gulf of Mexico. Broad evidence over the past two decades has revealed strong and dynamic links between anoxia in the Gulf of Mexico and land use practices in the Mississippi watershed basin. Land use practices include watershed flood control and navigational channelization, landscape alterations (such as deforestation and conversion of wetlands to agricultural lands), and nitrogen input (Rabalais, et al., 2002).

Obviously these interactions cross temporal, spatial, political, and ecosystem boundaries. But perhaps less obvious to the public is the degree of interdisciplinarity necessary within the sciences. To examine this issue fully requires a remarkable collaboration of scientists from vastly different specialties. Parts of this analysis hinge on an understanding of hydrology, terrestrial and aquatic ecology, zoology and botany, as well as chemistry, geology, and environmental engineering.

In addition to the scientific complexity, the research involves a huge constituent of stakeholders, interacts with a vast body of legal regulation and has far-reaching economic implications. How does this expansive human policy arena interact productively with a growing and incomplete understanding of the science of the linked riverine-ocean system? These are exactly the questions being asked by Rabalais and her colleagues. The tremendous scope of the issue, the myriad of interactions, the need for a broad, informed and collaborative team of professionals and the urgency for practical, implementable solutions are all trademarks of this developing area called biocomplexity.



Mississippi Watershed, Basin and Subbasins: ***http://wwwrcolka.cr.usgs.gov/****, Nitrogen Inputs into Gulf of Mexico:* ***http://wwwrcolka.cr.usgs.gov/****, Hypoxia in the Gulf of Mexico:* ***http://www.csc.noaa.gov/products/gulfmex/html/rabalais.htm***

Clearly, there is a compelling need for biocomplexity research. The study of biocomplexity is computationally intensive and frequently includes modeling, spatial analysis and manipulation of data from large databases (genomic, climatological, environmental, etc.). Fortuitously, recent mathematical studies of complex phenomena and the current availability of powerful supercomputing capabilities are facilitating much of the work.

While the synthesis of the field of biocomplexity is still young, we cannot afford to wait for the field to "settle" to begin to integrate this new paradigm of scientific research into undergraduate education. Too frequently we hesitate to bring new and leading-edge science into the classroom. However, if we want to produce citizens and scientists who can contribute practically and conceptually to the field of biocomplexity, we would be well advised to expose them now to the kind of synthetic, multidisciplinary, and computationally intensive approach typical in biocomplexity. If we wish to, as Rita Colwell put it, "develop a view of earth that is startlingly different from that of the past" (Colwell, 1998), then we must concurrently work with the scientists of the present and of the future. And it is with both scientists of the present and future that BioQUEST wants to begin.

References

Across Tropic Level System Simulation Biocomplexity Project, http://atlss.org/

Colwell, RA. 1998. Ecological science in the new millennium: A bold step into the next thousand years. Ecological Society of America NewSource 61: 2-3.

Colwell, RA. 2001. "World enough, and time": A global investment for the environment. Bioscience 51(11): 908-914.

Covich, A. 2000. Biocomplexity and the future: The need to unite disciplines. Bioscience 50(12): 1035.

Emmett, A. 2000. Biocomplexity: A new science for survival? The Scientist 14(19):1.

Gross, L. 1999. Computational Ecology. Ecological Society of America NewSource 65: 1-4.

Maienschein, J. 2000. Old wine in new bottles. Nature 407: 21.

Neuhauser, C. 2001. Mathematical challenges in spatial ecology. Notices of the AMS(48)11:1304-1314.

Rabalais, NN., Turner, RE., Scavia, D. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. Bioscience 52(2): 129-142.

University of Minnesota's Biocomplexity Project, http://www.entomology.umn.edu/biocomplexity/.