From LTER to LTSER: Conceptualizing the socio-economic dimension of long-term socio-ecological research

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Abstract
Concerns about global environmental change challenge long term ecological research (LTER) to go beyond traditional disciplinary scientific research to produce knowledge that can guide society towards more sustainable development. Reporting the outcomes of a two-day interdisciplinary workshop, this article proposes novel concepts to substantially expand LTER by including the human dimension. We feel that such an integration warrants the insertion of a new letter in the acronym, changing it from LTER to LTSER, "Long-Term Socio-Ecological Research," with a focus on coupled socio-ecological systems. We discuss scientific challenges such as the necessity to link biophysical processes to governance and communication, the need to consider patterns and processes across several spatial and temporal scales, and the difficulties of combining data from in-situ measurements with statistical data, cadastral surveys and soft knowledge from the humanities. We stress the importance of including pre-fossil fuel system baseline data as well as maintaining the often delicate balance between monitoring and predictive or explanatory modeling. Moreover, it is challenging to organize a continuous process of cross-fertilization between rich descriptive and causal-analytic local case studies and theory/modeling-oriented generalizations. Conceptual insights are used to derive conclusions for the design of infrastructures needed for long-term socio-ecological research.

Key words
Long-term ecological research (LTER); Long-term socio-ecological research (LTSER); Society-nature interaction; Scale; Socio-ecological systems; Socio-ecological metabolism; Land use; Governance; Communication.

INTRODUCTION

In the last few decades considerable effort has gone into setting up a network of research and monitoring facilities devoted to long-term ecological research (LTER). LTER projects focus on documenting, analyzing and explaining ecological patterns and processes operating over long time spans and broad ecological gradients. In particular, one mission of LTER is to detect signals of global environmental change and its impacts on ecosystems across the world (Hobbie et al., 2003, NRC, 2004). Given the large amount of information on several ecosystem compartments required for LTER to be successful, the number and size of LTER facilities is limited. Traditional LTER focuses mainly at the local or "site" level, and on ecosystems under little or no human influence (the two Urban LTER sites are an exception).

The global extent of such natural or semi-natural ecosystems, however, is comparably small (Sanderson et al., 2002), and is dwindling rapidly. Moreover, in order to mitigate, and appropriately react to, global environmental change it may be more important to understand impacts of global change on systems in which humans play a major role than to understand its effects on pristine areas (Wilbanks and Kates, 1999). This concern challenges LTER to go beyond classical disciplinary research and engage in the production of knowledge useful for solving society's sustainability problems, which require, as most researchers agree, the integrated efforts of both ecologists and social scientists. The LTER network recognized this challenge and convened a series of meetings and workshops, among them a broadly attended one in Tempe, Arizona, in 2000. That meeting resulted in a publication (Redman et al., 2004) that in many ways formed the starting point for the writing of this paper. Other related, parallel initiatives have been underway in the US, such as the HERO program (http://hero.geog.psu.edu), and international efforts by IGBP, IHDP such as the LUCC project (http://www.geo.ucl.ac.be/LUCC/lucc.html), and its successor, the Global Land Project (GLP 2005, http://www.glp.colostate.edu/). A follow-up meeting of social scientists involved in LTER from across the US in August 2005 reported that much still has to be done (Gragson and Grove, 2006). Several scholars who participated in one or both of these activities are authors of this article and carry the accumulated experience of many of these efforts.

Figure 1 shows sustainability as a dynamic balance between socio-economic demands on ecosystems, and the capacity of ecosystems to maintain resilience while supplying life-supporting services (Haberl et al., 2004). Sustainability thus challenges science to embrace new, interdisciplinary approaches that cut across traditional disciplinary boundaries, thus resulting in the endeavor of "sustainability science" (Kates et al., 2001, National Research Council, 1999, Parris and Kates, 2003a,b, Turner et al., 2003). Sustainability science moves beyond a conventional view that sees human activities as disturbances to otherwise properly functioning ecosystems and recognizes the distinction between local activities and global environmental change (Clark et al., 2004). For LTER to be useful in this context it has to address socio-economic concerns and integrate them consistently into both monitoring and analysis, implying a shift from a site-based to a regional approach – LTSER regions or platforms. A recent paper (Rivera-Monroy et al., 2004) based on 13 case studies demonstrates that such a concept improves the utility of LTER for solving pressing environmental and sustainability problems.

To help integrate social science into LTER, the Institute of Social Ecology in Vienna held a workshop jointly sponsored by the IHDP and IGBP programmes in February 2005 (http://www.iff.ac.at/socec/events/workshopltser/). The participants jointly wrote this paper, which summarizes the workshop's outcomes. A unique aspect of the Vienna workshop compared to US LTER efforts was the substantial input of European researchers who not only bring different intellectual traditions, but also experience working at field stations whose definitions are more diverse than the relatively coherent US LTER program.

Integrating socio-economic issues shifts the research focus sufficiently to justify the new label of “Long-Term Socio-Ecological Research” or LTSER (Figure 2). LTSER focuses on socio-ecological systems, i.e. complex, integrated systems that emerge through the continuous interaction of human societies with ecosystems (Redman et al., 2004). Throughout this paper we use the term “socio-ecological systems” synonymously with other terms that have been used in the literature such as “(coupled) human-environment systems” (GLP, 2005, Turner et al., 2003) and “(coupled) socio-environmental systems” (GLP, 2005, Dearing et al., in press). LTSER not only investigates changes in the state of the environment, but analyzes societal pressures on ecosystems and the forces driving them, while proposing measures that might alleviate these pressures. Conversely, the effects of ecological change on society (socio-economic impacts) are legitimate subjects of research. LTSER regards society-nature interaction as a dynamic process in which two autopoietic systems, society and nature, interact (Fischer-Kowalski and Weisz, 1999, Weisz et al., 2001). Autopoietic, literally “self-creating,” systems are dynamic, self-organized entities that create and reproduce their structure through internal processes, maintain a boundary vis-à-vis their environment, and often evolve over time (Varela et al., 1974).

The key challenge for LTSER is thus to develop concepts for integrated analysis of socio-ecological systems, which requires interdisciplinary collaboration by scholars in the natural and social sciences and the humanities. Such an endeavor faces the following challenges:

- How to conceptualize interaction processes between societies (human systems integrated by communication) and ecosystems (biophysical systems integrated by material and energy flows),
- How to deal with issues of scale. Natural boundaries often do not coincide with political and administrative borders, and many societal processes are almost completely independent of geographic space (trade and modern communication technologies, for example),
- How to distinguish between site-specific and generic dynamics, and
- How to establish links between explanative and predictive modeling, data generated from monitoring, and reconstructions of past situations established by combining historical data from sources and modeling (van der Leeuw, 2004).

We believe that a transition to sustainability (Clark et al., 2004, Kates and Parris, 2003, Parris and Kates, 2003a), if possible, will require fundamental changes in society-nature interaction for which no historical analogues exist (Turner and McCandless, 2004). The extent of these changes may be comparable to those associated with the transition from agrarian to industrial society. Historical studies seldom allow one to draw lessons by analogy. But one value of LTSER for sustainability science depends on its ability to capture a centuries-long perspective and to learn from the transition from agrarian to industrial modes of subsistence. Even in regions where the transition from the agrarian to the industrial regime is still underway, or has hardly begun, a centuries-long perspective is often possible thanks to colonial archives (Wardell et al., 2003).

In agricultural societies, limited by technology and high transportation costs, locales or regions (“hinterlands”) had to provide all or most functions necessary for the everyday life of the local population. Under industrial conditions, the spatial division of labor increased. This spatial expansion improved people's ability to meet their needs and fulfill their social functions because the supply of goods and services was no longer constrained by local resource availability or costly transport. The connections between people's way-of-life and their cultural landscapes weakened (Berglund, 1991, Toupal, 2003), and it became increasingly difficult to link local and regional ecologies with the behavior and consumption patterns of their human inhabitants.

To address these challenges, we first discuss conceptual requirements of LTSER, then present four core themes of LTSER studies: metabolism, land use, communication, and governance. Finally, we use these themes to discuss future directions of LTSER, identify future research needs, and make recommendations for an appropriate research framework.

CONCEPTUAL REQUIREMENTS OF LTSER

LTER has been one important branch of ecological research during the past decades. For social science to integrate successfully into LTER it is essential to offer a conceptual framework, a heuristic (or operational) model of society-nature interaction that reflects theoretical assumptions, guides methodology, and facilitates substantive interpretations. LTER sites and potential LTSER platforms are, appropriately, highly diverse. To develop a single overarching framework that would be effective everywhere, one has to argue on a generalized level which might not prove effective. Challenges to sustainability differ depending on local natural resources and social structures. This is poignantly shown by the identification of syndromes of global change (Schellnhuber et al., 1997). Therefore, while all LTSER models have to address basic challenges, one of their prerequisites is to set the modeling effort at a suitable, but not too high, level of abstraction. Consequently, we recommend that a series of more specific conceptual or operational models be developed that each reflects commonalities in a group of LTSER platforms characterized by shared interpretive objectives and socio-ecological conditions. Hence, the goal for LTSER platforms should be to develop specific LTSER models that are sensitive to the characteristics of their respective sites and research teams.

What we offer here is a set of meta-principles guiding the development of such models. This approach recognizes the widely different objectives and history of LTSER platforms around the world and gives flexibility to researchers, while maintaining coherence to ensure comparability of monitoring and analysis and to provide LTSER with clear identity. The meta-principles refer to three domains: design, transitions, and research processes and participants.

Design

LTSER meta-principles encompass the identification of themes for study. Building on previous efforts to develop conceptual frameworks for socio-ecological interactions (Ayres and Simonis, 1994, Boyden, 1992, Fischer-Kowalski and Haberl, 1997, Holling, 1986, Lee, 1993, Ostrom, 1990, Sieferle, 2001, Waltner-Toews and Kay, 2005), we identify four general themes which are central to any LTSER effort: socio-ecological metabolism, land-use and landscapes, governance, and communication. All four issues require interdisciplinary approaches, as they are cross-cutting issues focusing on interactions between social and natural systems. They receive more attention in the next section.

But where are the major driving forces of change, such as population, politics, or the economy, and why are they not the focus here? Organizing our thoughts along these lines could be misleading because the above-mentioned drivers are part of functionally differentiated societal subsystems, and fundamental barriers inhibit communication between such societal subsystems. Functionally differentiated subsystems treat all other subsystems as "environment," but integration between them is difficult, if not impossible (Luhmann, 1986). According to Luhmann, each subsystem of society is integrated by a specific communication code; e.g. power in politics or costs in the economy, and these codes are incompatible. Identifying key LTSER themes which are not tied into one of the functionally differentiated subsystems is necessary when studying interactions across such subsystems. This is not to deny the importance of any of those systems. Each of our themes calls for exploration of the role of economy, technology, politics, or even religion, but without prioritizing one above the other. Rather than mapping any of these subsystems in the four themes (e.g., talking about land use as an economic or political problem), the themes deserve attention in their own right.

LTSER focuses on interaction processes between social and natural systems. It would be an oversimplification to represent this process solely as either disturbance of nature by humans or as adaptation of humans to natural conditions. Instead, this interaction can be seen as a process of co-evolution by two structurally coupled systems (Fischer-Kowalski and Weisz, 1999). The conceptual framework needs to account for the fundamental differences between social and natural systems and to find ways to analyze their interaction. As observers we know that what we study is not nature as such. We suggest an approach to the study of natural systems that acknowledges this constraint. We do not wish to deny that cultural representations are useful for our interaction with the outside world.

Natural systems emerge through interdependencies between biophysical processes and may be characterized by describing material and energy flows (Odum, 1959). By contrast, the analysis of social systems usually focuses on information flows through countless communication channels characterized by different codes (Luhmann, 1986), and is often less concerned with biophysical flows (van der Leeuw and Aschan-Leygonie, 2005). Fischer-Kowalski and Weisz (1999) suggested studying socio-ecological systems by viewing society as a hybrid between biophysical and symbolic realms. Fischer-Kowalski and Erb (2003) and Haberl et al. (2004) put this approach into practice by analyzing society's material and energy flows. People incorporate experiences with nature into the symbolic realm of culture not directly, but by means of representation. Within the cultural realm, representations then guide subsequent actions. While people can minimize the amount of direct physical labor employed in these actions by means of technological artifacts, the interaction remains a biophysical one (Winiwarter, 1997). The metabolism of a society, its energy and material throughput, can be measured and accounted for (Fischer-Kowalski, 1998, Fischer-Kowalski and Hüttler, 1998). The communicative processes that shape this metabolism according to cultural preferences (which might be economically, religiously, or scientifically grounded), depend on the specific culture and can only be understood in cultural terms (e.g., the study of communication itself or of governance, as its political branch).

In both systems, natural and social, research has to cope with processes of markedly different velocities, occurring at the same place and time. It has to account for the cyclical or recurrent properties of some processes, and for feedbacks and non-linearity (Gunderson and Holling, 2002). Society and nature interact on several spatio-temporal scales, a process termed co-evolution by those who approach it with a long-time perspective in mind (Norgaard, 1994, Weisz, 2002).

Equally, LTSER research must permit the study of phenomena on different spatial and functional scales (Wilbanks and Kates, 1999). Hierarchies of scale have to be accounted for in order to avoid scale mismatches. Similarly, changes in the perception of human relationships to nature, the ecological and social legacies of institutional and jurisprudential models introduced in the past, and of stochastic disturbance events need to be the subject of LTSER studies. While there is an abundant literature reflecting scale problems (e.g., Allen and Starr, 1982, Allen and Hoekstra, 1992, Dovers, 2000, Gibson et al., 2000, Peterson and Parker, 1998), scale has so far received insufficient attention in existing LTER frameworks, as LTER operates mainly at the site level. This will be a major challenge, and LTSER must include multi-level phenomena as well as cross-scale interactions. Co-evolutionary approaches encompass a concept of emergent properties, and the scale question might be integrated into such a framework by looking at emergent properties across scales (Norgaard, 1994, Weisz, 2002).

Existing LTER sites often link poorly, if at all, to socio-economic monitoring efforts. Both social (e.g., census data) and natural properties (e.g. air, water quality, etc.) are monitored, yet these data are largely ignored by LTER research. LTSER should define interfaces to incorporate regional monitoring systems and official statistics and should work with those collecting these data to refine approaches and archive results. Information on socio-economic systems is patchy and can only be included in LTSER if consistency over time is ensured. Techniques developed by social historians will have to be included in the LTSER toolbox in order to tap these rich sources.

Socio-ecological transitions

Socio-ecological transitions, i.e. fundamental changes in the relation between natural and social systems (Martens and Rotmans, 2002, Raskin et al., 2002), are one result of co-evolution meriting special attention. In order to understand the challenge of sustainability, such transitions are of particular importance. Transitions from the agrarian to the industrial mode of subsistence entail qualitative changes in the sustainability problems experienced by a society (Haberl et al., 2004). This very transition process is currently underway in developing countries, accompanied by soaring energy consumption and greenhouse gas emissions (Haberl 2006). The industrial revolution expanded human alteration of the global environment to an unprecedented scale and extent (Steffen et al., 2004). Sustainability science must grapple with this transition, in the past and in the present.

Socio-ecological transitions are not only interesting from the viewpoint of sustainability issues such as energy consumption. They also represent fundamental linkages between social and ecological sciences. The relation a society has to nature is central to its entire makeup, to its social structure and to the type of events it will likely encounter and its coping strategies in response to such events (Godelier, 1990, Turner, 1992). Changes in societies are closely intertwined with ecological transformations. As Godelier has argued, to change society means to change its relationship to nature. Studying such processes over time allows researchers to evaluate the likely consequences of changes suggested by sustainability concepts.

There are at least two approaches towards the role of history in understanding our current socio-ecological situation. The first could be denoted as the “analogy” approach, characterized by its interest in case studies which have seemingly come to an end. Easter Island, the Mesoamerican Maya or the Anasazi of Mesa Verde are prominent examples of past collapses (Diamond, 2005). From such cases one can only draw rather abstract and general conclusions pertaining to our current situation. It has been argued that we are in a no-analogy situation today, with humans having become a geobiophysical force unparalleled in history (Turner and McCandless, 2004, Steffen et al., 2004), therefore it is of limited value to draw conclusions by analogy for sustainable development today.

The second, "legacy," approach argues that history has to be studied because our current situation is dependent on our material and immaterial inheritance. In this framework, "completed" case studies are less interesting than histories of places and people that have a past, present and future. Examples include communities having to cope with toxic legacies from mining, radioactive contamination or massive soil erosion. As these legacies show, the co-evolutionary trajectory of societies is shaped by their lasting interventions into nature. This creates the need to study the transformations of the geobiophysical arrangements which are at the center of our current practices (Schatzki 2003). Some of these transformations are called transitions because the character of the arrangements in terms of society's metabolism changes drastically. As socio-ecological systems operate on short and long time scales, we need to study such processes over appropriately long periods.

LTSER will therefore be much more useful for sustainability science if it is able to monitor change over time and recognizes the dynamics and impacts of transitions. Shifts from agricultural to industrial economies, from centrally-planned to neo-liberal politics, from biomass to fossil fuel consumption, from rapid population growth to population stagnation, or historical events such as the colonization of America by Europeans following Christopher Columbus' voyage across the Atlantic, are examples of grand transitions that profoundly modified relationships between social and ecological systems (McNeill, 2000, Sieferle, 1997, Turner and Butzer, 1992). Other transitions may be equally important to consider for a more complete and nuanced understanding of socio-ecological systems. The ongoing transfer of organisms between Old and New Worlds since 1492 has profoundly altered social and ecological structures around the globe (Crosby, 1972, Turner and Butzer, 1992). Changing legal frameworks and international treaties, fundamental changes in perceptions and beliefs such as the growth of the modern environmental movement (Dunlap and Mertig, 1991), and overlooked transitions such as female empowerment over resources transformed socio-ecological processes and patterns (Mies and Shiva, 1993). Institutional and regime change can also disrupt or modify socio-ecological dynamics (Young, 2002).

Baseline data are critical for gauging the temporal dynamics as well as the magnitude and character of transitions. Since social and ecological change can happen over very long periods, it is valuable to mine the past for data in order to detect and discern those transitions. The impact of successive waves of investment and disinvestment in land use, for example, can be observed only through historical examination. Looking backwards is also critical for examining the impact of historical legacies (Foster et al., 2003) on present-day socio-ecological systems. Sites can be affected by a multiplicity of legacies: social, ecological, engineered and institutional. Past ecological conditions, along with social, cultural, and legal structures, influence current structures and functions of socio-ecological systems. The contemporary built environment is a cumulative landscape reflecting varying degrees of addition, erasure, and replacement. The relevance of these factors has to be assessed. A contextualizing approach will include the specificity of a site in terms of perceptions, impacts and responses, and the time lags between the latter two. Examination of legacies also provides a means to examine the unintended consequences of human action, the surprises that were not or could not be foreseen (Holm, 2005).

Historical data and present-day monitoring can be used as an empirical basis for scenario building. A *longe durée* analysis provides a solid empirical basis and also an opportunity for scenario or model validation (Leemans and Costanza, 2005, Wardell and Reenberg, 2005). It is well known that activities in the past are key to understanding the current condition of an ecosystem (Foster et al, 2003). Equally important, especially for a socio-ecological perspective, the past provides insight into the limits to ecosystem and human interactions. Moreover, the legacy of past decisions, especially when they involve land-cover change, landscape transformations, or the built environment, guide future options by facilitating certain actions and erecting barriers to others (Gragson and Bolstad, 2006). Therefore, analyses based on long-term studies are useful in guiding transitions in ways that lead towards sustainability, a fundamental policy goal of LTSER.

Research process and participants

The study of society-nature interaction as described above involves researchers trained in different disciplines. It is important that human society addresses the long-term consequences of its interaction with nature. LTSER is more useful to local people and to society at large if it is designed not just as yet another scientific exercise, but as a transdisciplinary endeavor. This implies the involvement of local stakeholders (Brand, 2000, Pezzoli, 1997). Including stakeholders, however, inevitably raises concerns about the role and self-interests of researchers in the research process (e.g., Waltner-Toews and Kay, 2005). A self-reflective research process results, one that explicitly considers the perspectives of involved citizens, scientists, and managers, and the dominant narratives of each of these groups. Cybernetics has termed such a process a second order observation approach. In order to incorporate systematically the contradictory narratives of multiple groups, while enabling self-reflection, LTSER should incorporate processes of perception, valuation, communication, and response into its design. While we strongly favor a systems-approach in the basic research design, that alone will not suffice to include actors, communication, and governance. To tackle these issues LTSER needs to recognize the epistemological distinction between systems and agent-based approaches (Giddens, 1984) and to find ways to relate both (Funtowicz and Ravetz, 1993). The functional scale problem addressed above means that different types of actors with unique characteristics have to be incorporated within LTSER (individuals, institutions, organizations, etc.).

Such a research process facilitates effective knowledge transfer between the disciplinary domains of scientists, between scientists and policy-makers, and between scientists and stakeholders. The problem of communication between different actors cannot be managed easily (Waltner-Toews and Kay, 2005). The use of professional ‘translators’ could help to overcome such problems.

THEMES OF LTSER

Any LTSER project will have to analyze long-term changes in socio-ecological metabolism, i.e. biophysical flows governed by socio-economic as well as by natural drivers; land use and landscapes; governance, in particular as it affects the use of natural resources; and communication processes, especially those relevant for society-nature interaction. Although in every particular case emphasis can be placed on one or several of these themes, we feel that no LTSER project can completely omit even one, let alone several, of these themes. The following subsections briefly discuss the relevance of each theme, and relate it to the overall LTSER concept.

Socio-ecological metabolism

Biologists have defined metabolism as the sum total of the chemical processes that occur in a living organism, resulting in growth, production of energy (useful work), elimination of waste materials, transport and reproduction (Beck et al., 1991). The analogy to social systems is obvious: The reproduction of human populations as well as economic production and consumption processes require material and energy flows that have, in their entirety, been denoted as “socio-economic metabolism” (Ayres and Simonis, 1994, Fischer-Kowalski, 1998). All of these processes are subject to the laws of thermodynamics and other physical constraints, including land availability, but socio-economic metabolism is also driven by human activities which are, in turn, directly or indirectly affected by communication processes and governance.

The metabolism concept as applied in recent decades in Ecological Economics, Industrial Ecology and Human Ecology has achieved agreed-upon, theoretically grounded definitions of boundaries between societal and natural flows (Eurostat, 2001, Fischer-Kowalski and Hüttler, 1998). One methodology linked to the metabolism concept is Material Flow Analysis (MFA), which is now incorporated into the collection of official statistics (Eurostat, 2002). This approach allows the definition of biophysical structures of society that are driven by human activities and directly related to ecosystems through material and energy exchanges. In an LTSER context, the metabolism concept can be expanded by explicitly linking socio-economic flows to the material and energy flows within regional ecosystems. The result is an integrative analysis of a region’s full socio-ecological metabolism, the grand total of socio-economic and ecological biophysical flows. This in turn facilitates integrated analysis of natural and cultural drivers of change.

The principal measures of socio-ecological metabolism are physical entities – stocks and flows of materials and energy that are important characteristics of both ecosystems and industrial and social systems. The flows and stocks of greatest interest in the LTSER context include those of air and water, soil, living biomass and dead organic matter, nutrients and toxic materials. Global and local biogeochemical cycles (involving carbon, oxygen, nitrogen, phosphorous, sulfur, etc.) can be, and have been, significantly affected by human activities. Long-term climate change is one of the likely consequences of global socio-economic metabolism (IPCC, 2001). Among the best-known consequences are the acidification of the environment resulting from fossil fuel and biomass combustion, and eutrophication from intended as well as unintended release of nitrogen and other plant nutrients, a process that may contribute to biodiversity loss (Bobbink et al., 1998).

Besides agriculture and fisheries, extractive industries like mining have the greatest impacts on socio-ecological systems. Urban agglomerations strongly affect socio-ecological metabolism (Brunner, 1994, Lohm et al., 1994). River basins figure prominently in studies of socio-ecological metabolism, as catchments provide an easy delineation. Major studies of the Hudson River (Ayres and Ayres, 1988, Ayres and Tarr, 1990) and the Rhine (Stigliani and Anderberg, 1993) provide examples. With the increasing capacity of mass transport, social metabolism becomes less and less regional, a fact which also holds true for river basins.

The Hudson-Raritan study discussed in Appendix 1 illustrates the phenomenon of disproportionality (Freudenburg, 2005, Nowak et al., 2006), and shows how industrial activity can leave a legacy of environmental harm for many decades after the activity itself has ceased. This study also shows how indirect methods can provide information at a regional level, for which direct measurements rarely exist. The metabolism approach can help researchers understand coupled systems. Above all, it disentangles the complex interaction of socio-economic drivers like economic structure and growth or lifestyles from ecological drivers such as natural forces (e.g., volcanic eruptions) and human-induced, but external (for scales smaller than global) influences such as climate change.

An important advantage of the metabolism approach is that it applies on several spatial and functional scales. Although methodological uniformity is most developed at the national level, material flow analysis can work for supra-national entities such as the European Union (Eurostat, 2002) or for sub-national entities such as economic sectors (Schandl et al., 1997), cities, or regions (Brunner, 1994, Burke et al., 2002). However, because material and energy flow accounts always refer to a defined socio-economic system, limits to spatial resolution exist. Territories used by socio-economic systems do not necessarily correspond to “pixels” (Liverman et al., 1998), nor do socio-economic systems confine their impact to their own territory. This is one important reason why metabolism studies in LTSER should be linked with explicitly spatial studies of society-nature interaction as described in the next section.

Land use and landscapes

Cultural landscapes emerge in historical processes through interaction between social systems and ecosystems. As results of co-evolutionary processes, they are a biophysical expression of socio-ecological change through time (Haberl, 1999). Cultural landscapes are dynamic; they change as socio-economic and biophysical systems evolve at a variety of time scales. Dynamics of landscapes are interactive, with socio-economic drivers affecting natural systems and natural systems driving human activities in a reiterative process (O'Rourke, 2005). Cultural landscapes thus reflect the social and economic history of a region, including dominant economic activities and their spatial organization, settlement patterns, demography, mobility and migration. These patterns and processes are, among others, shaped by communication, in particular by the way governance is executed, and simultaneously depend on ecological conditions such as geomorphology and climate and their changes over time (Luig and Oppen, 2005).

Land use and its change over time is a critical factor creating landscapes (Gutman et al., 2004, Lambin and Geist, 2006). In the absence of humans, land-cover patterns reflect natural conditions such as soil, climate, topography, hydrology and biotic communities. While being dependent on these biophysical conditions, human use of the land results in significant changes to these conditions, often to the extent that human activities largely shape or even control a significant proportion of the biophysical patterns and processes on the landscape level. In cultural landscapes (Berglund, 1991, Buttimer, 2001, Farina, 2000), land cover depends on natural and socio-economic factors. While biophysical processes, including flows of materials and energy, are relevant for their understanding, studies of cultural landscapes also address perceptions of spatial landscape patterns and their cultural representation (Foster et al., 2003, Ramakrishnan et al., 1998, Tuan, 1968). Landscapes are thus socio-ecological systems, and the analysis of landscape change over decadal and centennial periods is crucially important to render LTSER useful for sustainability science (Leemans and Costanza, 2005). For example, Appendix 2 demonstrates how a long time perspective can improve understanding of land-related phenomena, and thus to developing better management strategies.

One important parameter to be monitored, reconstructed and studied, then, is the evolution of land cover over time, including its spatial patterns. Land cover is a readily observable property of landscapes which reflects both natural preconditions and human use. LTSER should strive to understand natural conditions and drivers of their change, socio-economic conditions and drivers of their change and the ecological, biophysical and socio-economic consequences of land-use and land-cover change (GLP, 2005). Such studies refer to a range of socio-ecological systems, including agricultural, forestry, aquatic, and urban landscapes, and their interrelations. Drivers to be considered include demography, institutional forces such as economic structures, government regulation and subsidies, technology, and family dynamics.

In this context the issue of spatial scale is relevant. Trajectories of change are different at the plot, community, landscape, national, and global scale. Case studies suggest that during the past several centuries forces driving landscape dynamics have often shifted from primarily local to regional, national, or international contexts (Bicik et al., 2001, Krausmann, 2001, Krausmann et al., 2003, Wardell et al., 2003). Scale issues are also relevant for analyses of sustainability. For example, nutrient dynamics may appear sustainable at field level, even when nutrient flows are out of balance at the village level (Krogh, 1997). Under current patterns of human mobility, the global communication and trade sustainability of any particular community cannot be judged by analyzing only that particular place. Its spatial reach, or „footprint," can extend far beyond its boundaries. Many systems today are maintained by shifting costs elsewhere, in particular to developing countries. Dynamics of such systems can not be understood from within the system (Fischer-Kowalski and Erb, 2003, Wardell, 2005). Concepts of sustainability also depend on temporal scale. What appears sustainable over years or decades may not be sustainable over centuries (Fresco and Kroonenberg, 1992). Long-term historical studies can help to understand what is possible in terms of sustainability, and what rate of innovation of socio-ecological systems may be required.

Ecosystem services are of considerable socio-economic importance (Daily, 1997). Land use often maximizes certain services (e.g., biomass production) at the expense of others (e.g., regulation of water flows, biodiversity, resilience; Maass et al., 2005). Moreover, the economic or social value of services strongly depends not only on preferences, but also on the mode of subsistence (e.g., industrial vs. agrarian), market access, and the organization of the economy (Maass et al., 2005).

This means that LTSER transcends traditional LTER in the following respects: It offers a multi-scale approach in both space and time. Results from all relevant habitats, including the full range from anthropogenic to pristine systems, have to be integrated into a larger picture. Besides well-established core research areas, such as inorganic inputs and nutrient cycling, net primary productivity, organic matter, biotic communities, etc. already established in LTER studies, LTSER needs to consider a variety of social and economic variables, including human demography, political and social institutions and organizations, economic structures (e.g., markets) and processes (e.g. production and consumption), as well as perception and communication (Marcussen and Reenberg, 1999, Reenberg, 2001) How such factors may be integrated into interdisciplinary long-term socio-ecological studies to gain a more complete understanding than is possible by means of any single disciplinary approach in isolation, is demonstrated in the case study of the "Dust Bowl" included in Appendix 2.

Land-use studies within LTSER can draw from a wealth of methods such as ecological methods for landscape characterization and analysis (Naveh and Liebermann, 1994, Zonneveld and Forman, 1990), remote-sensing and GIS-based methods for land cover and landscape classification (Liverman et al., 1998, Cunfer, 2005), reconstruction of historical land cover based on historical maps and cadastral surveys (Bicik et al., 2001, Krausmann, 2001), reconstruction of past and assessment of present material and energy flows based on historical and recent statistical data combined with cadastral maps and surveys (Cunfer, 2004, Krausmann and Haberl, 2002, Krausmann, 2004), or the use of interviews and surveys to characterize households and other important social agents that are moulding land use and thus inform mapping of land cover and land use (Moran and Brondizio, 1998, Reenberg and Fog, 1995). Links to economics exist, such as through the quantification of monetary values of ecosystem services (Bockstael et al., 2000, Costanza et al., 1997, Loreau et al., 2002), although these methods remain controversial. Moreover, approaches from neoclassical economics can contribute considerably to improving our understanding of socio-economic drivers of land-use change (Geoghegan et al., 1997, Irwin and Bockstael, 2002, Pfaff, 1999).

Governance and decision-making

In order to support a transition toward sustainability, LTSER goes beyond LTER to explore the decision-making processes at different scales, to understand conflict as a basis for reconciling divergent goals amongst stakeholders (Adams et al., 2003, Dietz et al., 2003), and to reduce the vulnerability of people, places, and ecosystems (Turner et al., 2003).

Local studies highlight the need for multiple approaches to grasp the complex spatial and temporal dynamics of environmental change (Bassett and Crummey, 2003, Lambin et al., 2003, Maass et al., 2005), and the links between social, economic and environmental change (Beinart and McGregor, 2003, Tiffin et al., 1994). A key goal is to understand better the effectiveness of current ecosystem conservation and management. This requires identifying discrepancies between formal rules at different levels of governance, and discovering the gaps between formal and actual practice at each level of governance.

We suggest that one analytical focus be local actors, because they mediate the efforts of other actors at higher levels of governance (Andersson, 2004, Rigg and Nattapoolwat, 2001, Wardell and Lund, in press). As the analysis of local actors was a cornerstone of the LUCC project (Lambin et al., 1999), and will remain so in the Global Land Project (GLP, 2005), such a focus represents another important link between LTSER and land science. Local actors may modify, ignore or even completely counteract instructions emanating from public policy and regulators. They are nevertheless affected by governance systems at higher scales of influence, including national environmental laws, multilateral trade and environmental agreements, and by institutional and jurisprudential antecedents (Adams and Mulligan, 2003, Barton, 2002). Customary institutions are themselves dynamic and imperfect (Abraham and Platteau, 2001). The production and consumption patterns of local actors, on the other hand, reflect economic structures and opportunities as well as technical solutions that are typically developed, established, and re-inforced on higher socio-economic levels. These economic structures, opportunities and technology choices today bear little relation to regional or local ecological conditions, but they guide and constrain decisions by local actors and generate local ecological impacts (Fischer-Kowalski and Erb, 2003).

Within LTSER, good governance is understood as the combined effort of society to implement and enforce rules related to the provision of individual and collective goods and services to sustain local livelihoods without compromising ecosystem health. This requires understanding how access to, use, and exchange of resources are managed and negotiated in practice. An urgent overarching question is: How effective are public policies and attendant regulatory frameworks at achieving sustainable development? The following issues should be explored within LTSER frameworks to understand what happens in practice at the local level. (See the case studies on property rights in Bolivia and agricultural policy in Austria in Appendix 3.)

- Gaps between formal and actual governance systems: Laws are often subject to routine negotiations, circumvention, or outright non-observance by a broad array of stakeholders. This does not mean that laws and regulations are not important. In fact, they constitute significant reference points for actors and politico-legal institutions in their negotiations of access and rights – even if they are not enforced.
- Complex networks of actors involved in resource use: Knowledge processes are embedded in social processes. Agency denotes the capacities of local communities to adapt, to harness their own experiences, and to act in accordance with changing circumstances and opportunities. The identification of networks of actors at different scales is critical to the LTSER approach. Local communities are capable of formulating decisions, acting upon them, and innovating or experimenting even under severely restricted conditions (Long and Long, 1992).
- The tension between local resource users and external parties: The meaning and effect of law in a particular place depends on the history, the social setting, the power structure and the dynamic configuration of local and distant opportunities. Local perceptions of resource use can be explored through different lenses, such as religious, cultural, socio-political, and socio-economic practices. Environmental history provides a framework to cross spatial and temporal boundaries (Batterbury and Bebbington, 1999, Myllyntaus and Saikku, 1999, Pawson and Dovers, 2003), and to integrate the multiple influences on, and perceptions of environmental change (Dovers, 2000, Hays, 2001).

To grapple successfully with the co-evolution of social and natural systems on local scales, LTSER requires teams of researchers who are familiar with the respective specific social, economic, political and ecological contexts (e.g., Reenberg, 2001, Reenberg and Fog, 1995, Wardell, 2005, Wardell and Reenberg, 2005). The analysis of long-term socio-ecological change requires multiple sources of evidence to facilitate data triangulation. These may include the use of historical archives, archaeological and pollen records, oral histories, mapping of land cover and land use dynamics, and the use of existing research networks (Campbell and Sayer, 2003, Poteete and Ostrom, 2004). Oral traditions can provide useful explanations of relevant social or socio-political relationships. Social memories continue to inform, and to shape the strategies adopted by local resource users in negotiating rights of access to, and use of, land and resources (Hagberg, 2003).

LTSER research faces an enormous complexity of actors, processes, interactions and feedbacks. The difficulties are compounded by spatial and temporal (scalar) dynamics (Gibson et al., 2000a); local and national forms of governance that are increasingly challenged by the simultaneous transfer of authority to regional or other multilateral institutions; the incompatibility of goals, particularly in landscapes where several actors hold, and exercise different rights to use the same resource; and a persistently random element in human actions (Berry, 1993).

Governance studies within LTSER should address past reductionist perceptions and environmental narratives associated with the role of humans in resource management. They should deconstruct the influence of those perceptions on contemporary policy, management, and conservation schemes. And they should develop new, integrated socio-ecological models and illuminate long-term regional disparities. The International Forestry Resources and Institutions (IFRI) Research Network provides an example of how these complex issues may be addressed by an interdisciplinary research program (Gibson et al., 2000b). There is a need to harness indigenous knowledge, and to listen to interpretations of the local past, while embracing new technologies that help to understand patterns of social and environmental change (Bassett and Crummey, 2003, Beinart and McGregor, 2003, Hagberg, 2003). While pressures on resources grow, local conservation and development projects are increasingly giving local resource users control over the resources on which their livelihoods depend. LTSER reminds us who the real custodians of the land are, and that conservation and equity are related objectives (Zerner, 2002).

Communication, knowledge and transdisciplinarity

Nature as such is inaccessible to us. It is, therefore, also meaningless, unless we assign significance to it. One of the mechanisms by which such significance is created is the distinction between resources and nature. People assign significance through the acquisition of knowledge about nature, a process which depends on communication. The processes of knowledge formation and communication are important to LTSER when dealing with the interface between social uses of nature (in its symbolized, cultural form) and impacts of humans on natural systems. Foucault (1971) discussed the intimate relation between knowledge and power in society. Based on his theory of discourse, Luke (1996) proposed an approach to define the role of environmental sciences in support of governance processes. We suggest incorporating the study of discourse, knowledge formation, and communication into LTSER on two levels.

In a less abstract form, interdisciplinary research teams have long been aware of the issue of communication, in particular when assessing perceptions of change. The change of communicative settings over time is a prime goal of understanding. Perceptions of environmental change vary among different groups (Ribot, 1999, Grim, 2001, Waltner-Toews et al., 2003). Efforts to conflate the past and present are notoriously difficult since they overlook changes in context that defined past environments, and the human conceptions of them. Nevertheless, narratives about social and environmental change are continually promoted and peddled to privilege specific institutions or particular interest groups (Roe, 1991). Some dominant ideas still inform policy and shape the actions and strategies used by different resource users despite the lack of empirical evidence to substantiate them.

If one acknowledges the importance of communicative settings and the power structures created through them, the role of the researcher within LTSER must become a theme, too (Waltner-Toews and Kay, 2005). LTSER is interdisciplinary due to its themes: metabolism, landscape, governance and communication. It is trans-disciplinary through its – voluntary or involuntary – involvement with policy issues. Rather than trying in vain to keep scholarly work detached from policy issues, we suggest a proactive approach that incorporates actor participation and communication. Within LTSER, human groups and individuals are not only objects of study, but actors capable of processing social experience and responding accordingly (Long and Long, 1992). Consequently, LTSER has to reflect the fact that its scientific endeavor influences the course of future events.

The social sciences are relevant in gathering data for the construction of adequate pictures of human interactions with ecosystems (Endter-Wada et al., 1998), but they also provide tools for the involvement of scientists and the use of scientific findings in social contexts. A new kind of interaction is therefore expected between LTSER scientists and others that shapes communication processes to facilitate the utilization of research results (Beal et al., 1986, Röling, 1991), and bridges gaps between stakeholders with different perspectives. Through the views and expectations of various actors, in particular those directly affected by socio-ecological problems, different pictures of a problem emerge that may not coincide with the pictures drawn by scientists (Waltner-Toews et al., 2003). This diverging understanding of problems by different researchers, and by other actors, creates barriers for dialogue and understanding which are key obstacles to the establishment of partnerships (Walters, 1998, Castillo and Toledo, 2000).

Research on knowledge generation, communication and utilization shows that knowledge cannot be packaged, moved, opened, and then used (Beal et al., 1986). The use of knowledge is a complex transactional process, the success of which depends upon a potential user's pre-existing knowledge, beliefs and experiences. If users are to benefit from science, generators of scientific knowledge must work closely with them to identify problems, find solutions, and involve themselves into decision making processes ranging from the local level to that of policy formulation (Castillo et al., 2005, Funtowicz et al., 1998, Kates et al., 2001). Such transdisciplinary research – that is, research that systematically includes users in the research process – yields innovative questions and methodologies. In addition, including local actors in long term data collection such as monitoring (for social monitoring, see Appendix 4), is a cost-effective, empowering way to conduct research. Scientists and users must interact within novel scientific frameworks to define research agendas, set research questions, execute projects, and implement results.

Participatory and action-oriented research can offer LTSER interesting tools for the collective, collaborative, self-reflective and critical generation of information that helps to solve socio-ecological problems (Chambers, 1995). Participatory approaches, if carried out appropriately, can be liberating, empowering, and educational for stakeholders whose everyday livelihoods depend upon the management of ecosystems (as is the case in many developing countries) and can help bring local communities into the policy debate in a way that validates their knowledge.

The study of communication and the processes of knowledge formation becomes an integral part of LTSER, both as an aim of the study and as a reflective process for the research team. Implementing such an approach involves active participation by LTSER teams in transdicisiplinary processes. From traditional radio to modern information technology, interpersonal and group communication serves to share information, to exchange views about problems, and to facilitate negotiations among stakeholders when conflicts arise (Adams et al., 2003). Communication interventions should be designed to enhance dialogue among stakeholders and to promote social learning (Maarleveld and Dangbégnon, 1999).

DISCUSSION AND CONCLUSIONS

Conceptual considerations

In contrast to LTER which, aside from a small number of urban LTER sites, mostly focuses on studying changes in ecosystems in which current direct human activities are thought to play a minor role, LTSER focuses on socio-ecological systems that emerge through the interaction of social and natural systems (Wilbanks and Kates, 1999). Combining methods and approaches from various natural-scientific disciplines, LTER is already an interdisciplinary endeavor, but LTSER is far more demanding in this respect, as it also has to bridge the gaps between social and natural sciences and the humanities. Table 1 compares some of the key features of LTER and LTSER.

While these challenges are significant, the four LTSER themes identified here provide a framework that can facilitate such a broadly interdisciplinary research agenda:

- Drawn from Ecological Economics, Industrial Ecology and Human Ecology, the metabolism provides a way to integrate biophysical and socio-economic processes. With its empirical, quantitative assessments of physical stocks and flows in socio-ecological systems, analysis of metabolism differentiates between natural and socio-economic drivers. Analyses of socio-ecological metabolism combine field data with statistical social data, and use historical sources to reconstruct past states of the system. They thus contribute to socio-ecological models that integrate economic and ecological dynamics (Ayres, 2001, Ibenholt, 2002). Stock-flow models may be combined with agent-based models (Janssen, 2004) to understand better the interplay between actors' decisions and biophysical flows.
- The land use/landscape approach emphasizes the importance of spatial patterns in socio-ecological systems. Led by the Land Use / Cover Change (LUCC) project (Lambin et al., 1999), recently supplanted by the Global Land Project (GLP, 2005), an interdisciplinary scientific community has emerged in the past fifteen years that can contribute valuable conceptual and methodological insights to LTSER. For example, considerable progress has been made in linking social dynamics and spatial patterns, thus addressing critical scaling issues relevant to LTSER (Liverman et al., 1998). Recently, researches have improved methods to reconstruct long-term changes in landscapes, resulting in a greater consideration of long-term land-use changes (Lambin et al., 2003). Many land science projects have gained from a long-term perspective (e.g., Foster and Turner, 2004, Klepeis, 2004, Klepeis and Turner, 2001) and would benefit from the long-term monitoring efforts integral to an LTSER network. Important linkages exist between metabolism and land use: Changes in socio-economic metabolism have transformed landscapes (Krausmann et al., 2003). Land use not only provides inputs to socio-economic metabolism, it also results in changes in ecological material and energy flows (Vitousek et al., 1997).
- The governance approach emphasizes the importance of a broad array of actors and institutions, and of temporal patterns in socio-ecological systems. In Environmental History and Political Ecology the governance approach has demonstrated its ability to integrate different time periods, to explore the complex multi-scalar interactions of different agents of change, and to undertake comparative analyses which highlight the critical importance and contingency of historical contexts. Four issues underpin this approach: understanding the condition and organisation of 'nature' in the past; exploring the interactions between social conditions, the economy, and the environment; environmental policy and decision-making in society in general; and the intellectual history of environmental consciousness (Worster, 1977). Among other approaches, Environmental History and Political Ecology have been instrumental in improving our understanding of non-European representations of culture, landscape and environmental narratives (Fairhead and Leach, 1996, Grove, 1995, Leach and Mearns, 1996, White, 1991, Zimmerer and Bassett, 2003). The actual governance of access to and use of land and natural resources can often put the ambitions of past and future governments into perspective. Laws, regulations and policies do not determine access to and use of resources as such, but erect a structure of opportunities for negotiation about these rights. The discretionary and capricious enforcement of laws and regulations often provides

possibilities for monetary and political rent-seeking in the heart of local politics (Wardell and Lund, in press).

- The explicit study of communication and knowledge formation in long-term processes of interaction between nature and society allows an assessment of transformations which includes the role of actors in their networks. As knowledge is a crucial intervening variable in dealing with nature, we need to study its change over time to understand transformation. In addition to the study of governance, which addresses the organization of nature in the past, the study of knowledge and communication allows us to understand mechanisms leading to a particular form of organization, in which non-institutionalized power structures are included. The study of discourse makes possible a reflection on the role of the research itself in the processes of change. Such a reflexive approach prevents LTSER teams from abusing the knowledge they generate and opens the possibility for active involvement into environmental policy-making. By involving stakeholders, those concerned about the issues under consideration, a "transdisciplinary" form of research offers a new way to conceptualize interaction processes as observations involving us and those we study on equal terms.

The issue of research facilities is important. Traditional LTER is organized around relatively small research sites, focusing on single habitats or catchments, often of tens to hundreds of hectares. LTSER requires a different approach, as socio-economic systems are rarely organized in a spatially explicit way; this fact becomes especially obvious on smaller scales. For example, households are among the smallest relevant social units above the level of the individual, but apart from farm households they often don't have a meaningfully defined "territory." In many socio-ecological studies the village or municipality will therefore be the smallest unit of investigation, and higher levels (districts, provinces, nation states, etc.) must not be neglected, as the growth in communication and transportation results in interregional dependency. Moreover, historical (and contemporary) statistical data, an important source of information within LTSER, only exist for administrative units which often must become the unit of analysis within LTSER. This fact contrasts with ecological studies that define their units of analysis along natural discontinuities.

Wilbanks and Kates (1999, p. 603) argue that agency, by which they mean intentional human action, is often intrinsically localized, whereas institutions and other regularized, formal social relationships are almost always more encompassing and not spatially confined. LTSER therefore needs to transcend the site concept of traditional LTER and adopt a concept of "Multifunctional Research Platforms" (Mirtl, 2004), here referred to as LTSER platforms. Such platforms might be on a landscape scale, encompassing larger regions in the range of 10-1000 km^2. LTSER platforms could encompass classic natural-science based LTER sites on which key parameters of important ecosystems or processes are continually monitored and would be complemented by (1) a long-term historical database extracted from archival and statistical sources that reconstructs important socio-economic changes (Gutmann et al., 2005, Krausmann, 2004, Winiwarter, 1999) and (2) a socio-economic monitoring system that traces important contemporary changes and aids decision-making processes (Fischer-Kowalski et al., 2004). Platforms should be seen not only as physical infrastructure consisting of measurement equipment, etc., but rather as social processes, as attractors for innovative research. LTSER platforms would yield considerable added value by focusing research on a particular region and by integrating multiple cross-fertilizations between several research and monitoring activities and their respective teams. The definition and selection of platforms are therefore of significant importance so as to cover a broad spectrum of socio-ecological conditions in a network that spans larger regions.

Integration between LTSER platforms is another important issue. In a globalizing world, isolated landscape-scale studies would fail to address important issues. National and supranational levels must be considered as well, and cooperation between LTSER platforms, e.g. in the form of comparative studies or meta-analyses (Geist and Lambin, 2002), are required. Especially important is the inclusion of pre-fossil fuel system baseline data and attention to the often delicate balance between monitoring and analysis and modeling. It is essential that there be continuous cross-fertilization between rich descriptive and causal-analytic local case studies on the one hand, and theory and modeling-oriented generalizations on the other, at multiple scales.

Research networks such as the global, continental, and national LTER networks will play a crucial role in this process. Capitalizing on more than two decades of operative experience important national networks are currently being redesigned. For example, US-LTER is now adopting the so-called NEON concept (NRC, 2004). Funded by the National Science Foundation, a network of US universities has established a "Human-Environment Regional Observatory (HERO) Network" that can provide useful input (http://hero.geog.psu.edu/). Under the auspices of the European Commission, an European LTER network is currently emerging, facilitated by the EU project ALTER-Net (Delbaere, 2005; http://www.alter-net.info). Several European countries have decided to establish national networks alongside the international process. All of these conceptual and design initiatives aim to include the human dimension. Such efforts help distinguish site-specific from general patterns and processes. Broadly generalizable insights are crucial for the whole global change research community.

Integrated socio-ecological models will play a significant role in LTSER, for several reasons. First, on a landscape scale it is impossible to achieve an integrated picture of ecological processes with measurements alone, so modeling tools, including process-based ecosystem models and GIS models, will be important. Second, historical and statistical data are never sufficient to reconstruct past socio-economic, let alone socio-ecological conditions. Various methods, ranging from cross-checks to full-blown integrated models will have to be applied to get a reasonably rich picture (Krausmann, 2004, van der Leeuw, 2004). Third, models are important tools to integrate social, economic and ecological parameters in a consistent way, thus aiding interdisciplinary analyses. For example, agent-based modeling approaches have been combined with land-use studies (Parker et al., 2002) and may also be combined with stock-flow models to yield integrated representations of socio-ecological systems. Fourth, as one important goal of LTSER is to facilitate decision-making processes, models that immediately demonstrate the consequences of different decisions in an interactive process between researchers and stakeholders can be of great help.

LTSER will facilitate the transition to participation-oriented, sustainability science (Waltner-Toews and Kay, 2005). The scientific community is part of the experiment of modern society, like it or not. The foresight to deal with current problems in a sustainable way cannot be achieved without long-term hindsight, and this is what LTSER can ultimately accomplish.

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Appendix 1

Socio-ecological metabolism of the Hudson river basin

River basins provide an opportunity to understand the interactions between human activities and the state of the environment, to observe changes of stocks and flows in the environment over time, and across a range of spatial scales. The Hudson River Basin constitutes an interesting example (see Ayres and Ayres, 1988, Ayres and Tarr, 1990, Tarr and Ayres, 1990). An in-depth study was initiated in 1982 to review the history of fish catches in the Hudson and Raritan Rivers and associated Estuary. The purpose of the study, financed by NOAA, was to establish correlations between fish catches in different stretches of the river and emissions of a specified series of pollutants into the water. Three principle flow paths were considered, direct point source emissions from industrial sites along the river, sewage from urban areas and diffuse non-point pollution in the for, of run-off and leachates from the surrounding land.

One of the interesting features of this case was the radical changes in land use that took place over the period 1880 to 1980, including dramatic growth in the population of the urban area (New York city and suburbs), and changes in the patterns and intensity of agricultural in the hinterlands. Sewage treatment facilities, including those for storm run-off (storm sewers) were introduced and improved over the period, capable of treating 100% of by the end of the period. Another major change during the century was the shift from use of coal for household heating to oil and gas, and this resulted in a major change in the quantity and composition of the wastes that were generated and collected during the period. Much of the coal ash was used as landfill under Laguardia Airport. A third major change during the century could be described as de-industrialisation. At the end of the 19th century for example the New York area boasted no less than four large copper refineries, as well as cable manufacturing facilities, other activities associated with the burgeoning market for electrical goods, and chemical products. Polychlorinated biphenols (PCBs) which are highly toxic to fish were being produced as a insulation materials for the electrical industry. Wastes simply accumulated behind a dam on the Mohawk River, a tributary of the Hudson, which circa 1980 gave way, releasing large amounts of PCBs to sediments which are to this day still moving down river. In recent years most of these industries have moved away, New York losing its primacy as an entrepot (oil refineries remained, such as that of Standard Oil). Nowadays the city is centre of finance, retail activity, publishing and consumption. All of these changes have reduced dramatically the immediate emissions burden, however the history of the region still determines the quality of the river ecosystem, its properties and patterns.

The level of copper in the lower Hudson and harbour areas is still exceptionally high due to leaching from wastes from the former copper refineries, the last one of which closed in the mid 1980s. As a result of the aforementioned accident significant levels of PCBs are still measureable. Sediments in New York Bay contain high levels of a suite of heavy metals, thanks to uncontrolled emissions from the chemical industry in the early 20th century. The waters of the bay circulate slowly, sediments accumulate and do not move out to the sea at large. An ambitous project is underway by the Army Corps. Eng. to bury these sediment in a deep hole under the bay itself, hence avoiding issues of reoxidation and mobilisation of toxic metals.

This study illustrates one of the problems and one of the possible approaches to carrying out historical LTSER. The problem is that there is virtually no useable data on pollutants and toxic emissions prior to the 1970s. However, it is possible to make use of historical information on socio-economic activities and conditions to make reasonable estimates of emissions in earlier periods. This was done in the case of the Hudson-Raritan Basin study and a few other cases (Rhine, Danube; see Stigliani and Anderberg, 1993).

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Appendix 2

Land use case study: the Dust Bowl

As soon as the Dust Bowl began in the early 1930s, observers asked why it happened when and where it did and what caused it. Government bureaucrats quickly provided answers. The Dust Bowl was caused, they said, by the recent arrival of farmers on the southern plains. Settlers had plowed land unsuitable to crop farming, exposing bare soils to high winds. When the 1930s drought arrived dust storms drove miserable people from their homes. Almost immediately the U.S. government set out to reform land use in order to stop the dust storms and to prevent their recurrence (Hurt 1981, Worster 1979).

In the decades since the 1930s scientists have explored the physics of wind erosion. Field and wind tunnel research established the basic parameters of when and how soils erode. William S. Chepil's wind erosion equation (WEQ) identifies five factors that contribute to blowing soils: climatic forces (precipitation, temperature, wind), soil texture, surface roughness, length of field, and quantity of vegetation. By specifying these parameters it is possible to measure and predict wind erodibility. These studies have focused narrowly within the realm of crop agriculture; the WEQ refers specifically to plowed fields. Scientists, assuming that cultivation was the primary cause of dust storms, focused their attention on how farmers should alter land use practices to avoid or diminish the incidence of wind erosion. For example, farmers can plow furrows perpendicular to prevailing winds, rather than parallel to them. They can corrugate their fields by plowing steeper furrows to increase surface roughness. And they can break up long stretches of bare soil with intermittent grass strips (Argabright 1991, Bisal and Hsieh 1966, Lyles and Allison 1976, Woodruff and Siddoway 1965).

This branch of land use and landscape science yielded worthwhile results. But without a broader historical understanding of dust storm dynamics it may be too limited. Historians, for their part, have addressed similar questions. Why did the dust storms happen when and where they did, and what caused them? In the decades after the 1930s historians traced in considerable detail the history of agricultural settlement and land use change on the southern plains between 1870 and 1935. It is clear that in the 30 years before the Dust Bowl farmers plowed a considerable amount of new land for crops (Worster 1979). But there is other historical evidence that does not fit the standard narrative. Carefully drawn maps of the erosion region held in the National Archives indicate that dust storms also happened in places with little cropland, where more than 90 percent of land area remained in native grassland cover (Cunfer 2002, Cunfer 2005). Laborious research in nineteenth century newspapers reveals that repeated, intense dust storms occurred routinely before 1900, when very little of the plains had yet been plowed for crops (Malin 1946). Archeological excavations of Native American occupation of the southern plains show that cultural occupations spanning thousands of years are often separated by deep deposits of wind-blown soils. It appears that dust storms were not a new phenomenon in the 1930s nor were they restricted to high cropping areas. Perhaps dust storms are a routine part of southern plains ecology that arise whenever and wherever there are deep and extended droughts.

The plains have experienced repeated episodes of dust storms over thousands of years. Settlement between 1900 and 1930 put farmers in the path of the next cycle of drought and wind erosion. It is unclear to what extent land use practices may have exacerbated the severity and duration of the Dust Bowl, but the story of causation is more complex than we once thought. The mechanisms of soil erosion in native grassland also remain unexplored. A combination of ecological and socio-economic research can provide a broader and fuller understanding of agroecosystems. Without scientific studies historians may misunderstand the mechanisms of wind erosion. Without historical studies to provide broader temporal and geographic contexts scientists may focus their research too narrowly on cropped fields only. Brought together a LTSER approach can provide broader understanding of human-managed ecosystems that, after all, cover the majority of the earth's land surface.

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Appendix 3

Governance case study 1: Introduction of formal property rights in Bolivian forestry

Prior to 1996, smallholders and indigenous groups in Bolivia were not authorised to harvest any timber resources, not even products for household consumption, without government permits. As a result, formal rules were largely ignored by these groups. Because the central government did not have the financial or the human resources to monitor and enforce the formal rules, they became meaningless in terms of influencing actual forest use. A new regulatory framework introduced in 1996 gave smallholders and indigenous groups formal rights to use all forest resources within their property boundaries. As long as this use is limited to household consumption, no government permits are now needed. For the first time in Bolivian history, previously excluded groups are potentially empowered to harvest timber for commercial purposes, although this requires as many as 27 administrative steps (Andersson and Pacheco, forthcoming, Contreras-Hermosillo and Vargas, 2001). Because of the complicated procedure, very few smallholders have actually been able to take advantage of the opportunities offered by the new set of formal rules. This example shows the limitation of formal rules to influence local people's natural resource use, and illustrates the need for formal rules to consider local practices.

Governance case study 2: Long-term dynamics of governance and land-use change in Austria

The development of spatial patterns and the intensity of agricultural land use is shaped by environmental constraints, available technology, political regulations and economic conditions, e.g. the development of agricultural markets. In Austria, the years after World War II were characterized by sincere shortage of food and consequent political efforts to increase agricultural production. The so called "green plan" combined the establishment of protected markets and guaranteed prices for agricultural products with financial subsidies for farmers and effectively triggered modernization of the backward structures of Austrian agriculture and an increase in the physical and monetary output of agricultural production. Agricultural modernization was related to a fundamental restructuring of spatial patterns and the intensity of agricultural production: Large-scale mechanization replaced draught animals and labour force, fertilizer and pesticide inputs increased. Specialization and spatial differentiation resulted in a transformation of locally closed agricultural production systems into throughput systems with large external inputs and outputs. This resulted in transfers of large amounts of bulk materials (food, feed and plant nutrients) across large distances both at a national and an international level. Austrian agriculture got increasingly integrated in global markets and consequently the environmental impact of agriculture shifted from a predominantly local level before WWII to a global level. From the 1970s onwards local production and consumption patterns increasingly affected land use in distant regions (Erb, 2004).

In the 1970s continuing growth in area productivity triggered by guaranteed prices resulted in increasing environmental pressures on agricultural ecosystems and ground water and in severe overproduction. The latter was not competitive on international markets and was significantly subsidised. Political actors reacted slowly but in the mid- 1980s Austrian agricultural policy was fundamentally restructured and a range of political measures were implemented to get a grip of the agricultural dilemma. A number of measures, among others, can be highlighted to illustrate this: A newly implemented tax on fertilizer decreased fertilizer application which in turn had a positive impact on ground water contamination. In combination with a fallow program which paid farmers to take cropland out of production this contributed to agricultural extensification. A third measure shifted the subsidy system from guaranteed prices to financial subsidies related to the area under cultivation which slowed down further intensification but still protected small scale farming operations. Finally the government aggressively promoted and subsidised the cultivation of oil and protein crops (so called crop alternatives): This should (1) reduce import dependency with respect to protein feed (large amounts were imported from the US and Brazil), (2) help to reduce overproduction of cereals and (3) substitute biofuels (RME, ethanol) for fossils. These political efforts resulted in significant changes in land use intensity and patterns in the Austrian landscape: Fallow and the new crops increased from 3% to more than 20% of cropland between 1985 and 1993 and changed the colour of the Austrian landscape to yellow. Since Austria's accession to the European Union the increasing liberalization of agricultural markets triggers the delayed structural adjustment of agriculture. This accelerates reforestation of agricultural areas in regions of marginal productivity and intensification of production in fertile regions. The coming GATT rounds and the expected liberalization are likely to severely affect agriculture in sensitive alpine regions (a reduction in grassland based milk production) and wipe out the production of sugar beets in Austria (Krausmann et al., 2003).

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Appendix 4

Including users in Baltic Sea research

The Baltic Sea is one of the most-studied seas in the world. It is a semi-enclosed, shallow northern estuary sized 420 000 km^2 with a drainage area about four times its size. Its natural dynamics are characterized by an interplay of stagnation periods and nutrient-rich upwelling due to salt pulses from the North Sea. This interplay is linked with the frequency and extent of algal blooms because salt pulses break the stagnation period and make nutrients from sediments available to algae in the upper layer of the sea (Furman et al., 2004). Blue green algal blooms are a natural phenomenon of the Baltic Sea and have been recorded as early as 1885. At present, around 90 million people live in the Baltic Sea's drainage area. Since the mid-19th century, algal blooms and the overall level of eutrophication has increased in the Baltic Sea due to anthropogenic nutrient discharges. This eutrophication is having various impacts in the ecosystem, including changes in fish populations, increase in filamentous algae, withdrawal of perennial fucoid algae and increased frequency of toxic algal blooms (Kautsky et al. 1986, Lindström and Virtanen 1992, Niemi 1982).

The Archipelago Sea National Park, sized 220 km^2 and consisting of thousands of islands, was established in 1983 in the South-West of Finland. It is an area where eutrophication has been clearly demonstrated, and where impacts on humans have arisen (Hänninen and Vuorinen 2001). The Biosphere area of the Archipelago Sea, the core of which is the national park, has 1200 inhabitants. The local inhabitants earn their living, among other things, from fishing, fish farming, agriculture, forestry and tourism. Hundreds of summer cottages owned or rented by people who stay in the area during vacation are situated in the area. In the 1980s, first human and animal toxification reactions caused by blue-green algal blooms were recorded. In addition, conflicts between fish farmers and other residents of the Archipelago Sea deepened due to impacts of smells and the prevalence of slimy algae. The conflict around fish farming has been maintained not least by the provision of contradicting information by various researchers and other stakeholders through the media without a synthesizing analysis (Peuhkuri 2002).

To gain local knowledge and to raise the awareness of users, the Finnish environment institute (SYKE) decided in 1998 to start a process of collecting data of the algal impacts throughout the country. The aim was to provide up-to-date information on the occurrence of cyanobacteria and their spatial and temporal variation during the summer months as a joint-venture of local and regional authorities, SYKE and Finnish Institute of Marine Research (FIMR). This process is still ongoing.

Each week a report is prepared at SYKE which of the following parts: (1) A summary which is a short one-page description of the weekly situation. (2) A map which shows by colour codes the situation at each observation site. (2) A cyanobacterial "abundance barometer" which allows comparison of the current situation to previous years. The barometer is calculated as the balanced mean of the observation sites and cyanobacterial abundance. (4) Descriptions of regional situations are also sometimes included in the report.

The media transmit this up-to-date scientific information, occasionally with big headings, to the users around the Archipelago Sea. The users thus learn about the present extent and impacts of the algal bloom and are thus able to react by calling the algae-line, a telephone line was opened for the users of the coast where anyone can report on the occurence of harmful algae and related problems, and get answers to his or her questions.

When the algae-line was opened in 1998, awareness rose quickly. After the first year, the number of calls reached 200-700 calls /year. No deeper analysis was carried out, however, whether the user reports to the algae-line was based on their reflections of the news or on objective documentation of the algal impacts in their own environment, and thus both alternatives remain as potential options. The aim of the process is to reach a more holistic picture of the algal problem. However, the reflections showed such a high complexity that a synthesizing long term approach such a LTSER would be needed before a holistic picture could be drawn and a more balanced communication strategy found.

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Table 1. A comparison of key features of LTER and LTSER.

	LTER	LTSER
System studied	Ecosystem	Socio-ecological system
Humans are dealt with as...	...human populations, treated like populations of other species, causing disturbances in ecosystems.	...human societies / cultures engaged in an interactive process with their natural environment.
Methods / approaches	Natural sciences approach: observation – analysis – explanation. Intervention occurs only in controlled experiments.	Inter- and transdisciplinary approach: gets involved and is aware that the research may change the systems under investigation.
Products	Expertise, measurement data, models, understanding of system dynamics.	As LTER plus socio-economic and statistical data. Actively uses research results as a basis for participation in decision making.
Basic epistemological assumptions	Natural-scientific values: aims at objectivity and reproducibility, may sometimes have the illusion to be independent of social values and norms.	Self-reflexivity: Is aware that research is a social process inextricably entangled in (historically contingent) social values and norms.

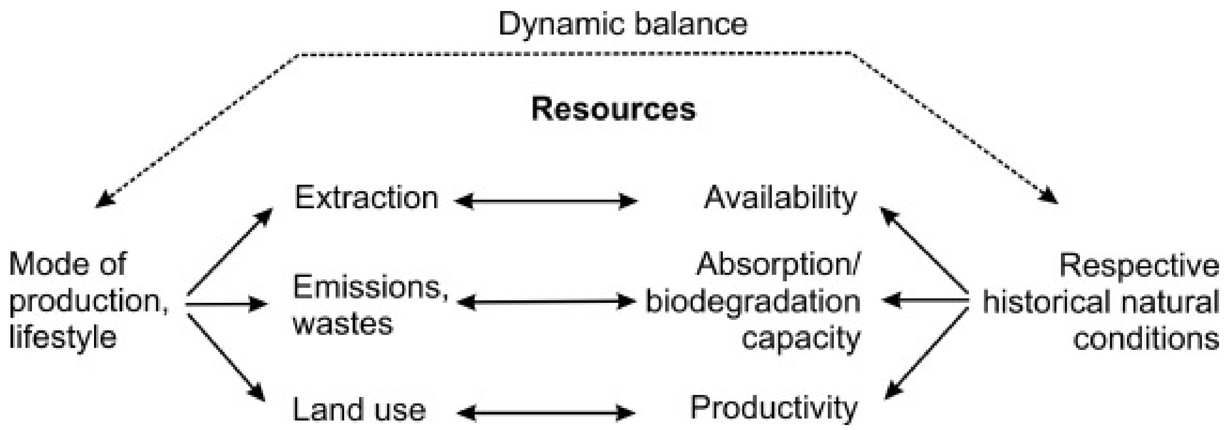

Figure 1. Sustainability as the dynamic balance between mode of subsistence / lifestyle and the respective historical natural conditions.

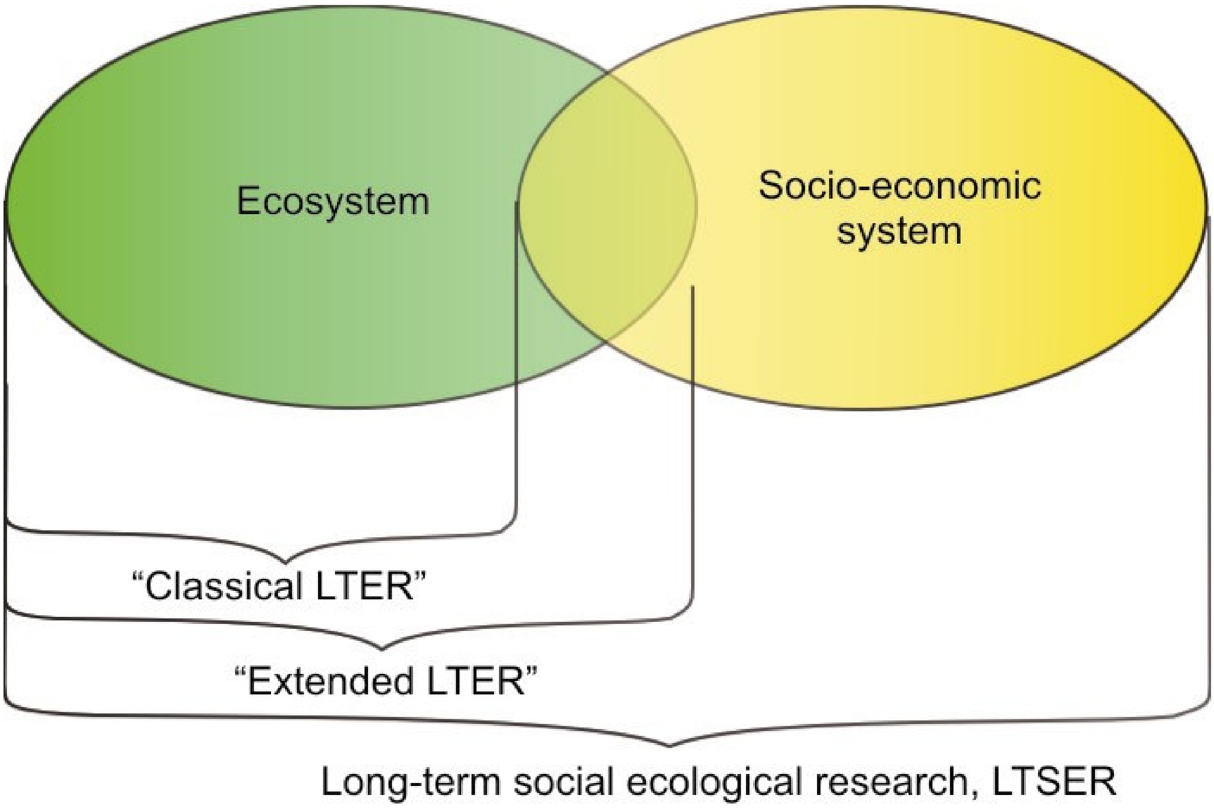

Figure 2. While (extended) LTER focuses on more or less human-modified natural systems, LTSER must deal with socio-ecological systems that emerge through the interaction between ecosystems and socio-economic systems.