Research Statement
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As a systems ecologist, I am fascinated by the processes that create, constrain, and sustain ecological systems. Consequently, my research has been interdisciplinary in nature and focused on aspects of ecosystem organization and transformation. The overarching goals of my research program are (1) to understand the processes responsible for ecosystem formation and maintenance, and (2) to develop a formal science of environment that we can use to understand the causes and consequences of both local and global environmental changes. In this essay, I highlight past accomplishments, briefly describe my current work, and characterize my interests for future research.

Indirect Effects and Ecological Network Analysis

To achieve my research goals, I initially focused my research on factors that regulate indirect effects in ecosystems because they are a significant force in the organization and transformation of ecological systems and a key component of ecological complexity. In ecosystems, organisms and their environments are coupled by an intricate network of energy–matter exchanges that enables one species to affect the distribution, abundance, and behavior of other species without direct contact. For example, when the marine phytoplankton *Phaeocystis pouchetii* changes from its primary solitary-cell life form to a gelatinous colonial form, it triggers a reorganization of the ecosystem. Species that primarily consumed the solitary cells either shift their diet or are replaced by organisms that can eat or coexist with the colonial form. This change cascades through the network, ultimately shifting the community composition, altering rates of energy–matter transfer and storage, and affecting global atmospheric chemistry by increasing the rate of carbon sequestration. Thus, indirect effects create an extended environment of interactions that link species together in new and non-obvious ways, and may alter how the whole system responds to external environmental changes.

My research addressed a central problem with indirect effects, which is that they are difficult to predict *a priori* because we do not fully comprehend the factors controlling their development. I addressed this primarily through analysis of network models of energy–matter flux in ecosystems and made several contributions including:

- **Pathway Proliferation.** I discovered how biodiversity and the number and pattern of direct trophic linkages ultimately determine the number of indirect energy–matter pathways that connect species in food webs. With this work I also identified one or more strongly connected components (i.e. groups of species) in 10 of 17 large empirical food webs that are functionally integrated through indirect effects.

- **Temporal Dynamics of Indirect Effects.** My analysis of the temporal dynamics of indirect effects in 16 consecutive seasonal models of nitrogen flux in the Neuse River Estuary, NC (1985–1989) revealed surprisingly little seasonal and no significant interannual variability in the proportion of total nitrogen flux derived from indirect flows. Indirect flows were large (>80%) in all seasons. Despite changes in species composition and abundances, the underlying ecosystem organization was remarkably consistent. Biologically mediated nitrogen recycling was the primary driver of these indirect flows. This is the first study characterizing the temporal dynamics of indirect effects in ecological networks.

- **Uncertainty Analysis.** I determined the sensitivity of nine indicators of ecosystem growth and development, including indirect effects, to uncertainty in flow magnitudes in a model of phosphorus flux in Lake Sidney Lanier, GA. This work showed that five of the nine indicators are relatively robust to flow and storage uncertainty, which lets us draw strong conclusions about the organization...
of the Lake Lanier ecosystem despite the uncertainty. Specifically, phosphorus flux in the lake is dominated by internal recycling. In addition, 80% of the common variation in the nine indicators could be projected onto two latent factors, which I interpreted as (1) the degree of system integration, and (2) boundary influences.

Computational Induction of Process-based Models

In my current position, I am developing and applying a new computational approach to facilitate model construction called Inductive Process Modeling (IPM). By definition, models are non-unique abstractions of natural systems; therefore, the major model making problem is determining which system elements to include (i.e. species and relationships) and how to best represent them. With IPM, scientists first encode potentially relevant background knowledge of the system type into a reusable library of entities and processes. With this information and a set of time-series observations, the IPM algorithm then searches through the space of possible models defined by the library for the ones that best explain the observed system behavior. I expect this technique to assist construction of ecological models for both theoretical development and environmental assessment and management. Currently, I am using this approach to build and evaluate ecosystem models of the Ross Sea to explain the observed spatial variability in the phytoplankton community. Initial results suggest that photoinhibition of phytoplankton growth is not required to explain the dominant bloom of *Phaeocystis antarctica* in the Ross Sea polynya. The next step is to determine if photoinhibition of *P. antarctica* is required to explain why diatom species dominate the phytoplankton bloom in the Terra Nova Bay polynya where the organisms are exposed to a more intense light environment. Determining which processes regulate phytoplankton production in the Ross Sea is an important step toward understanding the global carbon cycle because carbon fixed by *P. antarctica* and diatoms is differentially entrained into the long term storage associated with the deep water formation that occurs in this region.

Toward a Formal Science of Environment

This research experience is an important step toward building a formal understanding of the ecological environments that envelop species and that determine how a system can respond to external changes. It also provides a strong foundation to continue investigating a number of intriguing questions on the path toward a formal environmental theory.

- **Temporal and Spatial Dynamics of Indirect Effects.** In previous work, I have uncovered evidence that supports the hypothesis that indirect effects tend to dominate direct effects in ecological networks. This analysis, however, was mostly limited to spatially aggregated systems at static, steady-state. The study of the 16 consecutive seasonal models of the Neuse River estuary models was a first step toward understanding the temporal dynamics of indirect effects. However, this hypothesis needs to be rigorously tested in both continuous-time models and models that consider spatial heterogeneity. It is quite possible that the integration of ecological systems through indirect effects is limited by rapid temporal changes that impede their transmission or spatial boundaries. Testing this hypothesis with network analysis will require an extension of the existing methodology, but it may also be possible to use existing sensitivity analyses to address the question.

- **Model Discrimination.** Distinguishing among models is a key challenge raised by inductive process modeling. The current algorithm returns the top models ranked according to their goodness-of-fit to the data, but in some cases there is very little difference in fit among several models. This makes model selection difficult and reduces our confidence in the process-based explanation. One possible cause for this problem is too little data to guide the search, which begs the question: how much data is enough? How many system variables must we observe to distinguish among models? Perhaps some variables contain more information than others such that their observation is more discriminating. What characteristics of the variables or of the system cause these variables to be essential?
Answering these questions would address a fundamental modeling problem and provide guidance for future empirical work to obtain the most information for the research time and money spent.

- **Invasive Species.** Invasion of exotic species can radically transform ecosystems and substantially alter the goods and services the system provides to human populations. However, species invasions provide natural experiments with which to study ecosystem organization and transformation. In the future, I would like to develop collaborative research projects that use my modeling and systems analysis expertise to investigate factors that determine whole ecosystem response to invasive species.

    Ultimately, my research program is building new insight into ecosystem structure and function and advancing our understanding of the causes and consequences of indirect effects in ecological systems. It will also help clarify important concepts such as ecosystem health, integrity, and sustainability.