Ecological Genomics: Extending the genome revolution to the environment around us

Loretta Johnson, Michael Herman
Division of Biology, KSU and Co-Directors of the Ecological Genomics Institute
Steve Welch, Department of Agronomy, KSU

In 1995, the sequence of nucleotide bases (the genetic alphabet) comprising the DNA code for a free-living organism was determined for the first time. This sequence completely describes the protein building blocks of a small bacterium that causes ear and respiratory infections in children. Since then hundreds of species have been sequenced, including the human genome in 2004. Most of these genomes have applications to human health, agricultural improvement, and other important areas of biological research. Today the challenge is using our knowledge of billions of nucleotide bases to improve the human condition and better understand the living world around us. Currently, we are learning how to evaluate individuals' health (infectious disease states, tumors, drug and toxin responses, etc.) in terms of the activity of tens, hundreds, or thousands of genes. Already it is known, for example, that gene activity changes as some breast cancer patients become increasingly resistant to tamoxifen. In the future, gene activity levels may provide advance clues if a cancer patient is a good chemotherapy candidate or even reveal the earliest warning signs of impending disease. Ultimately, each individual may have his or her own genome sequenced in order to aid in disease diagnosis and therapy.

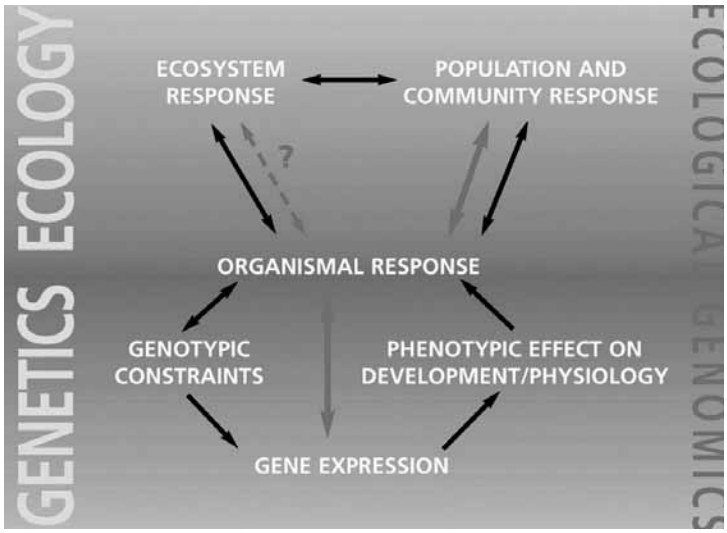
Similarly, genomics provides unprecedented opportunities to assess the health and integrity of ecological systems. An ecological system is the assemblage of living organisms interacting with each other and their physical environment. Just as genomics can characterize human responses to disease onset, so might it characterize the functions of ecological systems. Specifically, we may be able to use genomics to detect how ecological systems respond when challenged with human-dominated global change in the environment. Our Earth system is changing at an unprecedented pace due to carbon dioxide emission; temperature increases; excess fossil fuel emissions and fertilizers are causing an increase in nitrogen, which was once a limiting nutrient; and either excessive or, in other regions, insufficient rainfall. Synthetic chemicals and/or toxins such as heavy metals increasingly contaminate our water, soils, and air. The assemblage of plants, animals, and microbes that surrounds us is

changing in response. Species are being threatened or, in other cases, expanding into regions they have not previously inhabited (sometimes with intentional or inadvertent human assistance). Analogous to human medicine, it may be possible to use genomic methods to monitor ecological system responses to the challenges of global changes in environmental health.

We all depend on ecological systems to sustain us – ecological applications of genomic technologies are therefore likely to be as important as medical uses. A fundamental question concerns organisms' genetic capacity to adapt to drastic environmental changes on short time and spatial scales. This capacity will undoubtedly vary across the spectrum of living organisms that beneficially or adversely contribute to human well-being. Just as we can use genomics in the pursuit of human health, we envision using these same methods to assess adaptive capacity, predict, and maintain the health of our environment. This, in the broadest sense, is the realm of the new field of ecological genomics described in more detail below.

The newly emerging field of ecological genomics

Ecological Genomics seeks to understand the genetic mechanisms underlying responses of organisms to their natural and changing environments. These responses include modifications of biochemical, physiological, morphological, or behavioral traits of adaptive significance. Previously, the complexity of these ecological interactions and organismal responses has made their genetic and mechanistic dissection difficult. However, recent advances in high-throughput genomic technologies and computational methods to handle the enormous amounts of data now make these complex questions tractable. Ecological Genomics refers to the use of any genome-enabled approach to identify and characterize genes with ecological and evolutionary relevance. In other words, 'finding the genes that matter'.



By its very nature, ecological genomics is an interdisciplinary field, requiring a multidisciplinary approach that combines field studies with laboratory experiments with in ecologically relevant framework. Thus, while traditionally, ecological and laboratory-based genetic/genomic studies have occupied different areas of biological investigation (see Figure

1), Ecological Genomics seeks to integrate these disciplines by using genomic approaches in an ecological context. Furthermore, the rationale for such an integrated approach is compelling. Even though many organisms have had their genome sequenced, functions of the majority of the genes still remain unknown. Perhaps, the function of these genes will be revealed if the organism is placed in the evolutionary context and biotic and abiotic environment in which the organism has evolved. Recently, the importance of the ecological and evolutionary context for genomic studies was highlighted when parallel studies conducted in the growth chamber and under field conditions revealed a completely different set of genes expressed in these two experimental environments. Thus, the failure to conduct such studies under the field conditions can lead to misinformed research programs.

Building the Ecological Genomics Institute

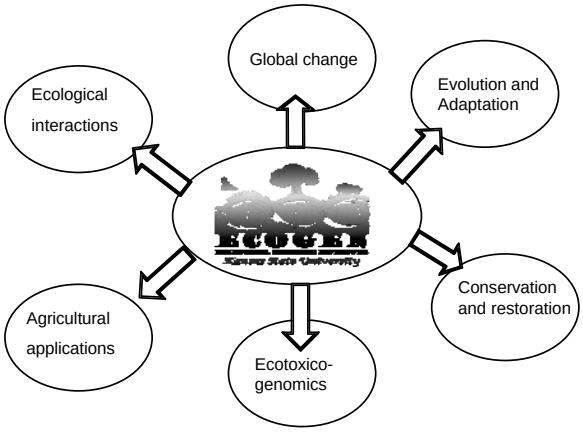
"It is the science, stupid". Building an Institute must have firm foundation in an exciting science question. The overarching science question guiding the institute is: How are organisms adjusting to human-induced biotic and abiotic environmental changes at the genetic level? Today there is no more important ecological question than this in order to understand and predict the effects of human-induced changes to global abiotic and biotic environments. Prior studies of ecological phenomena in changing environments have focused primarily at the ecological system level. However, the ultimate controls of biological mechanisms are lodged in the genome. Thus, genetic and genomic studies of organismal responses to global environmental changes will provide the most complete understanding. For example, adaptive organismal responses to changes in the biotic environment, can be viewed as emerging from interactions between or among genomes. We can use genomics to get beyond phenomena to the genetic mechanisms.

Our institute seeks to examine environmental effects on organisms at the level of genes and gene expression, and identify major genes and pathways directly involved in the organismal response to a changing environment. Specific cross-cutting questions addressed in our institute include:

- What is the genetic basis for ecological responses to a changing environment?
- What are the regulatory and genetic pathways involved in organismal responses to their environment?
- What is the ecological context necessary to understand gene expression within organisms?

The Kansas State University Ecological Genomics Institute is positioned to lead this new field. Much of our research platform takes advantage of the long-term environmental experiments at Konza Prairie, that manipulate nutrients, water, and rainfall application. This

focus is important because grasslands are the dominant native vegetation of North America, are relied upon heavily by humans, and provide the resource base for much of the global agricultural economy. In addition, grasslands supply us with clean water, recycle essential nutrients and preserve biodiversity. Some of our studies include the genomic responses of plants and soil animals to additions of nitrogen and changes in water availability. By taking advantage of the known genome sequences of laboratory or agricultural species, we are able to assess genomic responses of their native close relatives. For example, this research revealed that prairie grasses turn off genes involved in photosynthesis (carbon uptake needed to make plant biomass) in response to drought. Grasslands and global change is just one of several research foci (Fig 2) at the interface of ecology and genomics. The Kansas State University Ecological Genomics Institute is bringing the genomic revolution to the environment around us to better understand the health of the environment on which we all depend.



The goals and mission. The mission of the Ecological Genomics Institute is to advance the discipline of ecological genomics and to make EGI the center for ecological genomics locally, nationally, and internationally by providing a fertile intellectual environment as well as resources to enable integrated research approaches. Ecological Genomics originated as a novel scientific idea that was funded as the main state-wide research initiative by Kansas NSF-EPSCoR (Genomic Approaches to Study Organismal Response to Global Change (Co-PIs Johnson and Herman) in 2003-2006. Since then, the discipline has matured and grown in stature and reputation. The research is now supported through the KSU Provost's program in Targeted Excellence to build a research initiative into an institute and has enabled Ecological Genomics at Kansas State University to expand and develop into the national and international leader in the new field of Ecological Genomics.

The specific goals of the Kansas State University Ecological Genomics Institute are to:

- provide a fertile intellectual community of diverse participants (faculty, post-docs, students) from varied disciplines who are committed to advancing the field of ecological genomics. This requires promoting and enhancing the climate for interdisciplinary and collaborative research that transcends KSU departments and colleges, and universities, nationally and internationally.

- provide programs that support and promote collaborative ecological genomics research at the Institute as well as advance and guide the field at the national and international levels. Provide forums for dissemination of ecological genomics research within the university, nationally, and internationally.
- promote the use and development of the newest state of the art technology and tools to enable ecological genomics projects to prosper and to spawn new projects. Facilitate the development of research infrastructure.
- train the next generation of scientists in cutting-edge ecological genomics research by developing an interdisciplinary curriculum, while promoting ethnic and gender diversity, Provide training in relevant techniques, give them the skill set to enable them to be productive, contributing members of the ecological genomics community in science and education.
- provide visibility and recognition of EGI and the Ecological Genomics field by disseminating results and attracting extramural funds to allow us to conduct ecological genomics research. Solidify our role as a national and international leader and set the agenda for ecological genomics research. Use the ecological genomics program as a magnet to recruit top-notch faculty, post-docs, and students.
- promote diversity in science by providing research opportunities to members of under-represented groups (by partnering with the KSU SUROP and DSP programs).

Disseminate knowledge to the general public by performing outreach activities that include educational opportunities for K-12 educators.

- develop applications for ecological genomics research using knowledge of genetic diversity and patterns of gene expression in tallgrass prairie communities.

Activities and Accomplishments

Scholarly Achievement. Science is the foundation of our institute. We have 3 new faculty hires in ecological genomics to advance the field. Furthermore, since the beginning of our TE institute up to and including June 2007, members of the KSU Ecological Genomics Institute have published 41 manuscripts, one book and two book chapters related to Ecological Genomics. As evidence of our leadership in this new field, we were invited to contribute an introduction and synthesis of the field for a recent issue of Heredity dedicated to evolutionary and ecological functional genomics (Ungerer, Johnson and Herman, 2007). Ecological genomics has also enhanced the research climate, making faculty more competitive for grants. Our seed grant program provides approx 250K per year in funding for pilot studies to make researchers more competitive. Members currently hold 18 extramural grants ($5,468,790) relevant to Ecological Genomics, of which 10 ($2,344,160) were funded since the beginning of the TE project. Six intramural grants have been funded ($4,008,944). $1.15 million investment

from TE in first 2 years has resulted in $2.3 million in extramural funds .

Programs. The KSU Ecological Genomics Institute has implemented a number of programs that stimulate and provide support for research in this new field. Our annual ecological genomics symposium, now in its 5th year, attracts ~150 attendees from 45 different universities nationally and internationally. Others activities include technical workshops (AFLP, Bioinformatics and Genomics), visiting scholar programs, international student exchange with the ecogenomics program in NL, graduate student training program , and weekly journal club. Our institute has brought recognition to the new discipline and the university. Our website continues to be the top choice when one "Googles" Ecological Genomics. Statistics indicate a total of over 17,500 hits to date with international exposure. Through these activities, we have successfully increased the visibility of ecological genomics at Kansas State University.

A new paradigm for interdisciplinary research

Why is this institute so successful? First and foremost, the institute starts with cutting edge and big science questions as its foundation. The science questions are the basis for interdisciplinary collaboration that transcend departments and colleges. The science and intellectual exchange is the mortar that holds the foundation together. Furthermore, we take advantage of unique skills and opportunities such as the research platform at Konza Prairie. We provide state of the art infrastructure to do cutting edge research and provide funding opportunities such as seed grants that promote competitiveness. We demonstrate an effective management style such that tasks are delegated to committees to share the responsibility and to promote member buy-in, oversight is provided by a three-member external advisory board and five member steering committee and periodic independent program assessment and evaluation are provided by our KSU Office of education, innovation and evaluation. Perhaps, most importantly, inception of the ecological genomics institute began at the grass roots level, at the level of researchers who have a willingness to "think outside the box" and to "work outside their usual comfort zone". We posit that the next great discoveries in science will be at the intersection of diverse disciplines. Ecological genomics is a new model for such interdisciplinary research.