TOWARD A UNIFIED UNDERSTANDING OF HUMAN ECOSYSTEMS: INTEGRATING SOCIAL SCIENCE INTO LONG-TERM ECOLOGICAL RESEARCH

INTRODUCTION

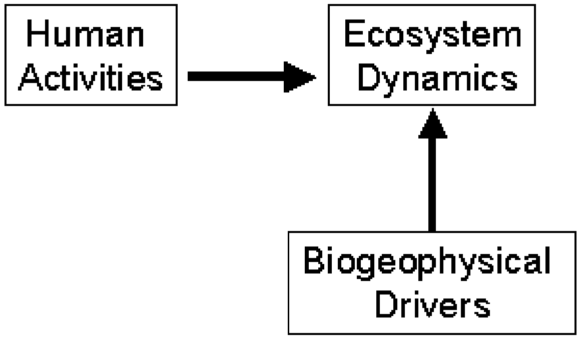
In pursuit of a thorough, scientific understanding of the world around us, biological ecologists and social scientists have each worked within their own academic disciplines to develop a wide range of empirical studies, methods, and models to identify key drivers, processes, and controls that regulate human behavior and interactions with the environment. However, most studies have pursued answers to fundamental questions about pattern and process in the ecological and human world from within the boundaries of one discipline or another, neglecting the feedbacks that cross between ecological and social systems.

Studying ecological and social systems in isolation of one another is no longer tenable (Low et al. 1999; Redman 1999). Humans are an integral part of virtually all ecosystems (McDonnell and Pickett 1993; Vitousek et al. 1997); almost all human activity has potential relevance to global environments (NRC 1992), and biogeophysical contexts strongly condition human decisions (Diamond 1997). Although it is not novel to recognize the interconnectedness of humans and the environment (Marsh 1864; Thomas 1955), constructing a new approach emphasizing an integrative framework equipped with comprehensive models, reinforcing methods, and complementary data is a growing and urgent priority.

A uniquely well-suited group of scientists to achieve new levels of integrated research are those associated with the National Science Foundation’s long-term ecological research (LTER) network. The first LTER projects were established in 1980 and now include 24 different projects located in diverse biomes all dedicated to the investigation of ecological processes operating at long time scales and over broad spatial scales. The network promotes synthesis and comparative research across sites and ecosystems by its 1100 scientists and students. Having already made notable strides in integrating a variety of biological and physical approaches in their research, scientists representing the LTER network met in Madison, Wisconsin in October 1998 and voted to create a committee on integrating social science into their investigations. In addition, a smaller group met to discuss substantive issues involved in promoting social science within the LTER network. The complexity of this task quickly became evident, and the primary suggestion was to hold a planning workshop to develop an agenda for further action. In January 2000, LTER scientists and colleagues from other large interdisciplinary projects funded by NSF gathered in Tempe, Arizona to craft this agenda (Appendix A, Participant List). After reviewing case studies of projects that have successfully bridged the social/natural science divide, it was agreed that much more had to be accomplished.

During this workshop, sufficient consensus emerged over many aspects of integrated human ecosystems to allow for discussion to advance to more specific issues. It was noted that ecologists have defined and implemented a core set of concepts to understand the long-term dynamics of ecosystems for the LTER network (http://www. lternet.edu.research). Participants agreed that a core set of social patterns and processes analogous to the ecological core areas would greatly aid the integration of social sciences into LTER research. Although these core social science patterns and processes were preliminarily defined in the Tempe Workshop, and consensus reached on a broad conceptual framework for investigating integrated human ecosystems, participants fully expected that further definition would be needed before these core research areas could be implemented throughout the LTER network. They proposed a series of workshops where discussion on three domains of ideas could serve as a road map for integration: one workshop would further detail the proposed core social science patterns and processes and their articulation with ongoing research. Another would formulate multi-scale investigatory frameworks considered key to implementing integrated research projects. The third workshop would focus on practical approaches to integration and propose specific pilot projects to pursue. Taken together, these efforts would help to form long-term research initiatives to better understand the complex interactions between human, biological, and earth systems.

SOCIAL PATTERNS AND PROCESSES: PROPOSED CORE AREAS FOR THE STUDY OF HUMAN ECOSYSTEMS



The central goal for ecologists, especially those in the LTER network, has been to develop a better understanding of the long-term dynamics of ecosystems. Although approaches, ecosystem types, and disciplinary expertise differ among sites, conceptual similarities override these differences. In their common commitment to understanding long-term ecological dynamics, for example, most LTERs recognize two classes of variables that drive ecosystems. The first and better-studied class of variables includes ecological drivers such as geologic setting, climate and its variation, patterns of primary productivity, hydrologic processes, and other biogeophysical factors. Investigating how these drivers interact with ecological processes to produce long-term dynamics has been the grist of most LTER programs. The second class of variables includes drivers directly associated with human activities, such as land-use change, introduction of exotic species, and overexploitation of resources Russell 1993; Likens 1991). The simplified model in Figure 1 defines the intellectual arena within which most ecologists work.

Figure. 1. Traditional conceptual framework for ecosystem studies.

Although this conceptual model is powerful in its inclusion of both ecological and human-induced processes, important interactions and feedbacks influencing long-term ecosystem dynamics are absent. For example, an activity such as land use, traditionally seen as a driver, should be viewed as the result of more fundamental patterns and processes. Because many of these missing features relate to the social sciences, contributions from these disciplines would greatly enhance our understanding of human ecosystems.

Although incorporation of existing social science models into the best of ecological theory would provide a starting point, the development of a new integrative ecology that explicitly incorporates human decisions, cultural institutions, and economic systems will ultimately be needed (Grimm et. al. 2000). A start on such a model was created outside of the LTER network, but has been influential since the Baltimore team joined the network. It is an amalgamation of ideas extant in social science literature adapted by Grove (1996) and Machlis, Force, and Burch (1997). It is a combination of ecosystem and landscape approaches transformed into a redefined conceptualization of the human ecosystem. In this perspective, the human ecosystem:

- is a coherent system of biophysical and social factors capable of adaptation and sustainability over time;
- can be described at several spatial scales, which are hierarchically linked;
- is a set of critical resources (natural, socioeconomic, and cultural)
- the flow and use of these resources is regulated by the social system;
- and adaptation is continuous in human ecosystems; it is a perpetually dynamic system.

The social system, itself, is comprised of:

- social institutions that are collective solutions to universal social challenges or needs;
- social cycles that are the temporal patterns for allocating human activity; and
- social order that is the set of cultural patterns for organizing interactions among people and groups.

Spatial heterogeneity of human ecosystems is established by some institutions and maintained by others. Humans, as individuals and as groups, are self aware, capable of learning quickly, and engaged in extensive networks of rapid communications.

An essential step in developing a powerful, integrated model for human ecosystems is to acknowledge that social and ecological systems share a general set of properties, including resilience and complexity. These properties are linked through feedback relationships, and the various social and ecological components of human ecosystems can be characterized by these properties and their feedback relationships. For instance, social and ecological systems have varying structural complexities that may be transformed over time and space. Describing the social and ecological organization of human ecosystems depends upon understanding rates of change, scale(s) of phenomena, strength of linkages, boundary conditions, and threshold values. Using this "systems" framework, we propose a more integrated framework that explicitly states that what is often divided into separate "natural" and human systems be conceptualized as a single complex, human ecosystem, as seen in the more comprehensive model portrayed in Figure 2.

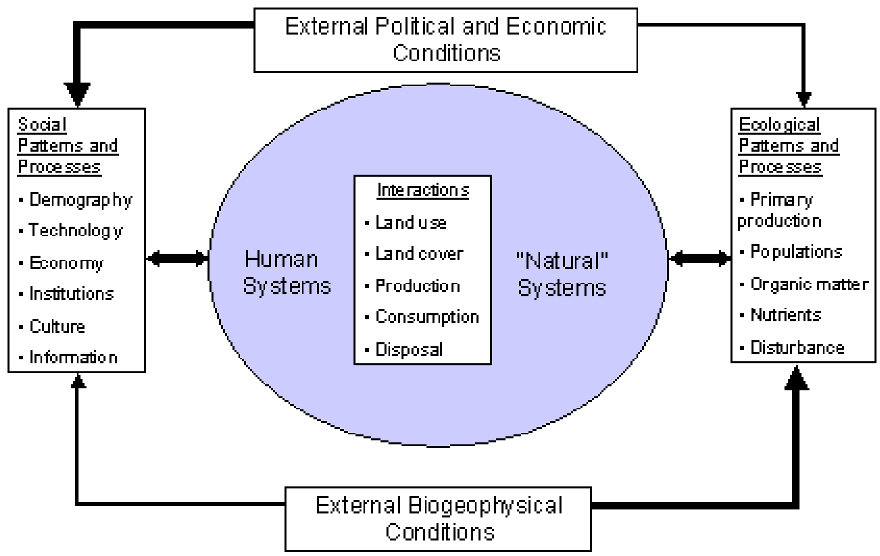


Figure 2. Conceptual framework for investigating the integrated human ecosystem.

Although disciplinary training and traditional research design often treat elements of human and ecological systems as distinct, we emphasize the linkages in the framework. To emphasize the linkages, we focus on the *interactions* that are at the interface of the human and ecological components of the system. We define these interactions as the specific activities that mediate between the human and ecological elements of the broader human ecosystem, including activities involved with:

- Land-use decisions
- Land cover and land-cover changes
- Production
- Consumption
- Disposal.

Although each of these activities can take place on their own, we acknowledge their strong interdependencies. We are sure there are other points of articulation, but the above activities are a good starting point, as they were already identified by both ecologists and social scientists as prominent areas of concern and relevance.

Having defined a set of specific activities that are at the interface of the human and ecological aspects of the integrated system, the next step is to develop a perspective on what motivates these activities. The integrated social-ecological system is defined by and acted upon by a series of what are often called "drivers." For conceptual convenience, we divide these drivers into two categories: 1) ecological patterns and processes and 2) social patterns and processes. The ecological patterns and processes include, but are not limited to, the five biogeophysical core areas (http://www.lternet.edu/research) that LTER sites have already implemented:

Ecological Patterns and Processes

- pattern and control of primary production,
- spatial and temporal distribution of populations selected to represent trophic structure,

- pattern and control of organic matter accumulation in surface layers and sediments,
- patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters,
- and patterns and frequency of site disturbances.

By broadly defining these ecological core areas and acknowledging that more elements could be monitored, most ecologists accept these areas as describing the central biogeophysical processes that underlie any ecosystem.

To integrate the social, behavioral, and economic aspects of human ecosystems into long-term ecological research, we propose a comparable list of *social patterns and processes*. We propose this list to better understand the long-term dynamics of human ecosystems and to serve, as does the list of ecological patterns and processes, as a practical guide for field investigations. These recommended social patterns and processes include, but are not limited to:

Proposed Social Patterns and Processes

- Demography
- Technology
- Economy
- Political and social institutions
- Culturally determined attitudes, beliefs, and behavior
- Information and its flow

In devising this list, we followed the social drivers identified in the National Research Council's report on Global Environmental Change (1992:2-3), with one important addition: we have added a sixth driver, *information and its flow*, in recognition of its great and growing importance in society. We expect that aspects of the last three drivers on the list—institutions, culture, and information—will be hardest for our biological colleagues to integrate. Part of each of these drivers (and the first three to a less obvious extent) are guided and constrained by our perception of the driver and how knowledge of the driver is already integrated into the ongoing system. In a human ecosystem, all choices are not equally available but are conditioned by what we "know" and by our "attitudes." Although we are interested in all aspects of these six drivers listed above, we are especially concerned with their influence on the accessibility and use of ecosystem goods and services. For each driver, and in a manner similar to the ecological core areas, social patterns and processes will need to be characterized with explicit reference to scale, location, and history.

Operationalizing this human ecosystem framework involves data collection to illuminate three different parts of the model portrayed in Figure 2:

- background information on "external" biogeophysical conditions and political and economic conditions that set the stage;
- describing and monitoring changes in both ecological and social patterns and processes that drive the system; and
- investigating the nature of and monitoring changes in the interactions that are the results of the operation of the patterns and processes.

HUMAN PERSPECTIVE ON UNIFIED ECOSYSTEM UNDERSTANDING

All research, whether on human ecosystems or other subjects, should respond to specific research questions, fundamental understandings of relevant disciplines, and human perspectives through which we view the research. Without undermining the scientific rigor of our approach, we, as responsible members of society, must also relate our scientific understanding of human ecosystems to the goal of maintaining our quality of life without threatening global sustainability. Figure 3 and the following discussion suggest an approach to integrating the human perspective with two fundamental parameters of ecosystem structure and function: resilience and complexity.

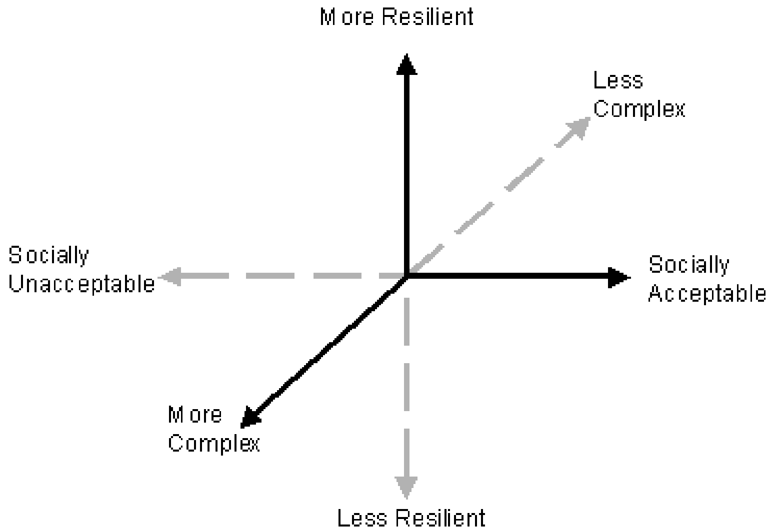


Figure 3. Stability landscape of social-ecological system.

Relative changes in an ecosystem's resilience and complexity are fundamental to understanding the sustainability of that system (Holling 1973). An equally fundamental parameter, from a human perspective, is determining whether the state of the system is "socially acceptable." This difficult-to-measure variable is essential to land-management decisions as well as attitudes in the scientific community, yet it is seldom explicitly examined in ecosystem analysis. As scientists, we are directly concerned with how specific forces affect the complexity and resilience of the system, but we must also seek to understand what interactions might lead the system to shift to a new sector within Figure 3, such as transforming a socially acceptable, resilient system into one either socially unacceptable or vulnerable to external forces. Clearly, a system may move among all eight quadrants of Figure 3, given the appropriate forces.

LINKING PATTERNS AND PROCESSES FROM ECOLOGICAL AND SOCIAL CORE AREAS

In the context of the processes in Figure 2 and the parameters described in Figure 3, the next step in linking patterns and processes from the ecological and social core areas is to pose the following broad question and three subsidiary questions:

> *How did the social-ecological system develop into its current state, and how will it change in the future?*

This question focuses on the fundamental aspects of the system, such as the nature of feedback linkages, the rates of change, system components, and the specifics of resource use and production. Three subsidiary questions allow us to focus our inquiry further:

- How have the characteristics of ecological systems in the region under study influenced the social patterns and processes that have emerged?
- How have social patterns and processes influenced the use and management of ecological resources?
- How are these interactions changing over time and what does this mean for the state of the social-ecological system?

These questions can help guide our inquiry to the fundamental aspects of system composition, system history, and system operation. They also guide our inquiry from a perspective that not only includes humans as part of the system, but acknowledges that humans are explicitly concerned with the operation of the system and its content at any point in time. It is key that one not approach the system, or these questions about it, from two distinct perspectives (which are?), each reflecting disciplinary experience. Rather, a unified approach must be negotiated between differing scientists, each expanding their traditional viewpoint. For most social scientists, this will mean a greater emphasis on the flows of matter and energy in the system. For ecologists, issues surrounding information flow and decision making may take on greater relevance. With this unified approach agreed upon, the next step is to identify investigatory tools that reflect the complexity of the given human ecosystem.

A FOCUS ON MULTI-SCALE APPROACHES

The physical, biological, and social sciences are struggling with the issue of scale and appropriate frameworks for collecting and analyzing data at different spatial and temporal scales. This issue infuses many elements of research, from sampling design, to data analyses, modeling, and interpretation of results. In a "human" spatial sense, scales of interest will range from individuals to groups of increasingly large size until they encompass global networks. In a similar fashion, we must be concerned with processes acting at varying temporal scales so that we may understand processes acting with great rapidity as well as those operating over geological time. The importance of this challenge is even more pronounced when researchers consider integrated studies. For example, social and ecological processes may be associated with specific scales in some cases, while processes may occur across multiple scales in other cases. Further, ecological and social processes may not operate at the same scale(s), and linkages may have to connect across scales. Finally, it is unknown whether theories that explain processes at one scale can be used to explain processes at other scales. To date, no ecosystem study combining social and ecological processes has completed a multi-scale approach. Thus, fundamental research paradigms may need to be rethought; classic notions of "stratified random sampling" and "gradient analyses" may need to be altered; and substantial basic research may be required.

We will need to develop a number of capabilities for a multi-scale approach. These include the ability to determine how:

- Optimal scale(s) and resolution(s) for specific questions can be determined,
- Time lags, nonlinear relationships, and defining events affect the responses among social and ecological processes,
- Spatial characteristics of certain phenomena such as shape, adjacency and matrix, affect social and ecological processes,
- Boundary conditions relative to space and time affect social and ecological processes,
- Large-scale data can be used to explain small-scale behavior (ecological inferences) and small-scale data can be used to explain processes at other scales.
- Data associated with one unit of analysis can be dis/aggregated to another unit, (e.g., from census tracts to watersheds),
- Metadata protocols can incorporate spatial parameters (units, intervals, spatial statistics, and
- Data protocols can protect confidentiality in spatial depiction of human structure and process.

This multi-scale approach will require new data protocols. For instance, it may be necessary to collect and analyze data at an "optimal" scale as well as at a scale above and a scale below. In response to this challenge, several LTERs have adopted a hierarchical patch dynamic approach to model their sites (Wu and Levin 1994; Wu and Loucks 1995; Pickett et al.). As an example, transects may be a more useful and necessary approach than point samples in discovering and characterizing boundaries. The recognition of the complexity of investigating human ecosystems demands a reformulation of research strategies and methods with the same concern for integration that we call for in our conceptual approach. Once multi-scale techniques are developed, we can begin to emphasize guiding these new methodologies using practical approaches to integration.

PRACTICAL APPROACHES TO INTEGRATION

The general framework and core areas we have identified provide a focus for integration, but real-world success requires practical ways of encouraging scientists of varying training and perspectives to collaborate. Many different methods, tools, and data approaches for integration have been useful already. For example, Geographic Information Systems (GIS) and simple maps can be effective in forging integrated thinking on social and ecological processes. Remotely sensed data could be integrated with this effort or used alone (National Resource Council 1998). Similarly, simple models can be used as heuristic devices to articulate linkages and as preliminary activities to test theories with data (Carpenter et al. 1999). Graphic and modeling approaches are particularly important because of the need to work with multiple scales. Work at multiple scales also reinforces the need to consider the linkages among theoretical approaches at different scales and the predicted relationships among physical, biological, and social variables. Further, this requires that data be collected with complementary protocols in order to measure cause and response relationships among social and ecological processes. This effort necessitates coordinated approaches rather than identical sampling protocols.

Other conditions and methods that promote discussion and integration are many. First, historical analyses provide a relatively safe environment for researchers to work together to understand "why" and "how" social and ecological processes have produced certain patterns (Pickett et al. 1999). For social and ecological scientists whose primary focus is the functioning of the contemporary system, investigating the past is informative, but not so threatening because it is beyond their immediate expertise. This approach helps to build trust among researchers, which is an intangible, but crucial and constructive element to integrated research. Second, programmatically defined core research areas, in otherwise large and dispersed research programs, provide a foundation for identifying and prioritizing research. Third, place-based, problem-solving research helps to focus discussions and develop hypotheses; this approach may help avoid the problem of "what" to research and center discussion on "how" to research. Fourth, comparative studies help us to share expertise and perspectives that can be used to promote integrated research and strive for answers to the elusive question of "why."

CONCLUSION

The focus of this paper has not been to provide a refined model for an integrated understanding of human ecosystems, but to identify useful concepts and describe the path necessary to achieve this objective. The ultimate measure of success of any theoretical endeavor is whether it stimulates innovative research that provides answers to important questions. To put ourselves firmly on that path, we propose that further discussion of three domains of ideas would enable the kind of research we seek.

To ground these discussions in reality, it is necessary to identify a number of potential research projects where investigators agree that bringing together social, biological, and earth scientists would lead to a better understanding of the mechanisms that govern ecosystem dynamics. With the specifics of a reasonable number, yet diverse sets of case studies in mind, it is then possible to refine the theoretical ideas to the point where they can be applied. The first domain of ideas to be expanded upon would be the practical issues that would help implement an integrated research approach. Past experiences have shown that certain approaches and datasets are more immediately amenable to bringing scholars together, and these should be highlighted in the new projects.

The refinement of the substantive questions these projects will pursue would benefit from a more in-depth treatment of the social patterns and processes suggested as core areas, the second domain of ideas. Each area offers a vast field of inquiry in their own right, so it is imperative to focus on the most relevant linkages, a process best done in the context of actual research. Hence, as a second set of activities, measures for each of the six social patterns and processes relevant to the proposed research would be developed.

The third focus of activities would be to implement these practical approaches and substantive ideas in terms of the specific research projects. Of primary concern would be how to accommodate the multiple spatial and temporal scales upon which a human ecosystem operates. Once again, having specific case studies to work with would allow for pragmatic solutions to emerge.

Achieving a greater integration of social, biological, and earth sciences in the study of ecosystems will depend on the sustained efforts of many researchers. Hence, it is essential that the ideas suggested herein, the approaches developed for new projects, and the substantive results of these integrated efforts be brought to as wide an audience as possible. It is through continued discussion of these concepts and the renewed efforts at field testing that a unified understanding might someday be reached.

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APPENDIX A

JANUARY 2000 TEMPE WORKSHOP: LIST OF PARTICIPANTS

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