Part F

Future Directions: the Global Land Project

Chapter 25

The Future Research Challenge: the Global Land Project

Dennis S. Ojima · William J. McConnell · Emilio Moran · Billie L. Turner III · Josep G. Canadell · Sandra Lavorel

25.1 Introduction

Human transformations of ecosystems and landscapes are the largest source of environmental change on Earth, affecting the ability of the biosphere to sustain life (Steffen et al. 2004; Vitousek et al. 1997). As a species, humankind has become ever more adept at appropriating and altering the Earth's resources for human needs. Intensification and diversification of land use and advances in technology have led to rapid changes in biogeochemical cycles, hydrologic processes, and landscape dynamics (Melillo et al. 2003). Changes in land use and management affect the states, properties, and functions of ecosystems. In turn, these consequences affect human well-being. There is a need for improved understanding of how human actions affect natural processes of the terrestrial biosphere, and an even greater need to evaluate the consequences of these changes (Kates et al. 2001; NRC 1999). The research goal of the Global Land Project (GLP) is to measure, model, and understand the coupled human-environmental system (Fig. 25.1) as part of broader efforts to address changes in Earth processes and subsequent human consequences (GLP 2005).

Early ecologists had already pointed out that the ecosystem concept originally included human actions and needs explicitly. Nevertheless, until recently humans were largely treated as exogenous to ecosystems in many studies of the effects of global change on the terrestrial biosphere. For example, ecosystem responses to changes in atmospheric CO_2, plant invasions, or fire were evaluated with a given scenario of disturbances that did not take into

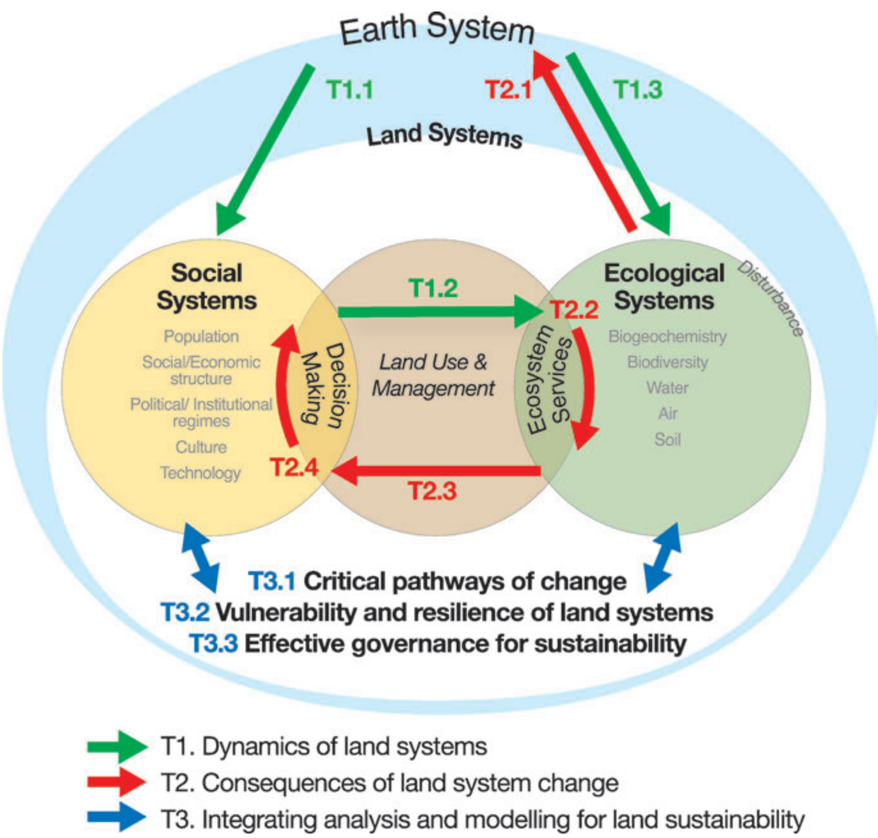

Fig. 25.1. GLP analytical structure (GLP 2005)

In: Canadell JG, Pataki D, Pitelka L (eds) (2007) Terrestrial Ecosystems in a Changing World.
The IGBP Series, Springer-Verlag, Berlin Heidelberg

account the socio-cultural factors leading to disturbance, or feedback between ecosystem function and decision-making by individuals and institutions. However, decision-making, ecosystem processes, disturbance, and ecosystem services are inextricably intertwined, and a consideration of ecosystems as coupled human-environment systems is a critical next step in understanding the changing Earth System.

Global environmental changes affect the coupled human-environment system differently in different regions of the world. Biophysical alterations, such as increased atmospheric carbon dioxide concentrations or enhanced erosion of soils, and social forces, such as globalization of markets, generate different responses in Northern vs. Southern hemispheres, urban vs. rural environments, and developed vs. developing countries. These changes, in turn, affect local land-use decisions and the delivery and maintenance of ecosystem services. Links between decision-making, ecosystem services, and global environmental change define important pathways of coupled human-environment activities at the local and regional scale to and from global scales (Fig. 25.2).

The focus of the Global Land Project is largely land-centric which includes the people, biota, and natural resources (air, water, plants, animals, and soil). In addition, critical feedbacks and interactions between the land and the atmosphere, and between the land and oceans will be researched (GLP 2005). This research strategy is designed to bring together elements resulting from over 10 years of research of the individual IGBP and IHDP core projects, Global Change and Terrestrial Ecosystems (GCTE) and Land-Use and Land-Cover Change (LUCC), and assessment efforts such as the Millennium Ecosystem Assessment (Mooney 2003). From a programmatic sense, the GLP is the evolution of the GCTE and LUCC core projects into a new phase of more integrated research and coupled developments between natural and social sciences. This legacy of research and recent efforts in integrated environmental research have opened the opportunity to undertake a more integrated human-environment system set of studies in ways not possible in the past.

Given this focus on the human-environment system, the research activities need to be formulated to account for place-based differences and to consider the time and spatial scale of changes in human-environmental properties. The human-environment system approach provides a context to better understand the cultural landscape in which changes in the land environment are taking place and the manner in which regional differences in social structures at multiple scales affect biogeochemical cycles, biodiversity, and biophysical processes. The development of the research activities will require the joint efforts of scientists from various communities, including the social, economic, and environmental sciences.

25.2 Research Objectives

The Global Land Project has three objectives that provide the framework for the research:

- to identify the agents, structures and nature of change in coupled socio-environmental systems on land and quantify their effects on the coupled system;

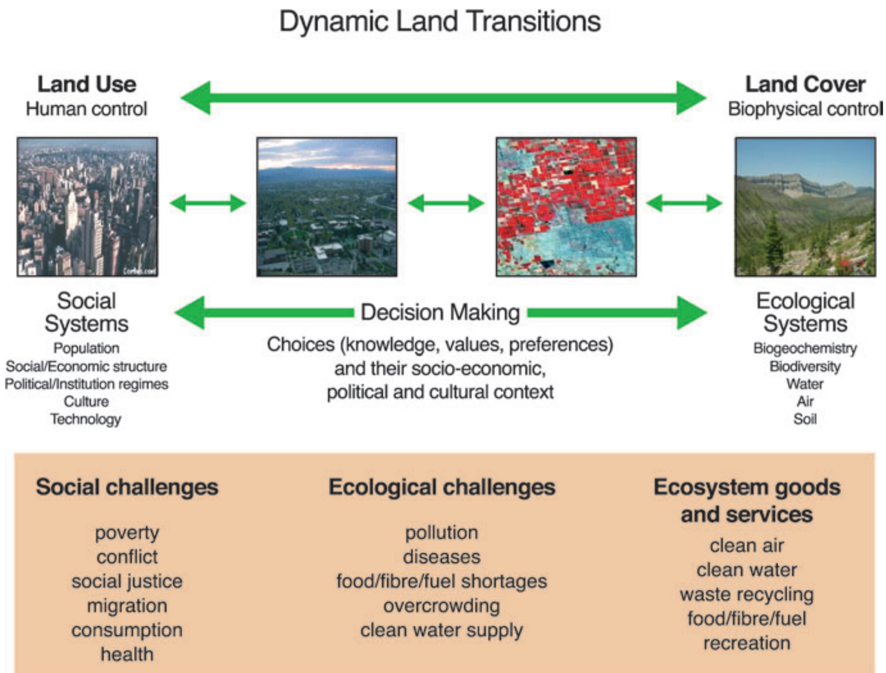

Fig. 25.2. The continuum of states resulting from the interactions between societal and natural (GLP 2005)

- to assess how the provision of ecosystem services is affected by the changes in the coupled socio-environmental system;
- to identify the character and dynamics of vulnerable and sustainable coupled socio-environmental LAND-SYSTEMS to interacting perturbations, including climate change.

Three thematic research areas define the Global Land Project research framework: (1) Dynamics of Land-Systems; (2) Consequences of Land-System Change; and (3) Integrating Analysis and Modeling for Land Sustainability. These research themes are depicted in Fig. 25.1, and additional research areas are indicated related to *(a)* factors affecting decision making, *(b)* the implementation of land-use management, *(c)* the effects on ecosystem and environmental dynamics, *(d)* the provisioning of ecosystem services, and *(e)* the evaluation of the coupled human-environmental land system's vulnerability to global environmental changes.

25.3 Emergent Concepts

The scope of the Global Land Project includes research on the effects of atmospheric, climatic, and land-use change on ecosystems, but in addition, several emergent concepts provide new directions for land research. These emergent concepts are associated with a greater focus on the social and environmental aspects of land system decision making, the valuation and provisioning of ecosystem services, and factors affecting vulnerability and sustainability of the coupled human-environment system. The following section provides a brief overview of these emergent concepts.

25.3.1 Land-Use Decision Making and Adaptive Management

Our increased understanding of the decision-making process related to land management provides a basic foundation for evaluating the interactions between human activities and their impacts on ecosystem structure and function. In this context, the decision making processes affecting land management are of particular interest in understanding how the range of settlement patterns, extraction of natural resources and production practices, land conversion methods, and conservation practices affect ecosystem dynamics.

The turn of the century has been marked by political and economic processes labeled globalization. The term refers to the worldwide reach and dominance of market institutions, engendered by the virtual instantaneous delivery of information, whose spread carries with it political and cultural implications (Stiglits 2002). These changes, associated with demographic and labor-flow trends, are occurring concurrently with climate change, CO_2 effects, and N deposition across different regions around the world. One outcome of globalization is the increasing separation of places of consumption from places of production, such that land systems often cannot be adequately understood without considering linkages to decisions made elsewhere (Blaikie and Brookfield 1987; Kasperson et al. 2001). For example, commodity crops throughout Africa are directly contracted from Europe (Bassett 2001) and large-scale deforestation in Borneo is driven by Japanese timber and pulp wood industries, although the translation of the demand to land systems is typically mediated by local policies and institutions (Angelsen and Kaimowitz 1999). In either case, the dynamics in question are embedded within and often directly tied to decisions made halfway around the world or processes operating globally.

Research is needed on the ways in which the socio-economic forces of globalization are tied to specific land-use practices and the role of institutions in mediating their outcome, including their impacts on ecosystem services. Analysis of economics, institutions, and the role of multiple stakeholders in land-use decision-making in regions undergoing socio-economic and environmental change is critical for various kinds of land change models. This research will provide insight into what types of coping strategies might be utilized at the local and regional scale. An area of emphasis will be socio-economic and political changes resulting in the relocation of significant numbers of people, both between regions, and within them. Understanding these interactions and how they affect ecosystem services (which are in many cases altered by changing land-use practices) will facilitate the development of coping and mitigation strategies to offset further perturbations.

Demographic factors, including growth, density, fertility, mortality, age, and sex composition of households, are known to be important factors influencing land-use and cover change. Research in the past decade has shown that while population growth is strongly related to land-cover dynamics, such as deforestation (Allen and Barnes 1985), this relationship is mediated by many other factors, such as land settlement policies and market forces (Geist and Lambin 2002). A key aspect of demographic dynamics is human migration, including shifts to and from rural and urban areas, and migratory flows linked to globalization processes. While urban areas continue to draw labor from rural agricultural areas, global labor markets induce the movement of large numbers of people across countries and continents (Massey 1998). Meanwhile, large-scale planned re-settlement continues in Amazonia and Indonesia, where land-use patterns have been found to depend on household composition, income, soil fertility, distance to markets, and the duration of tenancy (Pichon 1997; Perez and Walker 2002). Land tenure itself can affect fertility decision-making at the household level, with more secure tenure, *ceteris paribus*, resulting in lower fertility rates (Moran 1993). Establishing the generality of such findings is an important research challenge.

25.3.2 Ecosystem Services

Interactions between ecosystem structure and function, and with society, have consequences for the provisioning of ecosystem goods and services. There is much progress to be made in explicitly linking ecosystem processes as they have been traditionally evaluated and the services that ecosystems provide to society. Because of this focus on ecosystem services, it is essential that natural and social scientists develop reasonable sets of metrics of these services. Recent research has heightened awareness among scientists, policy makers and the public of the vital role of ecosystem services not only in the provisioning of key economic goods but also in the services that sustain, regulate and support life on Earth (Constanza et al. 1997; Daily 1997; Daily et al. 2000; Mooney 2003). Human well-being depends on a wide array of goods and services that terrestrial ecosystems provide. Whereas consumptive goods provided by land systems, such as grains, animal protein, and fiber and wood products, are typically valued through well developed markets, the contributions to human well-being and ecosystem functioning of the 'underpinning' services provided by ecosystems often remain 'invisible' and unvalued (or undervalued).

The array of such services is broad, from those services that regulate critical human-environment processes (e.g., climate, disease, flooding, detoxification) to services that support economic activity (e.g., soil formation, primary productivity, nutrient cycling, pest control, pollination). Indeed, our reliance on ecosystem services extends well beyond economic welfare, encompassing income, assets and capabilities, to health, security, food and nutrition, as well as, cultural identity, aesthetics and spirituality. Changes in land systems (in land-use practices and land cover) can disrupt the provisioning of services, degrade the quality of ecosystem services, and reduce the ability of ecosystems to maintain delivery of essential services upon which human well-being depends. One major feature of coupled human-environment systems is the notion that ecosystem services are not independent from each other, and that any change results in positive and negative outcomes depending on services considered, i.e., on the trade-offs.

Changes in the delivery and the maintenance of ecosystem services are also being affected by modifications of ecological systems through alterations of community composition or structure brought about by human activities. Inadvertent or sometimes purposeful actions by humans have led to creation of new ecosystems with unique combinations of organisms under modified environmental conditions. Examples of these emergent ecosystems can be found along a range of conditions ranging from urban environments to more natural settings. Examples include invasive species introduced in South Florida which have altered fire and hydrological regimes (Ewel et al. 1986) landscape alteration of hedge row communities in agricultural landscapes of Europe affecting predator-prey and pollinator communities, and salinization of Australian woodlands due to hydrological shifts resulting in changing forest dynamics (Hobbs et al. 2006). These "emergent ecosystems" may lead to modification of ecosystem structure and function in novel ways. However, management regimes can change abruptly as a result of environmental and/or human perturbations. For example, expansion of agricultural lands due to market or local demands for food production, sudden changes in prices of agricultural inputs (e.g., oil prices), policy shifts which alter environmental valuation of certain ecosystem properties, or political crises can result in rapid transitions in land management regimes. This set of examples point out the need to develop an analysis of the ways in which ecosystem processes are affected in terms of changes in biogeochemical cycles, biodiversity characteristics, and biophysical properties along urban-wildland continuums.

25.3.3 Vulnerability and Sustainability Science

The interaction of the coupled human-environment system with global change effects determines the vulnerability or the ability to take advantage of opportunities emerging from global change and access to markets and technologies. Vulnerability is the degree to which a system is likely to experience harm due to exposure to a hazard (Kasperson et al. 1995, 2001; Turner et al. 2003a). Resilience refers to the ability of a system to recover to a reference state following a disturbance and/or its capacity to maintain certain structures and functions despite disturbance (Carpenter et al. 2001; Gunderson 2000; Gunderson and Holling 2002; Harrison 1979). Emerging from risk-hazard studies and ecology, respectively, vulnerability and resilience have been incorporated in frameworks applicable to land systems (Downing et al. 2001; Kasperson and Kasperson 2001; McCarthy et al. 2001; Turner et al. 2003a,b; Watson et al. 1997). These frameworks evaluate how hazards-disturbances and exposure to them affect the sensitivity and resilience of the land system, including the consequences of adjustments and adaptations resulting from the hazards. Their applications have shown, for example, how the changing political economic structures in Mexico due to economic liberalization interact with drought to change the vulnerability of land systems on *ejidos* (communal lands) in different parts of the country (Turner et al. 2003b).

Vulnerability-resilience assessment is central to the Global Land Project for at least two reasons: (1) land systems are exposed and respond to hazards and disturbances, with the resulting mechanisms sustaining the systems or placing them at risk of change; and (2) the identification of those components of the land system most at risk and the mechanisms that enhance risk mitigation are central societal concerns. Information associated with these two reasons will be useful to decision makers. Most vulnerability-resilience work to date, however, has not addressed the land system per se. Risk-hazards approaches have focused on human vulnerability hazards (e.g., hurricanes) or on natural resources (i.e., the provisioning component of ecosystem services). Resilience research, in turn, has focused on ecosystem functioning. Recent work indicates that a more integrated approach is needed and the coupled human-environmental system perspective provides a framework to evaluate these linkages between ecosystem services and society (Adger et al. 2000; Luers et al. 2003).

Multiple perturbations and stresses operating at different spatio-temporal scales affect goods and services, challenging the science community to develop methods and metrics to achieve effective vulnerability analysis. Vulnerability involves more than the exposure of the system to a hazards, such as drought. It also includes the coupled human-environment system's sensitivity to the exposure and its resilience to the consequences. Resilience involves the copying capacity, adjustments, and adaptation of the system. Vulnerability analysis, therefore, must be holistic and integrative in design, and owing to the complexity and variation of coupled human-environment systems and their impacts on environmental goods and services, should be placed-based but explicitly linked to other places, drivers, and consequences to which it is connected.

25.4 Research Framework

The research approach of the Global Land Project is designed around the challenges of integrating the social and biophysical sciences. Three major themes have been developed to enable the research community to better engage in different facets of the research framework. The following section provides an introduction to this research which is being implemented through a network of research activities.

25.4.1 Theme 1: Dynamics of Land System

Research Questions

- How does globalization and population change affect regional and local land-use decisions and practices?
- How do changes in land management decisions and practices affect biogeochemistry, biodiversity, biophysical properties, and disturbance regimes of terrestrial and aquatic ecosystems?
- How do the atmospheric, biogeochemical and biophysical dimensions of global change affect ecosystem structure and function?

Understanding of global change is dependent on better understanding of the role of human activities in altering the structure and functioning of terrestrial and aquatic ecosystems, and the effect of changes in the Earth System on coupled human-environment systems operating at smaller scales. Increased understanding of the decision-making processes related to land-use management provides a foundation for evaluating the interactions between factors influencing human activities and feedbacks within the coupled human-environment system. Particularly dramatic are the impacts of land-use decision-making on the human use of land and the consequent changes in land cover and ecosystem dynamics.

This theme contributes to understanding the mechanisms by which human activities and global environmental changes affect terrestrial and aquatic ecosystems. The research undertaken for this theme will develop and synthesize knowledge on the proximate and underlying causes of land-use change, and hence ecosystems, with particular attention to the role of broader social, demographic and economic forces in shaping land-use decisions. The effects of land-use practices (e.g., agricultural, silvicultural, and pastoral systems) and global change effects on ecosystem services and the resulting feedbacks to the Earth System have not been well studied or quantified. Particular attention is given to the effects of human domination of landscapes, as these effects relate to urbanized areas, habitat management, increasing impact of invasive species, and other environmental characteristics. Likewise, this theme seeks a deeper understanding of the functioning of ecosystems within the context of global environmental change, assessing the effects of changes in atmospheric composition and physics on hydrological and biogeochemical cycles, biodiversity, and ecological disturbance regimes (Box 25.1). The greatest challenge, then, is the integration of this knowledge to forge an understanding of the combined and interactive effects of land-use and broader global environmental change on ecosystem structure and function.

Box 25.1. Fire and Pests

Fire and pest outbreaks have been part of the natural cycle of many forested ecosystems world wide. Fire has often a necessary component of a forested ecosystem to reset the successional cycle of these ecosystems. However, recently studies have indicated the frequency of pest outbreaks have increased due to increased growing season temperatures resulting in large areas of dead or damaged trees (Logan et al. 2003). These expanded areas of insect damaged forests have the potential to enhance the fire extent and intensity under these climate altered conditions.

Fig. 25.3. **a** Pine forest in Eastern Oregon, two years after the catastrophic fires of 2002. Note the lack of regeneration in detrimentally burned soils. Provided by Kathy Hibbard. **b** Pine beetle damage (provided by Kathy Hibbard); with inset showing mountain pine beetle (provided by USDA Forest Service)

25.4.2 Theme 2: Consequences of Land-System Change

Research Questions

- What are the critical feedbacks from changes in ecosystems to the coupled Earth System?
- How do changes in ecosystem structure and functioning affect the delivery of ecosystem services?
- How can ecosystem services be linked to human well-being?
- How do people respond to changes in ecosystem service provision, considering the various scales and contexts of decision making?

Land ecosystems, both terrestrial and aquatic, provide a multiplicity of ecosystem services that are vital to human well-being. Agricultural systems, for example, both rely on and contribute to services, such as, soil formation and fertility renewal, freshwater, genetic crop resources, and pollination that result from agro-ecosystem processes. Changes in the availability of ecological services affect the viability, productivity and stability of the coupled human-environmental systems upon which humans rely for sustenance and economic livelihood.

Decisions about land management often result in trade-offs in the delivery of different ecosystem services. A number of factors may change through time which can affect the decision-making process and the evaluation of particular ecosystem services. A first objective of the research for this theme will be to identify these trade-offs, their causes, and the consequences they impose on land management in the context of global change. An effort will be undertaken to quantify how reductions in ecosystem services caused by changes in disturbance or management regimes may provoke shifts in land productivity by modifying physical inputs and economic returns.

Theme 2 addresses the consequences of changes in ecosystems brought about by land-use and global environmental changes studied under Theme 1. These consequences include feedbacks to the people within an ecosystem, and to the broader Earth System. Feedbacks to people are understood as changes in the delivery of a broad range of ecosystem services, such as agricultural productivity, clean air, potable water, and many others. Feedbacks to the broader Earth System occur through biogeochemical cycles, biodiversity, and natural disturbance regimes (Box 25.2). Finally, Theme 2 examines the combined effects of such ecosystem feedbacks, along with the effects of broader social, demographic and economic forces, in shaping local land-use decisions.

25.4.3 Theme 3: Integrating Analysis and Modeling for Land Sustainability

Research Questions:

- What are the critical pathways of change in LAND-SYSTEMS?
- How do the vulnerability and resilience of LAND-SYSTEMS to hazards and disturbances vary due to changes in human and environment interactions?
- Which institutions and policies enhance land sustainability?

Box 25.2. Urban Carbon Dioxide

Just as most ecosystems on Earth are now influenced by human activities, human dominated land systems such as cities remain influenced by ecological processes, including plant and soil biogeochemistry. The Biosphere-Atmosphere Stable Isotope Network (BASIN) organized within IGBP uses isotopic tracers to detect the influence of ecosystem processes on the atmosphere and how these processes are modified by global change. In this figure from Pataki et al. (2003), measurements of CO_2 isotopes in Salt Lake City, Utah, USA were used to separate nighttime CO_2 concentrations into a biogenic component originating from respiration of the urban forest and anthropogenic components originating from fossil fuel combustion. The results show that despite the large influence of fossil fuel emissions on the urban atmosphere, biological processes are easily detectable. These processes contribute to the urban carbon cycle and provide a variety of services for urban residents, including carbon sequestration, removal of atmospheric pollutants, and the cooling effects of transpiration and altered albedo.

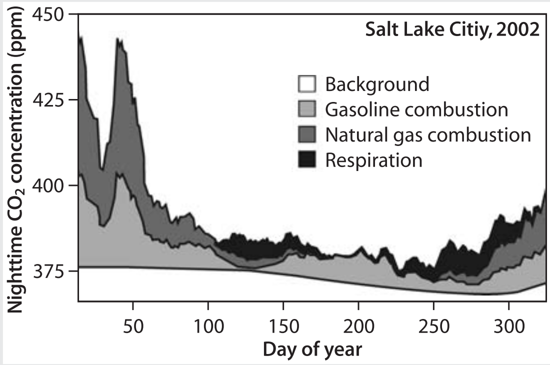

Fig. 25.4. Partitioning of 2002 night time carbon dioxide concentrations for Salt Lake City, Utah (Pataki et al. 2003)

Theme 3 seeks to integrate the dynamic interactions of human and environment subsystem characteristics (i.e., integrated land-change science) for assessment of vulnerability, resilience, and adaptation towards sustainable land systems and to provide this understanding in ways that are meaningful to decision making and policy (Box 25.3). To accomplish this goal, Theme 3 integrates findings from Themes 1 and 2 of the Global Land Project.

The sciences addressing complex systems have revealed the roles of emergent and path-dependent properties of coupled human-environment systems, and the thresholds in these systems that change their structure and function (e.g., Berkes and Folke 1998; Holling 1978; Levin 1998; Schellnhuber and Wenzel 1998). The sciences addressing vulnerability, resilience, and ecosystem services have demonstrated the nature of threats to land systems, especially in regard to the provisioning of food, fiber, and water (Daily et al. 2000; Dow and Downing 1995; Folke et al. 2002; Kasperson et al. 1995; Raskin et al. 1996; Rosenzweig 2003; Turner et al. 2003a,b). Studies of social learning and decision making have improved understanding of how coupled human-environmental systems, including land systems, are sustained or cope with forces of change (Cash et al. 2003; Kates et al. 2001; Lubchenco 1998; Mooney 2003; NRC 1999; Raven 2002). Recent advances in agent-based and other integrated modeling permit these complex factors to be treated systematically and holistically, providing land-based outcomes and near-term projections (e.g., Parker et al. 2001, 2003). The complexity of land systems, the variability in the forcing functions acting on them (e.g., Berkes and Folke 1998; Lambin et al. 2003; Lambin et al. 2001; Levin 1998) and the synergy of the human and environmental subsystems (Schellnhuber et al. 1997) enhance the need for place-based analysis (e.g., production unit, ecosystem, landscape) to address vulnerability, resilience, and sustainability (Cutter et al. 2000; Cutter 2001; NRC 1999; Wilbanks and Kates 1999). Yet, profound scalar dynamics (Parker et al. 2003; Schellnhuber and Wenzel 1998; Steffen et al. 2004) in land systems and the multiple needs of science and society regarding these systems also require that integrative analysis and assessment address multiple spatio-temporal resolutions to the problem.

25.5 Implementation Strategy

The GLP will engage in a variety of approaches to achieve its research goals. Working groups and networks of researchers will serve a fundamental role in the implementation of the science plan. The guiding principle associated with the GLP is that studies will *(a)* be place-based research studies, *(b)* require the establishment of interdisciplinary teams, *(c)* be cognizant of the need to be able to scale up and down and across disciplines, and *(d)* define the relationship of the research to the broader coupled human-environmental framework.

The research activities will include:

- case studies, manipulative studies and comparative studies
- networks of experimental and case studies across gradients of land systems
- long-term observations/experiments (remote sensing, sites, cross-site analysis)
- process models (e.g., vegetation/ecosystem, agroecosystem, agent-based models)
- land-use meta-analyses
- integrated analytical tools, not only models but also advances in field techniques
- decision-making models
- integrated regional studies
- interdisciplinary database development and archival systems

Box 25.3. Vulnerability

Determining and examining linkages between vulnerability and resilience with reference to LAND SYSTEMS and among the varying perspectives of the participating sciences remains an exciting challenge.

The vulnerability theme emerged from the social and application sciences dealing with risk-hazards. It invariably addresses the characteristics of individuals or groups in terms of their capacity to anticipate, cope with, resist, and recover from the impacts of a hazard (Blaikie et al. 1994), natural hazards for LAND SYSTEMS. Resilience, implying the opposite of vulnerability, is used in the wider ecological community (e.g., Folke et al. 2002) to understand how components of an ecosystem are configured to enable it to rebound after a perturbation of stress (for vulnerability, both are hazards). To date, natural systems are transparent in most vulnerability assessments, while ecosystem resilience focuses primarily on the biophysical processes in question.

The vulnerability and resilience of LAND SYSTEMS is determined by complex interactions among ecosystem and a suite of political, economic and social conditions and processes. Not only do shocks or perturbations (e.g., war, conflict, and climate change) and 'every day' stressors (e.g., economy, land use, and nutrient cycling) affect the environmental and human components of the LAND SYSTEM, but the consequences on either component interact in ways that change vulnerability-resilience. LAND SYSTEMS are coupled human-environment systems that require their vulnerability-resilience to be treated in an integrated manner. The vulnerability and resilience of land systems must be studied in an integrated manner: a research challenge for GLP.

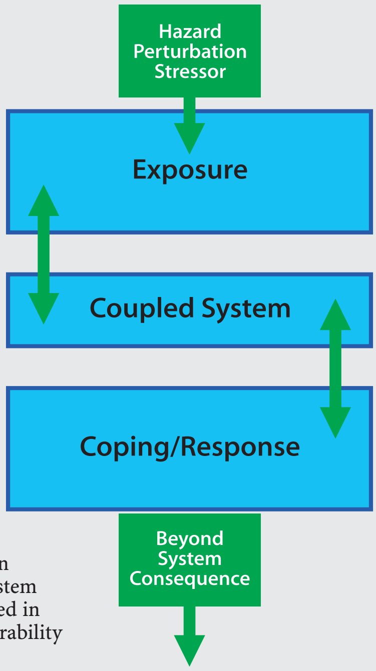

Fig. 25.5. The linkages between perturbation and system response encapsulated in the concept of vulnerability (GLP 2005)

Initial implementation Steps

Taking advantage of existing case study examples and initiatives, e.g.:

- On urban-rural gradient, linking GLP efforts to studies of the effects of conversion of rural to urban land on ecosystem functioning, and the subsequent effects and feedbacks related to ecosystem services.
- On arid lands to address dryland problems in a comprehensive an integrative way.
- On mountain ecosystems providing opportunities for comparative regional studies and for analyses of regional differentiation of environmental change processes in fragile ecosystems threatened by both systemic and cumulative human impacts.
- On managing the carbon cycle by contribution to the assessment of carbon sequestration potential; this is of the potential gain in carbon stocks in biomass and in soils within a given land area resulting from a change in land use, land cover or land management.
- On agricultural land, responsible for growing food, fiber and energy as primary provisional services for humankind, and the impact of global environmental change on agricultural production.
- On aquatic ecosystems, which closely interact with terrestrial ecosystems in providing habitat for diverse flora and fauna species, transport of nutrients and sediments and numerous other elements, and support diverse biogeochemical activity.

25.6 Summary and Conclusions

The Global Land Project (GLP) represents the joint, land-based research agenda of two major global change science programmes: *(i)* the International Geosphere-Biosphere Programme (IGBP), which originally focused mainly on biophysical processes in the Earth System through its Global Change and Terrestrial Ecosystems (GCTE) core project, and *(ii)* the International Human Dimensions Programme through its core project on Land-Use and Land-Cover Change (LUCC). The focus of the new project includes people, biota, and other natural resources (air, water, and soil). The strategy presented here critically emphasizes changes in the coupled human and environmental system, which is an extension of the ecosystem concept to explicitly include human actions and decision-making. The research planning builds upon the extensive heritage of global change research including the research discussed in the other chapters in this volume. The Global Land Project is designed to promote greater integration of social and biophysical sciences to meet the current challenges to coping and adapting to global change impacts the world is facing today and the near future. The sustainability of the coupled human-environment system and of ecosystem services is highly vulnerable to global change impacts as we move toward Earth System dynamics not yet faced by our societies.

References

Adger WN, Brooks N, Kelly M, Bentham S, Eriksen S (2004) New Indicators of Vulnerability and Adaptive Capacity. Tyndall Centre Technical Report 7. 126 pp

Allen MJ, Barnes MR (1985) The Causes of Deforestation in Developing Countries. Annals Assoc of Amer Geograp 75:163–184

Angelsen A, Kaimowitz D (1999) Rethinking the Causes of Deforestation: Lessons from Economic Models. The World Bank Research Observer. 14:73–98

Bassett, T (2001) The Peasant Cotton Revolution in West Africa. Côte d'Ivoire, 1880–1995. Cambridge University Press, Cambridge

Berkes F, Folke C (1998) Linking Social and Ecological Systems. Cambridge University Press, Cambridge

Blaikie P, Brookfield HC (1987) Land degradation and society. Methuen: London

Blaikie P, Cannon T, Davis I, Wisner B (1994) At Risk: Natural hazards, People's Vulnerability and Disasters. Routledge, London

Bohle H-G (2001) Conceptual Approaches to Vulnerability: Searching for Common Ground. In: Kasperson JX, Kasperson RE (eds), International Workshop on Vulnerability and Global Environmental Change, Stockholm Environment Institute, October, 4–17

Brookfield H, Potter L, Byron Y (1995) In Place of the Forest: Environmental and Socio-economic Transformations in Borneo and the Eastern Malay Peninsula. UNU Press, Tokyo. 310 pp

Carpenter S, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? Ecosystems 4:765–781

Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jager J, Mitchell RB (2003) Knowledge Systems for Sustainable Development. PNAS 100:8086–8091

Costanza R, d'Arge R, De Groot RS, Farber S, Grasso M, Hannon B (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260

Cutter S (2001) American Hazardscapes: The Regionalization of Hazards and Disasters. Washington, D.C., Joseph Henry Press

Cutter S, Mitchell JT, Scott MS (2000). Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina. Annals of the Association of American Geographers 90:713–737

Daily GC (ed) (1997) Nature's Services: Societal Dependence on Natural Ecosystems: Island Press, Washington, D.C

Daily GC, Soderquist T, Aniyar S, Arrow K, Dasgupta P, Ehrlich PR, Folke C, Jansson AM, Jansson BO, Kautsky N, Levin S, Lubchenco J, Maler KG, David S, Starrett D, Tilman D, Walker W (2000) The value of nature and the nature of value. Science 289:395–396

Dow K, Downing TE (1995) Vulnerability research: Where things stand. Human Dimen Quart 1:3–5

Downing TE, Butterfield R, Cohen S, Huq S, Moss R, Rahman A. Sokona and Stephen L (2001) Climate Change Vulnerability: Linking Impacts and Adaptation. Environmental Change Institute, University of Oxford, Oxford

Ewel JJ (1986) Invasibility: Lessons from south Florida. In: Mooney, Harold A.; Drake, James A (eds). Ecology of biological invasions of North America and Hawaii. Ecol Studies 58:214–230, Springer-Verlag, New York

Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS, Walker B, Bengtsson J, Berkes F, Colding J, Danell K, Falkenmark M, Gordon L, Kasperson R, Kautsky N, Kinzig A, Levin S, Maler K, Moberg F, Ohlsson L, Olsson P, Ostrom E, Reid W, Rockstrom J, Svenije H, Svendin U (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. ICSU Series for Sustainable Development, No. 3 www.resalliance.org/reports/resilience_and_sustainable_development.pdf

Geist HJ, Lambin EF (2002) Proximate Causes and Underlying Driving Forces of Tropical Deforestation. BioScience. 52:143–150

GLP (2005) Science Plan and Implementation Strategy. IGBP Report No. 53/IHDP Report No. 19. IGBP Secretariat, Stockholm. 64 pp

Gunderson LH (2000) Ecological resilience – In theory and application. Annual Review of Ecol and System 31(2000):425–439

Gunderson L, Holling CS (2002) Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, D.C

Harrison G (1979) Stability under environmental stress; Resistance, resilience, persistence and variability. American Naturalist 13:659–669

Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein R, Ewel JJ, Klink CA, Lugo A, Norton D, Ojima DS, Richardson DM, Sanderson EW, Valladares F, Vilà M, Zamora R, Zobel M (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecol Biogeogr 15:1–7

Holling CS (1978) Adaptive Environmental Assessment and Management. Wiley, London

Kasperson JX, Kasperson RE, Turner BL II (1995) Regions at Risk: Comparisons of Threatened Environments. United Nations University Press, Tokyo. 582 pp

Kasperson JX, Kasperson RE, Turner BL, III (2001) International Workshop on Vulnerability and Global Environmental Change 17–19 May 2001. Stockholm Environment Institute (SEI). Stockholm, Sweden: A workshop summary. SEI Risk and Vulnerability Programme Report 2001–01, SEI, Stockholm

Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, ILowe I, McCarthy JJ, Schellenhuber HJ, Bolin B, Dickson NM, Faucheaux S, Gallopin GC, Grübler A, Huntley B, Jäger J, Jodha NS, Kasperson RE, Mabogunje A, Matson P, Mooney H, Moore B, III, O'Riordan T, Svedin U (2001) Sustainability science. Science 292:641–642

Lambin EF, Turner BL II, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skanes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environ Change 11:261–269

Lambin EF, Geist HJ, Lepers E (2003) Dynamics of Land-use and Land-Cover Change in Tropical Regions. Annual Review Environ Resour 28:205–241

Levin SA (1998) Ecosystems and the biosphere as complex adaptive systems. Ecosystems 1:431–436

Logan JA, Regniere J, Powell J (2003) Assessing the impacts of global warming on forest pest dynamics. Frontiers Ecol Environ 1:130–137

Lubchenco L (1998) Entering the Century of the Environment: A New Social Contract for Science. Science 279:491–497

Luers AL, Lobell DB, Sklar LS, Addams CL, Matson PA (2003) A method for quantifying vulnerability applied to the agricultural system of the Yaqui Valley. Global Environmental Change (Part A) 13:255–267

Massey D (1998) Worlds in Motion: Understanding International Migrations at the end of the millennium. University Press, Oxford

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (Eds) (2001) Climate Change 2001: Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change: Working Group II. Cambridge University Press, Cambridge, UK, 1042 pp

Melillo JM, Field CB, Moldan B (2003) Interactions of the major biogeochemical cycles. Island Press, Washington, D.C

Mooney, H (ed) (2003) Ecosystems and Human Well-Being: A Framework for Assessment: Island Press, Washington, D.C

Moran, EF (1993) Deforestation and Land Use in the Brazilian Amazon. Human Ecology 21:1–22

NRC (1999) Our Common Journey: A Transition Toward Sustainability. National Academy Press, Washington, D.C

Parker D, Manson S, Janssen MA, Hoffmann MF, Deadman P (2001) Multi-agent systems for the simulation of land-use and land-cover change: a review. Center for the Study of Institutions, Population and Environmental Change, Indiana University, Bloomington, IN

Parker DC, Manson SM, Janssen MA, Hoffmann MF, Deadman P (2003) Multi-agent systems for the simulation of land use and land cover change: a review. Annals Assoc Amer Geograp 93: 316–340

Pataki DE, Bowling DR, Ehleringer JR (2003) Seasonal cycle of carbon dioxide and its isotopic composition in an urban atmosphere: anthropogenic and biogenic effects. J Geophys Res –Atmospheres 108: 4735
Perez S, Walker RT (2002) Household life cycles and secondary forest cover among small farm colonists in the Amazon. World Development 30:1009–1027
Pichon F (1997) Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier. Economic Develop Cultural Change 45:707–744
Raskin P, Chadwick M, Jackson T, Leach G (1996) The Sustainability Transition: Beyond Conventional Development. Stockholm Environment Institute, Stockholm
Raven PH (2002) Science, Sustainability, and the Human Prospect. Science 297:954–958
Rosenzweig ML (2003) Win-Win Ecology: How the Earth's Species Can Survive in the Midst of Human Enterprise. Oxford University Press, New York, NY. 211 pp
Schellnhuber H-J, Wenzel V (eds) (1998) Earth System Analysis: Integrating Science for Sustainability. Springer-Verlag, Berlin. 530 pp
Schellnhuber HJ, Black A, Cassel-Gintz M, Kropp J, Lammel G, Lass W, Lienenkamp R, Loose C, Ludeke MKB, Moldenhauer O, Petschel-Held G, Plochl M, Reusswig F (1997) Syndromes of global change. GAIA 6:19–34
Steffen W, Sanderson A, Tyson PD, Jäger J, Matson PA, Moore B III, Oldfield F, Richardson K, Schnellhuber H-J, Turner BL II, Wasson RJ (2004) Global Change and the Earth System: A Planet Under Pressure. Springer-Verlag, Berlin, pp 336
Stiglits J (2002) Globalization and its Discontent. New York, NY WW Norton Publisher
Turner BL II, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Hovelsrud-Broda GK, Kasperson JX, Kasperson RE, Luers A, Martello ML, Mathiesen S, Naylor RL, Polsky C, Pulsipher A, Schiller A, Selin H, Tyler N (2003a) Illustrating the coupled human-environment system for vulnerability analysis: three case studies. PNAS 100:8080–8085
Turner BL II, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003b) A framework for vulnerability analysis in sustainability science. PNAS 100:8074–8079
Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277:494–499
Watson RT, Zinyowera MC, Moss RH (eds) (1997) Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis. International Panel on Climate Change. Cambridge University Press, Cambridge, pp 878
Wilbanks TJ, Kates RW (1999) Global Change in Local Places. Climatic Change 43:601–628