

Theme 3: Integrating Analysis and Modelling for Land Sustainability

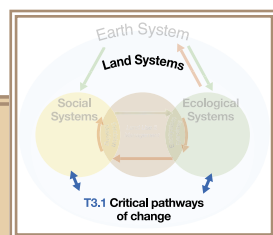
Themes 1 and 2 provide the building blocks for Theme 3, which examines the combined effects upon the broader Earth System of feedbacks that occur through biogeochemical cycles, biodiversity and natural disturbance regimes, as well as feedbacks in response to land ecosystem change. Theme 3 seeks to integrate the dynamic interactions of human and environment subsystems in order to assess vulnerability, resilience and adaptation towards sustainable land systems, and specifically aims to provide this understanding in ways that are meaningful to decision making and policy. To accomplish this, Theme 3 will integrate findings from Themes 1 and 2 and from related projects of IGBP, IHDP, DIVERSITAS, MEA and other programmes.

Diverse scientific studies have provided a rich foundation on which integrated analyses can build. Research has highlighted the roles of emergent and path-dependent properties of coupled socio-environmental systems, and the thresholds in these complex systems that change their structure and function (e.g. Berkes and Folke, 1998; Holling, 1978; Levin, 1998; Schellnhuber and Wenzel, 1998). Work on vulnerability, resilience and ecosystem services has demonstrated the nature of threats to land systems, especially regarding the supply of food, fibre 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 the understanding of how coupled socio-environmental systems are sustained and cope with forces of change (Cash et al., 2003; Kates et al., 2001; Lubchenco, 1998; Mooney, 2003; NRC, 1999; Raven, 2002). Additionally, advances in agent-based and other integrated modelling now permit these complex factors to be treated more systematically and holistically (e.g. Parker et al., 2001, 2003).

Land systems are complex, are driven by highly variable forcing functions (e.g. Berkes and Folke, 1998; Lambin et al., 2003; Lambin et al., 2001; Levin, 1998) and

exhibit locally specific responses to the synergies between the human and environmental subsystems (Schellnhuber et al., 1997). All these factors emphasise the need for place-based analysis (e.g. by household, production, consumption and distribution unit, or ecosystem) to address vulnerability, resilience and sustainability (Cutter et al., 2000; Cutter, 2001; NRC, 1999; Wilbanks and Kates, 1999). At the same time, profound scalar dynamics in land systems (Parker et al., 2003; Schellnhuber and Wenzel, 1998; Steffen et al., 2004), and their diverse benefits to society require multiple spatio-temporal resolutions to be addressed in integrative analysis and assessment.

The three issues of Theme 3 identify the major advances in science required to meet the Theme's integrative and decision-relevant objectives. They address, in turn, (i) critical pathways of change in land systems, including ideas about the necessary progress in data and modelling integration; (ii) the coupled nature of the vulnerability and resilience of land systems and their relation to various hazards and disturbances; and (iii) the role of institutions in the sustainability of land systems.



Issue 3.1: What Are the Critical Pathways of Change in Land Systems?

Significant improvements have been made in understanding the dynamics of specific ecosystems, vegetation complexes and land uses. While refinement of this work is required, the importance of certain ‘systemic’ characteristics of land change dynamics has been revealed and warrants special attention (Schellnhuber et al., 1997; Holling, 2001; Steffen et al., 2004). The history experienced by land systems may shape future pathways of change (or their probability), bringing about a reconfiguration of land systems or their vulnerability and adaptive capacities, a process known as “historicity” or “path dependency”. Land

use dynamics are increasingly seen as spatio-temporal patterns that emerge from the interactions among system components (Lambin et al., 2003; Reynolds and Stafford Smith, 2002). In addition, the dynamics of land systems encounter thresholds that once crossed, shift the system into new states in non-linear ways. These characteristics of land systems appear to be pivotal given the pace, magnitude and novelty of land changes underway worldwide. It is fundamental to other Theme 3 issues to understand the critical factors, and the dynamics and pathways of land system change.

System Dynamics and Interactions Across Multiple Levels of Organisation

The interactions of the properties of various systems across multiple levels of organisation and scale are poorly understood for most land systems. Changes in biophysical or anthropogenic variables (like climate change or management practice changes) affect these interactions and in turn, often lead to emergent properties or coupled-system outcomes that could not be determined in advance. Changes in the fundamental character of a land system can trigger shifts to another state and hence function. In southern Yucatán, for example, repeated burning of sufficiently large parcels of land triggers an invasive fern. Once established, the fern impedes natural forest succession for lengthy periods, with implications for biota, biomass and nutrient cycles, and disrupts the usual slash-and-burn cycle of land use thus triggering the cutting of more forest (Turner et al., 2001). It is essential to improve our understanding of these system dynamics, as well as the thresholds and feedbacks in the development of complex adaptive systems.

When ecosystem structure or function is altered, the biogeochemical cycles and biophysical properties of the

ecosystem are also likely to change, including the fluxes of carbon, nutrients, water and energy. Because of the importance of these fluxes in influencing regional and global atmospheric chemistry and climate, there will be significant feedbacks to the Earth System.

Long-term Perspectives on Land Change (Historicity)

The recognition of historicity (or path dependencies) operating in land systems is an outcome of system research and integrated modelling. Decisions made in the past constitute the initial conditions for our present-day landscapes. That is, past land system practices may ‘lock out’ future options, constraining the pathways that can be taken. For example, loss of biodiversity (especially keystone species) critically reduces the number of possible pathways for ecosystem change, including the chances for return to former structure and function. Brown-fields are a strong example of this at the urban-rural interface. The regulations surrounding the use of these lands contaminated by toxic wastes commonly inhibit their rehabilitation leading to their abandonment, and pushing urban land uses into less densely settled and open lands. In these cases urban areas lose

their tax base as well as potential areas for urban occupation (e.g. Colten, 1994).

While brown-fields constitute an extreme case, conditions and contingencies of past land systems affect future land systems by a large range of factors. Most of these factors have not been well documented or incorporated into land modelling. Research needs to be structured in such a way that study designs include the search for path dependency and emergent properties as well as non-linear characteristics of change, adopting a very long-term perspective that covers past, present and future developments.

Models of Varying Degrees of Complexity

Many of the advances in Issue 3.1 will be generated by synthesis and comparative case study assessments which link expertise on the structure and function of land systems in different world regions with expertise on

complex dynamic modelling. Models of varying degrees of complexity in space, time and process representations have been developed to test hypotheses of past, present and future behaviour against different data sets (Irwin and Geoghegan, 2001; Parker et al., 2003). The simpler models are easier to formulate, reduce the probability of human-induced errors, are computationally inexpensive, can be run through multiple sensitivity experiments, and produce results that are easier to analyse and understand. Indeed, the use of simpler models, with their level of abstraction, often enhances understanding of major system controls.

However, these simpler models often neglect important processes or scales at which real world phenomena act, requiring the use of more complex models. One of the major challenges is to incorporate second order dynamics of change (change of change over long time horizons) into such modelling, as well as incorporating feedbacks

Box 9. Biomass Enhancement

Increases in atmospheric carbon dioxide concentrations due to human activities may affect the growth of terrestrial plants – a possible negative feedback on atmospheric carbon dioxide. This feedback is being investigated in many ecosystems around the world, coordinated by IGBP in the international Terrestrial Ecosystem Responses to Atmospheric and Climatic Change (TERACC) network. Consistent patterns have emerged, including a linkage between water availability and ecosystem carbon dioxide responses, particularly in water-limited grasslands.

The effects of elevated carbon dioxide on ecosystems are not constant over time, but vary in response to spatial and interannual variability in climate, such that global and regional changes in temperature, precipitation and other variables may enhance or offset the effects of elevated carbon dioxide. GLP will help to advance the understanding and quantification of these complex interactions.

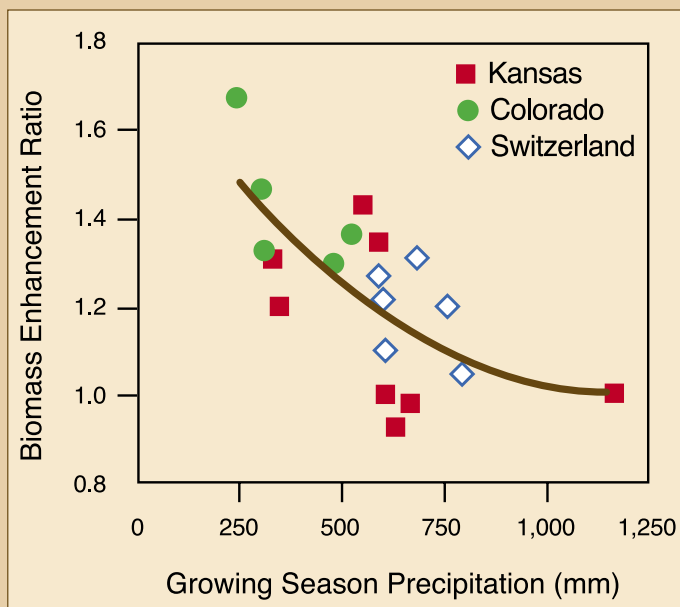


Figure 12. The enhancement in above-ground plant biomass from elevated carbon dioxide was greatest in dry years in three grassland experiments. From Morgan et al. (2004); reprinted with permission from Springer-Verlag.

within and across spatial and temporal scales. While the more complex models are better representations of actual system mechanics, their results are more difficult to understand, have the possibility of compounding errors that lead to unstable solutions, and are computationally expensive. A comprehensive understanding of the land system necessitates nested and linked models of varying degrees of complexity to address the same region or problem. Issues of uncertainty and error propagation should be a specific target of this research.

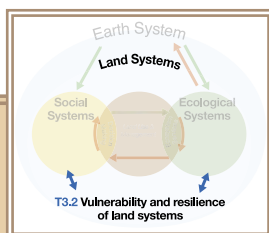
Much land system knowledge is predicated on semi-quantitative and qualitative information. Methods need to be developed to integrate such qualitative data into existing models and scenarios in such a way that the inherent uncertainty of qualitative data and knowledge is obvious to the modeller as well as the model user. Integrated models can be invaluable in the governance of land systems, and various scenario techniques and agent-based models can provide insights about the decision process itself (see *Implementation Considerations*). To ensure the policy-relevance of this work, the ultimate logic of these modelling activities needs to be directed towards the future. They need to deal with the unpredictability of land system changes by formulating outcomes in terms of alternatives, perceptions, choices, risks and opportunities.

Summary

- Improves the understanding of the dynamics of land systems, as well as the thresholds and feedbacks in the development of complex adaptive systems.
 - Further develops and improves dynamic regional and global models of ecosystems to synthesise and test the understanding of the controls on feedbacks and the temporal and spatial patterns of feedbacks, and to project future trends in regional or global feedbacks from terrestrial systems.
 - Designs research activities that adopt a very long-term perspective which covers past, present and future developments, to contribute to improved understanding of the historicity of land system change and the emergent properties and non-linear characteristics of these changes.
- Applies and promotes the improvement of models of varying degrees of complexity to integrate quantitative data sets with qualitative data on the structure and function of land systems in different world regions.
 - Attempts to incorporate the second order dynamics of change into complex dynamic models as well as the feedbacks within and across spatial and temporal scales.
 - Tries to achieve policy relevance by formulating outcomes in terms of alternatives, perceptions, choices, risks and opportunities.

Contributing Community

GCTE, AIMES, iLEAPS, MEA, LOICZ, GECHS, IDGEC, LUCC, PAGES, GCP, GWSP, GECAFS, Resilience Network, TERACC, BASIN, FluxNet, BATREX.



Issue 3.2: How Do the Vulnerability and Resilience of Land Systems to Hazards and Disturbances Vary in Response to Changes in Human-Environment Interactions?

Vulnerability and resilience research themes are gaining importance in several natural, social and application science fields (e.g. Kasperson and Kasperson, 2001; Turner et al., 2003a; Blaikie et al., 1994; Carpenter et al., 2001; Gunderson, 2000; Gunderson and Holling, 2002; Harrison, 1979). Emerging respectively from risk-hazard studies and ecology, vulnerability and resilience have been incorporated in frameworks applica-

ble to land systems (e.g. 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 and disturbances and exposure to these, affect the sensitivity and resilience of the land system, including the consequences for the land system of resultant adjustments and adaptations.

Vulnerability-resilience assessment is central to GLP for at least two reasons. Firstly, land systems are exposed and respond (adjust, adapt or resist) to hazards and disturbances, the resulting mechanisms sustaining the systems or placing them at risk of change. Secondly, the identification of those components of the land system most at risk and the mechanisms that enhance risk mitigation are central societal concerns. Decision makers request information on both.

Metrics and Measures for Analysing Land System Vulnerability and Resilience

Recent work indicates that the concepts of vulnerability and resilience can be applied to land systems, including through the use of quantitative indicators (e.g. Adger et al., 2000; Luers et al., 2003). There are various recent or current attempts to develop metrics and measures relevant to the assessment of land system sustainability, and it is generally recognised that these tools and methods must be highly sensitive to place-based analysis, incorporate quantitative and qualitative data, and explore land system syndromes and complex indicators, integrated modelling and simulation techniques, and statistical downscaling (Turner et al., 2003a). Many researchers and practitioners have also begun developing metrics and measures of vulnerability and resilience.

For the most part, however, these efforts address one or the other of the human and environmental components of land systems, but not the vulnerability and resilience found in their coupling. Hence, vulnerability assessments to date have largely focused on the consequences of one kind of hazard or disturbance on defined and separate human or environmental subsystems, but have missed the synergies that follow from the interactions of people with their environment.

An important element of analysing these interactions and of defining metrics is to understand the values, knowledge structures and preferences of various social actors in different societies, including policy makers. Development of a categorisation of the potential future conditions or states preferred by different community interests would be beneficial, so as to ensure that the considered metrics of sustainability inform and empower all protagonists equally in debates over future options.

Coping Capacities of Land Systems

Land systems commonly experience multiple hazards and disturbances, and the pace, sequencing and extent of them ultimately affect land systems and the mechanisms of adjustments and adaptation strategies that follow to compensate for the damages incurred (Turner,

2003b). Treating vulnerability and sustainability in this way is a relatively new research perspective and requires an improved understanding of how the types and properties of hazards and disturbances affect land systems and their coping capacities.

An equally fundamental issue is how the adjustments and adaptations of land systems and their coping capacities, alter their exposure to hazards and disturbances, and how changes in coping capacities affect the impacts experienced. For example, the large-scale engineering works erected along the lower Mississippi River to

control 'normal' flooding, have reduced flood events on settlements and cultivated lands, changing the preparedness of these lands for the catastrophic floods of 1993 that overwhelmed the engineering works (Mathur and da Cunha, 2001).

It can be assumed that land systems the world over have incurred, or will incur, changes in their coping capacities due to global socio-economic transformations and global environmental change. No land system is closed to these external factors (Blaikie and Brookfield, 1987). The impacts of climate change on land systems drives home

Box 10. Vulnerability

Determining and examining linkages between vulnerability and resilience with reference to land systems across the varying perspectives of the participating sciences remains an exciting challenge.

The concept of vulnerability emerged from the social and application sciences dealing with risks and hazards. It considers the characteristics of individuals or groups in terms of their capacity to anticipate, cope with, resist and recover from the impacts of hazards (Blaikie et al., 1994). Resilience – the opposite of vulnerability – is used in the wider ecological community (e.g. Folke et al., 2002) to understand how ecosystem components are configured to enable it to rebound after perturbation. 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 are determined by complex interactions among ecosystems 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 more constant stressors (e.g. economy, land use and nutrient cycling) affect the environmental and human components of the land system, but the consequences interact in ways that change vulnerability and resilience. The vulnerability and resilience of land systems must be studied in an integrated manner: a research challenge for GLP.

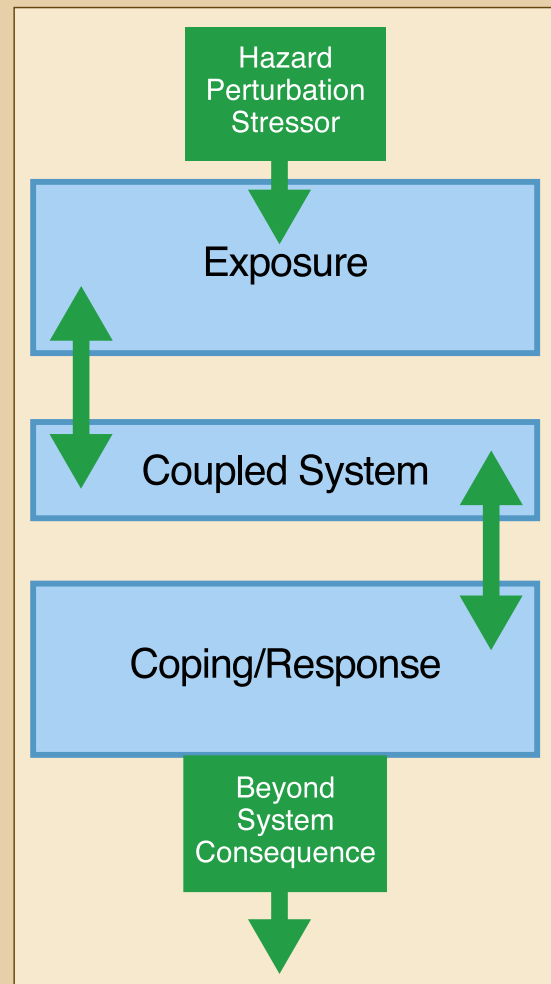


Figure 13. The linkages between perturbation and system response encapsulated in the concept of vulnerability.

this point for natural processes. However, the world-wide connectedness of economic activities increasingly requires an understanding of how land systems account for external human factors as well. The large-scale forest fires in Borneo in 1997, for example, followed from a constellation of factors, including international timber demands, ineffective controls on logging concessions and El Niño (Wooster and Strub, 2002). What are the factors and processes beyond land systems that affect their vulnerability and resilience, and how do the associated adjustments and adaptation in land systems affect those factors and processes?

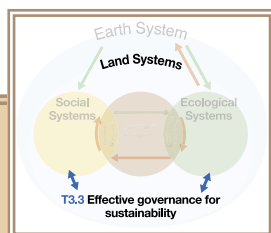
To analyse the vulnerability, resilience and adaptation of land systems in their coupling, a series of activities joining the different communities is required, including case studies designed specifically to address the vulnerability and resilience of the coupled land systems. They need to follow various recently developed holistic frameworks, as well as incorporate a comparative assessment of extant research. The scale of these types of research efforts needs to be expanded to deliver quality products, which must then be synthesised through modelling exercises (see Issue 3.1).

Summary

- Develops metrics and measures of vulnerability and resilience for the analysis land systems in their coupling.
- Analyses how the various types and properties of hazards and disturbances affect land systems and their coping capacities.
- Explores how changes in coping capacities affect the exposure to, and consequences of, hazards and disturbances.
- Assesses which factors and processes beyond a land system affect its vulnerability and resilience, and how the associated land system adjustment and adaptation affect these factors and processes.
- Develops case studies and designs to address the vulnerability and resilience of land systems in their coupling.
- Feeds back the results of these activities into complex dynamic modelling.

Contributing Community

People Land Management and Ecosystem Conservation, MEA, Resilience Network, iLEAPS, LOICZ, IHDP, GECHS, IDGEC, LUCC, Global Change SysTem for Analysis Research and Training (START), South East Asian Biosphere-Atmosphere Stable Isotope Network, GCP, GWSP, GECAFS, Global Energy and Water Cycle Experiment, GCTE, Resilience Network, International Centre for Tropical Agriculture, United Nations Environment Program, World Bank.



Issue 3.3: Which Institutions Enhance Decision Making and Governance for the Sustainability of Land Systems?

Institutions, clusters of rights, rules and decision making structures, play important roles in governing human interventions in land systems. Virtually no land remains ‘open to access’ on the part of users or is completely unaffected by institutions, although weak compliance mechanisms in some parts of the world lead to ‘open access’ outcomes resembling those referred to in the ‘tragedy of the commons’ (Hardin, 1968, 1998; Ostrom et al., 2002). Various situations also exist in which unsustainable land use practices are triggered by strong and well-enforced institutions, such as the recent, large-scale and out of control burning of forests in Indonesia (e.g. Jepsen et al., 2001; Vayda, 1999) and the demise

of the Aral Sea (Kasperson et al., 1995). Detrimental impacts on land systems may also occur in places where multiple institutional arrangements, supported and enforced by different authorities (e.g. local managers, the state and NGOs) compete for control over the same resources or land, often with different uses or land cover outcomes in mind. Examples include local versus state control over woodlands in Rajasthan (Robbins, 1998) and the burning of savannah-woodlands in Mali and elsewhere in western Africa (Laris, 2002). A better understanding of the institutional dimensions of land use practices is essential for addressing the sensitivity, vulnerability and resilience of land systems.

The institutional dimensions and governance of land systems is precisely what provides a bridge to stakeholders and civil society. Policy of course, is linked to governance systems, and changes in international regimes, national, regional and local governance and NGO policies, affect land use practices with impacts on ecosystems, agriculture and water (Lambin et al., 2001). Policy shifts, for instance can: (i) affect the flow of migrants into sparsely populated lands, for example, the Brazilian Amazon (McCracken et al., 2002); (ii) open new lands for international operations, for example, Indonesian logging (Jepsen, 2001); (iii) change subsidies affecting the profitability of agriculture and the occurrence of land degradation (at least in the short-run), for example, livestock production in Karoo, South Africa (Archer, in press); or (iv) move subsistence cultivation into commercial cultivation, often with perverse outcomes, for example, expansion of pasture lands in south-eastern Mexico (Klepeis and Vance, 2003).

These examples illustrate the impact of institutions and associated policies on both the human and biophysical

components of land systems. However, these aspects of land systems are less well understood and conceptually developed than, for example, those dealing with decision making by land managers. It is therefore important to address the consequences of the interactions among ecosystem services, land uses, institutions and policies for the maintenance of different land systems, including the roles of institutions in causing and confronting land system changes.

Institutions for the Long-term Maintenance of Land Systems

Different suites of institutions, governance and policies intersect with land systems in different ways, leading to different outcomes for the long-term maintenance of land systems. Research is only beginning to tackle these dynamics for different land systems, such as various use and enforcement practices in preserving biotic diversity within reserves (Bruner et al., 2001). A major lesson from the initial work is the need for local-state cooperation in the design of effective rules of governance and

enforcement (Narayan-Parker, 1996). However, increasingly international accords affect land use and thus land systems worldwide, from agreements to keep almost all human activity out of Antarctica to carbon set-asides.

It is essential that Issue 3.3 identifies the institutional linkages from the international to the local scale. There are different levels of institutional connectivity between scales of governance or jurisdiction that influence decision making on land use under different levels of government representation or control. Institutional settings for the governance of, for example, land tenure, access to markets, or conservation of environmental properties, describe a complex suite of interactions, and there is a need to understand how national and international policies translate down to household activities as major drivers of land use decisions.

It is equally important to analyse the effectiveness and performance of international environmental and resource regimes aimed at land uses, for example, the International Tropical Timber Agreement. Some of these efforts have been effective while others have not, and the reasons for these differences need to be understood to guide the design of future institutions. Several projects, such as IDGEC, address this issue in regard to specific resources (e.g. timber) or generic issues (e.g. loss of biodiversity) (Young et al., 1999). However, far less attention has been given to this linkage regarding land systems and specific sets of coupled socio-environmental systems (e.g. tropical forest biomes, xeric grasslands and irrigation systems).

Factors for Changes in the Governance of Land Systems

Changes in land systems feed back to institutions and the political economy, affecting their efficacy in management and governance. For example, a common property regime may be highly effective in maintaining grazing lands under sparse use, but not under intensive use. As intensity of use increases, changes in governance are required if the ecosystem services of the land system are to be maintained. The issue is more complex than the common-property-private-land ownership dichotomy, and often entails adjustments made internally within the land system rather than externally derived institutions. Research is needed to improve the understanding of the land system factors which interact to trigger fundamental changes in governance. This includes those sets of factors triggering endogenous institutional change, as

well as the external factors enabling decision making, constraining options for land use activities, or determining coping and sustainability strategies. The effects of these factors also need to be linked to their emergent cross-scale implications.

Linking Institutional Development to Ecosystem Structure and Functioning

Most institutions do not govern land systems *per se*, but govern the use of specific goods and services in the system such as timber, water quality, food security or air quality. These goods and services have identifiable institutional constructs to monitor, with defined policy goals and a set of incentives or penalties. However, institutional agencies over many ecosystem services, such as nutrient cycling, soil formation or biological complexity, are poorly defined. Even if there are institutions associated with particular environmental components, the linkage back to ecosystem structure and function is not well formulated, and institutions are not necessarily constructed at the scale that is most appropriate to match the ecological processes. Research is required to understand how different institutions incorporate information regarding changes in ecosystem services into their framework, so that better governance can be attained.

The issues embedded in Issue 3.3 can be addressed through a series of syntheses and comparative studies, drawing on the range of research from common property networks to institutional theory. A synthesis activity needs to pull together the large array of this research to determine the insights gained for land systems, and to assess where there is a critical mass to answer major questions. Another effort requires linkages to IDGEC to address the question of international regimes and land systems, identifying and addressing those governance issues that directly and indirectly affect land systems. The products from these activities should be incorporated into modelling assessments.

Summary

- Seeks to understand the roles of institutions in causing and confronting land system changes.
- Assesses the effectiveness of institutions on different scales and seeks to understand the interplay between these institutions.
- Seeks to understand how policies at different levels translate down to household activities as major drivers of land use decisions.

- Draws lessons for effective future governance from the performance of institutions in managing land systems.
- Improves the understanding of the land system factors which interact to trigger fundamental changes in governance, including those sets of factors triggering endogenous institutional change, as well as external opportunities and constraints for institutional development.
- Seeks to understand how institutions associated with particular environmental components link back to ecosystem structure and function, and how this knowledge can be used for institutional development and sustainable governance of land systems.

Contributing Community

MEA, LOICZ, GECHS, IDGEC, LUCC, GCP, GWSP, GECAFS, Resilience Network, Common Property Network.