Global LAND Programme

GLP.earth

Science plan and implementation strategy

2016-2021

Contributors

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Executive summary

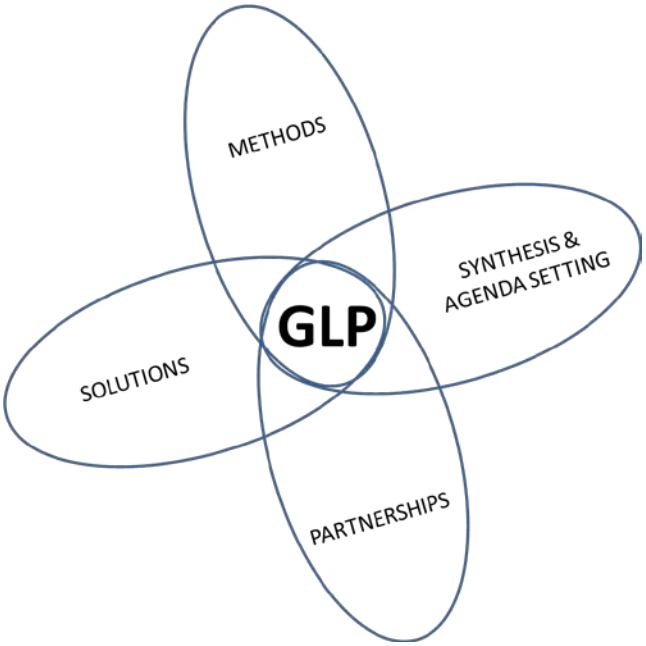
Land systems are the result of human interactions with the natural environment. Understanding the drivers, state, trends and impacts of different land systems on social and natural processes helps to reveal how changes in the land system affect the functioning of the socio-ecological system and the tradeoff these changes may represent. The Global Land Programme aims to lead advances in land systems science by synthesizing land systems research across different scales and providing concepts to further understand the feedbacks between socio- and environmental systems, between urban and rural environments and between distant world regions. Land system science has moved from a focus on observation of change and understanding the drivers of these changes to a focus on using this understanding to design sustainable transformations through stakeholder engagement and through the concept of land governance. Land use can be seen as the largest geo-engineering project in which mankind has engaged. Land system science can act as a platform for integration of insight from different disciplines, design of novel land system solutions and for translation of knowledge in action. GLP aims to provide such a platform contributing to wise and sustainable decision making on land use.

1. What is the Global Land Programme (GLP)?

GLP is an interdisciplinary community of science and practice fostering the study of land systems and the co-design of solutions for global sustainability.

Land use is a major driver of global change. GLP sees land as the nexus of crucial societal and environmental challenges and opportunities to address food security, access to water, livelihoods, land degradation, biodiversity loss, and climate change. Solutions to these challenges must balance complex trade-offs and synergies at multiple scales, demanding multiple paradigms and perspectives.

Within GLP collaboration is fostered amongst a network of scientists, institutions and stakeholders engaged in building and enhancing scientific capacity through identifying core questions, synthesizing research and setting future agendas. GLP aims at creating synergies among researchers and stakeholders, and bridging science and decision making.



What are land systems?

Land systems constitute the terrestrial component of the Earth system and encompass all processes and activities related to the human use of land, including socioeconomic, technological and organizational investments and arrangements, as well as the benefits gained from land and the unintended social and ecological outcomes of societal activities (Verburg et al., 2013). Changes in land systems have large consequences for the local environment and human well-being and are at the same time pervasive factors of global environmental change. Land provides vital resources to society, such as food, fuel, fibres and many other ecosystem services that support production functions, regulate risks of natural hazards, or provide cultural and spiritual services. By using the land, society alters and modifies the quantity and quality of the provision of these services.
Land system changes are the direct result of human decision making at multiple scales ranging from local land owners decisions to national scale land use planning and global trade agreements. The aggregate impact of many local land system changes has far reaching consequences for the Earth System, that feedback on ecosystem services, human well-being and decision making (Crossman et al., 2013). As a consequence, land system change is both a cause and consequence of socio-ecological processes.

2. Positioning of GLP

GLP is fully endorsed by Future Earth (http://www.futureearth.org) as a core project. Positioned at the interface of social and natural systems the topic of land system science is addressed by different scientific, policy and practitioner communities and has relation to a wide variety of international programmes, networks, and stakeholders. The study of land systems across different scales and from different disciplinary perspectives and the engagement with different economic sectors demands platforms to bring the different communities and disciplines together, exchange approaches and create a mutual understanding of the challenges and knowledge gaps. GLP and its predecessors, the international global change programmes LUCC and GCTE have been successful in creating such platforms. Next to creating an awareness of different perspectives and methods, the interactions in these projects have facilitated, at various stages, knowledge synthesis and evolution of research agendas and priorities. Collaboration goes beyond the land system science community, but also includes interactions with other projects under the global change programme umbrella. The knowledge gaps related to global environmental change cannot be addressed by a single research community, re-iterating the grand challenge for more interdisciplinarity in global change research identified during the process towards the establishment of Future Earth (Reid et al., 2010) and now one of the core principles of the Future Earth initiative. Land systems at the interface of human and environmental systems, being both a result of global change, but also providing solutions for adapting and mitigating global change, provide a unique platform for interaction amongst the different global change communities.

GLP is engaging in and collaborating with various land related initiatives and aims at acting as a platform for integration across the many international programmes and networks that address land related issues. Figure 1 shows a snapshot of selected networks and international programmes that are related to GLP. Please note that collaborations and interactions are dynamic and continuously changing.

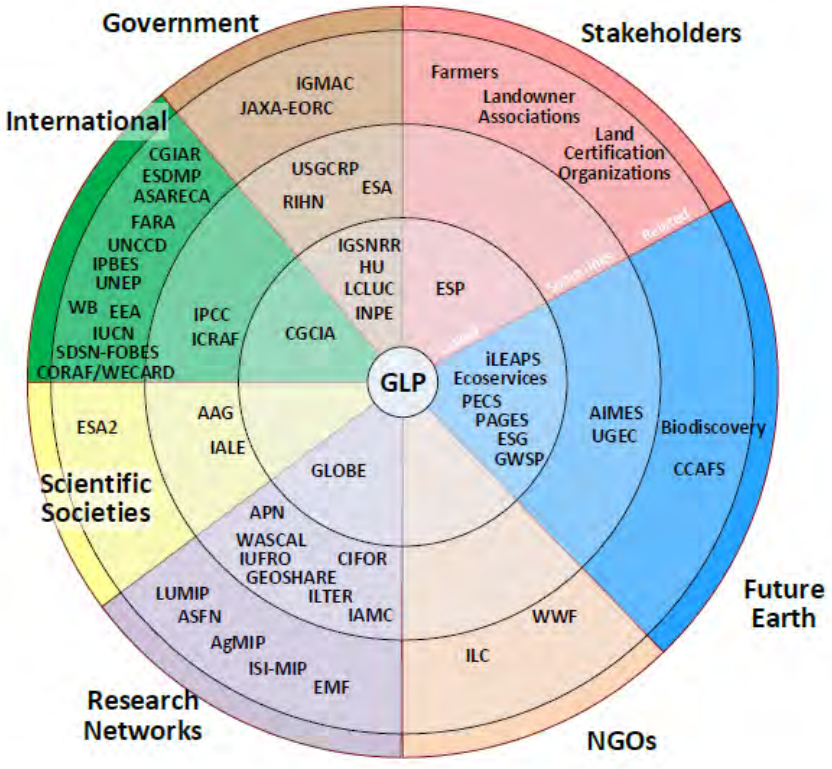


Figure 1. *A snapshot of current GLP relations with international programmes, networks, and stakeholders (as of 2015).*

3. The evolution of the Global Land Programme

Land system science has developed over the past twenty years. The study of land use and land cover change (coordinated through the former LUCC project) was initially dominated by monitoring and modelling of the ecological impacts of major land cover changes such as deforestation and desertification on the natural system (Turner II et al., 1993; Lambin et al., 2000; Lambin and Geist, 2006). Achievements were made in terms of observing land cover changes by remote sensing for single case studies as well as in global datasets (Walsh and Crews-Meyer, 2002). As part of LUCC activities, Belward (1996) developed definitions of land cover classes. The legend employed was developed to meet the needs of IGBP projects, providing for a consistent and objective representation of significant landforms for all projects. One of the main achievements of the early LUCC work was the synthesis of case studies to identify common driving factors of change and causation patterns (Geist and Lambin, 2002, 2004). At the same time, land use models were developed that allowed the exploration of future scenarios of land use change (Verburg et al., 1999; Pontius et al., 2001).

Besides the LUCC project the Global Change and Terrestrial Ecosystems (GCTE) project contributed by the research on terrestrial ecosystem changes under local, regional and global environmental changes such as increasing concentrations of greenhouse gases, changes in global and regional climate, habitat destruction, and increases in number and impacts of exotic invasive species (Pitelka et al., 2007). The overarching goal of the GCTE project was to predict the effect of changes in climate, atmospheric composition, and land use on terrestrial ecosystem and to determine how these effects lead to feedback to the atmosphere and physical climate system. GCTE took the lead in analyzing the nature of nonlinear change in Earth System functioning. This work played a central role in the emergence of abrupt change, surprises and extreme events as unifying themes in the second phase of IGBP research.

Gradually, the research field of land use and land cover change matured and became more integrative, focusing on both the drivers and impacts of land change and including a wider range of interacting processes of land use change. The growing group of researchers engaged in this field led to the emergence of 'Land Change Science' as a separate, interdisciplinary, research field engaging scientists across the social, economic, geographical and natural sciences (Rindfuss et al., 2004; Turner et al., 2007). The increasing attention to feedbacks between drivers and impacts including adaptive behavior (Verburg, 2006), the interactions between social and ecological systems and teleconnections between world regions (Lambin and Meyfroidt, 2011; Liu et al., 2013) and between cities and their rural hinterlands (Seto et al., 2012b) have motivated an integrated socio-ecological systems perspective. In this integrated concept, land systems are conceptualized as the result of dynamic interactions within the socio-ecological system. This perspective has also moved land system science from a focus on the most dramatic land cover changes to greater attention for subtle changes of human interactions with the natural surroundings, including land management (Erb et al., 2013; Kuemmerle et al., 2013) and the provisioning of a wide range of ecosystem services (Crossman et al., 2013).

Over the past decade the Land System Science community has been organized through the Global Land Project, now renamed into the Global Land Programme (GLP). The orientation of land system science at the interface of social, physical and ecological systems was reflected in GLP being a core project of both the International Geosphere Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) commissioned by the International Council for

Science (ICSU) and the International Social Science Council (ISSC). The Global Land Project started in 2006 for a 10-year period after publishing its science plan in 2005 (GLP, 2005). GLP is a successor of the previous Land Use and Land Cover Change project (LUCC; 1994-2005) and the Global Change and Terrestrial Ecosystems project (GCTE; 1992-2003). GLP aims at synthesis and integration of insights, knowledge and methodologies in research across the land system science community. A core task of GLP is the identification of scientific priorities and agenda setting through synthesis of existing knowledge, meta-analysis of land-based research and targeted workshops. In addition, GLP provides a platform for the land system science community through networking activities, such as the organization of workshops and conferences.

In the final years of first phase of GLP several synthesis activities have been conducted to summarize the state-of-the-art of scientific achievements of GLP and define science priorities for the research community. A survey amongst the participants of the GLP Open Science Meeting in 2013 and an internal evaluation process by the GLP Scientific Steering Committee have identified the future needs for coordination of the GLP community and its priorities. A major conclusions of this evaluation was that Land System Science is more important than ever: many of the important global change challenges are related to the use of land resources and many of the Societal Grand Challenges are related to the sustainable use of land. More than ever research is being done on land systems from different disciplinary perspectives as well as from an interdisciplinary perspective. Land system science is evolving as a discipline with strong connections between scientific understanding and the communities of practice and policy that govern and manage the use of land. In this context the scientific and practice communities still require synthesis and agenda setting activities, as well as a platform for exchange, collaboration and innovation.

To fulfill this role, GLP should operate more as a Programme or Network rather than as a traditional research project, bounded to specific research questions and hypotheses to be answered in the middle term. Hence, the second phase of GLP uses ‘the Global Land Programme’ as its full name to reflects its networking, synthesis and agenda-setting functions. The following sections present the scope of the Global Land Programme based on the achievements over the past decade and the challenges for the next decade.

4. Global Land Programme research themes and priorities

The following sections highlight important achievements, knowledge gaps and science priorities of the Global Land Programme for the period 2016-2021. An overarching challenge for land system science is to connect the improved understanding and empirical data on land systems to the practice and policy that aim at influencing and steering the ways in which land is used and managed. Within GLP we acknowledge that understanding and data per se do not necessarily lead to improved practice and policy. Therefore, the pillars of the research approach consist of thematic areas where research aims at addressing those themes that relate the understanding of land systems to the realms of practice and policy. These priority thematic research areas are identified as a two-way interaction between science and policy and practice. Land system science has the responsibility to identify emerging issues and create awareness based on the continuous improvement of the understanding of land systems. At the same time, land system science should respond to the knowledge needs from policy, practice and society at large. Thereby, priority thematic areas are dynamic in time and the current choice is only a starting point. Notwithstanding the need to target science at those topics that are relevant to policy and practice, we acknowledge the need for continuous innovation in the ways we use data, monitoring, modelling and synthesis methods to improve our understanding of land systems and provide the knowledge base to support addressing the thematic areas, but also to identify critical areas of land system change relevant to practice and policy. Science should not only follow the requests from practice and policy, but also lead practice and policy toward addressing emergent issues and propose innovative methods.

Figure 2 shows the structure of the research themes and priority areas of GLP by distinguishing those topics that are and remain at the core of land system science, the priority themes that represent our main knowledge needs and knowledge gaps, and an outer circle that aims at integrating our understanding of the land system towards implementing the knowledge and thematic insights into the design of sustainable land systems and novel ways of land management and policy.

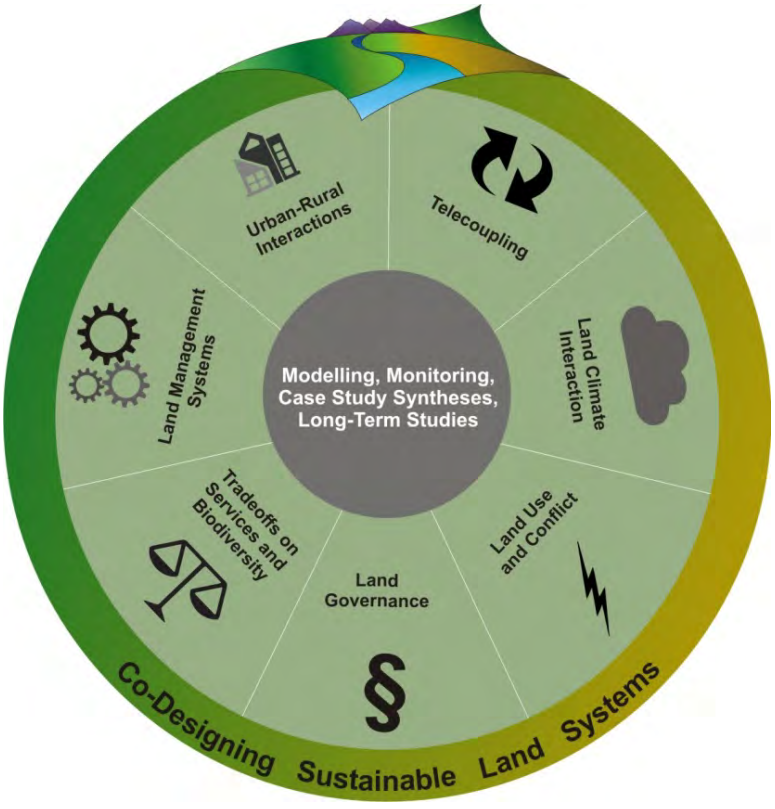


Figure 2: *GLP research priorities*

4.1. Data and methods for understanding Land Systems

4.1.1 Case-study synthesis

A typical characteristic of land system science is the multi-scale approach central to this field of research. While land system change has global implications, it is the result of individual decisions made locally, in response to both the local physical and socio-economic context and the regional and global drivers of the economy, demography and environmental change. Place-based research in small case-studies has, therefore, always formed a key component of land system science. Place-based case-study research will remain important to understand how different drivers of land change lead to changes in land use, how actors make land use decisions and what is the potential to influence decision making through policy or information. At the same time, generalization beyond the level of individual case studies is important to understand the larger scale implications of case-study findings, the representativeness of individual case-studies for larger areas and to separate context-dependent findings from findings that have more generic validity. In order to be able to better contextualize individual case studies and identify generic patterns across case-studies, meta-analyses were conducted, focusing on the causes of specific land change processes or impacts (Geist and Lambin, 2002, 2004; Keys and McConnell, 2005; Seto et al., 2011; van Vliet et al., 2012; Van Asselen et al., 2013) and consequences of land system change (Don et al., 2011; Gibson et al., 2011; Ziegler et al., 2012). Methodological development of meta-analysis for the specific purpose of global environmental change and land system science has also been carried out, e.g. on the utility of qualitative comparative analysis for comparing highly diverse case studies from different regions and the possibilities and caveats of using statistical analysis when case studies are not designed in a similar way (Rudel, 2008). A recently published study provides an overview of synthesis and meta-analytical studies in land system science since 1995 (Magliocca et al., 2014). From the total of 181 studies analysed it became clear that while the number of meta-studies is increasing rapidly more interaction between researchers focusing on meta-studies and case studies is needed to ensure that meta-analyses capture the essence of case studies and that case studies aim at filling the research gaps identified in meta-analysis. A tool developed in GLP context to further such integration is the GLOBE project. GLOBE (global collaboration engine; http://globe.umbc.edu) is an online collaborative environment designed for real-time assessment of the global context and relevance of local case studies, both individually and in collections, as used for meta-studies. To make this possible, GLOBE leverages an advanced geocomputation and visualization engine that couples local case study locations with more than 100 global datasets characterizing social and environmental patterns across the Earth. Using GLOBE, site-based researchers quantify, map and publish the global relevance of their studies while identifying additional studies and researchers working in globally similar environments around the world. Researchers can engage in cross-site synthesis to assess geographic biases and global knowledge gaps across their case study collections (Figure 3) and can correct them by adding more studies in understudied areas and by reweighting studies to better reflect their global abundance. With this type of tools, researchers can collaborate globally across sites, environments and social contexts with the ultimate aim of nurturing a robust culture of globally relevant knowledge creation and sharing in land system science.

Challenges of land science case study synthesis is to move beyond simple counts of frequencies in which driving factors are mentioned in case-studies to quantitative assessments which contextual conditions determine drivers and how driving factors relate to agent decision making and land system change in more quantitative ways. This involves moving beyond the classical model of meta-analysis in land change that distinguished proximate causes and underlying factors towards a model that explicitly recognizes a diversity in actors and modes of decision making. Such insights are essential to inform

models of land change, all of which assume in some way, a relation between driving factors and land change. Especially for agent-based modelling detailed information is needed on agent decision making which is now mostly derived from theoretical models. Many of these theoretical models are known to have limited validity for land change decision and this is where meta-analysis could contribute in revealing the conditions over which alternative model specification are valid.

Current meta-analysis focusses on archetypical land changes such as deforestation and shifting cultivation while important processes such as changes in agricultural or forest management intensity are less frequently addressed (van Vliet et al., 2015). Synthesis can also be used to identify biases in thematic and regional cover of land change case-studies, revealing potential bias in our understanding of land change and potentially targeting new case-studies to thematic or geographic areas where we lack case-study insights.

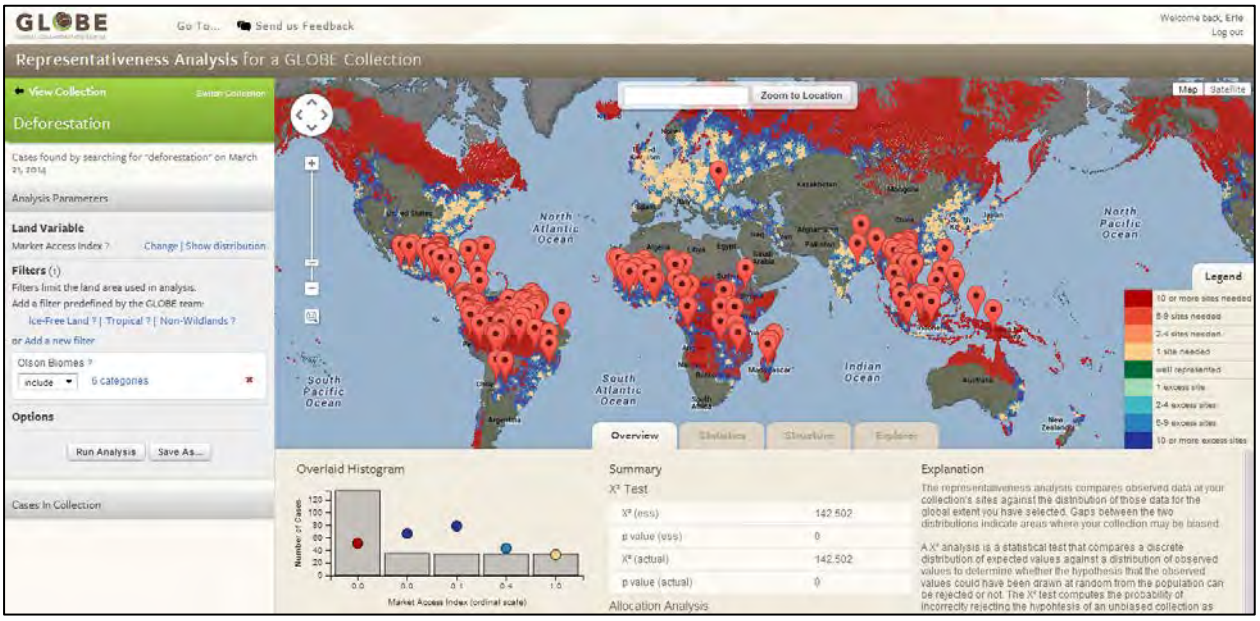


Figure 3. *Global representativeness of 273 "deforestation" case studies identified by searching in GLOBE (of 875 total; published collection data citation:(Ellis, 2014)). Study coverage of patterns of market access across Earth's woodlands are highlighted, with red areas indicating significant gaps in study coverage in more remote regions.*

4.1.2 Observing land change

Progress in land system science depends strongly on the availability of accurate land change data. Accelerating global change forces land system scientists to strive for more timely and accurate data. At the same time, our increasing knowledge of land change and the more sophisticated questions arising from that knowledge enforce the need for increased semantic depth in land use data. Data for land use change analyses largely derived from remote sensing analyses or census information, or from finer scale field surveys, cadastres or participatory mapping. While much progress has been made in harmonizing such heterogeneous data, there are multiple challenges associated with spatially, temporally and thematically heterogeneous data sources (Verburg et al., 2011). With a focus on global change and remote sensing, land systems analysis will therefore experience a shift from land cover change analyses to rather process-oriented monitoring of land use change and changes in land use intensity (Kuemmerle et al., 2013).

Land system scientists are regularly interested in processes and change regimes of regional to global extent that at the same time act at fine scales. Today, most regional to global land change products are

based on coarse spatial resolution satellite data, though (Achard et al., 2007; Fritz et al., 2013). Only recently, freely available, fine-scale and accurately pre-processed satellite data, new IT capabilities, and smart processing algorithms allow land change monitoring at finer scales and appropriate temporal resolution (Roy et al., 2014; Hostert et al., 2015).

The key for improved monitoring of land systems will therefore be to better exploit long and dense satellite data time series at better spatial resolution than previously available. First examples of continental to global forest monitoring exemplify the great potential of such methodologies (Hansen et al., 2013; Potapov et al., 2015). Future approaches will expand towards more complex land system changes, including changes in land use intensity (Griffiths et al., 2013; Estel et al., 2015), improved differentiation of croplands and grasslands (Fritz et al., 2011), or of tree plantations and natural forests. The key for creating such improved maps will be to better exploit the temporal signal in dense time series to link phenology to relevant land change processes (Kennedy et al., 2014; Zhu et al., 2015). Agricultural monitoring needs several observations per phenological season to allow retrieving crop types and rotational cycles. Such dense time series at appropriate scales will only become feasible using sensor constellations, e.g. from combined Landsat and Sentinel-2 data (Hostert et al., 2015), that will offer major improvements in cropland and grassland monitoring.

In the coming years new remote sensing data will become available, such as the Sentinel-2 data that improve spatial resolution but especially the temporal frequency of images obtained. Also airborne sensors will start playing a more dominant role in land system science. In spite of these advances most of the limitations of remote sensing in observing actual land management will still remain. However, the growing popularity of crowd-sourced data has the possibility to fill this gap by providing high-density ground-based information or expert interpretations of aerial images. New methods for assimilation of different data sources including statistical data, remote sensing observations and crowdsourced data are emerging (See et al., 2015). Making the best use of these different data streams towards making new datasets available to the larger land system science community (under open data protocols) is a top priority.

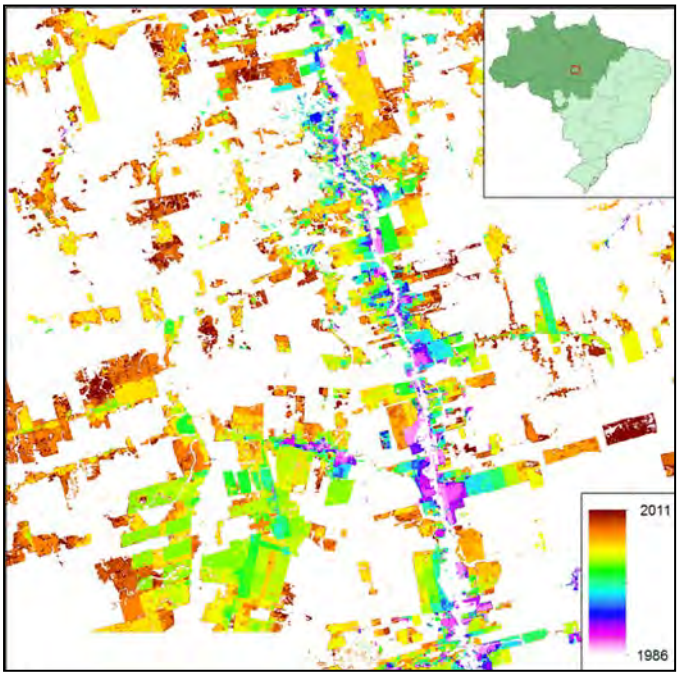


Figure 4. *Yearly map of primary forests converted to rangelands in the Brazilian Amazon along the BR 163 highway. Improved food production services on the expense of carbon sequestration, biodiversity and habitat.*

4.1.3 Long-term histories of land use change

Land system science is the study of the past, current and forecast state and dynamics of land use. Human use of land is a major component of the long-term anthropogenic global changes in the Earth system that have underpinned the call for the Anthropocene as a new epoch of geologic time. A collaborative effort was made to review and compare the latest global datasets on human populations and land use over the course of the Holocene to evaluate human use of land as a global force transforming the terrestrial biosphere (Ellis et al., 2013). Different reconstructions of historic land use rely on different evidence and theory on the emergence, history, and future of land use as a process transforming the Earth System (Klein Goldewijk et al., 2011; Kaplan et al., 2012). The review used synthesis to explain why relatively small human populations likely caused widespread and profound ecological changes more than 3000 years ago, while in recent times the largest and wealthiest human populations in history are using less arable land per person every decade. While human population as well as biomass consumption by humans has grown fourfold and economic output 17-fold in the last decade, the global human appropriation of net primary production (HANPP) has only doubled in this period of time (Krausmann et al., 2013), mainly due to surges in land-use efficiency and the use of external inputs in agriculture. Reconstructions of past developments that take such adaptive changes in land-use systems over time into account, including land-use intensification, offered a more spatially detailed and plausible assessment of our planet's history, with a biosphere and perhaps even climate long ago affected by humans (Figure 5). Based on this assessment, further work to empirically validate a date for the emergence of land use as a global force transforming the biosphere and initiating the Anthropocene has been proposed (Ellis et al., 2013). The GLP community aims to contribute to historic reconstruction efforts such as the one in the PAGES LandCover6k effort (http:// http://pastglobalchanges.org/ini/wg/landcover6k/intro) and participate in long-term monitoring efforts and historic landscape studies (e.g. LTSER). While land-use processes are now diverging rapidly from historical patterns into new patters and novel land systems, integrative global land-use models that incorporate dynamic adaptations in human-environment relationships help to advance our understanding of both past and future land-use changes, including their sustainability and potential global effects.

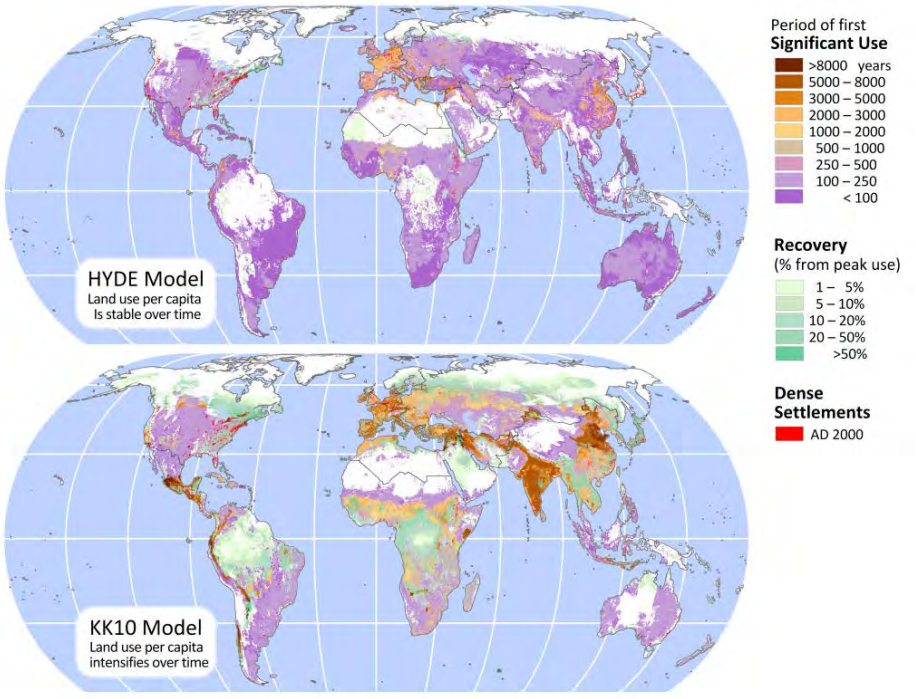


Figure 5. *Time period of first significant land use and recovery from peak land use, 6000 B.C. to A.D. 2000, based on two different historical land-use reconstructions (upper plate, HYDE, and lower plate, KK10 model that accounts for changes in land productivity per person). Reproduced with permission from Ellis et al. (2013).*

4.1.4 Modelling land system change

Land use modelling takes place using simulation tools covering a wide range of different model concepts originating from different disciplines. Models used in land system science range from global scale, coarse resolution models assessing global demand and supply of commodities produced by land systems (e.g. Computational General Equilibrium models), to local multi-agent models that simulate individual land use decisions at the level of individual actors. This wide range of models and modelling approaches can be explained by the different scales that land system science is addressing, the different research and policy questions to which land use models are applied and the different disciplinary traditions from which land system science is originating. The range of different modelling approaches available is synthesized in various review papers (Verburg et al., 2004; Matthews et al., 2007; Priess and Schaldach, 2008; Brown et al., 2013). In a recent review for the National Research Council of the United States models were classified according to the role they play within the process of supporting policy decisions (Brown et al., 2013; National Research Council, 2013). While some models are targeted as learning-tools to test alternative conceptualisations of land system dynamics, other models are specifically designed and applied to evaluate alternative policy proposals to support decision making by assessing effectiveness and identifying potential trade-offs resulting from the direct and indirect impacts of the intended policies on land use. Other models are targeted at scenario analysis, either to inform large scale assessments of climate change or biodiversity impacts (Lotze-Campen et al., 2010; Pereira et al., 2010) or to detect specific land use trajectories foreseen under alternative scenarios (Verburg et al., 2010; Sleeter et al., 2012) in order to raise important policy issues and provide an early warning signal that policies can anticipate.

Each model type and approach has its own specific niche of applications, and it is not possible to classify one approach as superior to other approaches. While pixel-based approaches using spatial data of location conditions as major determinants of the transition probability of land use are extremely popular due to their good fit with available data, many have made pleas for a wider adaptation of so called multi-agent models that can explicitly address variation in decision making and interactions amongst decision makers (Brown et al., 2013; Filatova et al., 2013; Rounsevell et al., 2013). At the same time, in spite of the many developments of multi-agent models in land system science at the local scale it has proven difficult to operationalize and parameterize such models at regional and larger scales, largely due to data limitations and lack of empirical knowledge of decision mechanisms.

Apart from using different land use model types for different types of applications and at different scales, the linking of models is becoming more popular: pixel-based models are used to downscale results of macro-economic models and nested approaches in which local dynamics feedback to higher-scale dynamics are being explored, making optimal use of the complementarities of different model types (Verburg et al., 2008; Rounsevell et al., 2012; Herrero et al., 2014). In most cases model linkage is still done in a top-down mode in which global multi-regional models are used to constrain regional land allocation models, while feedbacks from regional and local responses are not accounted for. New empirical techniques are needed to being able to better specify feedbacks between system components and scales to allow the specification of the important feedback mechanisms in (linked) land system models. At the same time, models can be used to explore the possible consequences of such feedback mechanisms, enabling to better understand the relation between global developments and local land system change trajectories, but also understand how land systems are steered through governance at multiple scales.

While models of land change have strongly evolved over the past decade large challenges remain. Current models mostly fall short in capturing changes in the functioning of socio-ecological systems

(emergent or evolutionary change through time) because most often, stationary system behavior is assumed. Feedbacks between system functioning and underlying endogenous drivers should be represented, rather than assuming the drivers to be exogenous to the modelled system. To explore sustainable futures, social processes and anthropogenic drivers of biophysical processes must be better represented, to allow for a spectrum of potential impacts and responses at different societal levels. Important in this respect is to move the rational choice decision making, often implemented as profit optimization, in many land change models. It is known that these representations of decision making have limited validity and are not necessarily scalable. However, in practice profit optimization algorithms are still underlying many land change models.

Design of models in response to questions posed is essential to choose appropriate representations of complex Anthropocene dynamics and to achieve model legitimacy and credibility. The diversity of stakeholders and potential questions requires a diversification of models, avoiding the convergence towards single models that are able to answer a wide range of questions, but without sufficient specificity. Novel understanding and data of land systems can help to develop innovative model representations that are better suited to assist in designing sustainable solutions targeted at the users of the models and model results.

Finally, while model uncertainty and validity are important topics nog given full consideration in most land change models. Often data limitations constrain a full validation of land change models. While progress is made in validation of regional scale models (Pontius et al., 2008), none of the global scale land change models has been fully validated. Alternative to waiting for better validation data to enable standard validation of such models is more attention for model sensitivity analysis and model comparison. Validation efforts not only serve to improve credibility of land change models for use in practice, they also serve as a learning tool to evaluate to what extent our model representation of the land system corresponds to reality. Model comparison and evaluation of model differences is also instrumental to identify critical areas of disagreement and the need to improve on the representation of the land change processes in these areas.

4.2. Priority thematic areas

4.2.1 Telecoupling of land use systems

Globalized markets, decisions by distant governments, and global agenda setting (e.g. in light of global change) influence local land use decisions to an ever increasing degree. Land System Science has taken up the challenge to both enhance our understanding of the interaction of coupled human-environmental system in a telecoupled world as well as providing new frameworks and concepts to approach it in terms of enhancing evidence based decision and policy making.

For example, it has been shown that the recent reforestation in Vietnam is to a large share based on displacement of land use through import of wood products from other countries (of which 50% was illegal logging) (Meyfroidt and Lambin, 2009). On a global level 52% of the reforestation (2003 – 2007) of seven countries that have recently undergone forest transition is based on such displacement effects (Meyfroidt et al., 2010). Economic globalisation therefore facilitates forest transition in one country through displacement effects and leads to an export of negative externalities (frequently to countries with weak land governance systems). The second example of forest exports and imports of China in 2010 (Figure 6) illustrates the degree to which land is now a globalized good. Between 1997-2010 China exported forest products to over 160 countries and imported forest products from over 170

countries (Liu, 2014). Such empirical evidence is crucial to enhance respective global policies e.g. related to global deforestation.
There have recently been different attempts to quantify these displacement effects of resource use, and land use specifically based on trade and consumption data (e.g. (Qiang et al., 2013; Weinzettel et al., 2013; Yu et al., 2013)). While the results are partly contradictory, they all show the high degree to which land and the resulting respective externalities have been globalised. These results motivate the clear need for further methodological advances in this field (Kastner et al., 2014) so that the land system science community can provide critical information and tools to support global policy decision-making.

Land system science has reacted to the conceptual challenge of these increased interactions of distant places and has already proposed different conceptual frameworks to address the challenges (e.g. (Seto et al., 2012b; Liu et al., 2013). Liu et al (2013) discussed an integrated concept of telecoupling that encompasses both socioeconomic and environmental interactions among coupled human environmental system over wide distances. Their concept centres on differentiating between sending, receiving and spill over systems, the flow between these systems, and the agents, causes and effects within these systems. This move from place based to process based conceptualisation offers much potential to enhance the system understanding of a telecoupled world and contributes to more effective policies and action towards sustainable development. While the concept of telecoupling has gained popularity one of the challenges is to develop operational methods for studying telecoupled systems and working with stakeholders to design interventions in telecoupled systems that respond to the needs of the Sustainable Development Goals.

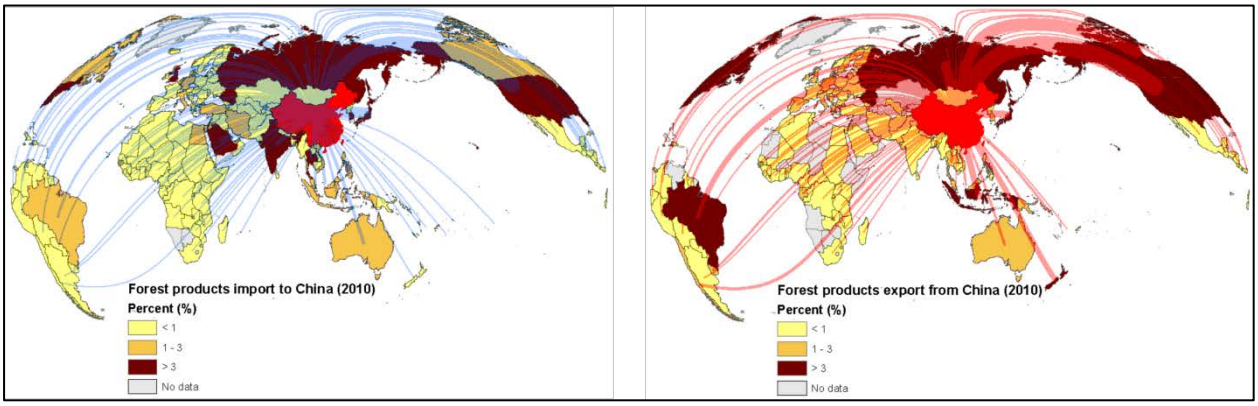


Figure 6. *Map of imports and exports of forest products to and from China. (The countries are classified cased on the percentage of imported or exported value.) (Source: Liu 2014, p. 7; reproduced with kind permission of the author)*

4.2.2 Land use and conflict

Land systems play a critical role in conflict, as both causes of conflict and as victims of conflict. Competition for land resources is a major cause of conflict between and within nations and there can be significant impacts on land from violent conflicts. Violent activities such as bombing and forest burning can be a direct force of land degradation and land use change (Witmer, 2015), but usually occur across small spatial and temporal scales. More significant, but also more complex, is the indirect forces and impacts of land change that follow the mass movement of people and the collapse of states and economies during and after conflict. McNeely (2003) summarizes conflict as having restorative or

degrading environmental impacts through the processes of: i) exclusion of activities from within conflict zones; ii) increased or inefficient natural resource use to support mass migrations during conflict, and iii) the collapse of economies and institutions during and after conflict.

More than 80% of armed conflicts since 1950 have occurred in biodiversity hotspots, particularly in tropical forest areas (Hanson et al., 2009), suggesting that conflict has had substantial impacts on tropical biodiversity. Mass migration into settlements typically increases pressure on nearby natural resources, but alleviates resource use pressure in areas people have fled to avoid violence. For example, resource use and biodiversity impacts have reduced since the establishment of the demilitarized zone between North and South Korea (Kim, 1997) because of the exclusion of people. In sub-Saharan Africa, Glew and Hudson (2007), estimate that 35,000 ha of timber was required to support refugees generated by conflict between 1990-2005; it's unlikely this timber was harvested sustainably. Ordway (2015) demonstrate the spatially explicit nature of conflict-driven mass migration and deforestation and reforestation in Rwanda. Local conflicts and the breakdown of long-standing institutions, such as between the rural indigenous poor and recent arrival of wealthy landed elite, have been suggested as a major driver of deforestation in the Brazilian Amazon (Aldrich et al., 2011).

Agricultural abandonment can be an outcome of conflict-induced migration. Land abandonment has been recorded following conflicts in Columbia (Sánchez-Cuervo and Aide, 2013), Nicaragua (Smith, 2003), Bosnia (Witmer and O'Loughlin, 2009), the Caucasus (Baumann et al., 2014), and Sri Lanka (Suthakar and Bui, 2008). In the case of the Caucuses, Baumann et al. (2014) found that about 30% of the abandoned agricultural land in the conflict zone was offset by new agricultural areas away for the conflict, and that only 17% of the abandoned land was re-cultivated after the conflict ended. They conclude that conflict can drive distant land use changes.

The dynamics of land use change from conflict and the many drivers of conflict are complicated at spatial and temporal scales, and a challenge is to synthesize the many dynamics of land abandonment, reforestation, deforestation and new agricultural land during and after conflict. Previous studies have focused predominantly on single types of land use changes (e.g. deforestation-reforestation, or agricultural land abandonment-new agricultural land), yet the processes are inter-dependent so future assessments of conflict and land use change should be integrative across multiple land uses (Baumann et al., 2014). Further work needs to assess impacts on land systems of the recent and expected future interrelated drivers of conflict, such as globalization, anthropogenic climate change and food insecurity, which are not well understood. Recent studies (Salehyan and Hendrix, 2014; Raleigh et al., 2015). report contradictory relationships between climate change impacts on environmental and resource scarcity, food production and conflict.

4.2.3 Land-atmosphere processes

Land-use and land-cover changes have contributed substantially to climate change and are expected to continue to do so in the future (Le Quéré et al., 2009; Pitman et al., 2009; Houghton et al., 2012) due to the release of large quantities of carbon when natural ecosystems (mostly forests) are converted into croplands or pastures, or due to changes in management or land-use intensity (Erb et al., 2013). Intensification of crop management leads to release of additional greenhouse gases, like N_2O from fertiliser application (Zaehle et al., 2011), or CH_4 from cattle and rice production (Verburg and Denier van der Gon, 2001; Steinfeld et al., 2006). Changes that follow land use change in the surface reflectivity and the way absorbed energy is distributed towards evapotranspiration or heating at the near-surface affect regional climate substantially (Pitman et al., 2009; Pongratz et al., 2009). Changes in land systems

can also result in increased carbon sequestration, due to e.g. the land-sparing effects of intensification, if not overcompensated by rebound effects (Lambin and Meyfroidt, 2011) or due to management changes in forests that do not result in changes in land cover, such as forest grazing or litter raking. These examples illustrate that studying the complex and highly dynamic interactions and feedbacks among climate and natural ecosystems is not sufficient to adequately describe the functioning of the Earth System and its components. Land use and its change over time is an important component of the Earth system. Nevertheless, the recent 5th Assessment Report by the IPCC WG1 is the first where land use change has been explicitly, although rudimentarily, accounted for in projections of climate change. Recent, model-based studies, have shown that land use change has an important impact on the radiative forcing calculation (Jones et al., 2012). From a human system's perspective, climate and climate change also contribute to land use change (Mertz et al., 2010). Climate determines the types of crops that can be grown (Easterling et al., 2007; Gornall et al., 2010). Harvest failures following floods, heat-waves or droughts can lead to food-shortages, and increases in local and global grain prices (Beddington, 2010). Indirect climate-effects like fires or insect-outbreaks can also affect the yield of forests and crops. At the same time, in other regions climate change also favours higher agriculture yields in areas limited by temperature and rainfall. As an example, the agriculture production of Argentina (one of the major global food producers) has been clearly favoured by climate change (represented here as rainfall increase) in recent decades.

An emerging challenge is, therefore, to quantify impacts and feedbacks between land systems, the societies managing these systems, and the climate system, and to take into consideration regional to global scales and short- and longer-term time perspectives. A global scale perspective is needed because climate systems operate on global scales, and increasing land systems also operate at such scales, as illustrated in section 2.4. The debate on indirect land use change arising from land-based bioenergy production is a prominent example of global-scale dynamics (Fargione et al., 2008), but equally important is the possibility to supply food to regions that suffer from, for example, a climate-induced crisis. Issues of time arise from legacy effects of land use change in the climate system (Houghton et al., 2012) or from time-lags between introduction of a climate policy and its actual take-up by local farmers (Alexander et al., 2013). The climate, environmental and socio-economic research communities are confronted with providing the required understanding of the fundamental processes that operate at the interface of the climate and land systems, and their manifold interactions across local, regional, and global scales. A key challenge is to find ways to bridge, epistemologically and methodologically, the diverse scientific communities. Finding ways to synthesise available data and knowledge in these communities will allow further development of the mechanisms represented in models, advance our capacity to evaluate model performance, and yield information to support policy development and societies towards successful adaptation and mitigation strategies (Hibbard et al., 2010; Rounsevell et al., 2013).

4.2.4 Land governance

Land systems are increasingly affected by changes in global governance and wider revalorizations of land, and in turn influence the wider transformations in governance and value (see Figure 7). For example, global demand for food and biofuels drives one of the most visible revalorizations of land over the past decade, giving rise to large-scale land acquisitions by states, transnational corporations and financial investors (Anseeuw et al., 2012; White et al., 2012). The land acquisitions have been enabled by larger governance changes at the international, national and local levels, such as the ascendance of the World Trade Organization, national policies on food, agriculture and trade, and the rolling out of commercial land markets (Peluso and Lund, 2011; McMichael, 2012; Margulis et al., 2013). Simultaneously, indigenous peoples and peasant movements have mobilized in the pursuit of political

and cultural goals, highlighting the value of land as a place of belonging, territory for self-determination and religious practice (Sikor and Stahl, 2011). At the same time, changes in land systems drive global revalorizations of land and wider transformations of governance, as illustrated by the inclusion of forests in global climate mitigation efforts due to concerns over land-related carbon emissions. Thousands of small-scale reforestation projects in the so-called voluntary sector and the United Nations initiative of Reducing Emissions from Deforestation and Forest Degradation (REDD+) have caused increasing attention to carbon storage and changes in climate governance (Bumpus and Liverman, 2008; Corbera and Schroeder, 2011).

In reaction to shifts in governance, value and land systems, land governance is shifting from 'territorial' toward 'flow-centered' arrangements (Sikor et al., 2013). Flow-centered governance targets particular flows of resources or goods, such as certification of agricultural or wood products or voluntary regulation in the mining sector (Auld, 2014). For example, concentration in global agri-food supply chains has enabled industry to introduce production and sustainability standards (Bailis and Baka, 2011). Initially NGOs but later also governments have promoted certification schemes for food at global or regional levels (Auld, 2010). The European Union and USA are now seeking to regulate global timber production through trade-related measures. These forms of flow-centered governance complement classic territorial forms of land governance, such as the designation of protected areas, regulation of land use, and land use planning (Sikor and Müller, 2009). They also add to the new instruments used in territorial governance, in particular novel financial mechanisms such as Payments for Ecosystem Services (Muradian et al., 2010).

Although land governance has been receiving increasing attention in recent years there is a requirement for novel research methods to describe and assess land governance systems. This requires a closer interaction between research communities from political science, the social sciences and those working on observations and models of land system change. Such integration is extremely challenging due to differences in research practice and tradition. Besides understanding of land governance ways in which the science community can develop instruments to support improved land governance are needed to operationalize research findings in reality.

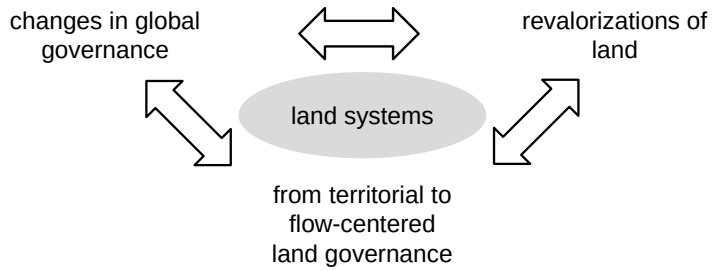


Figure 7. *Dynamics of land governance and value*

4.2.5 Land change trade-offs for ecosystem services and biodiversity

Ecosystem services are supplied directly by natural capital, i.e. the major components of the land system: soil, water, vegetation and other biotic components. Land use decisions therefore have direct bearing on natural capital and ecosystem services supply (Crossman et al., 2013). The impacts of these decisions typically unfold at local to regional scales, affecting local livelihoods that depend on ecosystem services and biodiversity (Wu, 2013b). Trade-offs often arise between bundles of ecosystem services supplied by alternative land uses (Chisholm, 2010; Crossman et al., 2011; Smith et al., 2013). For example, conversion from natural forest to annual cropping or grazing systems (Figure 5) may enhance food production, but at the cost of a number of other services, such as water purification, ,

carbon sequestration, and habitat quality for biodiversity. The conservation or promotion of cultural and spiritual values that are associated to particular land uses may also be favoured or disfavoured following major land use changes . To understand (and eventually manage) these trade-offs between alternative land use scenarios, we need robust quantifications or estimates of the many services supplied by natural and transformed ecosystems. Land system science plays a pivotal role in modelling and quantifying the bio-physical processes underpinning ecosystem services; some of which are better understood (e.g. sediment transport processes under alternative land use arrangements, biomass content of different land covers), while others are less so (e.g. the distribution and dynamics of some components of biodiversity and the supply of habitat-related ecosystem services (Nagendra et al., 2013a).

Land science can also help understanding the social dimension of natural capital and ecosystem services. Arguably, ecosystem services are co-produced by human-environment interactions, and do not exist if there are no beneficiaries. In consequence, there is a clear need to better understand the spatial and temporal dimensions of the beneficiaries and the nature of their connections; whether they co-occur or are far apart from where ecosystem services are supplied (Serna-Chavez et al., 2014). Moreover, land management for ecosystem services should be linked to the demand for services by potential beneficiaries. As societies and climate are changing, demand is changing both in terms of amount and spatial dynamics. Managing land in such ways that services are supplied to those areas where they are required is challenging and requires a major research effort, as the spatial flow and transport of services vary with the service type and beneficiary access; and these as channels of flows are rapidly changing.

A full consideration of the trade-off among alternative land management strategies and spatial allocation of resource use is needed to inform the public and policy debate on which developments of land use are most desirable. This includes aspects of composition, management and configuration of different land uses across multiple scales and organization levels, ranging from the farms to the whole planet. Such an approach goes beyond simple strategies of either multifunctional land use or spatial segregation of land functions (Grau et al., 2013) to a more nuanced, multi-scale assessment of alternative, context-sensitive, options; and should include (in addition to frameworks for specifically addressing future scenarios), strategies for adaptations to unpredicted ones.

4.2.6 Land management systems

Virulent knowledge gaps relate to aspects of land management and livestock systems. Dynamics, drivers as well as socio-ecological changes in management, e.g. in land-use intensity, remain still underresearched, but preliminary evidence indicates that land management changes could be associated with significant impacts on key parameters of the Earth system (Erb et al., 2013). Fostered research activities are required to improve data availability on land management, its impacts on e.g. terrestrial ecosystem parameters, as well as the generic understanding of the management dynamics.

A particularly important component of land systems are livestock systems, which is also expected to gain in importance due to global population growth and anticipated dietary changes. Many trade-offs relate to livestock production, as livestock is an effective way to increase the resource base of society, in particular under subsistence production (by allowing to make use of otherwise not usable land), but at the same time is associated with efficiency losses in terms of input-output ratios, in particular in cases where human-edible biomass is used as feedstuff, large GHG emissions and other environmental detriments. However, severe data and knowledge gaps related to livestock systems that hamper the systematic analysis of these aspects. While production of livestock products is relatively well

documented (e.g. by the FAO), many severe data gaps remain. For instance, only fragmented information is available for feedstuff that is not traded or not marketed such as roughage, grazed biomass and fodder crops. Furthermore, the extent of areas subject to grazing is largely unknown, and most databases neglect grazing land altogether. This severely hampers the analysis impacts of grazing on the Earth system, such as impacts on biogeochemical cycles or biodiversity. The development of robust spatially explicit information on grazing areas requires advancements in the characterization of livestock grazing systems and improvement of global datasets. This is one prerequisite for the analysis if important aspects of livestock systems, such as its role for human-induced soil degradation (Xiao et al., 2015) . Moreover, in many regions of the world livestock plays a key role for food security, while in other regions the consumption of animal based products is associated with issues of overconsumption, obesity and environmental degradation. Many aspects of this function remain unexplored. Concerted efforts of the land science community and beyond are required to close knowledge gaps an advance the fundamental understanding of the relation between livestock systems and human-wellbeing.

While forest management systems have been better studies, information on the extent of these systems globally is missing. For Europe a new data assimilation effort shows the large variation of forest management across the continent, indicating the importance to address spatial variations in management systems (Levers et al., 2014).

4.2.7 Urban-rural interactions

Over half of the world's population already lives in cities, with a massive increase in urban population projected by 2050, and an anticipated increase in urban land cover that is about twice the increase in urban population (Seto et al., 2011). Rates of urbanization are spatially uneven, with Asia and Africa projected to account for as much as 86% of projected urban growth (United Nations, 2010). Alongside rapid growth, urban shrinkage is also taking place in many parts of Europe and north America (Haase et al., 2012). Urban land change is generally considered one of the most problematic trajectories of land change, due to its perceived irreversibility. In particular, urban land change has severe consequences on climate, biodiversity, ecosystem quality and ecosystem services, which are difficult to mitigate and manage (Elmqvist et al., 2013). Urban green spaces, wetlands and water bodies provide critical biodiversity and ecosystem services that are especially important for poor and vulnerable populations, such as urban slum residents (Nagendra et al., 2013b). Thus, protecting and restoring urban ecosystems is an important issue for sustainable urbanization.

Economic and demographic factors appear as particularly strong drivers of urban land change in China, India and Africa (Seto et al., 2011). African urbanization further constitutes a particular information gap, with studies of land change in African cities being relatively sparse compared to other parts of the world, as a recent meta-analysis indicates (Seto et al. 2011).

Peri-urban regions constitute areas of particularly rapid change that are especially vulnerable to land acquisitions and tenure changes with potentially disrupting socioeconomic effects and ecosystem degradation (Seto et al., 2012a; Seto et al., 2012b), further increasing the social vulnerability of the urban poor, migrants and people practising traditional rural livelihoods. In order to understand, model and manage the multi-level drivers of urbanization in cities and their peri-urban surroundings, recent efforts are beginning to focus on developing a better understanding of urban-rural teleconnections but this requires further elaboration and translation into the implications that this understanding may have on land use planning (Seto et al., 2012b). While urbanization is often seeing as having an adverse impact on land resources and ecosystem service provisioning, a more nuanced view is needed. As an example, Aide and Grau (2004) show that by reducing rural population pressure in areas marginal for agriculture production, rural to urban migration may facilitate the recovery of natural ecosystems while at the same time, the life quality of the rural-to-urban migrants improves.

Land change science requires the development of approaches for the continuous representation of urbanity and rurality, integrating multiple dimensions including of livelihood, lifestyle and telecoupling. For more sustainable urban planning, land change research needs to be connected with research on biodiversity and ecosystem services, to understand how increasing urbanization, expansion of the urban footprint, and urban-rural teleconnections impact the quality and accessibility of ecosystem services. This requires collaborative research between ecologists and land system scientists. Finally, while urban studies have been focused in specific regions of the world, we need a systematic focus on new areas of urban growth in parts of Africa, Latin America and the Middle East, which represent knowledge gaps.

4.3. From understanding to sustainability solutions

As land systems are both a cause of global environmental change and a possible powerful means of mitigation of and adaptation to global environmental change. In order to exploit this potential, the community needs to move from a dominant focus on exploratory research towards understanding the functioning of the land system and its dynamics to approaches that use this knowledge together with stakeholders to adapt and mitigate to the changing environmental and socio-economic context.

While interdisciplinarity is central to land system science, a stronger engagement of stakeholders in the development of sustainability solutions provides an important opportunity for the researchers engaged in this field. A lot of research in land system science is focused on understanding the drivers and impacts of land system changes. There are still large knowledge gaps remaining that need to be addressed. However, at the same time there is a need to further engage in using the acquired land system knowledge towards the development and prototyping of sustainable land management practices and policies. Traditionally, land system science is closely related to the fields of land use planning and land use policy. However, scientific insights are not always easily integrated in these processes and much land is owned and managed by private land owners that are, for various reasons, not always responsive to planning and policy. Therefore, new ways of linking science and practice need to be developed to effectively create scientific findings that contribute to sustainability solutions and implementation.

Important ways forward in this perspective include the evaluation and design of alternative ways to govern land resources (Deininger et al., 2011; Bourgoin et al., 2012; Sikor et al., 2013). Examples from Laos exemplify how trans-disciplinary research can contribute to this. In Laos there is an immense commercial pressure on land while the traditional agricultural practice, dominated by shifting cultivation practices, and local land rights are not recognized by the authorities. In this setting development oriented research endeavors have been co-designed with local and governmental stakeholders leading to more effective approaches to local level land use planning (Bourgoin et al, 2012). These approaches capture and contextualize for the first time the immense magnitude of land investment for the whole country (Schönweger et al., 2012) as well as traditional smallholder claims on land through shifting cultivation (Heinimann et al., 2013; Hurni et al., 2013). This co-production of knowledge not only led to the recognition by officials of the need for more efficient and participatory strategies for land management and improved access to land for smallholder communities. It also contributed to the declaration of a land concession moratorium (rubber, eucalyptus and mining) by the prime minister office of Laos, and to increased recognition of the importance of shifting cultivation in the new Upland Strategy of the government of Laos.

Land system science can also make a major contribution to the search for solutions for meeting the multiple, conflicting, demands on the land system. In particular the challenge to produce more food for a growing and more demanding population while avoiding the detriments of many output-enhancing land-use practices, such as biodiversity loss and the degradation of ecosystem service provision, has given rise to debate about alternative strategies of land management (Rosegrant and Cline, 2003; Godfray et al., 2010; Ingram, 2011; Lambin and Meyfroidt, 2011). The debate about alternative land management strategies to meet food production challenges has been influenced by strong opinions in favour of either intensification of agricultural production on a relatively limited area, so-called land sparing, or multi-functional agriculture areas, referred to as a land sharing strategy (Phalan et al., 2011; Butsic et al., 2012; Tscharntke et al., 2012). While intensive agriculture has been characterized by negative environmental and social externalities, multi-functional agriculture is often characterized by lower yields, thus requiring larger areas to produce the same quantities of agricultural product. However, these tradeoffs are very dependent on the biophysical and socio-economic context. In sensitive environments organic agriculture or other extensive, multifunctional, forms of agriculture can be a suitable option. At the same time, intensive agriculture can, with the right technology and management, produce large quantities of commodities fulfilling the food demand of many people through a relatively small area. Matching land use systems with the abilities and willingness of the land managers, the local environmental conditions and the demand for ecosystem services is important to achieve sustainable land management. In a globalized world locally optimal solutions need to be contextualized as choices that always have wider implications: the choice for relatively unproductive systems has trade-offs due to displacement of production to other places (Lambin and Meyfroidt, 2011). At the same time, it would be incorrect to assume that intensification will always spare land that can be used for conservation purposes. Increased production can trigger increased consumption as result of lower prices and improved agricultural opportunities may attract new activities on 'spared' land (Matson and Vitousek, 2006; Lambin and Meyfroidt, 2011; Phalan et al., 2011; Grau et al., 2013). Land system science can provide insights in both the local and global tradeoffs. The quantification of such tradeoffs can inform land management and conservation decisions and enforce discussions about the global tradeoffs of locally sustainable solutions. Such insights will help to bring nuance in discussions about land sparing and sharing paradigms by accounting for local context and environmental heterogeneity (Bryan and Crossman, 2013).

Based on these conceptual and methodological tools to evaluate tradeoffs, land system science can help the design of novel land systems that more optimally account for spatial and temporal land system interactions and landscape configuration (Bateman et al., 2013; Crossman et al., 2013; Seppelt et al., 2013; Turner II et al., 2013). Such land system architecture uses the principles of landscape ecology where spatial structure and pattern are seen as important determinants of the functioning of landscapes (Wu, 2013a). By modifying spatial landscape structure and allocating land use activities to the most optimal place in the landscape, it is possible to enhance the production of multiple services and enhance the resilience of the land system as a whole (Bryan et al., 2011). Such a design-based approach needs to account for the full range of land system science knowledge and can only be successfully conducted in a fully trans-disciplinary manner by engaging into a co-design approach with stakeholders. Only this way can the designed systems fit the local interests and ecosystem service demand, be sustainable from both local and global perspectives and fit to the local socio-economic and land governance systems (Bryan et al., 2010). Such research requires not only the use of participatory techniques, but also the involvement of practitioners to prototype the newly designed land systems and test their suitability in reality. The approach aims to use the capacity of land systems and the architecture of these systems to respond to changing demand by society, but also provides options for

mitigation and adaption to environmental change. That way, land system science would not only play a role at the interface of the social and natural sciences, but also at the interface between science and practice. The next chapter describes in more detail how these roles can be conceptualized and implemented in GLP.

5. Co-production of knowledge in land system science: the Global Land Programme at the interface of science and society

5.1 Introduction and conceptual overview

Developing solutions towards a more sustainable world requires the integration of natural and social sciences as well as the integration between science and society (Pahl-Wostl et al. 2013). In its 2014 strategic research agenda document, Future Earth asserted its commitment in supporting more integrated and more socially relevant science, in which scientists work in partnership with society and decision-makers (Future Earth 2014). This chapter has the objective of establishing pathways on how to enhance such a new kind of science in the framework of GLP, and, more broadly, the land system science community. More specifically, it aims at enhancing co-design, co-production and dissemination of social-ecological knowledge to promote sustainability and resilience (Grove, Roy Chowdhury, and Childers 2015).

As co-design, we understand the joint formulation of research questions, objectives and methods involving science and society. Co-production of knowledge means the generation of "*new knowledge involving both academics and non-academics in a strongly interactive way, so that the research process requires forms of knowledge and expertise that cannot be supplied by the researchers alone*" (Robinson and Tansey 2006:). Dissemination of knowledge is a two-way process; it both improves the consideration and incorporation of science into decision-making, and provides scientists with new feedbacks, insights, data, and interpretations (Grove, Roy Chowdhury, and Childers 2015).

These concepts are in line with the idea of transdisciplinarity, a well-known concept in the European context, which has been defined as "*research that addresses the knowledge demands for societal problem-solving regarding complex social concerns*" (Hirsch Hadorn et al. 2006: 122). A similar idea is "Mode 2" knowledge production, which emphasizes the production of "socially robust" applied knowledge (Nowotny, Scott, and Gibbons 2001). Because transdisciplinarity might have a different meaning in the American context, with some authors using the concept to describe collaborative science involving several disciplines (Zscheischler and Rogga 2015), we prefer to use the three associated concepts of co-design, co-production and dissemination. To facilitate reading, we will use the broad term of co-production to mean the three in this chapter.

The need to perform co-production of knowledge has both theoretical and practical justifications. From a theoretical point of view, it has to do with the nature of knowledge systems which cannot be reduced to scientific production alone. First, "real life", knowledge systems are made up of actors, practices, institutions and networks to produce, share, and use knowledge. Practice involves skills that cannot be fully coded in academic terms (Ingold 2000). Second, the search for sustainability and resilience is a normative endeavor, which involves values, opinions and social influences about what is to be sustained and made resilient (Lélé and Norgaard 1996). Third, social-ecological systems are complex and their dynamics cannot be predicted without accounting for varying levels of uncertainty about the parts of the system and their interactions under varying conditions. Complexity can only be tackled through the integration of contextualized and holistic practical and local knowledge. The need to co-produce knowledge is particularly true for land systems, which include dynamic interactions among social and natural drivers that are often multifunctional.

From a practical point of view, co-producing knowledge stems from a need for more democratic and more transparent science and building trust between science and society. Co-production has several benefits for both science and society, which are much broader than the advancement of applied science. These benefits include providing "socially robust" and implementable knowledge, preventing conflicts, and integrating various perspectives and sources of knowledge (Zscheischler and Rogga 2015).

GLP will take a two-fold approach to enhance co-production of knowledge in land system science. On the one hand, it will encourage the land system science community to perform high-quality co-production of knowledge in the daily practice of research processes involving endorsed projects, working groups, and nodal offices. On the other hand, GLP will perform synthesis activities targeted to better understand processes of co-production of knowledge in land system science, identify challenges, and develop solutions. As co-production of knowledge itself, these two approaches are not conceived of separately, but as a continuous process of mutual feedback between GLP and its core components.

This chapter takes a set of examples of practical experiences of co-production of knowledge which were presented in a thematic GLP Newsletter (Boillat et al. 2015) as a starting point, and derived lessons learnt from them. The experiences focus mainly on three cases from the long-term ecological research (LTER) in the United States, and complementarily on nine additional experiences from all continents. Based on these, as well as on existing literature, we outline pathways for research and action to be addressed by GLP in its next phase, as well as an action plan and a list of expected outcomes.

5.2 Co-production of knowledge at GLP

The LTER experience

The long term ecological research (LTER) program has operated since 1980 with funding from the U.S. National Science Foundation, performing ecological research in 25 American sites that represent diverse ecosystems and landscape types, climates, land uses and degrees and histories of human influences (Grove, Roy Chowdhury, and Childers 2015). LTER projects are funded in 6-years funding cycles and provide long-term ecological data which are made accessible to the public. Three LTER sites are embedded in social-ecological systems and have a dominant urban component: the Baltimore Ecosystem Study (BES), Central Arizona-Phoenix (CAP), and Florida Coastal Everglades (FCE). At these sites, LTER researchers interact with multiple and diverse stakeholders and have developed durable trust relationships with them. They engage in a cycle of feedback loops that involve the following phases: (1) identify and frame questions, (2) collect and analyzing data, (3) interpret results, (4) disseminate and apply findings and (5) identify new questions. Figure 1 shows a dynamic model of decision-making and science derived from the co-production of knowledge process at these three LTER sites.

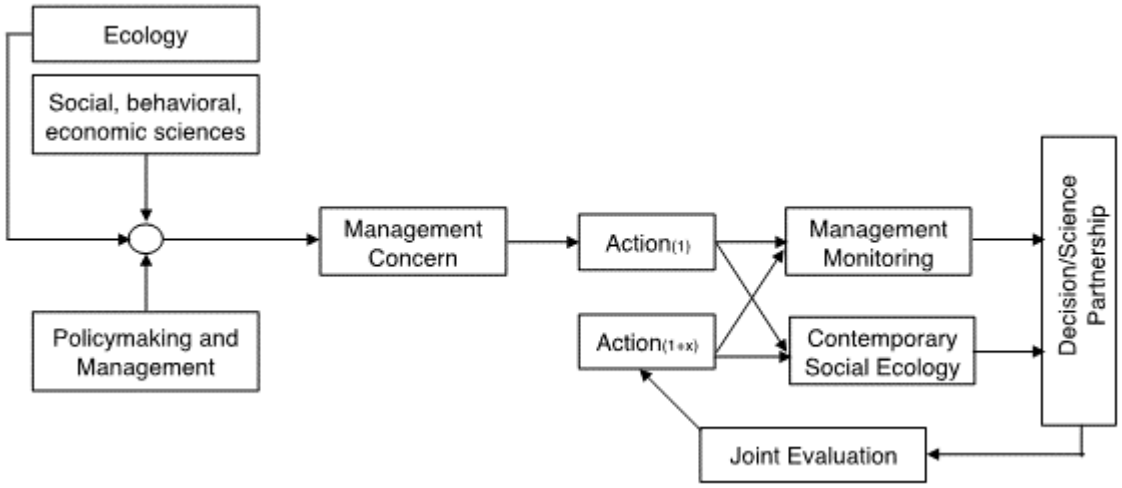


Figure 8. *Dynamic feedbacks between decision-making and science (Grove, Roy Chowdhury, and Childers 2015)*

While separate disciplines (ecology, social sciences) engage in research, a management or policy *action (Action1+x) may result from this research-policy engagement. Additionally,* management may include a monitoring process to assess the reach of desired goals. The LTER experience has led to consider a new interdisciplinary approach, labelled social ecology, which interacts with decision-making to jointly evaluate concerns over time.

Other experiences of co-production of knowledge at GLP

Table 1 summarizes the characteristics of the nine cases of co-design and co-production of knowledge presented into the thematic GLP Newsletter on co-design in 2015.

Table 1 *Summary of co-design experiences as reported in GLP Newsletter 2015*

Authors	*Countries*	*Non-academic stakeholders involved*	*Academic stakeholders involved (disciplines)*	*Main economic sectors involved*	*Main scale involved*
Frank et al.	Finland, Sweden, Germany, Slovenia	Land owners, forestry enterprises, tourists, land planners	Landscape ecology, forestry, agriculture	Forestry, tourism agriculture	Local
Srinivasan et al.	New Zealand	Farmers, irrigation operators	Hydrology, agriculture	Agriculture	Local
Dibi Kangah and Koné	Ivory Coast	Farmers, local governments	Climatology, meteorology, agriculture	Agriculture	Local
Lerch and Molina	Bolivia	National government, cooperation agencies	Geography, informatics	Communications	National
Görg et al.	Vietnam, Philippines	Farmers, business, local governments	Development economics, agriculture, social sciences	Agriculture	Sub-national

Lajaunie and Morand	Thailand, Lao PDR	Farmers, health workers, local governments	Biology, medicine, agriculture	Health	Local
Mertz et al.	China, Lao PDR, Vietnam, Indonesia	Farmers, land owners, government	Forestry, geography, development economics	Forestry	Local to national
Barau	Malaysia	Urban dwellers, business, local government	Urbanism, landscape ecology	Urbanism	Local
Aguiar	Brazil	Community organizations, NGOs, social movements, business	Forestry, geography, modelling	Development	Local / Sub-national

Lessons learnt from GLP co-production experiences

The main lessons learnt from the LTER experience (Grove, Roy Chowdhury, and Childers 2015) as well as other GLP co-production experiences can be summarized in seven points:

1) Several types of learning loops are involved in decision-science cycle. The deeper the values to be negotiated, more feedback learning loops are needed.

> "Single-loop" learning is evident when incremental improvement in actions occurs without questioning underlying assumptions. "Double-loop learning" arises when assumptions such as cause-and-effect or trade-off relationships are evaluated within a value-normative framework. Finally, "triple-loop learning" occurs when underlying values, beliefs, and world views begin to be rethought and challenged (Pahl-Wostl et al. 2013).

2) Long-term relationships are needed to enhance collaboration and coordination among a diversity of actors and researchers.

> Collaborations among decision-makers and scientists can enhance flows of information and improve the legitimacy, ownership, and accountability of management concerns, actions, solutions, and science

3) The distinction between basic and applied research is a false dichotomy.

> When several feedback loops involve scientists and stakeholders, the production of both fundamental and solutions-oriented knowledge can be enhanced. An example is the research performed by biologist Louis Pasteur, who advanced both the fundamental understanding of biology and saved countless lives. With this research, called "use-inspired basic research", scientists work to both advance theories and methods and to address practical problems.

4) New technologies including the Internet, social networking, and digital data are reshaping the relations between science and society.

> New technologies provide an opportunity for more effective dissemination of knowledge, which aims at incorporating knowledge into decision-making while providing scientists with new feedbacks. Digital media can be used to 1) support scientific research, 2) facilitate open participation in science, and 3) promote use of science in decision-making (Craglia et al. 2011),

and 4) establish forums for dissemination and exchange of ideas. Traditional forms of communication including group meetings and face-to-face interactions, however, remain important and should not be overlooked.

5) Scientists and practitioners must be trained in both breadth and depth.

Scientists and practitioners need to develop both deep understanding of a discipline and the ability to understand and interact with specialists from a wide range of other fields. Individually, however, they will still need to understand disciplinary academic cultures to assure their authority.

6) Access to knowledge and the integration of new information systems with traditional ones is a major challenge

Innovations happen and are required, but traditional forms of management and dialog still exist. On the other hand, new information systems do not necessarily mean more effective, transparent and equitable access to knowledge. Power relationships may appear between those who can access new forms of information and those who rely on traditional ones, and need to be carefully assessed to ensure effective co-production of knowledge.

7) The roles of scientists and decision-makers must be better understood

While scientists need to assess their roles more carefully in influencing sustainability transitions, decision-makers also need to assume a more active role in co-defining research questions and topics together with scientists.

5.3 Pathways for future research and practice

Given these considerations, we have identified five action-research priorities to enhance co-design, co-production, and dissemination of social-ecological knowledge in land system science, to be addressed in the next phase of the Global Land Programme (Fig. 9).

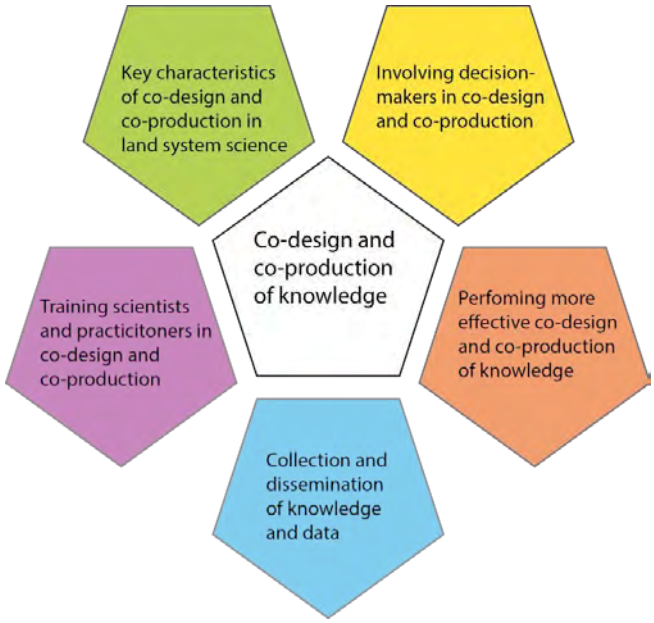


Figure 9. *Five action-research priorities for enhancing co-production of knowledge at GLP*

1) Key characteristics of land system science in relation with co-design and co-production

Land is at the same time a limited resource and an asset for multifunctional societal needs, thus making land system science particularly suitable for co-production of knowledge (Zscheischler and Rogga 2015). While these authors performed a meta-study on transdisciplinary experiences in land use science, there is a need to understand better the specificity of land systems in relations with co-production of knowledge processes. We believe that land system science as a field of applied and action-research can significantly contribute to both theory and practice of knowledge co-production.

Key action-research question: what are the specific characteristics of land system science in relation with theory and practice of knowledge co-production?

2) Involving decision-makers in co-design and co-production

Co-production of knowledge is a budget and time consuming process, especially when large numbers of disciplines and a high diversity of actors are required. A characteristic of most current decision-making systems are that they are mainly organized by sector and by scale. Based upon existing experiences of co-production up to now, we hypothesize that 1) advancing more sustainable and resilient land systems requires the integration of scales and sectors, 2) although multi-sector and multi-scale experiences of co-production exist, no processes have been able to cross both sectorial and scalar barriers simultaneously.

Key action-research question: how can co-production of knowledge be performed simultaneously across both sectors and scales?

3) Performing more effective co-production of knowledge on land systems

Effective co-production implies that sufficient learning loop processes have taken place in relation with the negotiation of actions, values and world views (Pahl-Wostl et al. 2013). Co-production involving different knowledge systems--such as local, traditional and indigenous knowledge systems--might be particularly challenging because of the need to address different world views, epistemologies and ontologies. Promising approaches such as the Multiple Evidence Base (MEB; (Tengö et al. 2014), and strong objectivity (Rosendahl et al. 2015) approaches are being developed to perform effective co-production of knowledge across diverse knowledge systems.

Key action-research question: How can different knowledge systems be incorporated to co-produce knowledge on land systems?

4) Collection, control and dissemination of knowledge and data

Information and communication technologies (ICT) and the exponential growth of both interconnections and processing capacities are opening up new prospects for earth observation for the next decade (Craglia et al. 2011). These increased capabilities provide opportunities to crowdsource and diffuse information, to analyze complex social-ecological systems, and to build global standards on earth data. Yet, this "digital earth" era poses some challenges, including the trade-offs between standardization and diversity of knowledge systems, privacy issues and last but not least, political and power relationships issues related with the control of social, ecological and geographical information. In this framework, GLP will, on the one hand, develop tools to enhance data sharing and exchange in the

community and especially between science and practice, and on the other hand, foster critical thought on the control of social-ecological information.

Key action-research question: How can information and communication technologies contribute to more transparent and inclusive co-production of knowledge on land systems?

5) Contributing to building an new generation of scientists and practitioners

Despite the fact that approaches of co-production and transdisciplinary are decades old, the majority of science is still organized in disciplines, has self-regulated and autonomously-set research agendas, and acts detached from society, politics, and media (Cornell et al. 2013). Furthermore, there are barriers to practice interdisciplinary research between natural and social sciences. Applied and user-engaged research is also often perceived as being of lower value and status than basic research. Finally, individual career building and advancement occurs in closed systems, with few career opportunities and pathways for transdisciplinary scientists and practitioners. We believe that enabling effective co-production of knowledge also means to influencing the scientific community. With this vision, the next phase of GLP will implement actions aimed at enhancing opportunities to involve land system scientists in co-production of knowledge processes.

Key action-research question: How can individual interdisciplinary and transdisciplinary skills be enhanced and mainstreamed into the community of land scientists?

Expected outputs

The following outputs are expected to emerge from GLP's activities related with co-design and co-production of knowledge.

- An account on "what exists" in terms of co-design and co-production of knowledge in land systems

- A synthesis and assessment of co-design and co-production experiences and identification of gaps to be filled

- A set of training materials in co-design and co-production available to students, practitioners, nodal offices and GLP projects as well as the wider GEC research community

- A set of guidelines for the implementation of co-production and transdisciplinary in academic curricula and career advancement.

Implementation strategy

1 Principle

GLP is an open community where all scientists, practitioners and policy makers interested and involved in land system change can participate and contribute. GLP has the objective to continuously engage new participants to share experiences and contribute to its overarching goals. As land systems require an inter- and transdisciplinary approach all participants are encouraged to initiate and undertake activities that strengthen the knowledge and practice of land systems to contribute to a sustainable management of land resources. Therefore, GLP does not have formal members or membership fees to keep the programme open to all that are willing to participate.

2 Governance

GLP is a core activity of the Future Earth initiative and follows the guidance towards managing the core activities as set by the Future Earth secretariat. GLP receives a very modest funding from Future Earth for one yearly meeting of the Scientific Steering Committee while resources for the International Project Office (IPO) and the Nodal offices are provided by their host institutions. Funding for activities is raised by the organizers of activities.

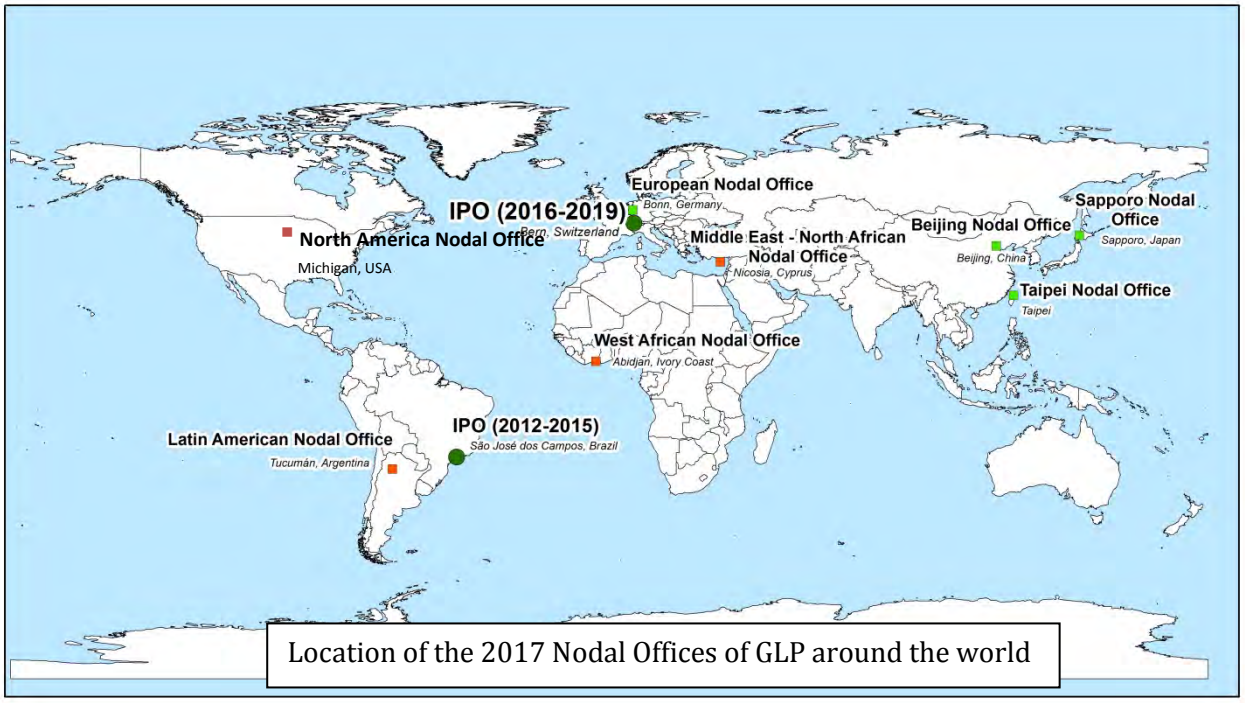
The ***International Project Office (IPO)*** is concerned with the day-to-day management of the project and coordination of activities initiated in the community. The IPO is also the contact point for the community and liaison with the Future Earth initiative. The IPO is responsible for community building, dissemination and the initiation of activities in the programme that contribute to the GLP objectives and research priorities. The IPO will consult the SSC on decisions that affect the functioning, scope or activities of GLP.

The ***Scientific Steering Committee (SSC)*** consists of both researchers and representation of practitioners in the field of land systems covering as broadly as possible the different thematic areas and regions of GLP involvement. SSC members are recruited through open calls for involvement for 3 year terms that may be extended by a second term and are expected to dedicate considerable time towards initiating activities that contribute to the GLP objectives. The SSC is responsible for agenda setting and approval of new initiatives such as nodal offices and the thematic scope of Open Science Meetings. Annex 3 provides a detailed list of the expected contributions of SSC members as part of the nomination procedure.

3 Community

The GLP has several mechanisms for community engagement described below. These mechanisms are intended to formalize initiatives taken within the community or initiated by the SSC in able to monitor progress and make these initiatives visible on the website and other dissemination channels. Any person belonging to the land system science community can propose or initiate activities after talking to the SSC or IPO and active participation and initiatives are strongly encouraged.

3.1 Nodal offices



Location of the 2017 Nodal Offices of GLP around the world

Within the GLP community the Nodal offices have allocated resources to contribute to the objectives of the GLP with either a regional or thematic focus or combination of these. They aim to organize the GLP community within a region or specific focus area and organize networking, synthesis or agenda setting activities within their region or thematic area that go beyond the activities of regular (collaborative) research projects. In contrast to working groups, as described below, Nodal offices combine a number of activities such as the organization of regional/thematic workshops and conferences, synthesis papers, books or special issues and other activities aligned with the overall objectives of GLP. Nodal offices have raised funds to ensure that there is a dedicated staff member available for the office and for conducting the activities. Nodal offices are approved by the GLP SSC based on an activity plan for periods of 3 years that may be prolonged upon evaluation. A proposal for establishing a nodal office is send to the IPO and reviewed by at least two SSC members. Nodal office directors are invited to participate in the yearly SSC meetings. odal offices are listed on the GLP website. The terms of reference and application procedure for nodal offices is indicated in Annex 1. Annex 2 presents the list and contact details of the nodal offices per 2017.

3.2 Working groups

Community members are encouraged to actively engage in initiating and organizing activities that contribute to the GLP. Activities may include the organization of workshops that address GLP science priorities, summer schools, stakeholder workshops, journal special issues, the development of land system science (collaboration) tools and many other activities. A working group that undertakes such an activity should be based of participants from more than one institution and country and the activities should be more integrative than those normally conducted within a normal research project. Examples of GLP working groups are those working on the development and implementation of the GLOBE (globe.umbc.edu) collaboration tool for land change science case-study synthesis or the working group

organizing a workshop on the theme of 'Land Use and Conflict'. Working groups should aim at clear deliverables within a two-year period and are approved, based on a simple proposal, by the IPO for a two-year period. In case of doubt the IPO will have the proposal reviewed by 2 SSC members. A template will be made available. Working groups will be listed on the GLP website. The IPO will make half-yearly enquiries on the progress obtained in the working group and may request once a year a contribution of the working group for the newsletter. Working groups should make the results available for dissemination to the larger GLP community. A funded project with clear synthesis or agenda setting objectives may also be labelled as a working group if the anticipated activities and outcomes go beyond those of a normal research project in terms of its synthetic nature or global relevance. Establishing such projects as a working group replaces the formerly used endorsement of individual projects. Working groups should take an effort to engage young scholars.

3.3 Registration

GLP will implement a simple, voluntary, registration tool to subscribe to the GLP mailing list which is used to send around the electronic newsletter with announcements on GLP related activities and opportunities. During registration it is possible to indicate if name and affiliation are listed together with key expertise on the GLP website to assist the community in building (international) partnerships. Registration is open and voluntary and nobody is excluded from participating in GLP activities.

4 Activities of GLP

4.1 Newsletters/e-news

The IPO is responsible for issuing regular (in principle monthly) digital newsletters that contain announcements of GLP community relevant activities (such as conferences and workshops), relevant vacancies and may also highlight publications. The policy for highlighting publications follows the attribution of the work to GLP and the broader interest for the GLP community. Therefore, requests for highlighting a publication in the digital newsletter will only be awarded if the publication mentions, as part of the acknowledgements, that the publication contributes to GLP or 'contributes to the GLP science plan'. Furthermore, the publication should be either providing a synthesis of GLP relevant topics, describe a new relevant dataset relevant to land system science or be agenda setting. Regular research papers will not be highlighted in GLP newsletter.

Furthermore, the IPO will, either digitally or in printed format, collect short articles of general interest or provide special issues of the newsletter on specific themes. Such thematic newsletters with articles will be prepared 1 or 2 times per year.

4.2 Open science meetings

At intervals of 2 to 4 years GLP aims at organizing Open Science Meetings for the entire GLP community. Open Science Meetings aim to be a place where the GLP community can exchange progress on science, be inspired by debates on advances and the links between science, policy and practice and make contact to other GLP community members. Such meetings are organized by a local hosts that takes care of all

logistic arrangements and has financial responsibility. The SSC will, in consultation with the local host, assemble a scientific committee for the OSM that is responsible for the calls for sessions and abstracts, the review of sessions and abstracts and the programme scheduling. Keynotes are selected by the scientific committee in consultation with the local host. The IPO will oversee the process and will act as a liaison between organizing and scientific committees.

4.3 Regional science meetings

Regional science meetings may be organized by the Nodal offices or by other community members from within the region (forming a working group to organize such a meeting). The objectives are similar to those of the Open Science Meetings but focused on a specific region. The IPO needs to be informed about the regional science meeting and will help in disseminating the call for abstracts and announcing the meeting.

4.4 Synthesis and agenda setting workshops

Synthesis and agenda setting workshops are activities centered on a specific objective that contributes to the advancement of land system science. Typical outputs of synthesis workshops are high-level scientific papers or meta-studies and theoretical contributions to land system science. Synthesis workshops can be proposed and organized by the IPO, SSC members, and Nodal offices in coordination with IPO and SSC. Also regular GLP community members can initiate synthesis and agenda setting workshops. Where relevant to GLP these may be labelled as 'GLP endorsed workshops' after informing the IPO. Requests for assistance in the organization of such workshops by the IPO or SSC members may be made. GLP endorsed workshops should provide, directly after the workshop, a short article on the workshop proceedings for the digital newsletter to the IPO. The IPO is willing to issue letters of support for acquiring funding for such workshops. The IPO does not have capacity for providing financial support to such workshops.

4.5 Tool development and data platforms

Software, databases, apps or other tools that may be useful to the GLP community may be developed under endorsement of GLP. The GLP IPO can be requested for a letter of support when applying for projects aiming to develop such tools that would become available for the larger community. On the GLP website links may be added to tools that are useful for the larger community, examples include the GLOBE case-study collection tool and the Geo-Wiki crowdsourcing tool.

4.6 Supporting land system research projects

Although GLP no longer provides official endorsement of individual research projects the IPO is willing to issue a standard letter to support a project application stating that 'the proposed research addresses the priority issues identified in the GLP science plan'. Individual applicants can contact the IPO for such a letter by indicating how the project will contribute to GLP and what activities/data/results will be made available to the GLP community during the project. The IPO will decide on the fit of the proposed research with the science plan and, if necessary, consult with an SSC member to decide if a support letter will be issued.

4.7 Supporting the sharing and availability of Land System datasets

GLP acknowledges the importance of sharing data on land systems, including data on underlying drivers and impacts of land system change. Therefore, (links to) new datasets may be announced in the digital newsletter or on the website. GLP supports an open sharing strategy of data and research tools and will strongly promote the open availability of data and software.

Annex 1.

Terms of reference Global Land Programme Nodel/Regional offices

The objectives of the Global Land Programme are to serve the Land System Science community and the broader Global Environmental Change science, policy and practitioners communities by providing:
-a joint, open, platform open for anyone to contribute to the integration, dissemination and sharing of knowledge on land systems
-the organization of Open Science Meetings, Workshops and other events to share and discuss land science research advances
-activities aimed at the synthesis of the state-of-the-art knowledge on land system science and the identification and priority setting of new challenges for land system science research.
-network activities to enhance global and regional collaboration between scientists, and between scientist, policy makers and other stakeholders.
More information on the activities of the Global Land Programme can be found at http://www.glp.earth

The GLP has an international Scientific Steering Committee (SSC), an International Project Office (IPO) and several nodal/regional offices. Together these coordinate and organize the activities mentioned above.

Within the network the Nodal/Regional offices have the objective to:
-organize regional/thematic events that contribute to the Global Land Programme objectives and that have a wider scope than a standard research project activity (i.e., simply labelling ongoing research project activities as GLP activities is not intended).
-organize network activities in the region/thematic area by maintaining a mailing list (that includes at least 100 participants outside the host institute and across multiple countries in the region) while expanding the list by engaging more interested people in the region. Either a regional newsletter of GLP news is send out or the mailing list is shared with the IPO for the normal newsletter in which also regional/thematic activities are reported.
-conduct synthesis activities on the theme/region by organizing review papers/books and other events that bring together multiple authors from various institutions across the region
-contribute to outreach and dissemination, e.g. by organizing courses, summerschools or science-policy-stakeholder communication
-contribute to the yearly SSC meetings (at costs of nodal office)
-other innovative ideas that contribute to GLP activities are welcome.

The nodal office commits itself to assure sufficient funding to have at least 0.5 fte medior/senior staff member working exclusively for the nodal office to conduct the above mentioned activities. The nodal office will raise funds to organize the planned activities.

To be eligible to host a nodal office a bid is submitted to the IPO of GLP describing:

1. The host institute and the reasons why the host institute is suited to host a nodal office
2. The thematic/regional scope of the office and why this office would make a good contribution to GLP
3. The activities proposed to be conducted within the coming 2 years by the nodal/regional

office with a clear description of the activities and possible outcomes
4. The ways in which the office would be funded

Within 2 months upon receiving the bid the SSC/IPO will make a decision and grant the host institute to host a nodal office for two years. After two years a bid for prolongation with a new activity plan can be submitted for approval by the SSC after evaluating the activities of the nodal office over the previous period. Each year the SSC will evaluate all nodal offices and has the right to stop a nodal office if activities have been insufficient.

Annex 2

Nodal offices (per 2017)

Based at	*Web*	*Focus*	*Coordinator*	*Personal Web*	*e-mail*
North American Nodal Office					
Center for Global Change and Earth Observations, Michigan	-	a. Social-ecological (or coupled human and natural) systems b. Water-Energy-Food Nexus c. Co-design, co-implementation, co-production of knowledge d. Africa (e.g., Kenya, Madagascar, Malawi, Tanzania) e. Asia (e.g., Mongolia, China, Lower Mekong Countries, Uzbekistan, Kyrgyzstan) f. North America (e.g., the US Midwest) g. South America (e.g., Brazil, Colombia)	William J. McConnell	http://www.globalchange.msu.edu/about/fac-staff/profile-bill-mcconnell.html	mcconn64@msu.edu
Middle-East-North-Africa (MENA) Nodal Office					
The Cyprus Institute	-	Research at the Energy, Environment and Water Research Center (EEWRC) of The Cyprus Institute is focused on: Climate change and impacts, mitigation adaptation strategies; renewable energies and energy efficiency in the built environment, environmental monitoring and observations; water scarcity and the management of water and natural resources, sustainable development.	Manfred A. Lange	http://www.cyi.ac.cy/index.php/eewrc/about-the-center/eewrc-our-people/itemlist/user/65-manfred-a-lange.html	m.a.lange@cyi.ac.cy
NODAL OFFICE OF THE GLOBAL LAND PROJECT (GLP) FOR WEST AFRICAN REGION (GLP-NOWA: GLP's Nodal Office for West Africa)					
Scientific and Innovation Pole (SIP), University Felix Houphouet Boigny (UFHB), Abidjan, Côte d'Ivoire		Research and training on land systems and related discipline (Climate Change, Biodiversity and lanscape ecology) at the national and regional levels, on behalf of the GLP and Future Earth.	Souleymane Konaté		skonate2@yahoo.fr or konatesoul_sn@una.edu.ci
Latin American Nodal Office, Tucumán, Argentina					
Universidad Nacional de Tucumán – CONICET, Tucumán, Argentina		Latin American land use change in relation to globalization; environmental services in land use frontiers and transitional zone; land use efficiency	H Ricardo Grau		chilograu@gmail.com
European Nodal Office - ELI, Germany					
European Land-use Institute (ELI), Center for Development Research (ZEF), University of Bonn, Germany	http://european-nodaloffice.eli-web.com/	land management, land use planning and land use policies	Christine Fürst		cfuerst@uni-bonn.de
Taipei Nodal Office, Taiwan					
National Taiwan University (NTU)	http://homepage.ntu.edu.tw/~yplin/Scales-Taiwan.htm	(1) Dynamics and resilience of social-ecological systems (SES) through systematic analysis of social-ecological feedbacks; (2) Vulnerability and residence on critical lands; (3) Modeling and analysis tools for land-use projects (4) Official partners of the European Union FP7 Securing the conservation of biodiversity across administrative levels and spatial, temporal, and ecological scales-SCALES Project	Rita Yam		ritayam@ntu.edu.tw
Sapporo Nodal Office, Japan					
Hokkaido University	http://www.teiwatanabe.com/index-e.html	vulnerability, resilience and sustainability of land systems	Teiji Watanabe	http://www.teiwatanabe.com/index-e.html	twata@ees.hokudai.ac.jp
Beijing Nodal Office, China					
Institute of Geographic Science and Natural Resources Research, CAS	http://english.igsnrr.cas.cn/pe/ps/201506/t20150630_149472.html	Land use and ecosystem interactions.	He Qing Huang		huanghq@igsnrr.ac.cn

Annex 3

Nominations for Global Land Programme Scientific Steering Committee

The **Global Land Programme (GLP)** is a core project **Future Earth** (www.futureearth.info). GLP represents the community of scientists working on land systems science and takes incentives to synthesize knowledge in the field, organize platforms for interaction between community members through workshops, conferences and web resources, and plays a role in setting the science agendas for emerging land system research themes to better integrate the understanding of the coupled human-environment system.

The activities of GLP are initiated, stimulated and overseen by an international **Scientific Steering Committee (SSC)**. The GLP SSC represents a broad spectrum of disciplines and nationalities, and includes both mid-level and senior scientists. SSC Members are selected based on their standing in the international scientific community and their willingness to serve the community by taking leadership in organizing activities, with due consideration to regional, gender and disciplinary balances. *The continuing success of GLP relies on the input of these people*, and in seeking nominations we are looking for scientific excellence and a *high level of commitment to GLP goals and activities*.

The general tasks of a GLP SSC are as follows:

- Advise and work together with the GLP **International Project Office (IPO)** in carrying out scientific synthesis research across the field of land system science. This may include activities as, for example, the editing of special issues, initializing high impact synthesis papers, initializing or contributing to working groups and organizing workshops.
- Serve as a channel of communication and promotion of the project between scientists working in different regions or on various aspects of global change. It is expected that SSC Members promote GLP in their institutions and network community, including the promotion of land system research with funding agencies.
- Explore and promote new directions of land system science, responding to societal priorities, where appropriate in close collaboration with stakeholders (co-design).
- Support the GLP IPO in collating information on national and regional programmes of global change research to ensure collaboration and effective use of existing knowledge on different aspects of land system research.
- Planning new and emerging research and science-policy activities that contribute to the overarching objectives of GLP; acting as a liaison to GLP workshop organizers; representing GLP at international meetings; planning, organizing and hosting GLP workshops and meetings.
- Make a contribution for acquiring funding for GLP initiated activities such as workshops.

- Establish and oversee GLP stakeholder engagement activates to implement a co-design approach for future land system research.

In addition, a GLP SSC Member is expected to:

- Provide long-term guidance to the GLP IPO and Nodal Offices, which include being responsive to requests, taking leadership on activities and providing inputs to communications of GLP.
- Review working group or nodal office proposals when requested by the IPO or Future Earth.
- Make an active contribution to the yearly 3-days SSC meeting.

The term for the GLP Scientific Steering Committee Membership is normally three years, and may be renewed for additional three years. Nominations to the SSC can be made by individuals and will be considered by the current GLP SSC and IPO, where needed in consultation with the Future Earth secretariat. When selected, the new SSC members will then receive a formal appointment letters.

GLP receives a small amount of funding to cover travel and accommodation for all SSC members during the yearly SSC meeting from Future Earth. It is, however, not possible to cover daily allowances during SSC meetings (but food will be provided). In addition, GLP has a small IPO staff with some resources to support dissemination activities and maintain network communication. For all other activities SSC members have to secure funding in close collaboration with the IPO. SSC membership relies on voluntary contributions of its members.

Candidates can nominate themselves by sending the filled-in GLP SSC Nomination Form including a short CV (max. 5 pages) by email to the GLP IPO within 6 weeks after the publication date of this call for nominations.

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