# Appendix 1 3.0 Conceptual Framework and Theoretical Foundations

As ecology expands from site-based science to regional and global scales, our conceptual scope must also expand to embrace not only climate, geology, hydrology, and soils, but also the increasingly pervasive human dimensions of ecological change. Every ecosystem on earth is influenced by human actions (Palmer et al. 2004), and the rate of change in social and ecological drivers is increasing (Fig 3.1). The environment must now be viewed as a social-ecological system.

Over the past 50 years, people have changed ecosystems more than at any time in human history (Vitousek et al. 1997, Chapin et al. 2000), with substantial consequences for human well-being (MA 2005). Consequences of these ecosystem changes for people have been mixed. Health and wealth have, on average, improved. Yet the geographic distribution of benefits remains extremely uneven and further improvements are often limited by insufficiencies of ecosystem services (MA 2005). Feedbacks between ecosystems and people are thus central for improving human well-being, yet these feedbacks are poorly understood and thus form a challenge for fundamental research in natural and social sciences.

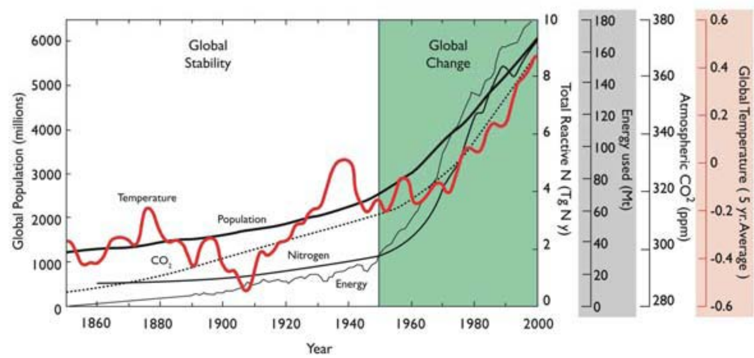


*Figure 3.1. Rates of change in major social and ecological drivers: human population, atmospheric $CO_2$, reactive nitrogen, energy use, and temperature.*

As the scope of social-ecological science has expanded, interdisciplinary linkages have evolved. Important advances were initially driven by the International Council of Scientific Unions (ICSU) through the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program (IHDP) (Mooney 1998, Steffen et al. 2004, Schlesinger 2006, Carpenter and Folke 2006). Collaborations among physical scientists and biologists have occurred since the beginnings of regional and global science, whereas collaborations among ecologists and social scientists are more recent and largely confined to applied sciences such as agriculture and forestry. Studies of ecosystem services formed the core of the Millennium Ecosystem Assessment (MA 2005), the first interdisciplinary global assessment of ecosystems requested by the world's decision makers. Meanwhile, in basic research, advances were driven by coalitions in ecology and economics (Mooney and Ehrlich 1997, Goulder and Kennedy 1997), the need to understand how institutions and economies solve common property resource problems (Ostrom 1990, NRC 1999, 2002, Dietz et al. 2003), advances in economic incentive design theory (Hahn 2000), and studies of the resilience of regional social-ecological systems (Gunderson and Holling 2002, Walker and Salt 2006). Liu et al. (2007) illustrate in a new review the diversity of approaches that have been taken to site-based research on social-ecological systems. Yet, they also pointedly note the enormous gaps in social-ecological research, the need for new theory, and the need for a better integration of conceptual and empirical research across a diverse set of approaches.

New research must focus on understanding the long-term dynamic processes that are unique to social-ecological systems versus purely social or purely biophysical systems. Ecosystems self-organize from evolved components; interactions of slow processes with fast ones, and big processes with small ones, create much of the pattern and dynamics that we observe (Levin 1999). Social systems also self-organize, change, and exhibit process scale-dependencies, but human self-awareness allows people to affect and direct system dynamics in ways qualitatively distinct from those that characterize the evolution of ecosystem components (Gibson et al. 2000, Arthur et al. 1997, Westley et al. 2002, Bettencourt et al. 2007). For example, people make forward-looking decisions (they act on expectations of the future), they generate and respond to abstract constructs that shape their world views and expectations, they create feedbacks that act on fast time scales over broad spatial extents, and they develop technology with far-reaching consequences (Westley et al. 2002). These consequences drive feedbacks not only on social systems but on the ecosystems in which they are embedded — in many cases across broad geographic extents and with long-lasting legacies. Because of these complex, nonlinear interactions and feedbacks, a new mechanistic research framework is needed that integrates the internal and interactive dynamics of social and natural systems.

Social and natural systems are deeply interwoven and their dynamics are inherently long-term. Liu et al. (2007) note that social-ecological systems exhibit nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and, above all, surprises. We are now beginning to see some of the emerging trends and surprises that are important for human well-being, but we are a long way from understanding, predicting, and managing them. A combination of theory development and place-based, cross-scale, long-term research that harmonizes diverse disciplinary perspectives is needed to develop understanding and build the capacity to sustainably manage social-ecological systems. Work at regional scales is particularly needed. Ecology has made great strides in understanding place-based change (e.g. Peters et al. 2007), and the field of global ecology is advancing rapidly (MA 2005). Progress has been slower at the intermediate scale of regions, areas larger than most study sites but smaller than continents or oceans. Yet ecosystem change is often most conspicuous at regional scales, and environmental management frequently acts on regions.

Most drivers of social-ecological changes can be characterized as press or pulse events (Ives and Carpenter 2007). *Presses* are environmental impacts driven by constantly increasing pressures on atmospheric, ecological, and social systems, such as atmospheric $CO_2$ change that occurs slowly in ecological time (decades to centuries) relative to a baseline of pre-industrial atmospheric concentrations. In contrast, *pulses* are events that occur once or at periodic intervals, such as fire and extreme climatic events. Human-caused global environmental change is increasing the strength of press events and altering the frequency and intensity of pulse events. As a consequence, through human actions and decisions, biophysical systems are being decoupled from traditional drivers such as 100-year fire cycles or slow biogeochemical change (Smith et al. *in revision*). This decoupling has important consequences for human social systems. For example, the widespread increase in reactive nitrogen — a key limiting ecological resource — is a press that will dramatically affect ecosystem processes (Schlesinger 2006, Galloway et al. 2003, Liu et al. 2003). Changes in nitrogen loadings coupled with more intense climate pulses could lead to increased leaching of nitrate into groundwater and streams, loss of ecosystem services, and ultimately threats to human health.

Understanding change is the fundamental challenge of social-ecological science. Social-ecological systems can change incrementally and more or less predictably. Some of the most important routine changes (for example, forest succession or the business cycle) are reasonably well understood and incorporated into management practice. Other changes are large in magnitude, spatially extensive, and alter social-ecological systems for long time periods. Examples include evolution or extinction of keystone species, land-use change drivers such as major shifts in food and fuel prices, technological change and land use policy, or the collapse and reorganization of polities such as the former Soviet Union. Although large changes may account for most of the cumulative change we see, they are infrequent events. As a result, observations are few, individual cases may be unique, and our ability to generalize or predict may be severely limited. Understanding extensive, pervasive, and subtle change is therefore one of the most important challenges for social-ecological science.

### *3.1. An Integrated Research Framework*

Scientists have increasingly called for more opportunities for social-ecological collaborations (Grimm et al. 2000, Palmer et al. 2004, Robertson et al. 2004, Newell 2005, Pickett et al. 2005, Kremen and Ostfeld 2005, Balmford and Bond 2005, Farber et al. 2006, Haberl et al. 2006, Liu et al. 2007, Vajjhala et al. 2007). Typically these calls describe case studies and provide general frameworks for why such research is needed, yet rarely do they propose viable, generalizable mechanisms for conducting truly integrated, large-scale, long-term research in human-environment systems. There thus remains a compelling need for a comprehensive conceptual framework that is built on relevant disciplinary research and at the same time emphasizes linkages among disciplines over the time frames and spatial scales at which social-ecological systems operate.

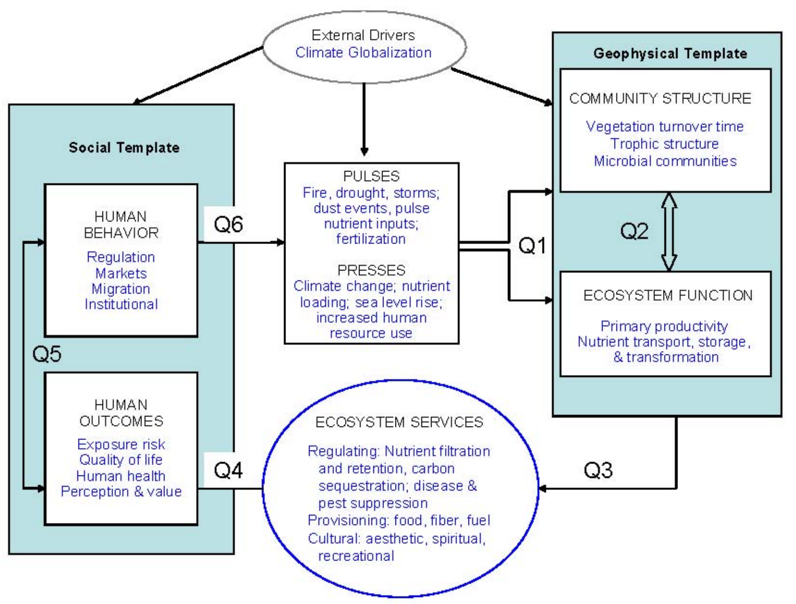


*Figure 3.2 The ISSE framework provides the basis for our network-level research questions. The right-hand side represents the domain of traditional ecological research; the left-hand side represents human dimensions of environmental change; the two are linked by the services provided by ecosystems (at bottom), and by pulse and press disturbances influenced or caused by human behavior (at top). Q1-Q5 refer to integrating questions in Figure 3.3. From Collins et al. (2007).*

**Q1:** How do long-term press disturbances and short-term pulse disturbances ***interact*** to alter ecosystem structure and function?

**Q2:** How can biotic structure be both a ***cause and consequence*** of ecological fluxes of energy & matter?

**Q3:** How do altered ecosystem dynamics affect ecosystem services?

**Q4:** How do changes in vital ecosystem services alter human outcomes?

**Q5:** How do perceptions and outcomes affect human behavior?

**Q6:** Which human actions influence the frequency, magnitude, or form of press and pulse disturbance regimes across ecosystems, and what determines these human actions?

*Figure 3.3. Framework questions; see Fig. 3.2.*

Figure 3.2 presents the basic components of such a framework and forms the basis for the research we propose. The framework is iterative, with linkages and feedbacks between biophysical and social domains. It allows relevant disciplinary questions (Fig. 3.3) such as "How can biotic structure be both a cause and consequence of ecological fluxes of energy and matter?" as well as crucial integrative questions such as "How do changes in vital ecosystem services feed back to alter human behavior?" Interdisciplinary linkages arise from understanding both the value and importance of ecosystem services, and how human actions and responses affect their provisioning. In sum, the framework provides a set of falsifiable hypotheses on how social-ecological systems interact over time.

To be useful, a unifying framework must also be flexible in order to address questions across relevant scales. Our framework does so: all of the questions in Fig 3.3 can be operationalized locally, regionally, and globally to conduct fundamental research related to biophysical systems, ecosystem services, and human responses and outcomes. Testing the hypotheses embedded in this framework, as well as its further development, will rely on theoretical, empirical, and methodological contributions from the biophysical and social sciences. Application of the framework will contribute substantially to development and testing of theory within these disciplines and, more importantly, will help to build a transdisciplinary science of social-ecological systems.

Many of the essential empirical and methodological building blocks needed to advance such a transdisciplinary science are increasingly emerging, particularly within the LTER Network.  Social scientists are employing progressively more biological facts to explain social variation (Grove and Burch 1997, Yabiku et al. 2007).  Likewise, ecological and geological scientists are using social facts to understand biophysical variations over the long term (e.g., Hope et al. 2003).  Social data are also increasingly spatially explicit (Irwin and Geoghegan, 2001), which permits testing and analysis of novel hypotheses that are spatially explicit, temporally contingent, and multi-scale.  Eventually, the use of spatial data may lead to synthetic theories to understand phenomena as social-ecological composites. The inclusion of long-term data and analyses will move theory from correlations and associations to deep probing of multiple causations, simultaneity, slow and fast rates of change, and non-linearities.

A network-level, long-term integrated program based on this framework and emerging empirical and methodological building blocks, with fully shared intellectual partnerships among disciplines, will be unique and transformative for the environmental sciences. Such a program is essential to better understand, predict, and manage the dynamics of human-environmental systems, to generate shared data sets, and to reveal generality through synthesis.