3rd UNCCD Scientific Conference

9-12 March 2015, Cancún, Mexico

Impulse Report

Climate change and desertification: Anticipating, assessing & adapting to future change in drylands

Written by **Mark S. Reed**, Birmingham City University
and **Lindsay C. Stringer,** University of Leeds,
with the contribution of an **international panel of experts**
(see the complete list of authors on page 2)

March 2015

The Scientific and Traditional Knowledge for Sustainable Development (STK4SD) Consortium

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Climate change and desertification: Anticipating, assessing & adapting to future change in drylands

Impulse Report for the **3rd UNCCD Scientific Conference** on:

"Combating desertification/land degradation and drought for poverty reduction and sustainable development: the contribution of science, technology, traditional knowledge and practices"

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Foreword

Drylands have always been subject to intra- and inter-annual fluctuations of climate conditions, with important consequences for ecosystem function and productivity. Humans who depend on drylands for their livelihoods have coped with these fluctuations through such risk-averse responses as migration, extensive agricultural practices, and collective tenure of land, water and other natural resources. These coping responses evolved over hundreds and even thousands of years of inter-generational learning, which is why traditional knowledge holders are invaluable to discussions on development or restoration of sustainable land use systems. Today, drylands are particularly prone to land degradation and desertification due in large part to practices that conflict with traditional knowledge, including excessive use of their natural capital (biodiversity, soil, water, etc.), insecure land tenure, and failing incentives or inadequate policies for sustainable land management. Climate change projections indicate that there will be additional stresses on these systems. This makes it all the more likely that, without the use of both modern scientific and traditional knowledge to develop sustainable land use approaches, human activities will soon exhaust the capacity of drylands to regenerate.

Just as human activities are preeminent in triggering land degradation or desertification in drylands, local action by communities that builds upon science and traditional knowledge can change the drivers of degradation. The implication is that solutions to land degradation and desertification have human roots that require societal answers. Environmental crises tend to be more acute in dry areas, where local societies often need access to external resources to secure their livelihoods. Local societies' response to environmental crises can occur in many forms, and include changes in demographics, migration, market distortions, consumer consumption habits, land tenure policies, and political tension. Additional stresses from climate change will likely disproportionately affect dryland regions, where environmental crises are already at critical stages, further threatening basic ecosystems services such as food and water, and placing even more pressure on the land's capital, which will lead to further loss of land productivity. Political tensions aside, land degradation and its linkages to climate change are relevant to the rest of the world, for while climate change will not lead to more arid conditions throughout, the combination of higher temperatures, greater rainfall variability, and more intense rainfall and drought events will likely decrease the sustained flow of ecosystem services in regions not traditionally viewed as dry, with real global consequences to human wellbeing.

In the literature, climate change is analyzed prior at global and regional level over long period of time, whereas DLDD refers to much shorter time processes. Many findings suggest that DLDD may extend gradually from localized to larger areas, by halos suggesting that this process is more context-specific or locally anchored. As stated in the report, "*although much is known about the processes and effects of land degradation and climate change, less is understood about the links between these two processes. Less still is known about how climate change and land degradation processes are currently interacting in different social-ecological systems around the world, or how they might interact under different scenarios in the future (…).* [The complexity of feedbacks] *may give rise to a number of potentially important but possibly unforeseen impacts on ecosystems and populations in regions affected by desertification, land degradation and drought (DLDD). Moreover, our poor understanding of feedbacks among these processes limits our capacity for anticipatory adaptation. There is an increasingly urgent need for research to elucidate these links, so that land users and policy-makers can respond in timely and effective ways*." At the local level, since the drivers of climate change are totally decoupled from local action, and no actions of the land user can alter the direction of climate change, the only option is to adapt to the consequences of climate change. This report emphasizes identification of the interfaces and development of synergies between DLDD and other major environmental challenges such as climate change and biodiversity. It develops conceptual frameworks linking land degradation, climate change and biodiversity to ecosystem services that benefit human well-being, and the vulnerability of these services without human intervention. As such, it feeds into ongoing global discussions intended to develop a conceptual framework and indicators that target activities and mandates of the three Rio Conventions (the United Nations Convention to Combat Desertification – UNCCD, the United Nations Framework Convention on Climate Change – UNFCCC, and the Convention on Biological Diversity – CBD). The report sheds light on current knowledge, and raises key questions about the anticipated effects of climate change on land degradation and desertification, with a view towards supporting pro-active adaptation in specific regions, especially in drylands. The report also aims to strengthen international science-policy actions meant to combat land degradation and desertification in a world facing climate change, biodiversity loss and decline in ecosystem services. The need for societies to adapt to DLDD is not restricted merely to dryland agro-ecosystems, but successful adaptation mechanisms in these drylands can serve not only to combat current land degradation and desertification in a vast and fragile region of the world that is home to most of its poor, but as well prevent further extension of these processes to other areas. The report rightly emphasizes the role of local knowledge, and promotes adjusting sustainable management principals to local specificities, such as geographical or cultural features.

The report was commissioned to inform discussion and debate at the 3rd UNCCD scientific conference, which will be held during the Fourth Special Session of the Committee on Science and Technology (CST S-4) of the UNCCD, in Cancún, Mexico, from 9th to 12th March, 2015. The final published version has taken into account several comments from an expert panel in reaction to an initial draft provided by Professors Mark Reed and Lindsay Stringer. The report is not intended to exhaustively cover all issues to be presented and discussed, but rather to initiate and guide the rich and diverse discussions to be held among multiple disciplines and stakeholders during the conference. One of the major challenges facing participants and delegates is the development of new scientific insights and recommendations to policymakers on the assessment of vulnerability of social-ecological systems to climate change, and current and future capacities to adapt. This report provides initial answers and additional questions in relation to each of the three major challenges that the conference will address: diagnosis of constraints, responses, and monitoring and assessment, by taking an interdisciplinary and integrated approach to climate change and land degradation as interlinked concepts that have both biophysical and human drivers, impacts and responses.

The 3rd UNCCD Scientific Conference Scientific Advisory Committee

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Acronyms

CBD	Convention on Biological Diversity
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
CRIC	Committee for the Review of the Implementation of the Convention
CST	Committee on Science and Technology (of the UNCCD)
DDP	Dryland Development Paradigm
DLDD	Desertification, Land Degradation and Drought
FAO	UN Food and Agriculture Organisation
GHG	Greenhouse Gas
GIS	Geographical Information Systems
GLASOD	Global Assessment of Soil Degradation
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ITPS	Intergovernmental Technical Panel on Soils
LADA	FAO's Land Degradation Assessment in Drylands programme
LDN	Land Degradation Neutrality
LDRA	Land Degradation and Restoration Assessment
MA	Millennium Ecosystem Assessment
N_2O	Nitrous Oxide
SDGs	Sustainable Development Goals
SLM	Sustainable Land Management
SPI	Science-Policy Interface
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UN-INWEH	United Nations Institute for Water, Environment & Health
WOCAT	World Overview of Conservation Approaches and Technologies

Executive Summary

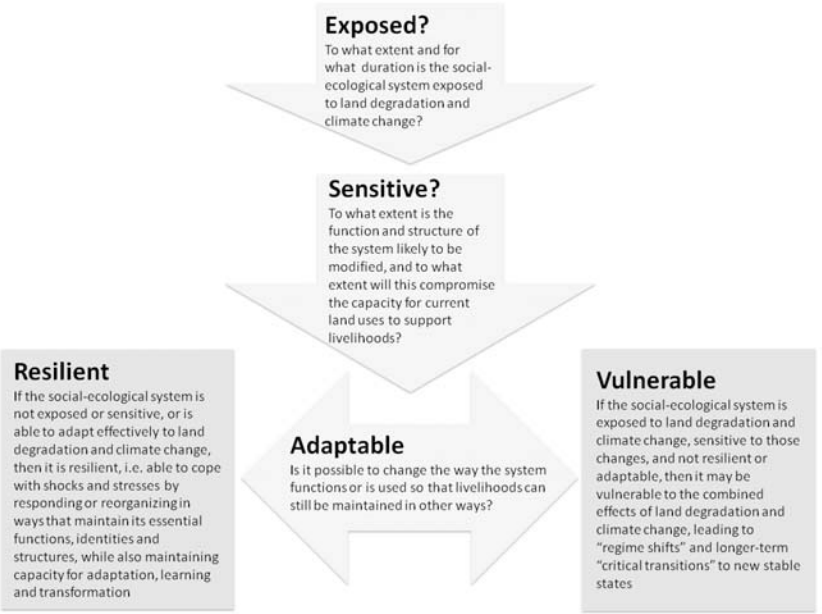
Climate change and land degradation are closely interlinked and most acutely experienced by ecosystems and resource-dependent populations in regions affected by desertification and drought. It is essential to understand and address the dual challenges of climate change and land degradation if we are to meet targets such as the proposed Sustainable Development Goals, tackle poverty and address many of the most pressing environmental challenges of the 21st Century.

Although much is known about the processes and effects of land degradation and climate change, less is understood about the links between these two processes. Less still is known about how climate change and land degradation processes are currently interacting in different social-ecological systems around the world, or how they might interact under different scenarios in the future. The numerous and often contradictory feedbacks inherent in both processes, operating differently in different habitats and under different forms of land management, means that links between climate change and land degradation are highly complex and difficult to predict. This may give rise to a number of potentially important but possibly unforeseen impacts on ecosystems and populations in regions affected by desertification, land degradation and drought (DLDD). Moreover, our poor understanding of feedbacks among these processes limits our capacity for anticipatory adaptation. There is an increasingly urgent need for research to elucidate these links, so that land users and policy-makers can respond in timely and effective ways.

This impulse report is designed to inform debate at the 3rd UNCCD scientific conference, which will be held during the 4th special session of the Committee on Science and Technology (CST S-4) of the UNCCD. It synthesizes current knowledge and raises questions in relation to each of the three major challenges that the conference will address: 1) diagnosis of constraints; 2) responses; and 3) monitoring and assessment. The report considers how land users, the policy and research communities, and other stakeholders can work together to better anticipate, assess, and adapt to the combined effects of climate change and land degradation. It also considers the behavioural, governance and policy changes that may be needed to facilitate effective adaptation at national and international scales. It takes an interdisciplinary and integrated approach to climate change and land degradation, treating them as interlinked concepts that have biophysical and human drivers, impacts and responses.

Conceptual and methodological frameworks

There are many ways of conceptualizing the links between climate change and land degradation, and how vulnerable ecosystems and human populations around the world might be to these interactions. Broadly speaking, there are three factors that are likely to influence vulnerability, and these form the basis for the conceptual framework presented in the figure below.



Conceptual framework for assessing the vulnerability of ecosystems and populations in regions affected by DLDD to land degradation and climate change (credit: the authors).

Exposure: considers the degree, duration and extent to which the ecosystems and populations are exposed to land degradation and climate change.

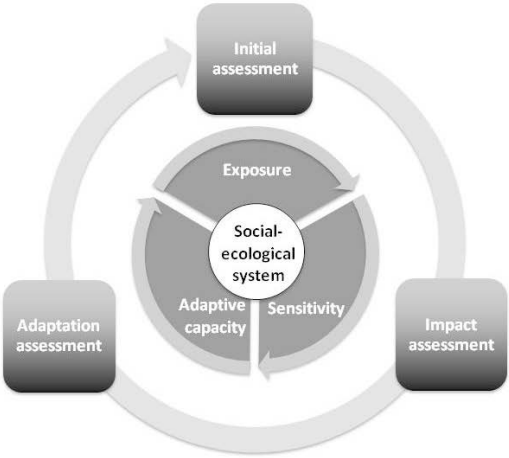
Sensitivity: if the system is exposed to land degradation and climate change, then its sensitivity can be defined as the extent to which the function and structure of ecosystems are likely to be modified by the changes they are exposed to, and the extent to which this will compromise the capacity for current land uses to support livelihoods and deliver essential ecosystem services.

Adaptability: if the system is exposed and sensitive to the effects of land degradation and climate change, then it is necessary to assess the adaptive capacity of the system, i.e. the extent to which it is possible to change the way the system functions or is used, so that livelihoods can still be maintained in other ways. Adaptation may take the form of: coping (short-term, immediate responses to reduce risk from climate variability and drought to livelihoods);

adjustment (more deliberate planned change, representing adaptation to longer-term climate change and land degradation); and/or transformation (fundamental changes to either system function or political economic structures, often involving behavioural change, leading to the establishment of new long-term social-ecological states). Many apparent adaptations to climate change and land degradation may in fact be maladaptive, if they are not sustainable or increase vulnerability.

If the social-ecosystem is exposed, sensitive and unable to adapt effectively to the effects of land degradation and climate change, then it will not be able to maintain its essential functions, identities and structures, or its ability to adapt to future changes, and it will become **vulnerable** to land degradation and climate change. This may lead to significant changes in the social-ecological system, (sometimes referred to as "regime shifts" and "critical transitions") when these shifts lead to new long-term stable states. On the other hand, if the system is not exposed or sensitive, or is able to adapt effectively to the effects of land degradation and climate change, then it would be considered **resilient**.

To take action to reduce vulnerability and enhance resilience to climate change and land degradation, the methodological framework in the figure below proposes:



A methodological framework (outer circle) for assessing the vulnerability (segmented middle circle, based on conceptual framework in Figure 1) of ecosystems and human populations to the combined effects of climate change and land degradation.

Initial assessment: evaluation of the degree to which the stocks of natural capital, ecosystem processes and flows of ecosystem services are *exposed* to climate change and land degradation. For example, exposure to climate change may be assessed from climate records and predictive models. Exposure to land degradation (whether actual or the risk of degradation) can be assessed via: i) direct measurement (e.g. of soil fertility and productivity); ii) indirect measurement via indicators (e.g. soil erosion features and vegetation cover); and iii) indirect measurement and projections via process-based computational

models, which would typically combine a range of indicators and be calibrated and validated via direct measurements. At local scales, such assessments may combine qualitative social science methods (e.g. semi-structured interviews, oral histories and ethnographic methods) with quantitative methods based on indicators (e.g. GIS mapping or process-based modeling of the effects of land degradation and climate change on land cover, populations of animals and plants, and livestock populations). At regional and international scales, assessments may be based on expert opinion (e.g. the Global Assessment of Soil Degradation – GLASOD), or process-based models (e.g. of future agricultural yields or forest cover)

Impact assessment: To understand the *sensitivity* of ecosystems and human populations to the combined effects of climate change and land degradation, it would be necessary to know the extent to which changes in air and soil temperature, precipitation (total amount, intensity/erosivity and patterns), humidity, atmospheric CO_2 concentrations and evapotranspiration rates are likely to affect land degradation processes such as soil erosion, and so compromise the supply of ecosystem services and the livelihoods and human well-being that depends on them. Many of the same models used to assess degradation severity, extent and/or risk may be used or adapted to assess these links. However, given the approximate nature of model outputs in such complex social-ecological systems, there are also strong arguments for including evidence based on locally-held knowledge of how these systems work. In particular, sensitivity might be non-linear, particularly with regards to extreme events. Conversely, the effects of land degradation on climate should also be considered: climate patterns are strongly influenced by vegetation cover, on the one hand, and, on the other hand, land degradation affects the organic carbon and nitrogen cycles, altering emissions of carbon and nitrogen from soils to the atmosphere and as such affecting the climate itself.

Adaptation assessment: this considers the potential and feasibility of *adaptive capacity* to reduce the sensitivity of the system to the changes it is likely to be exposed to, and provides specific recommendations to planners and policy-makers. Using social science methods, it may be possible to identify future adaptations based on how local communities have adapted to previous changes in the productive potential of the land or climate variability. Process-based models may provide insights into the future pressures likely to arise from land degradation and climate change, and help evaluate and refine adaptive options. Adaptation assessments typically require trans-disciplinary approaches, including a combination of experimental (field and laboratory) research, modelling and multi-level stakeholder engagement.

An initial assessment is done to assess exposure of the social-ecological system to climate change and land degradation, followed by an impact assessment to consider sensitivity of the system to the drivers of change that it is exposed to, and an adaptation assessment to identify adaptive options.

Diagnosis of constraints

Interactions between climate change and land degradation are likely to affect a range of different ecosystem functions and the consequent ecosystem services those systems can deliver. Provisioning services are particularly affected by climate change and land degradation, with consequent impacts on food production, livelihoods and human wellbeing. Besides provisioning services, land degradation affects other important services as well, not in the least regulating services like carbon sequestration. Moreover, there is an important feedback mechanism in carbon sequestration in soils and vegetation since loss of soil organic carbon and subsequent increased emission to the atmosphere increases climate change itself. Soil carbon loss then aggravates the negative impacts from climate change, since the soils water holding capacity and its potential to buffer periods of drought and floods will decrease. Under expected climate change, buffering water resources will become of vital importance, and so will maintaining or increasing soil organic matter content. It is difficult to anticipate how specific ecosystems and human populations are likely to be affected by climate change and land degradation, given the many uncertainties and feedbacks. However, it is possible to identify a number of key vulnerabilities to the combined effects of climate change (and subsequent increased climate variability) and land degradation at a more general, global level:

- In many parts of the world, climatic variations are recognized as one of the major factors contributing to land degradation, impacting on agricultural systems performance and management. The climate resources and the risk of climate-related or induced natural disasters in a region must be known in order to accurately assess sustainable land management practices. Only when climate resources are paired with management or development practices can land degradation potential be assessed and appropriate mitigation technologies developed (Sivakumar & Ndiang'ui, 2007).

- Exposure to climate change varies globally, with different regional projections of changes in temperature, rainfall and sea-level rise. Likewise, different regions are exposed to different types and levels of land degradation, and it is impossible to assess the vulnerability of populations and ecosystems to either climate change or land degradation solely on the basis of these differing levels of exposure. However assessments of current and likely future exposure to climate change and land degradation can provide an important basis for assessing the sensitivity of social-ecological (including economic) systems to those changes, as well as possible environmental, social, economic, political and cultural impacts. Many areas already experiencing land degradation and drought are likely to be exposed to potentially damaging interactions with climate change, if extreme weather events such as severe droughts or heavy rainfall events exacerbate wind or water erosion and contribute towards further reductions in or changes to biomass, or physical and chemical degradation of the land.

- The full extent to which exposure to risks from climate change and land degradation lead to negative impacts on ecosystems and human populations, can only be understood by considering their relative sensitivity to these risks.
- Further research is needed to understand how soil degradation processes such as water and wind erosion and physical (e.g. compaction and sealing) and chemical (e.g. soil organic matter loss and salinization) degradation might interact with changes in soil temperature, precipitation (amount, intensity and patterns), humidity, atmospheric CO_2 concentrations and evapotranspiration rates. Interactions between these soil variables and other components of land such as above ground biomass, water and biodiversity also need further research.
- Given the high temperatures and limited rainfall already experienced in drylands, where land degradation is known as desertification, these regions are likely to be particularly sensitive to the effects of climate-induced changes in temperature and moisture, combined with degradation-induced reductions in soil organic matter, biomass (both above and below ground) and soil fertility.
- These processes may in some cases be self-reinforcing, leading to feedbacks between climate change and land degradation. For example, feedbacks can occur when land degradation, via the loss of terrestrial carbon stores from soils and vegetation, leads to climate warming, or when the albedo effect of degradation-induced reductions in vegetation cover leads to climate cooling or other local climatic effects. Similarly, the dual effects of climate change and land degradation may have impacts on biodiversity that may further exacerbate land degradation, compromise ecosystem functioning and the provision of ecosystem services, consequently limiting capacities to adapt to climate change.
- Assessing the sensitivity of ecosystems and human populations to climate change and land degradation requires scientific, locally-held and other forms of knowledge. By definition, land degradation must be assessed in relation to the objectives of those using the land, and locally-held knowledge (including indigenous and traditional knowledge) is usually necessary to appreciate the full effects of climate change on livelihoods and human wellbeing. However, collecting and analyzing qualitative data from local communities and other stakeholders can be time-consuming and expensive.
- In addition to considering the sensitivity of ecosystems to these processes, it is necessary to understand the sensitivity of livelihoods to the combined effects of climate change and land degradation. Climate change and land degradation have the potential to disrupt established ecological and land use systems including land cover, which in turn may lead to the failure of food and water supplies, with consequent negative impacts upon livelihoods. This may in turn limit the adaptive capacity of households when they are faced with other perturbations or stresses.

Responses

There are a number of ways to enhance adaptive capacity and retain the integrity of ecosystems whilst maintaining sustainable livelihoods in the face of the interactive effects of climate change and land degradation. For example:

- There are number of different approaches to adaptation. Adaptation can be: autonomous, reactive and planned/anticipatory; can include coping, adjustment and transformation. There are also win-win, no-regret and low-regret adaptation options.
- Adaptation needs include biophysical and natural environmental needs, social needs (which vary with location, gender, age and socio-economic status), institutional needs (to facilitate cross-scale adaptations, establish incentives and shape behaviours), and knowledge exchange needs including access to information, technology and private sector engagement.
- There are a range of barriers to adaptation, including: a lack of available options to substitute one form of capital for another (e.g. due to a limited asset base, limited agro-ecosystem capacity or limited market access); limited political capacity to enact strategies to support adaptation; a lack of institutions or high levels of institutional inertia and rigidity; lack of access to information about adaptation options (including poor agricultural extension services); a lack of awareness and available knowledge and differences in perception of problems and solutions to the impacts from climate change and land degradation by different stakeholders; or financial constraints (including lack of access to credit).
- Other barriers can be cognitive in nature, linked to a lack of perceived risk, an absence of perceived agency and a sense of powerlessness, low aspirations, or the social norms that influence behaviour within particular socio-cultural settings, or a lack of incentives or resources to change behavior.
- Maladaptation to the combined effects of climate change and land degradation may for example: increase greenhouse gas (GHG) emissions (e.g. via fossil fuel use by desalinization plants); increase polarization between rich and poor or disproportionately burden the poor (e.g. by raising the costs of water and energy or privatizing communal rangeland); lead to high opportunity costs (whether economic, environmental or social costs); and create path dependencies where communities are locked in to particular technologies or livelihood strategies that may compromise their capacity or willingness to adapt in future.
- Once these barriers have been overcome, it is necessary to evaluate potential trade-offs between adaptations, so that complementary bundles of adaptations can be implemented together, avoiding maladaptation and reducing vulnerability to both climate change and land degradation.

Various options are available for simultaneously adapting to climate change and land degradation, including:

- Cropping systems can be adapted, using agroecology or "Climate Smart Agriculture" approaches (for example through a careful use of agroforestry techniques such as intercropping with leguminous woody species to access nutrients deeper in the soil profile, whilst simultaneously reducing the effects of erosion and increasing levels of soil fertility).
- Livestock systems can be adapted, for example through enabling migratory pastoralist activities or new/modern mobile animal husbandry systems, altering stocking rates to match changes in forage/ fodder production in response to climate change and/or land degradation, and increased provision of tree shade via silvopastoral systems to reduce heat stress in livestock whilst reducing erosion rates and providing fodder during drought.
- Ecosystem-based adaptation can be developed such as restoration (e.g. wetland restoration to provide water resources for livestock and cropping systems, whilst buffering against climate-induced flood risks) and green infrastructure (e.g. green roofs, porous pavements and urban wildlife corridors to reduce soil-sealing whilst improving storm water management, reducing urban flood risk and moderating the heat-island effect).
- Sustainable land management (SLM) may be able to harness positive synergy between climate change and land degradation via changes in vegetation and soil carbon stocks. Rather than losing carbon due to land degradation, SLM can build soil organic matter and sequester significant amounts of carbon, thereby helping mitigate climate change. SLM practices also directly link to the feedback between climate change and land degradation that is mediated through losses of vegetation cover. Certain SLM technologies and practices also have the potential to mitigate biodiversity-mediated feedbacks between climate change and land degradation.
- Adaptations based on scientific knowledge alone may not be suitable for the socio-cultural context in which they are needed, and this may significantly limit uptake and effectiveness. By combining scientific understanding of adaptation options with locally-held, contextual knowledge, it may be possible to develop more appropriate adaptations. It is therefore necessary to consider the benefits and drawbacks of locally-held, scientific and other kinds of knowledge for the development of adaptations to climate change and land degradation.
- Ecosystem-based approaches and SLM have the potential to simultaneously enable adaptation to climate change and land degradation, whilst in many cases protecting or enhancing biodiversity; what may be considered 'triple-win' adaptation options. SLM can also enhance food production.

Monitoring and evaluation

Decision-makers need to be able to effectively monitor and evaluate the success of response options, to inform the refinement of adaptations and enhance the capacity of ecosystems and populations to adapt to climate change and land degradation. The following considerations can be made:

- In addition to monitoring and evaluating effects of response options on ecosystem processes and services, it is essential to assess the socio-cultural and economic context in which adaptations might be implemented, and to evaluate and monitor the effects of those adaptations on livelihoods and human wellbeing.
- There are a range of benefits and drawbacks associated with direct measurements, proxy measures (or indicators) and model-based approaches for monitoring adaptation. A combination of these approaches is most appropriate for understanding the complex interactions between climate change and land degradation and monitoring their effects. A number of hybrid frameworks and approaches now exist that can enable this combined approach.
- Given the complex and uncertain interplay between land degradation and climate change, it is difficult to predict how different social and ecological systems around the world are likely to be affected by the combined effects of climate change and land degradation. A range of predictive, visioning and scenario-based approaches (including computational, process-based modelling) may therefore be needed to enable policy-makers to better anticipate future interactions between land degradation and climate change.
- Given the types of interactions likely to occur between climate change and land degradation in the future, monitoring and evaluation needs to consider biophysical, socio-economic and cultural changes arising from adaptations. There are a number of biophysical indicators that may be monitored cost-effectively via remote-sensing at broad spatial scales. However, field-based measurements are likely to be necessary to interpret this data, and to establish cause and effect.
- Even with more detailed field-based data, it may be difficult to directly attribute changes to adaptation interventions. Socio-economic (often qualitative) data is therefore essential to triangulate and supplement biophysical data, in order to understand whether observed changes in biophysical variables may be considered to be sustainable, triggering or further worsening land degradation. Such data are also necessary to understand changes in natural capital in the context of changes in other capital assets (social, physical, financial and human capitals), to interpret the overall impact of interventions on livelihoods and wellbeing.
- Understanding, adapting to and monitoring the interactions between climate change and land degradation requires the integration of many types of knowledge, from: specific to generalized; informal to formal;

novice to expert; tacit and implicit to explicit; and locally-held to scientific knowledge. Given the number of gaps in our understanding about links between climate change and land degradation, it is essential to pool knowledge from different sources to better understand the processes involved, the likely response options and to be able to effectively monitor our actions, identifying also where new research could fill knowledge gaps and effectively complement locally-held knowledge.

- Knowledge exchange needs to be facilitated through the development of cross-institutional initiatives and mechanisms for evidence-based policy, including Science-Policy Interfaces like the IPCC, IPBES, ITPS and the newly established Science Policy Interface (SPI) of the UNCCD, as well as multi-scale assessments like the Millennium Ecosystem Assessment (MA) and the Land Degradation and Restoration Assessment (LDRA). Knowledge exchange also needs to be facilitated between local communities, civil society, the private sector and policy makers at national and international scales, and between researchers and stakeholders affected by climate change and land degradation.
- Adaptation to climate change and land degradation will require engagement with diverse and often conflicting stakeholder priorities, needs and perspectives that link to core aspects of human survival such as food and livelihood security. Participatory approaches may be able to reduce conflict, build trust and facilitate learning amongst stakeholders, who are then more likely to co-develop and implement effective adaptations in the medium and long term.
- There are certain contexts where it may not be appropriate to seek engagement with stakeholders. However, where participation is appropriate, it is important to design participatory processes to effectively represent stakeholder interests, manage power dynamics, and be relevant to stakeholder needs and priorities.

Knowledge gaps

Building on the findings of this Impulse Report, the 3rd UNCCD Scientific Conference aims to provide new scientific insights and recommendations to policy makers about assessing the vulnerability of land to climate change and current capacities to adapt. The conference is expected to help combat desertification and land degradation, and reduce the impacts of drought by: i) better anticipating the impacts of climate change on land degradation and desertification; ii) identifying sustainable and adaptive methods of using ecosystems to reduce poverty and achieve sustainable development; and iii) identifying pathways towards a land degradation neutral world. To reach these outcomes, the conference is organized around the three major challenges that this report addresses. The report has identified a number of important knowledge gaps and questions under each of these challenges.

Diagnosis of constraints

- How to best characterize and understand the vulnerability and adaptive capacities of ecosystems (in particular agro-ecosystems) and human populations in affected regions, including regions newly susceptible to the consequences of climate change?
- Which disciplines, terminology and definitions need to be brought together to enable a holistic assessment of vulnerability and adaptive capacity?
- What methodologies can capture the temporal and spatial dynamics of vulnerability and adaptive capacity? To what extent can temporal and spatial analogues be used to identify possible trajectories of vulnerability?
- How might the effects of climate change be moderated by interactions with other future social-ecological trends and drivers of change to make ecosystems and populations less vulnerable to land degradation?
- What trade-offs might exist between climate adaptation options in terms of their effects on ecosystem service provision and land degradation? Are there complementary bundles of adaptation options that can reduce trade-offs and create win-wins for both climate change and land degradation?
- How are cultural factors likely to shape adaptation options and influence their uptake, and how might the implantation of these adaptation options influence the provision of cultural ecosystem services?
- Are there currently unused ecosystem services that may be combined with existing assets to provide new livelihood options that can increase resilience to climate change and land degradation?
- At what spatial scale do vulnerability maps provide the most useful information to decision makers whilst at the same time retaining richness of information?
- What steps can be taken to deliver a more equitable distribution of adaptive capacity across different social-ecological systems? What preventative measures can be undertaken to prevent the erosion of adaptive capacity?

Responses

- How to build efficiently on available knowledge, success stories and lessons learnt, to promote implementation of better adapted, knowledge-based practices and technologies?
- How do knowledge exchange activities, social relations and power shape the way knowledge is shared and created?
- What are the challenges associated with managing knowledge exchange at different organisational and spatial scales?

- How do contextual conditions (e.g. political, structural and funding) and the way knowledge is understood and framed influence the way knowledge exchange strategies are developed within international policy programmes such as UNCCD?
- How can existing knowledge exchange platforms on climate change and land degradation be strengthened and/or new ones established through UNCCD, UNFCCC, CBD and relevant scientific, socio-economic, political and cultural networks?
- What are the processes and mechanisms through which knowledge exchange activities (at these different scales) generate beneficial outcomes for the ecosystems and human populations that are affected by climate change and land degradation?
- How do different research (disciplinary) and decision-making contexts influence the likelihood that knowledge exchange delivers beneficial outcomes for ecosystems and human populations?
- What formats should knowledge and information take to enable widespread sharing of success stories across areas with comparable conditions?
- How can scientists and other stakeholders co-evaluate and jointly communicate success stories and adaptations?
- What drives the discontinuation of sustainable practices and technologies (and what incentives and disincentives need to be in place to promote continued adoption)?
- What actions need to be taken to assess the applicability of success stories in other locations? What analyses of cultural dimensions of practices and technologies are required?

Monitoring and assessment

- What are the new monitoring and assessment methods available to evaluate the effectiveness of sustainable practices and technologies that provide improved insights on whether or how their implementation should be scaled up?
- How can we reconcile results from the monitoring of variables that change over very different timescales?
- What are the most important variables to monitor interactions and feedbacks between climate change and land degradation?
- What resolution and frequency of monitoring provides optimal information to decision makers for important variables linked to climate change and land degradation?

- How can we identify the thresholds (temporal and spatial) at which adaptive practices and technologies may become maladaptive, such that their spread should be discouraged?
- How can we use modelling and mapping approaches to prioritise spatial areas for in-depth monitoring and assessment?
- Against what criteria should the success of practices and technologies be evaluated and who should decide?
- What resources are needed and how do the costs of monitoring (action) fare against the costs of not monitoring (inaction) over short, medium and long time frames?

Conclusions

Despite a number of known uncertainties and gaps in our knowledge about links between climate change and land degradation, it is possible to draw some broad conclusions about the vulnerability of ecosystems and human populations, adaptation needs and methods needed to monitor and evaluate interactions between these processes:

- Areas already exposed to land degradation are likely to be particularly sensitive to interactions between climate change and land degradation. Drylands, where land degradation is known as desertification, are particularly sensitive. A number of potential feedbacks between climate change and land degradation can be identified, which have the potential to disrupt established ecological and land use systems, and may in turn threaten livelihoods and human wellbeing.
- Ecosystem-based approaches, and response options based on sustainable land management, have the potential to simultaneously enable adaptation to climate change and land degradation, whilst protecting livelihoods and biodiversity. These may be considered 'triple-win' adaptation options in the context of the three Rio Conventions. Importantly, many of these adaptations have the potential to help avoid significant negative feedbacks between climate change and land degradation.
- Monitoring and evaluation of interactions between, and responses to, climate change and land degradation, needs to consider effects on livelihoods and wellbeing as well as ecosystem processes and services. Biophysical assessments need to be triangulated and interpreted in relation to socio-economic data within specific cultural settings to establish cause and effect.
- Co-operation and knowledge exchange between land management, research and policy communities and participatory approaches to research and development are needed to negotiate diverse stakeholder priorities and perspectives on the effects or and responses to climate change and land degradation. However, it is important to design participatory processes to effectively represent stakeholder interests, manage power dynamics, and be relevant to stakeholder needs and priorities.

1. Introduction

Climate change and land degradation are closely interlinked and have impacts on a range of different ecosystems[1] and ecosystem processes[2], which in turn influence the provision of ecosystem services[3] to human society. These impacts are most acutely experienced by ecosystems and resource-dependent human populations in dryland regions affected by desertification, and other areas affected by land degradation and drought. Together, the acronym DLDD is often used to describe these related issues of desertification, land degradation and drought. In this report, the terms DLDD and "land degradation" are used interchangeably, implicitly including desertification in dryland contexts. These terms are defined in depth in section 1.1. Understanding and addressing the dual challenges of climate change and land degradation is essential for meeting targets such as the proposed Sustainable Development Goals (SDGs), as well as for tackling poverty and addressing many of the most pressing environmental challenges of the 21st Century. This report considers how land users, the policy and research communities, and other stakeholders, can work together to better anticipate, assess, and adapt to the combined effects of climate change and land degradation in regions affected by DLDD. It also considers the behavioural, governance and policy changes that may be needed to facilitate effective adaptation at national and international scales.

This report has an emphasis on drylands, but considers all regions affected by DLDD. Using the UNCCD definition which encompasses arid, semi-arid and dry sub-humid parts of the world, drylands occupy around 41% of the Earth's land area and are home to around a third of the world's population (MA, 2005a). The proportion of drylands thought to be affected by land degradation in the form of desertification depends largely on the definition of dryland, as well as the assessment method used, with estimates ranging between 10% (Lepers et al., 2005), 38% (Mabbutt, 1984), 64% (Dregne, 1983), and 71% (Dregne and Chou, 1992). A key recent attempt to quantify land degradation was undertaken in the Millennium Ecosystem Assessment, which suggests a figure of 10–20% of drylands are degraded with "medium certainty" (MA, 2005a), with degradation severity and extent highest in Africa and Asia[4]. At the same time as the challenge of land degradation, climate change is leading to changes in temperature, rainfall, sea level rise, increasing concentrations of carbon dioxide and other greenhouse gases in the atmosphere, and the incidence and severity of extreme weather events. A possible increase of 1–3°C in drylands by 2050 (in

[1] Defined by MA (2005a) as "*a dynamic complex of plant, animal and micro-organism communities, and the non-living environment, interacting as a functional unit*"

[2] The biological, chemical, physical, and hydrological processes through which ecosystems function, for example decomposition, dispersal and fluxes of nutrients and energy

[3] Defined as "*the benefits provided by ecosystems that contribute to making human life both possible and worth living. The term 'services' is usually used to encompass the tangible and intangible benefits that humans obtain from ecosystems, which are sometimes separated into 'goods' and 'services'*" (UK National Ecosystem Assessment, 2012)

[4] It should be noted that the MA includes hyper-arid lands in its definition of drylands

response to a doubling of CO_2 to 700 p.p.m.) would increase global potential evapotranspiration by around 75–225 mm per year. Climate models have predicted that up to 50% of the Earth's surface will be experiencing regular drought by the end of the 21st century under a "business as usual scenario", with drylands in Northern Africa, Amazonia, the United States, southern Europe and western Eurasia likely to become drier while higher latitudes of the northern hemisphere being likely to become wetter (Burke et al., 2006; Seager et al., 2007; D'Odorico et al., 2013). However, in some more temperate locations, higher temperatures may lengthen growing seasons (Cantagallo et al., 1997; Travasso et al., 1999). Elevated concentrations of CO_2 in the atmosphere would have a fertilizing effect on plants, boosting primary productivity, and would likely increase the efficiency with which plants use water to create biomass; their "water-use efficiency" (Le Houerou, 1996; Chun et al., 2013; Keenan et al., 2013; Kaminski et al., 2014). At the same time, these effects are likely to be offset by negative effects of elevated tropospheric ozone and the impacts of changing distributions of weeds, pests and diseases, as well as changes to the composition of vegetation communities.

Although much is known about the mechanisms and effects of land degradation and climate change, less is understood about the links between these two processes. Little is known about how climate change and land degradation processes are currently interacting in different social-ecological systems around the world, or how they might interact under different scenarios in future. The numerous and often contradictory feedbacks inherent in both processes, operating differently in different habitats and under different forms of land management, means that links between climate change and land degradation are highly complex and difficult to predict (Neely et al., 2009). This may give rise to a number of potentially important unforeseen impacts on ecosystems and people in regions affected by DLDD, and so limit the potential for anticipatory adaptation. There is thus an increasingly urgent need for research to elucidate these links, so that land users and policy-makers can respond proactively in a timely and effective way. Although interactions between climate change and land degradation are likely to give rise to a number of new challenges, there may also be a number of synergies between the behaviours, governance models and policy instruments that may be needed to address these issues. By bringing together locally-held[5], scientific and other forms of knowledge from around the world about the likely effects of climate change and land degradation in regions affected by DLDD, it may be possible to reduce the vulnerability of ecosystems and populations in these areas to these threats, and to build overall resilience.

This report takes an interdisciplinary and integrated approach to climate change and land degradation as interlinked concepts that have both biophysical and human drivers, impacts and responses. The report considers a number of links between climate change and land degradation, with a particular focus on human adaptations to the challenges that land degradation and climate change present in regions affected by DLDD and elsewhere. It raises questions about

[5] In this report, we use the term "locally-held" to encompass local, traditional, indigenous and lay knowledge

how to achieve an integrated approach to addressing land degradation and climate change to achieve synergies and multiple benefits. It does this in five chapters:

- Conceptual and methodological frameworks: based on a synthesis of conceptual frameworks, a methodological framework for assessing the vulnerability of social-ecological systems to land degradation and climate change is presented. Frameworks presented in this chapter are then used to structure the rest of the report.
- Diagnosing constraints: this chapter focuses on assessing the vulnerability of ecosystems and populations in regions affected by DLDD to the interactive effects of climate change and land degradation.
- Responses: this chapter considers how adaptive capacity can be enhanced to retain the integrity of ecosystems in regions affected by DLDD and maintain sustainable rural livelihoods in the face of the interactive effects of climate change and land degradation.
- Monitoring and assessment: this chapter considers how to evaluate interventions designed to enhance the capacity to adapt to climate change and combat land degradation.
- Conclusions and future research questions: this chapter synthesizes the main points in the report and sets out key questions for further discussion.

1.1 Climate change and land degradation in regions affected by DLDD: key definitions

Before attempting to understand the nature of the interlinkages between climate change and desertification, land degradation and drought, it is important to begin by providing some clarity in the definitions we are using – not least because they are all terms that are used differently by different stakeholders and researchers working within different disciplines.

1.1.1 Climate change

Climate can be thought of as a statistical description of the weather, taking into account variables including temperature, wind speed and direction, and rainfall, over a long time period. The World Meteorological Organisation usually considers this long time period to span from more than 30 years up to thousands of millions of years. Often, we think of the climate as being the conditions we experience at the Earth's surface. However, climate is really a summary of the state of the broader climate system, which includes a range of complex interactions between the atmosphere (the blanket of gases surrounding the Earth), hydrosphere (the water components present on the Earth), the cryosphere (the frozen parts of the planet) and the biosphere (parts of the Earth where life is found). The broader climate system has its own internal dynamics but is also affected by external biophysical phenomena such as volcanic eruptions on Earth, changes to the sun, including variation in solar activity and the intensity of light energy, as well as human-induced changes in

the composition of the atmosphere. This results in direct or indirect (feedback mechanisms) changes in the Earth's climate that operate on different timescales (IPCC, 2007).

According to the Intergovernmental Panel on Climate Change (IPCC, 2001), the primary international scientific body providing advice to the United Nations on climate-related challenges, climate change refers to a variation in climate that persists over decades or longer, that is *statistically significant in terms of its mean state or its variability*. Other definitions attempt to attribute climate change either directly or indirectly to human activities such as deforestation and industrialisation, which change the balance of gases in the global atmosphere (e.g. UNFCCC, Article 1). Making these links to human activities is very important for political/decision-making reasons, especially if international action is to be taken to address climate change. It presents the issue as more than just a natural occurrence, implicating humans in the problem and legitimating the need for policy action.

1.1.2 Land degradation and desertification

Land degradation is a process that can happen in any climatic zone – not just in drylands. Land degradation in drylands is sometimes referred to as "desertification". UNCCD (1994) defines desertification as "*land degradation in arid, semi-arid, and dry subhumid areas resulting from various factors, including climatic variations and human activities*". UNCCD (1994) defines land degradation as a "*reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation*". This definition of land degradation therefore refers to:

- a decline in biological and/or economic resilience (i.e. the ability of a system to maintain the structure essential to support the basic system functions (such as biological habitat, biomass production, filtering, buffering, storage and transformation of nutrients, water retention) during times of stress or perturbation (Holling, 1986; Ballayan, 2000); or
- a loss of adaptive capacity (the ability – often measured in the time it takes – for a system to regain the structure essential to support basic system functions after stress or perturbation of the land system (Kasperson et al., 1995; IPCC, 2001)).

These considerations emphasise the importance of maintaining basic ecosystem system processes, functions and services that may (or may not) include human uses. This approach to defining land degradation conceptualises land as including all elements of the biosphere at or below the earth's surface, incorporating soil, terrain, surface hydrology, groundwater, plants and animals,

human settlements and the physical evidence of past and present human activity[6]. As such, any approach to tackling land degradation needs to consider how to mitigate impacts upon underpinning ecosystem processes and prevent critical thresholds in natural capital being crossed, in addition to mitigating the consequent loss of ecosystem services. For this reason, Reed et al. (2015:472) argue that mechanisms for tackling land degradation need to be "based on retaining critical levels of natural capital whilst basing livelihoods on a wider range of ecosystem services".

The role of human activities in causing land degradation is recognised to be important. Reductions or losses of productivity and resilience can stem from soil erosion caused by wind and/or water; a loss of quality or integrity of the physical, chemical and biological or economic properties of soil and a loss or change in natural vegetation, each of which are driven largely by human activities such as land use change, mining and habitation patterns (including urbanisation). Erosion can have particularly important economic impacts on agricultural land, where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure, and the decline in organic matter and nutrient, result in a reduction of cultivable soil depth and a decline in soil fertility (Morgan, 2005).

Despite the scientific evidence that supports the role of human activities as the key driver of land degradation, some scientists also consider that climatic variation (particularly drought) and longer-term drying out, aridification or 'desiccation' (due to climate change) are important contributing factors that underpin land degradation, particularly because desiccation can cause reductions in productivity and vegetation loss. Indeed, because drylands are water limited environments, it can mean that water degradation (in terms of quality and quantity) can have substantial effects on both ecosystem integrity and human wellbeing. However, drought and desiccation on their own do not cause land degradation, although both can increase the susceptibility of land to human-induced degradation.

Once more, this highlights the role of human activity in the occurrence of land degradation. Building on this, some scientists have suggested that land degradation can only be determined in relation to the goals of the management system at the time of investigation (e.g. Turner and Benjamin, 1993), and in the context of a specific time frame, spatial scale, economy, environment and culture (Warren, 2002). This means that the same biophysical environmental change (e.g. erosion) can create different problems and have different consequences in different contexts. Warren argues that if soil erosion is "*of no consequence to production at a larger spatial scale, it does not contribute to degradation in the wider context. If it has no impact on future production, it is not degradation in the longer term. A change in a component of the environment that*

[6] The FAO (1995) defined Land as: "*A declinable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately or below this surface; including those of the near surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings. etc.)*"

cannot be accessed with present technology or finance, or is inconsequential to a present way of life, does not, per se, amount to degradation" (2002: 449). As such, the extent and severity of land degradation may vary between land users with different management goals in different places at different times and in different socio-economic, environmental, cultural and technological contexts.

In summary it can be said that land degradation: i) is a phenomenon caused by human activities and exacerbated by certain climate and topographic characteristics; ii) is characterised by changes in ecosystem processes and levels of natural capital that affect the flow of ecosystem services to society; iii) causes an effectively permanent decrease in the capacity of the land system as managed to meet its user demands; and iv) is a threat to the long-term biological and/or economic resilience and adaptive capacity of the ecosystem and the populations who depend upon it. The 'official' definition of 'land degradation' is currently being discussed by an international working group in the framework of the UNCCD.

1.1.3 Regions affected by DLDD

Land degradation and drought affect a wide range of ecosystems and populations around the world and are not phenomena that are restricted to hot, dry areas that experience desertification. For example, Iceland experiences a climate that is maritime cold-temperate to sub-Arctic, with annual rainfall of the range of 500-2000 mm. However, severe land degradation and the large-scale loss of trees, forests and other vegetation due to human activities that date back to the time of the Vikings (more than 1130 years ago) mean that vast proportions of the country's land area are severely degraded.

Building on the FAO (1995) definition of land, it is possible to identify land degradation in terms of degradation to soil, water and biomass. Water may be degraded in terms of both its quality and quantity (both in terms of surface water and groundwater). For example, changes in vegetation cover can increase the speed with which water reaches watercourses, making flows more "flashy", leading to an increase in flash flooding immediately after major rainfall events, and exacerbating low flows in the absence of rainfall. Lower vegetation cover also increases the erosive potential of rainfall, increasing sediment and nutrient inputs to stream water, reducing water quality. Unsustainable rates of groundwater extraction may lead to salt-water intrusion, making water unusable for irrigation.

Degradation of biomass (both above and below ground) can also constitute land degradation, for example as seen in bush encroachment. Biomass degradation often occurs in areas used for livestock grazing and is linked to changing species and community composition. Overgrazing can lead to the degradation of plant cover and the increase of certain species that are less palatable (or in some cases poisonous) to the main species of livestock that use the land, reducing the productive potential of the land.

Degradation of the soil component of land takes four main forms: 1) water erosion; 2) wind erosion; 3) chemical degradation; and 4) physical degradation, all eventually leading to biological degradation. The first two forms of soil

degradation result in the loss or removal of soils in one location and their deposition in another. Often erosion removes the most fertile layer of topsoil, creating a negative implication for productivity and resilience in the place where it is being eroded (though perhaps a benefit in the area in which it is deposited). Areas of the world where soils are shallow and the land is particularly sloping (e.g. the Ethiopian highlands) are at risk from this type of degradation.

Chemical degradation can take place independently of climate and relates to nutrient and organic matter losses, salinization, pollution, acidification and alkalinization. It can also trigger land use change by causing vegetation to die off. Unlike erosion, chemical degradation is not always immediately visible and may take time for the effects to be realised. This is particularly so for the degradation of groundwater. While nutrient and organic matter losses can often be remedied through the use of sustainable land management (SLM) practices such as minimum tillage and conservation agriculture, including the use of green manure and cover crops, pollution and acidification can affect areas that are far away from the original site of emission, making responsibilities for addressing those forms of degradation more difficult to attribute. Such diffuse pollution linked to e.g. sulphurous emissions during the smelting of mineral ores can even cross national borders.

Physical soil degradation is used to describe processes of compaction, sealing/crusting, subsidence and water logging and often occurs during the construction of infrastructure, when the soil is covered with materials like concrete, plastic, etc., which prevent water from percolating through the land surface. This type of degradation is particularly problematic in developed, urban areas. For example, in Europe, approximately 9% of the total land area is sealed with impermeable material (Scalenghe and Marsan, 2009), with important effects for the relationship between the land and the climate. Surface sealing alters the balance of energy transfers and temperature regulation processes, water flows and gas diffusion, affecting the ability of the soil to act as a carbon sink. It also affects the soil biota.

These examples demonstrate the close links between land and climate and highlight that land degradation can occur under a range of different climatic conditions and land cover contexts, making it a problem throughout the world.

In general, drylands are distributed between latitudes of approximately 20 and 35 degrees. Their presence in these parts of the planet is largely attributable to the global climate system (UNCCD, 1994, MA, 2005a). Hyper-arid areas cover approximately 8 percent of the world's total land area, and are mostly found within the Sahara, Gobi and Arabian Deserts and are not included in the UNCCD's definition of drylands. The ratio of annual precipitation to potential evapotranspiration in hyper-arid areas is less than 0.05. Potential evapotranspiration is the amount of moisture that, if it were available, could potentially be lost from a given land area through processes of evaporation and transpiration. Water in hyper-arid areas is very scarce. This restricts both human activity and the production of biomass (vegetation), and as a result, few

crops are grown in the hyper-arid parts of the world, aside from those produced in oases or under irrigation (UNCCD, 1994; MA, 2005a).

Arid, semi-arid and dry subhumid regions are affected by an extreme form of land degradation known as *desertification*. Arid, semi-arid and dry subhumid areas are estimated to cover around 41 percent of the Earth's surface. In these parts of the world, the ratio of annual precipitation to potential evapotranspiration falls within the range 0.05-0.65, so there is slightly more water in these parts than in hyper-arid areas (UNCCD, 1994). While water availability still represents an important limiting factor for agricultural production, arid, semi-arid and dry subhumid areas nevertheless provide a wide range of commodities to the rest of the world, including fruit and vegetables, spices, meat, cotton, tobacco, fishery products, forest products and rubber. Indeed, many key crops such as maize, beans, potatoes and lentils originated from the drylands. Some of the dryland areas such as those in the Middle East are also rich in oil. These dryland commodities provide the main source of income for more than a billion people worldwide.

Drought can occur in areas other than the drylands. The research literature recognises different types of drought. For example, meteorological droughts are periods when there is dryness that exceeds the norm for a particular area, either in terms of the degree of dryness or its duration compared to average conditions. Hydrological droughts refer to lower than average water levels in river and surface water systems, as well as low groundwater levels, and often occur at the same time as meteorological drought. Agricultural drought relates to a lack of water at key points in the growing season, be it due to late onset or early cessation of rain, or due to meteorological drought. Farmers are often most concerned by agricultural droughts because they have an important socio-economic impact by reducing crop yields.

In the world's drylands, where the climate is inherently variable, drought is a common occurrence. The world's drylands are inhabited by more than 2 billion people, who suffer from some of the world's lowest levels of human wellbeing and highest incidences of poverty (Thomas, 2008). More people depend on the natural environment to meet their basic needs in drylands than in any other ecosystem (MA, 2005a). And yet, the lack of rain and its unpredictability significantly limits dryland productivity and the extent to which people can depend upon their environment to provide for them in any given year. This means that people's livelihoods (i.e. the ways in which they make a living and give meaning to their lives) along with the ways in which they live are strongly influenced by the climate. It also means that people who live in drylands have learned how to adapt their livelihoods over millennia to manage these types of conditions, creating a rich source of locally-held knowledge that could potentially be drawn upon to help manage future changes.

If we can learn from their collective experience, it may help people who face more frequent and severe droughts under climate change to prepare for the future. But we need to do this whilst feeding a rapidly growing global population on a land base that is shrinking due to conflicting land use interests (e.g. urbanisation, conservation or mining) and ongoing sea level rises. And we

must do this without compromising the medium- and long-term capacity of the land to provide the resources that populations in drylands and other biomes depend upon. Understanding the relationship between climate change and land degradation in drylands is therefore essential if the environment is to continue to provide humans with what we need for our survival and well-being long into the future.

1.2 Policy context

The UNCCD (1994) came into force in 1996 following its fiftieth ratification, and along with the UN Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD), it is one of the key legally binding international agreements that links environment and development to sustainable land management (Stringer et al., 2007). The mission of the UN Convention to Combat Desertification is: *"To provide a global framework to support the development and implementation of national and regional policies, programmes and measures to prevent, control and reverse desertification/land degradation and mitigate the effects of drought through scientific and technological excellence, raising public awareness, standard setting, advocacy and resource mobilization, thereby contributing to poverty reduction".* In 2014, twenty years after the UNCCD was first ratified, it has almost universal membership (195 parties), and is widely supported as an instrument for tackling DLDD, whilst contributing towards sustainable development and poverty alleviation. The UNCCD also provides a framework for moving towards land degradation neutrality (LDN). The concept of LDN is further unpacked later on in this section and in Chapters 2 and 3.

The Parties to the UNCCD adopted a 10-year strategy for 2008-2018 at the eighth Conference of the Parties (COP8) in Madrid in 2007, to help address the Convention's key challenges (ICCD/COP(8)/16/Add.1). The Strategy contains four strategic objectives (with associated expected impacts): 1) to improve the living conditions of affected populations; 2) improve the conditions of affected ecosystems; 3) to contribute towards global conservation and sustainable use of biodiversity and climate change mitigation; and 4) to build partnerships between national and international actors to implement the Convention. It also has five operational objectives (with associated expected impacts): 1) advocacy, awareness raising and education; 2) to create an enabling policy environment for promoting solutions to land degradation; 3) to become a global authority on scientific knowledge about land degradation; 4) to build capacity for reversing land degradation and 5) to target and co-ordinate financial and technical resources for the Convention.

At COP8, a decision was taken to strengthen the scientific basis of the work of the Convention as it pursues its 10 year strategy. Since then, its Committee on Science and Technology (CST) has held two Scientific Conferences, with a third due to take place in 2015. The theme for the first conference was "*bio-physical and socio-economic monitoring and assessment of desertification and land degradation, to support decision-making in land and water management*". Three working groups produced White Papers on: 'integrated methods for monitoring and assessment of desertification/land degradation processes and drivers';

'monitoring and assessment of sustainable land management' and 'monitoring and assessment of desertification and land degradation – knowledge management, institutions and economics'[7]. The theme for the second conference was "*economic assessment of desertification, sustainable land management and resilience of arid, semi-arid and dry sub-humid areas*". Two working groups produced White Papers on: 'economic and social impacts of desertification/land degradation and drought' and 'costs and benefits of policies and practices addressing DLDD'[8]. The third conference focuses on "*combating desertification/land degradation and drought for poverty reduction and sustainable development: the contribution of science, technology, traditional knowledge and practices*"[9].

A key conclusion of the first conference, relevant to this report, is the need to combine biophysical assessments of land degradation with an appreciation of stakeholder perceptions of changes in the capacity for the land to support their livelihoods (Winslow et al., 2011). To do this, the conference recommended the use of integrated assessment modelling using a flexible range of indicators that can draw on both locally-held and scientific knowledge about land degradation processes, severity and extent. In this way, it was argued that monitoring and assessment could feed into decision-making at national and sub-national scales, which could enhance the capacity for ecosystems and populations in regions affected by DLDD to adapt to land degradation. These themes will be revisited in relation to both land degradation and climate change in Chapter 3 of this report.

The second conference analysed the economic and social costs of land degradation versus the benefits of sustainable land management and identified a range of policy mechanisms that could incentivise more sustainable management, in an attempt to reach a land degradation neutrality (defined as a state where the rate of land degradation is equal to the rate of land restoration). These will be explored further in Chapters 2 and 3 of this report. The idea of land degradation neutrality gained traction as part of "The Future We Want" outcome document (UNGA, 2012) adopted at the United Nations Conference on Sustainable Development (Rio+20), and builds on existing environmental goals, such as Agenda 21 and the Millennium Development Goals. It is a framework for action, which seeks, via the UNCCD's strategic plan, to reduce degradation and scale up restoration activities from community to landscape scales. Taking an integrated landscape approach (Figure 1), it seeks to maintain and improve the quality of land and its capacity to supply ecosystem services that can support human well-being for current and future generations (UNCCD Secretariat, 2013), placing food production at the centre of its attentions. These goals are also shared by the UN Food and Agriculture Organisation's "Global Soil Partnership", which arose from discussions around the Millennium

[7] http://www.unccd.int/en/programmes/Science/Conferences/Pages/1st-Scientific-Conference.aspx
[8] http://www.unccd.int/en/programmes/Science/Conferences/Pages/2nd-Scientific-Conference.aspx
[9] http://www.unccd.int/en/programmes/Science/Conferences/Pages/3rd-Scientific-Conference.aspx

Development Goals, which aims to "create a unified and recognized voice for soils through coordination and partnership, to avoid fragmentation of efforts and wastage of resources"[10].

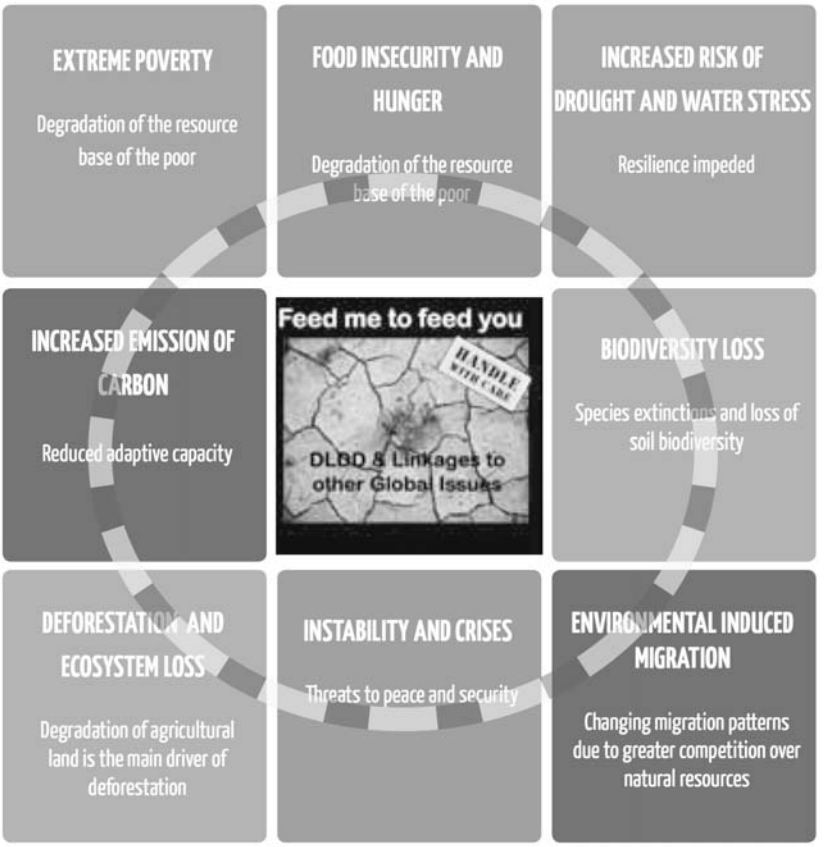


Figure 1: The benefits of achieving a transition to a land degradation neutral world via an integrated landscape approach (from UNCCD Secretariat, 2013)

The success of the three Rio Conventions hinges on their capacity to develop synergistic approaches to tackling the intertwined challenges of land degradation, climate change and biodiversity loss (Akhtar-Schuster et al., 2011; Chasek et al., 2011). Each of the Rio Conventions makes attempts to go beyond the issues they were created to address and make links to other sustainable development issues. For example, in addition to responding to the challenges of land degradation and climate change, ecosystems and people in regions affected by DLDD must deal with other stresses such as changing market prices and trade conditions, policy, population change and demographics as well as problems of disease (affecting plants, animals and humans). Land degradation directly contributes to the ongoing loss in biodiversity, while land degradation processes and impacts can be exacerbated by climate change in a range of complex and often unpredictable ways (MA, 2005a; Thomas, 2008). This

[10] http://www.fao.org/globalsoilpartnership/en/

presents numerous opportunities for synergies in the implementation of all three Rio Conventions. It also reduces the potential for conflicts and duplication of efforts between independent activities of each Rio Convention, and can enable resources to be used more efficiently. Collaboration in cross-cutting areas includes: knowledge management, research and monitoring (e.g. the Joint Liaison Group of the Rio Conventions and the work of the Intergovernmental Platform on Biodiversity and Ecosystem Services, which is expected to support the implementation of strategic plans of the three Rio Conventions), joint work programmes (e.g. the CBD's (2011) Strategic Plan for Biodiversity 2011-2020) and joint financing initiatives (e.g. the UNFCCC's Green Climate Fund which can be used to fund projects that reduce GHG emissions whilst reversing land degradation).

The shift in thinking during the UNFCCC, UNCCD and CBD negotiations away from viewing climate change and biodiversity loss as purely a biophysical phenomena and the acknowledgement of land degradation as a problem with global drivers and consequences has brought international policy more in line with local realities that implicitly take this kind of complexity into account. Second, by placing climate change, land degradation and biodiversity in the broader sustainable development context, links with other global challenges can be identified. These include, for example:

- the globally significant and urgent question of how to deliver food security for a growing population on a shrinking land base (shrinking due to both degradation/erosion and the flooding of coastal and low-lying areas due to sea-level rise), taking into about both availability (production) and accessibility (ensuring food is in the places where it is most needed);
- links between conflict and migration (often linked to land and water insecurity and a lack of, or conflicting, economic and livelihood opportunities in regions affected by DLDD);
- problems of biodiversity loss (species other than humans need to adapt as well);
- the global trend towards changing land use as policy, subsidies and private sector investment increase support for the widespread plantation of non-food biomass such as energy crops, tobacco, rubber and cotton, many of which are cultivated in dry areas with the use of irrigation;
- the development of a greener economy.

In each of the three Rio conventions, significant consideration has been given to the role of science and other forms of knowledge to inform policy. This led first to the engagement of the Intergovernmental Panel on Climate Change (IPCC) to provide advice to the UNFCCC, then to the development of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) linked to the CBD, and most recently to the establishment of a Science Policy Interface, which is a scientific advisory mechanism that includes both governmental and independent experts of equal number, and furthermore

comprises observers from a civil society organisation, an international organisation and a UN organisation[11]. In response to Decision 23/COP11, the UNCCD's Science Policy Interface and Bureau of the Committee on Science and Technology (CST) is providing inputs to IPBES to scope a thematic assessment on land degradation and restoration to meet objective 3(b)(i) of its work programme[12]. This Land Degradation and Restoration Assessment (LDRA) is intended to provide a knowledge base for future policies addressing land degradation and restoration of degraded land. The CST has proposed that it covers:

- The global status of and trends in land degradation, by region and land cover type
- The effect of degradation on biodiversity values, ecosystem services and human well-being
- The state of knowledge, by region and land cover type, of ecosystem restoration extent and options

The scoping process of the LDRA is ongoing, and in parallel with this Impulse Report, will feed into the UNCCD's 3rd Scientific Conference in 2015. Together, these processes will provide evidence on the processes through which land degradation, climate change and biodiversity are linked, and so will help to strengthen the relationship between each of the Rio conventions. In this way, it is hoped that the present report can contribute towards the aims of each of these conventions, in their pursuit of interlinked goals, as well as feeding into and being informed by the work of other bodies such as the ITPS.

1.3 Aims and objectives of this report

In the context of the policy developments outlined in the previous section, this impulse report is designed to help inform the design and focus of the third UNCCD Scientific Conference. One of the major challenges facing conference participants will be the development of new scientific insights and recommendations that can be translated to policy makers with regards to the assessment of vulnerability of lands to climate change and current capacities to adapt.

The conference is expected to contribute to the fight against land degradation and its dryland form, desertification and reduce the impacts of drought through delivering the following outcomes:

- Capacity building in better anticipation of the impact of climate change on land degradation and desertification and vice-versa, i.e. impacts of land degradation on climate change (feedback/interactive effects building on the water cycle)

[11] In addition to these developments, in 2013 the Intergovernmental Technical Panel on Soils (ITPS) was established to provide scientific and technical advice to FAO's Global Soil Partnership: http://www.fao.org/globalsoilpartnership/intergovernmental-technical-panel-on-soils/en/

[12] For more information, visit: http://www.ipbes.net/index.php/work-programme/objective-3/45-work-programme/459-deliverable-3bi.html

- Identification and promotion of sustainable and adaptive methods of using ecosystems to reduce poverty and achieve both food security and sustainable development
- Identification of pathways towards land degradation neutrality

By addressing these issues during its preparation and implementation phases, the conference will provide new scientific insights and recommendations to policy makers (particularly those participating in UNCCD COP12 and UNFCCC COP21) on the assessment of vulnerability of land to climate change and adaptive capacities, and a realistic pathway to achieving land degradation neutrality.

To do this, the report first develops a conceptual and methodological framework, and is then structured around the three major challenges that will be addressed during the conference:

Diagnosis of constraints: this chapter will identify key vulnerabilities of ecosystems and populations in regions affected by DLDD to the interactive effects of climate change and land degradation. To do this, it will:

- Review evidence for current and likely future effects of and interactions between climate change and land degradation on ecosystems and populations in regions affected by DLDD
- Using the conceptual framework developed earlier in this chapter, identify key vulnerabilities of ecosystems and populations in regions affected by DLDD to the interactive effects of climate change and land degradation

Responses: this chapter will consider how adaptive capacity can be enhanced to retain the integrity of ecosystems in regions affected by DLDD and maintain sustainable rural livelihoods in the face of the interactive effects of climate change and land degradation. To do this, it will:

- Review different approaches to adaptation, reflect upon adaptation needs in relation to climate change and land degradation, and consider the potential for maladaptation
- Consider options for simultaneously adapting to climate change and land degradation and the extent to which such adaptations might be able to address feedbacks between climate change and land degradation identified in the previous chapter
- Consider the role of locally-held and scientific knowledge in developing responses to the combined effects of climate change and land degradation
- Assess how barriers to adaptation may be overcome to achieve a 'triple-win' scenario in the context of the three Rio conventions whereby adaptation addresses climate change, land degradation and biodiversity loss

Monitoring and assessment: this chapter will consider how best to monitor and assess current and likely future effects of land degradation and climate change, and evaluate interventions designed to enhance the capacity to adapt to these effects. To do this, it will:

- Consider methods for monitoring the current effects of land degradation and climate change
- Review approaches for assessing likely future effects of climate change and land degradation
- Review approaches for assessing response options, including methods for monitoring adaptation
- Consider ways of improving co-operation and knowledge exchange for monitoring and assessment of adaptation options

The conclusion provides an overview of the key arguments from each of the preceding chapters, and generates hypotheses and questions for discussion at the 3rd International Scientific Conference of the UNCCD.

2. Conceptual and methodological frameworks

The interactions between climate change and land degradation in regions affected by DLDD are complex and in large part unknown. This is partly due to the fact that climate change and land degradation comprise many different processes operating over different temporal and spatial scales. It is therefore challenging enough to predict how either of these processes may play out in future on their own, let alone consider the way they may act together. This chapter therefore reviews conceptual frameworks within which to assess vulnerability. Then, based on a synthesis of these conceptual frameworks, a methodological framework for assessing the vulnerability of social-ecological systems to land degradation and climate change is presented. These frameworks are then used to structure the rest of this report, providing the conceptual basis for identifying key vulnerabilities (Chapter 3) and adaptations (Chapter 4) to the interactive effects of climate change and land degradation, and the methods to monitor and assess these changes (Chapter 5).

2.1 Conceptual frameworks

There are many different ways of conceptualizing the links between climate change and land degradation, and how these interacting processes might influence nature and human well-being. There are also many ways of interpreting the vulnerability of ecosystems and human well-being to these drivers of change (Reed et al., 2013a). This report uses two linked conceptual frameworks to explain how land degradation and climate change are linked to human well-being through effects on ecosystem processes and services, and then to explain how we can assess the vulnerability or resilience of these ecosystems and their human populations to land degradation and climate change.

Figure 2 provides the conceptual framework used by IPBES, to show the main elements and relationships for the conservation and sustainable use of biodiversity and ecosystem services, human well-being and sustainable development. Different forms of land degradation and climate change are conceptualized as drivers, which either directly (depicted by dotted arrows) or indirectly influence human well-being through their effects on biodiversity and ecosystem processes, and the provision of ecosystem services. It shows how drivers of change such as land degradation and climate change are part of a social-ecological system that can be influenced by institutions, governance, other indirect drivers of change, for example cultural factors that might enable or present barriers to tackling climate change and land degradation.

Similar conceptualizations in other knowledge systems include “living in harmony with nature” and “Mother Earth”, among others. In the main panel, delimited in grey, “nature”, “nature’s benefits to people” and “good quality of life” (indicated as black headlines) are inclusive of all these world views; text in light grey denotes the concepts of science; and text in dark grey denotes those of other knowledge systems. Solid arrows in the main panel denote influence between elements; the dotted arrows denote links that are acknowledged as

important, but are not the main focus of the Platform. The thick arrows below and to the right of the central panel indicate different scales of time and space, respectively (figure legend quoted from IPBES/2/17).

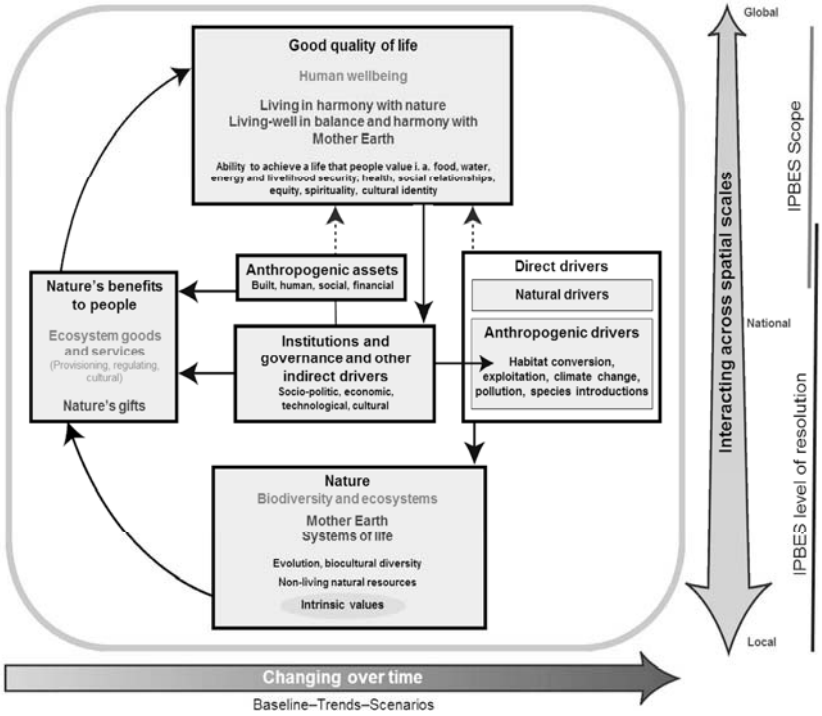


Figure 2: Conceptual framework used by the Intergovernmental Panel on Biodiversity and Ecosystem Services, showing the main elements and relationships for the conservation and sustainable use of biodiversity and ecosystem services, human well-being and sustainable development.

Although stocks of natural capital are not identified explicitly in the framework, they implicitly form part of "nature", and in combination with stocks of physical, human, social and financial capital can provide flows of ecosystem goods and services, that can support human well-being. The framework explicitly considers how these different components of social-ecological systems are linked and change at different spatial and temporal scales, from local to national and international scales. Although climate change is a global process, this report will show how it interacts with different forms of land degradation at different spatial scales, affecting ecosystem processes operating from micro- to macro-scales, which then impact upon the provision of ecosystem services and people's livelihoods. It will consider how baseline levels of natural capital are likely to change over time to generate trends under climate change scenarios, in the presence of land degradation. It will consider how different anthropogenic assets may be used to mitigate or adapt to the effects of climate change and land degradation.

However, it is important to recognize that impacts on human populations are not necessarily inevitable, if they are exposed to climate change and land degradation. Some ecosystems, ecological processes, ecosystem functions, ecosystem services and human populations may be more vulnerable than others to these drivers of change. It is therefore necessary to couple the conceptual framework in Figure 2 with an understanding of the factors that make different social-ecological systems more or less vulnerable to land degradation and climate change.

Understanding the vulnerability of ecosystems and populations in areas affected by DLDD

To understand the likely effects of land degradation and climate change on any given ecosystem or human population, it is necessary to understand how vulnerable they are to these drivers of change. The concept of vulnerability usually relates to the degree to which a human social and/or ecological system will be affected by some form of hazard (Turner et al., 2003). Hazards can take the form of major spikes in some kind of pressure (e.g., extreme weather events including drought), or stresses, which are continuous slowly increasing pressures (such as soil degradation). In addition, some spikes may have a cumulative effect, especially when added to underlying pressures. Hazards can arise from both within and outside ecosystems or communities regions affected by DLDD.

Although there are varying interpretations, three factors are regularly discussed in the literature with regard to vulnerability, and these form the basis for the second conceptual framework presented in Figure 3. By understanding each of these factors, it is then possible to identify how vulnerable or resilient different ecosystems and human populations might be to the joint effects of land degradation and climate change, and how to reduce this vulnerability. Figure 3 therefore summarises the three factors that determine the vulnerability or resilience of ecosystems and populations to land degradation and climate change:

Exposure: considers the degree, duration and extent to which the ecosystems and populations are exposed to land degradation and climate change.

Sensitivity: if the system is exposed to land degradation and climate change, then its sensitivity can be defined as the extent to which the function and structure of ecosystems are likely to be modified by the changes they are exposed to, and the extent to which this will compromise the capacity for current land uses to support livelihoods. Alternatively this can be conceptualized as the 'stability' of the system or its capacity to retain essential functions and structures in the face of pressures from land degradation and climate change, and its capacity to deliver essential services.

Adaptability: if the system is exposed and sensitive to the effects of land degradation and climate change (e.g. increased incidence and severity of droughts), then it is necessary to assess the adaptive capacity of the system, i.e. the extent to which it is possible to change the way the system functions or is used, so that livelihoods can still be maintained in other ways. Adaptation may

take the form of: coping (short-term, immediate responses to reduce risk from climate variability and drought to livelihoods); adjustment (more deliberate planned change, representing adaptation to longer-term climate change and land degradation); and/or transformation (fundamental changes to either system function or political economic structures, often involving behavioural change, leading to the establishment of new long-term social-ecological states) (Folke et al., 2010; Béné et al., 2012; Keck and Sakdapolrak, 2013; Stringer et al., in press). It is important to note here that many apparent adaptations to climate change and land degradation may in fact be maladaptive, if they are not sustainable or increase vulnerability, e.g. worsening the effects of these processes on other ecosystems and populations, or locking people into particular livelihood trajectories that compromise their future adaptive capacity. It is also important to note that adaptations are often context and scale dependent; an adaptation for one community or system at one scale may or not be useful in another community or system at a different scale (Stringer et al., in press).

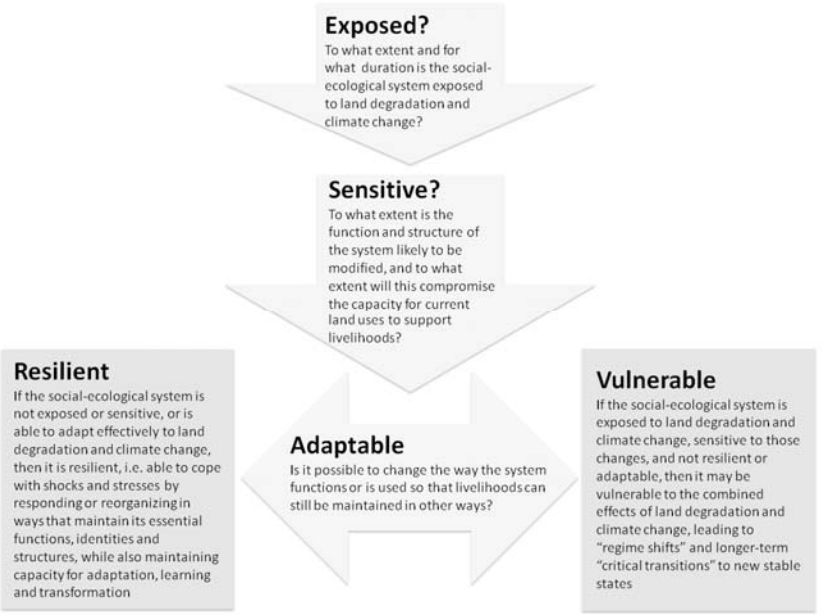


Figure 3: Conceptual framework for assessing the vulnerability of ecosystems and human populations to land degradation and climate change (credit: the authors).

If the social-ecosystem is exposed, sensitive and unable to adapt effectively to the effects of land degradation and climate change, then it will not be able to maintain its essential functions, identities and structures or its ability to adapt to future changes, and it will become **vulnerable** to land degradation and climate change. This may lead to significant changes in the social-ecological system, sometimes referred to as "regime shifts" (Scheffer et al., 2001; Carpenter, 2003) and "critical transitions" when these shifts lead to new long-term stable states (Scheffer, 2009).

On the other hand, if the system is not exposed or sensitive, or is able to adapt effectively to the effects of land degradation and climate change, then it would be considered **resilient**. Resilience considers the "*ability of a social-ecological system to cope with shocks and stresses by responding or reorganising in ways that maintain its essential functions, identities and structures, while also maintaining capacity for adaptation, learning and transformation*" (adapted from Arctic Council, 2013, cited in IPCC, 2014). In the context of land degradation and climate change, this is "general resilience" that considers the resilience of whole systems rather than the "specified resilience" of individual components, which may in fact reduce the overall resilience the system (Folke et al., 2010; Stringer et al., in press).

Broadly, the components in this conceptual framework correspond to the vulnerability framework developed by the IPCC, which has been widely adopted for assessing the susceptibility of systems to the effects of climate change and other human stressors such as land degradation (Mumby et al., 2014). The concept of risk in its broadest sense overlaps with vulnerability in a number of ways. For the purposes of this conceptual framework, risk is defined as the probability of that exposure to land degradation and climate change will lead to negative impacts on ecosystems and human populations in regions affected by DLDD, as mediated by the capacity for that system to adapt to the pressures it is exposed and sensitive to. Exposure is sometimes incorporated in the concept of risk (e.g. IPCC, 2012).

2.2 Methodological framework

There are many approaches to assessing vulnerability and responding to land degradation and climate change (Reed et al., 2013a). Following the IPBES framework in Figure 2, it is important that any methodological frameworks for vulnerability assessment should consider how impacts on human well-being are likely to be mediated by effects on ecosystem processes, ecosystem functions and the provision of ecosystem services to these populations. Methods for assessing vulnerability can be qualitative or quantitative, and can be applied from local to international scales. The following methodological framework (Figure 4) is designed to operationalize the conceptual frameworks outlined in Figures 2 and 3.

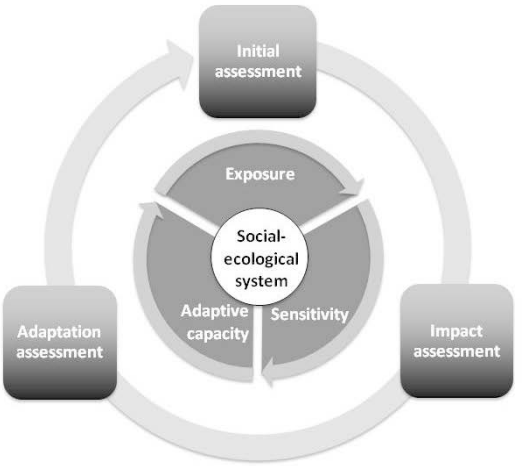


Figure 4: A methodological framework (outer circle) for assessing the vulnerability (segmented middle circle, based on conceptual framework in Figure 2) of ecosystems and human populations in regions affected by DLDD to the combined effects of climate change and land degradation (inner circle based on conceptual framework in Figure 3).

It consists of the following steps:

1. **Initial assessment:** evaluation of the degree to which the stocks of natural capital and ecosystem processes ("nature" in Figure 2), and flows of ecosystem services are exposed to drivers of change – in this case, climate change and land degradation (the upper arrow in the conceptual framework in Figure 3: exposure). The exposure of a system to climate change can be assessed historically from climate records, while future climates may be projected using the sorts of predictive models described in the next section. There is an extensive literature on methods for assessing exposure to land degradation (whether actual or the risk of degradation). Broadly, these can be classified as methods for: i) direct measurement (e.g. of soil fertility and productivity); ii) indirect measurement via indicators (e.g. soil erosion features and vegetation cover); and iii) indirect measurement and projections via process-based computational models, which would typically combine a range of indicators and be calibrated and validated via direct measurements (see Section 5). At local scales, such assessments may combine qualitative social science methods (e.g. semi-structured interviews, oral histories and ethnographic methods) with quantitative methods based on indicators (e.g. GIS mapping or process-based modeling of the effects of land degradation and climate change on land cover, populations of animals and plants, and livestock populations). At regional and international scales, assessments may be based on expert opinion (e.g. the Global Assessment of Soil Degradation; GLASOD upon which UNEP's (1997) World Atlas of Desertification was based), or process-based models, e.g. models of future agricultural yields or forest cover based on projections from Global Circulation Models.

2. **Impact assessment:** an evaluation of the sensitivity (the second arrow in Figure 3) of each of the core components of the social-ecological system described in Figure 2 to climate change and land degradation, and hence an assessment of likely impacts on human well-being in the absence of adaptation. To understand the sensitivity of ecosystems and populations in regions affected by DLDD to the combined effects of climate change and land degradation, it would be necessary to know the extent to which changes in air and soil temperature, precipitation (total amount, intensity/erosivity and patterns), humidity, atmospheric CO_2 concentrations and evapotranspiration rates are likely to affect land degradation processes such as soil erosion, and so compromise the supply of ecosystem services and the livelihoods and human well-being that depends on them. Many of the same models used to assess degradation severity, extent and/or risk may be used or adapted to assess these links. However, given the complexity of the links between climate change and land degradation and the complexity of the systems they are affecting, models can only ever provide an approximate assessment of plausible outcomes (see Section 5.2 for more details). Given the approximate nature of model outputs in such complex social-ecological systems, there are also strong arguments for including evidence based on locally-held knowledge of how these systems work, which can often provide highly complementary information (see Section 5.4). Locally-held and scientific knowledge along with qualitative, approximate and incomplete information may be integrated using techniques such as mediated or participatory modelling, dynamic systems modeling and Bayesian Belief Networks (see Section 5.2).

3. **Adaptation assessment:** this considers the potential and feasibility of adaptive capacity to reduce the sensitivity of the system to the changes it is likely to be exposed to, and provides specific recommendations to planners and policy-makers. Using social science methods, it may also be possible to catalogue how local communities have adapted to previous changes in the productive potential of the land or climate variability, and to provide insights into potential future adaptations to land degradation and climate change (this will be revisited in Chapter 4). It may be possible to use process-based models in a number of different ways to gain further insights into the future pressures likely to arise from land degradation and climate change and to evaluate and refine adaptive options based on local innovations and scientific research in light of model outputs (Prell et al., 2007; Reed et al., 2013b). However there are a range of limitations and uncertainties associated with these techniques, which are the subject of Section 5.2.

Initial impacts and adaptation assessments require trans-disciplinary approaches, and combination of experimental (field and laboratory) research, modelling, and multi-level stakeholder engagement. Multi-level stakeholder engagement is needed to include local knowledge, to select feasible tailor-made solutions fit to local socioeconomic and cultural conditions, and to establish buy-in from high level policy-makers and implementers (de Vente et al., in review).

Also, for the assessment of adaptive measures, in addition to stakeholder and modelling obtained information, field and laboratory experimental designs in which possible future climate conditions are simulated are crucial. The consideration of multiple stressors acting in the same area, together with the need of long time monitoring for both the analysis of pressures and the evaluation of adaptability policies, will require pilot areas that will enable the externalization of findings to places with similar circumstances.

Regional scale studies are typically done through modelling approaches. However, it's important to combine modelling with measured data also at regional scales. While experimental design is often difficult at regional scales, there are increasingly innovative methods available to make regional scale assessments, including, for instance tracer studies and remote sensing techniques (e.g. Boix-Fayos et al., 2014; Vanacker et al., 2014). Remote sensing, and geospatial technologies in general, are powerful tools to provide for initial assessments (or development of baselines) at multiple scales related to land degradation processes, including vulnerability to climate change assessments, mapping of hot (areas for intervention) and bright (e.g. examples of good policy/strategies) spots (Metternicht, 2014a). Such approaches can assist in capturing temporal and spatial dynamics of vulnerability and adaptive capacities of ecosystems. Here are a few examples:

- The UNEP's REGATTA (Regional Gateway for Technology Transfer and Action on Climate Change in Latin America and the Caribbean) project implemented in the Gran Chaco Americano used GIS to generate maps of ecoregions, land cover change and ecosystem services (regulation, support and provision) combined with stakeholder consultations to identify the threats, status and trends of the ecosystem services under the context of current and future climate conditions (Metternicht et al., 2014b).
- The 'Mapping Hotspots of Climate Change and Food Insecurity in the Global Tropics' project aimed at identifying areas that are food insecure and vulnerable to the impacts of climate change. The study used maps of variables that indicate the different aspects of food security (availability, access and utilization) and of thresholds of climate change exposure important for agricultural systems. Vulnerability was assessed as a function of exposure, sensitivity and coping capacity. Tropical areas of interest were classified by high or low exposure, high or low sensitivity, and high or low coping capacity. Such spatially explicit representations can assist prioritising areas for in-depth monitoring and assessment (see: https://cgspace.cgiar.org/handle/10568/3826).
- Multi-temporal GIS analysis of land cover and land capability dynamics together with the use of landscape metrics (general or specifics) may help understanding pattern and structures of land degradation, or at least the loss of cultural landscapes. Also, the development of such "permanent" evaluation techniques can help determining environmental thresholds that should prevent further land cover expansion (e.g. Pascual Aguilar, 2011).

- Analysis of vulnerability should consider aspects such as interconnection among environmental and/or landscape units and the incidence of direct and indirect pressures. Both set of pressures (e.g. land uptake by soil sealing and identification in surface waters of contaminants of urban origin) require specific methodological approaches and the use of new technologies such as geomatics spatial analysis and chromatography determination of emerging contaminants (e.g. Pascual Aguilar et al., 2015, about the Albufera Wetland in the surroundings of the metropolitan area of Valencia).

It is important to take a critical approach to adaptation, for example considering the potential for maladaptation (defined in section 4.1), and considering limits and barriers to adaptation (Stringer et al., in press). Maladaptation may for example: increase GHG emissions (e.g. via fossil fuel use by desalinization plants); increase polarization between rich and poor or disproportionately burden the poor (e.g. by raising the costs of water and energy or privatizing communal rangeland); lead to high opportunity costs (whether economic, environmental or social costs); and create path dependencies where communities are locked in to particular technologies or livelihood strategies that may compromise their capacity or willingness to adapt in future (Barnett and O'Neil, 2010; Pittock, 2011). de Bruin et al. (2009) suggest that one way to avoid maladaptation is identify options that are: 'no-regret' (measures which it would be beneficial to implement irrespective of climate change and land degradation); 'low regret' (feasible, cost-effective and low-risk responses with significant benefits for vulnerable sectors, geographical regions or populations); and 'win-win' options (those that contribute to adaptation but also have wider social, environmental or economic policy benefits).

It is important to note that there may be limits to adaptation, and that the extent and speed of climate change and land degradation in many locations will be unlike anything ever experienced previously. This may limit the capacity to base future adaptive strategies on lessons from past experience. For example, using model-based approaches, Thomas et al. (2005) suggested that a loss of biomass to below 14% vegetation cover combined with a temperature increase of between 2.5-3.5^{o}C would lead to dune re-activation across much of the Kalahari desert in southern Africa by 2100. This future scenario would likely be hastened by continued grazing by livestock, e.g. as herds are maintained by ground water and supplementary feeding during increasingly frequent and extended droughts. With insufficient forage available to support livestock, adaptation options would be increasingly constrained. There may also be barriers to adaptation, e.g. limited land area and inputs with which to increase agricultural production, limited human capital in terms of labour or time, or limited financial capital to invest in diversification options (Suckall et al., 2014).

Figure 4 shows how each step in the methodological framework relates to the conceptual framework presented in Figure 3. It is represented here as a circular process, to emphasise the fact that vulnerability assessments provide a snap-shot in time, and as systems are exposed to new threats, or change their sensitivity or adaptive capacity, assessments will need to be revisited. Each of

the steps in this framework is explored in greater depth in later sections of this report.

An initial assessment is done to assess exposure of the social-ecological system to climate change and land degradation, followed by an impact assessment to consider sensitivity of the system to the drivers of change that it is exposed to, and an adaptation assessment to identify adaptive options.

2.3 Synthesis

This chapter has reviewed literature on theory and methods for assessing the vulnerability of social-ecological systems to the combined effects of land degradation and climate change. Based on this literature, a conceptual framework has been synthesised and combined with the IPBES conceptual framework and insights from elsewhere. These concepts have then been used to develop a methodological framework for assessing the vulnerability or resilience of ecosystems and populations to land degradation and climate change. The methodological framework may be used by policy-makers, researchers, practitioners and other stakeholders to: assess the extent to which social-ecological systems are exposed to land degradation and climate change via direct or indirect measurements and projections; and evaluate sensitivity and capacity to adapt to those changes by combining insights from biophysical and social assessments, including locally-held knowledge. It is important to recognise the potential for maladaptation, and that there may be limits to adaptation, given the speed with which land degradation and climate change may occur in some contexts.

The next chapter considers existing evidence for current and likely future effects of interactions between climate change and land degradation on ecosystems and people in regions affected by DLDD. Then, using the conceptual framework developed in this chapter, it identifies key vulnerabilities of ecosystems and populations in regions affected by DLDD.

3. Diagnosis of constraints

3.1 Introduction

If land degradation is defined as a long-term, human-induced reduction in the resource potential of the land (see section 1.1) then climate change is likely to exacerbate and accelerate land degradation in many regions affected by DLDD, due to the effects on heat stress, drought, evapotranspiration rates and biodiversity, and new diseases and pests on yields from rain-fed agriculture and livestock production, which support the livelihoods of many of the world's poorest people. In addition to effects on provisioning services such as these, land degradation is increasingly being conceptualized more broadly as a reduction in the potential of land to provide other ecosystem services (regulating, supporting, and cultural services)(MA, 2005a; Reed et al., 2014). This section therefore examines likely effects of climate change on provisioning services first, and consequent effects for the sustainability of rural livelihoods dependent on these services. It then considers effects on other ecosystem services.

Climate change encompasses various factors that stem from the modification of the atmospheric composition: CO_2 concentration, air temperature, precipitation, tropospheric O_3 and other environmental pollutants, UV radiation, extreme events, etc. (IPCC, 2007). To assess the vulnerability of ecosystems and populations, it is necessary to pinpoint which are the most relevant climate change factors in regions affected by DLDD. The extent to which climate change may exacerbate land degradation may be softened by increases in primary productivity and water-use efficiency due to increased concentrations of CO_2 in the atmosphere, and longer growing seasons in some areas due to warmer temperatures. However, the synergistic effects of rising temperatures and changes in the hydrological cycle, which may result in more frequent and severe droughts in large areas of the globe (Dai, 2010), along with the increased frequencies in extreme atmospheric events (such as heatwaves and mega-drought), outweigh and may even nullify the fertilization effects of rising CO_2 concentration in areas affected by DLDD (Centritto et al., 2011a). Thus, the balance of effects on land degradation between these opposing climatic drivers is not clear, and is likely to differ depending on location and land management (MA, 2005a). Part of this uncertainty is due to the range of different, and sometimes opposing, feedbacks between climate change and land degradation processes, notably linked to carbon sequestration and storage in soils and vegetation, and the effect of changes in vegetation cover and type on the reflectivity (or "albedo") of land. There may also be feedbacks between the effects of climate change and land degradation on biodiversity and the provision of a range of ecosystem services, which may further exacerbate land degradation. These feedbacks often involve a number of degradation processes, which may affect the biological or economic productivity and resilience of land and livelihoods, for example the way carbon feedbacks and gas exchanges are mediated by changes in wind erosion (due to increased aridity under climate change), soil sealing (through urbanization and urban sprawl) and water

erosion (due to increased intensity and erosivity of rainfall under climate change). These problems also need to be considered in the wider context of global change challenges arising from increasing human populations: increasing food production using less water and land, and producing lower emissions of GHGs. The final part of this section addresses these feedbacks in greater detail.

Interactions between climate change and land degradation will be felt very differently around the world. This is partly because the climate is likely to change in different ways in different regions; there will be different levels of warming, and some areas will become drier while others become wetter. But the changing climate will also interact in different ways with different land degradation processes and land use/management systems. For example, climate change may reduce vegetation cover, and so increase rates of soil erosion and fertility loss under conventional tillage or intense livestock grazing. However, the same interactions may have very different consequences in different places. For example, a 10% loss of vegetation cover may lead to a significant rise in wind erosion on a sandy soil where the vegetation cover was relatively low to start with and a critical threshold is crossed (e.g. Wiggs et al., 1995, calculated a 14% vegetation cover threshold in south Kgalagadi District, Botswana, under which dunes are typically activated). However, the same amount of vegetation loss may have no effect on a system that started off with much more vegetation on a more mineral or a crusted sandy soil.

Climate change is already impacting many regions affected by DLDD (MA, 2005a). There was a global average increase in land and ocean temperatures of 0.85°C between 1880-2012, with each of the last three decades successively warmer than any of the preceding decades since 1850 (IPCC, 2013). There is little evidence for long-term drying trends so far, and predictions of future change in precipitation have relatively low confidence. However there have been more heat waves and heavy rainfall events in some parts of the world. According to IPCC (2013), increases in the severity and duration of droughts are likely by the second half of the 21st century (such predictions have low confidence for the first half of the century).

3.2 Effects of climate change on agricultural productivity, forests, fresh water provision and livelihoods in regions affected by DLDD

Climate change is expected to have a number of consequences for agroecosystems[13] and forests globally, including effects on crop yields, livestock productivity and forest cover. Conceptually, this provides a strong link to more anthropocentric definitions of land degradation, which focus on a "*reduction in the resource potential of the land*", i.e. its potential to provide benefits that can support human populations (often conceptualized as ecosystem services). Given the high dependency of many human populations on natural resources,

[13] Agricultural ecosystems, which can be defined as "*polycultures, monocultures, and mixed systems, including crop–livestock systems, agroforestry, agro–silvo–pastoral systems, aquaculture, as well as rangelands, pastures and fallow lands*" (Fuhrer, 2003).

particularly in developing countries, these effects are among the most important for understanding the likely effects of climate change and land degradation on livelihoods. This section therefore considers evidence for the probable effects of climate change on provisioning services (principally agricultural productivity and forests) and hence livelihoods. However, climate change is likely to have a number of effects on other ecosystem services, which are increasingly being conceptualized as integral to definitions of land degradation (Reed et al., 2014). This is the subject of section 3.3.

The majority of research on the effects of climate change on agroecosystems has focused on changes in yield and spatial shifts in the production potential of cropping systems (e.g. Reilly and Schimmelpfennig, 1999), and changes in the incidence of pests and diseases (e.g. Porter et al., 1991). However, there is a growing body of evidence on the likely effects on grasslands and animal productivity (e.g. Baker et al., 1993; Parton et al., 1995; Rounsevell et al., 1996; Riedo et al., 1999; Luo et al., 2012; Schwerin, 2012). Effects on livestock are likely to arise directly from heat stress (likely to be particularly significant in parts of the world where summer temperatures are already close to the maximum livestock can tolerate) and indirectly via effects of climate change on grassland productivity and forage crop yields (IPCC, 2013). For cropping systems, changes in productivity are likely to result from direct effects of climate change at the plant level, or indirect effects at the system level, for example through shifts in nutrient cycling, and interactions between crops and weeds, pests and plant diseases (Fuhrer, 2003).

The key climatic factors most likely to pose threats to agriculture in combination with land degradation are: increases in the incidence and severity of droughts, heat stress, increased soil temperatures and changing evapotranspiration rates (Morton et al., 2007; D'Odorico et al., 2013; IPCC, 2013). These processes underpin a number of model-based predictions of the likely impacts of climate change on global agriculture. For example, putting aside the loss of low-lying land to sea level rise, Zhang and Cai (2011) estimated that the total global area of land suitable for agriculture is likely to contract by between 0.8–4.4% by 2050, with the greatest contractions taking place in tropical and sub-tropical regions (up to 18% reduction in Africa), due to changes in soil temperature and humidity. Jones and Thornton (2003) suggested there may be a 10% drop in global maize production by 2055 due to climate change, with the greatest impacts likely to be felt in smallholder rainfed farms in Africa and Latin America (D'Odorico et al., 2013). Larger losses have been anticipated by other authors (e.g. see Hanjra and Qureshi, 2010, for a review). Similar concerns have been expressed for global wheat yields (Ortiz et al., 2008). Of course, accurate prediction is impossible in such complex systems, but these studies suggest that the effects of climate change on agricultural production are likely to be greatest in mid-latitude countries, which include some of the driest parts of the world at greatest risk from land degradation, with some of the poorest and most rapidly growing populations (Lee, 2009). In Europe, countries in the south that are already experiencing land degradation are likely to experience most disadvantages from climate change, with increases in water shortage and extreme weather events leading to lower, more variable yields and land abandonment in some areas (Olesen and Bindi, 2002).

When considering the likely interactions between climate change and land degradation, it is important to try and understand the balance between factors that may both increase and reduce the productive potential of the land. CO_2 and temperature are key variables affecting plant growth, development and function. Elevated CO_2 will directly influence plant physiology, through its effect on photosynthesis, transpiration and respiration. However, rising temperature will have contrasting influences on these primary processes. There is now an extensive literature on the direct effects of elevated CO_2 at levels ranging from the molecular to the global, that have substantially increased our knowledge of plant response to rising CO_2 per se. It is well known that elevated CO_2 increases plant growth by an average of 20-40%, and can compensate for environmental stress-induced reduction in growth by improving whole plant water use efficiency (Centritto et al., 1999a, 1999b, 2002). For example, it has been claimed that the CO_2 fertilisation effect can increase photosynthesis and plant development rates (Kimball, 1983), and may help reduce drought stress by enabling plants to use water more efficiently (by reducing stomatal conductance) (Ghannoum et al., 2000; Leakey et al., 2006). Some research has suggested that many crops may be able to retrieve nutrients more effectively from the soil under elevated CO_2 (Drake et al., 1997), and yet there is also evidence that many important staple crops are likely to be less nutritious under elevated CO_2, with decreases in the zinc and iron content of wheat, rice, field peas and soybeans at CO_2 concentrations of 550 ppm, which are expected by 2050 (Myers et al., 2014). Elevated CO_2 is more likely to have positive effects on the yields of C_3 crops, such as rice, wheat and soybean, through better use of resources and improved competition with C4 weeds, such as *Cyperus rotundus* (coco-grass) in rice (fourteen of the world's seventeen most damaging terrestrial weed species are C4 plants in C3 crops according to Morison, 1989). Of course, *vice versa*, C3 weeds such as *Striga* sp. are likely to have an increased competitive advantage over C4 crops such as sorghum and pearl millet, which are important staples in drier parts of sub-Saharan Africa. Positive effects on crops may also come from reduced susceptibility to the negative effects of ozone and improved pest and disease resistance (Fuhrer, 2003).

However, many of these beneficial effects may be offset by the negative effects of a warmer climate and changes in precipitation. The effects of warming on ecosystems will be more complex, in time and space, than the response to elevated CO_2 concentration, because temperature impacts virtually all chemical and biological processes, whereas the direct influence of CO_2 is almost entirely limited to leaves (Centritto et al., 2011b). Benefits of elevated CO_2 for C3 crops are likely to be offset to an extent by increased competitive advantage of C4 weeds and insect damage in a warmer climate. Similarly in grasslands, elevated CO_2 increases dry matter production (especially for N-fixing legumes), but these benefits are likely to be offset by increased temperatures, for example due to increased insect damage. Although elevated CO_2 concentrations in the atmosphere have a fertilizing effect on crops, elevated tropospheric ozone levels can have a damaging effect on crop yields, and there is an uncertain relationship between CO_2 and ozone, mean temperature, extremes, water, nitrogen and land degradation processes (Heagle, 1989; IPCC, 2013). Increases in rainfall intensity are likely to increase rates of water erosion, which will be

exacerbated by low vegetation cover as a result of land degradation (IPCC, 2013). Ultimately, the effects of climate change are more likely to be dominated by changes in temperature and precipitation than they are on elevated CO_2: "*agroecosystem responses will be dominated by [impacts] caused directly or indirectly by shifts in climate, associated with altered weather patterns, and not by elevated CO_2 per se*" (Fuhrer, 2003:1).

With this in mind, it is likely that the effects of climate change on agricultural yields will vary geographically, depending on the factors that currently limit crop yields and how close temperatures are to critical thresholds for plant or animal growth. For example, where temperature is currently a limiting factor in plant productivity, increases in temperature may provide more optimal growing conditions for some crops and lengthen growing seasons, leading to increased productivity. However, where crops are already growing at optimal temperatures, increased temperatures may lead to heat stress and reduce productivity. For example, within a range of 10-35°C, increases in ambient temperature enable maize crops to develop more quickly, and so complete phenological stages in shorter periods of time, but reductions in the rate of development have been noticed between 35-41°C (Yan and Hunt, 1999). Even within the same climatic zone, the effects of changing precipitation will be mediated by soil type, with crops growing on soils with high water holding capacity able to buffer the effects of a lower and/or more sporadic rainfall more effectively than freely draining, sandy soils with limited water holding capacity. The cropping system and other land management adaptations can also strongly mediate the effects of climate change, further spatially differentiating impacts (adaptation is covered later in this report). Although it is difficult to predict impacts precisely due to these mediating factors, it is likely that areas where crops are already experiencing water stress will face an increased likelihood of crop failure under future climatic conditions (Challinor et al., 2007).

Forests are particularly vulnerable to climate change, because their long life-span does not enable them to adapt rapidly to environmental changes (Lindner et al., 2010). In addition to the provision of timber, forests provide many of the poorest populations in the world with non-timber forest products, which form an important component of their livelihoods (Gitay et al., 2001; Shvidenko et al., 2005). The degradation and destruction of forests is an important cause of land degradation around the world, increasing the sensitivity of soils to erosion, which can potentially lead to the long-term loss of productivity (MA, 2005a). The principal mechanisms through which climate change is likely to affect forests are the effects of elevated CO_2 and ozone, the effects of increased temperatures and altered precipitation regimes on tree growth and susceptibility to wildfire and disease.

Forest ecosystems will experience a combination of numerous environmental stresses, which may significantly alter their physiological feedback on climate, through evapotranspiration, albedo and carbon cycling. The natural biogeochemical movement of carbon to and from the terrestrial vegetation is larger than that from anthropogenic activities. Forests also play a major role in regulating the global hydrologic cycle. Together with carbon sequestration, evapotranspiration, through feedbacks with clouds and precipitation, exerts a

negative "physiological" forcing on regional and continental climate. Climate change may critically alter the biogeophysical and biogeochemical functioning of forests (Bonan, 2008; Rotenberg and Yakir, 2010). However, the current ability to predict when regional-scale plant stress will exceed a threshold that results in rapid and large-scale shifts in ecosystem structure and function is lacking. Thus, it is fundamentally needed to assess potential climate-change impacts, including changes in vegetation and associated ecosystem services in order to predict the future feedbacks to the climate system.

The extent to which elevated CO_2 is likely to increase the growth of trees will depend on other limiting factors such as nutrient availability (Saxe et al., 1998, Norby et al., 1999 and Ainsworth and Long, 2005), with nitrogen-fixing trees more likely to respond to elevated CO_2 than other species of tree (Hungate et al., 2003 and Luo et al., 2004). Increased allocation of carbon to root growth may enable plants to exploit deeper soil water and ameliorate some of the effects of reduced water availability under climate change (Wullschleger et al., 2002). However increased concentrations of ground-level ozone are likely to increase drought stress in trees (McLaughlin et al., 2007). Although effects would vary between locations depending on site-specific factors, in general increases in temperature would likely benefit trees at higher latitudes, extending growing seasons and increasing rates of photosynthesis (Lindner et al., 2010). However, in drier climates where water already limits tree growth, heat stress is likely to inhibit photosynthesis, leading to stunted growth. An increased incidence and severity of droughts is likely to increase the likelihood, incidence and severity of wildfires (Lindner et al., 2010; for example see Canadian studies by Stocks et al., 1998; Podur et al., 2002; Gillett et al., 2004). The likely impacts of drought on forests has been projected for several regions (e.g., Amazon, Europe; Cox et al., 2004; Schaphoff et al., 2006; Scholze et al., 2006), showing impacts on forest net ecosystem productivity and wildfire risk, with the potential for a positive feedback to climate change through the release of carbon to the atmosphere and influences on regional climate. Dryland forests are less vulnerable to an increase in the incidence and severity of wildfires than forests in other areas, because they are usually already well adapted to cope with fire (Gonzalez et al., 2010). However, any reduction in forest cover has the potential to contribute towards land degradation, unless it is rapidly replaced with alternative vegetation cover to prevent soil physical and chemical degradation and maintain the productive potential of the land. An increase in the intensity of storms may lead to increased wind-throw of trees, reducing the amount of timber that can be recovered from forests (Lindner et al., 2010), and increased flooding may adversely affect riparian forests (Glenz et al., 2006 and Kramer et al., 2008). In forests where frosts and generally low temperatures currently limit insect outbreaks (Virtanen et al., 1996; Volney and Fleming, 2000), climate warming may lead to more outbreaks in future (Carroll et al., 2004). If trees are already drought-stressed, these outbreaks are more likely to lead to tree mortality (Logan et al., 2003; Gan, 2004).

However, although forest ecosystem responses to elevated CO_2 have been well studied and provide general knowledge, results from forest experiments do not necessarily translate to drylands. For example, the relationship between CO_2

enhancement of aboveground productivity and precipitation are fundamentally different for forests and for drylands (shrublands and grasslands) (Nowak et al., 2004). Drylands are pulsed systems with high temporal and spatial variability in availability of multiple resources, especially water. Thus, increased photosynthesis and water use efficiency with increased atmospheric CO_2 do not necessarily increase biomass production in drylands (Newingham et al., 2013) even though carbon sequestration occurs (Evans et al., 2014).

Existing water shortages are increasing in response to the combined effects of climate change, land degradation, land cover change and population increase (MA, 2005a). The MA (2005a) stated with "a high degree of certainty" that these pressures would lead to "*an accelerated decline in water availability and biological production in drylands*". From 1960-2000, global use of fresh water including regions affected by DLDD increased at a mean rate of 25% per decade (MA, 2005a). Water availability in drylands is projected to decrease further from an average of 1,300 m^3 per person per year in 2000, which was already below the 2,000 cubic meters required for minimum human well-being according to the MA (2005a). IPCC (2013) presents robust evidence that climate change will significantly reduce renewable surface water and groundwater resources in most dry subtropical regions. It is also likely to reduce water quality due to increases in sediment, nutrient and pollutant loadings as a result of increased rainfall intensity and reduced dilution of pollutants during droughts (IPCC, 2013). This is likely to have implications for agricultural production, notably livestock production, as noted above.

Whether from climate change, land degradation or a combination of the two, it would appear that without substantial adaptations, climate change is likely to increase food insecurity in regions affected by DLDD across the developing world that are experiencing rapid population growth. Indeed, Parry et al. (1999; 2005) have suggested that Africa is at greatest risk from the effects of climate change on food production and hunger, and predicted that there are likely to be millions more people at risk of hunger there by the 2080s. On the other hand, Fischer et al. (2008) suggest that reductions in yield in the developing world may be offset by yield increases of similar magnitude in the developed world (5-10% by 2050) as climate change makes conditions more favourable for agricultural production there. However, it is unlikely that these increases in yield for developed nations will provide any more than a small part of the solution for increasingly food insecure developing world countries whose population growth is likely to far outstrip these productivity gains. Furthermore, land degradation is likely to significantly exacerbate food insecurity as it interacts with climate change (Gregory et al., 2005).

Agronomic adaptations, such as changing sowing dates, supplementary feeding of livestock and irrigation may help sustain agricultural productivity under climate change (see Section 3). However when interactions with land degradation processes are considered, the benefits may be short-lived, leading to far worse degradation of agricultural land in the long-term than would have been seen from the effects of climate change alone. For example, irrigation may provide short term gains but ultimately lead to soil salinisation, especially if using groundwater from coastal aquifers that are threatened by salt-water

intrusion due to sea level rise. Similarly, maintaining livestock numbers through drought by supplementary feeding can undermine the natural resilience of some ecosystems, replacing perennial grasses with less palatable annuals or leading to thorny bush encroachment. Drylands are often naturally able to bounce back effectively from drought, and although there would probably be a gradual shift towards species that are suited to more arid climates, the productivity of most drylands would continue to recover after droughts under future climate change. But their ability to do this will depend on the way people manage the land during drought as well as afterwards when the phase of natural regeneration starts. Depending on our actions, climate change may or may not lead to medium- or long-term, irreversible land degradation.

Interactions between climate change and degradation have the potential to significantly affect livelihoods through their effects on provisioning services from agricultural, forestry and fresh water systems. The key climatic processes that are likely to interact with land degradation processes to threaten livelihoods are droughts, heat stress, and increased soil temperatures and evapotranspiration rates. These interactions are likely to particularly constrain the livelihoods of those most dependent on agriculture and natural resources, especially in contexts where adaptive capacity is low. Adaptive capacity may for example be limited by a lack of physical, human or financial assets in disadvantaged areas, or further constrained by a lack of effective governance[14] or a lack of incentives. Governance structures are needed to provide access to information and build capacity for co-ordinated action to adapt to the effects of land degradation and climate change. Furthermore, policy instruments including regulatory (e.g. prohibition or zoning of particular land uses), financial (e.g. incentives or taxes) and the creation of new markets (e.g. Payments for Ecosystem Services) may in some contexts be able to reduce sensitivity and increase the adaptive capacity of ecosystems and populations to climate change and land degradation.

Although many of the effects of climate change and land degradation on livelihoods will take place via changes in the provision of ecosystem services, both processes can directly affect livelihoods and human wellbeing. This may occur indirectly through the effects of climate change and land degradation on natural capital and subsequent effects on physical, human, social and financial capital, and can include important negative effects on economies. However, climate change and land degradation may also directly affect these other assets e.g. weakening social networks through heat and disease-vector related illness and mortality, compromising financial assets (e.g. due to reduced agricultural productivity or failed harvests) or rendering physical infrastructure (e.g. existing flood defenses) obsolete (Reed et al., 2013a).

[14] MA (2005b:77) define governance as, "*the sum of the many ways in which individuals and institutions, public and private, manage issues*".

3.3 Effects of climate change on supporting, regulating and cultural ecosystem services in regions affected by DLDD

In addition to the impacts on provisioning services outlined in the preceding section, there are likely to be a number of impacts of climate change on the delivery of other ecosystem services in regions affected by DLDD, many of which may further affect the sustainability of natural resource based livelihoods. If land degradation is conceptualized more broadly as a reduction in the capacity of the land to provide ecosystem services (Reed et al., 2015), then these effects are integral to our understanding of the vulnerability of populations and ecosystems to the interactive effects of climate change and land degradation. Principal among these impacts are changes in:

- Supporting services: for example, effects on soil formation and conservation, nutrient cycling and primary production
- Regulating services: for example, effects on water regulation, climate regulation and pollination
- Cultural services: for example, effects on aesthetic, cultural and spiritual benefits from nature

Climate change is expected to decrease rates of soil formation in a number of ways, for example via increased soil organic matter decomposition rates (IPCC, 2013). It is also expected that climate change will increase soil erosion rates, primarily through more frequent high intensity rainfall events with greater erosive power (Nearing, 2001; Pruski and Nearning, 2002). This is likely to interact with changes in temperature, solar radiation and atmospheric CO_2 concentrations, depending on how these influence plant biomass production and hence vegetation cover (Nearing et al., 2004). Reduced vegetation cover increases the likelihood of both water and wind erosion, and may in some cases lead to a loss of soil productivity, particularly in the absence of sustainable agronomic practices. Although soil physical and chemical erosion (nutrient and organic matter losses, salinization, pollution and acidification) are widely used as indicators of land degradation, the relationship between erosion and the productivity of land is complex. For example, there is evidence that the majority of wind erosion in the Kalahari results in the localized redistribution of soil and nutrients (for example collecting around the base of shrubs), with minimal loss of nutrients from the system (Schlesinger et al., 1990; Dougill and Thomas, 2002). Elsewhere, there is evidence of agricultural systems that have maintained yields despite significant levels of water erosion (e.g. Warren, 2002). Although the effects of elevated CO_2 on litter decomposition and soil fauna said by IPCC's Working Group II to the Fourth Assessment Report (Fischlin, 2007:226) to "*seem species-specific and relatively minor*", there are studies that suggest climate change may lead to changes in soil fungal communities that may have impacts on soil structure that, particularly if combined with unsustainable tillage and management practices, increase erosion risks (Zhang et al., 2005; Rillig et al., 2002; Fischlin et al., 2007).

Moreover, a 2.4°C warming leads to an approximately 20% increase in soil respiration (Norby et al., 2007), although this is moderated to an extent by acclimatisation of the soil microbial community to moderate increases in soil temperature (Luo et al., 2001). Although the temperature sensitivity of soil respiration is especially critical in semi-arid regions, little research has been carried out in these environments (for a metaanalysis, see Hamdi et al., 2013). Moreover, there are two different aspects: acclimatisation to a few degree shift, and acclimatisation to extreme events. In this last case, laboratory experiments using incubation of soils from Tunisia with temperature up to 50°C showed that the main determinant of soil temperature sensitivity is the amount of labile carbon rather than microbial adaptation of soil respiration to temperature (Hamdi et al., 2011). The resulting loss of soil carbon to the atmosphere may have long-term implications for soil fertility, water holding capacity and crop growth, with consequences for rural livelihoods, as well as posing the risk of a positive feedback to climate warming (Neely et al., 2009). Other aspects might be considered such as carbonates behaviour and climate change, soil respiration, wet-dry cycles changes and C cycle (for a review, see CSFD, 2014).

Climate change is likely to have a number of effects on nutrient cycling, including notable effects on the global carbon and nitrogen cycles, which have the potential to interact with land degradation processes, through their effects on plant growth via nitrogen availability and CO_2 fertilisation. Atmospheric concentrations of CO_2, methane (CH_4), and nitrous oxide (N_2O) have all increased since 1750 due to human activity according to IPCC (2013). 29% of all anthopogenic CO_2 emissions have been absorbed by terrestrial ecosystems, primarily forests, leading to increased Net Primary Productivity (see previous section) (IPCC, 2013). Concentrations of N_2O in the atmosphere have been steadily increasing over the last three decades, in addition to elevations in concentrations of other nitrogen compounds (primarily NO_x and NH_3) which have been implicated in the production of tropospheric ozone, which can impede plant growth (see previous section) (IPCC, 2013). However, where this nitrogen is deposited on terrestrial ecosystems, it can increase the productivity of plants, notably forests (IPCC, 2013). Climate warming can increase the rate at which soil organic matter decomposes and rates of nitrogen mineralization, which can increase nutrient uptake and carbon storage by vegetation, and enhance the productivity of the land for agriculture (IPCC, 2013).

Effects of climate change on the regulation of water quality and supply for agriculture is likely to have a major impact on land degradation processes, leading to land abandonment where it is no longer possible to irrigate crops and water livestock. At the same time, land degradation can contribute towards and exacerbate water quality and supply problems through erosion, which can lead to the sedimentation of dams used for irrigation and the release of nutrients and stored pollutants from historic atmospheric deposition (e.g. heavy metals). Although winter base flow and mean annual stream flow is predicted to increase in most regions under climate change (IPCC, 2013), reduced summer rainfall predicted in some parts of the world may reduce the volume of water in rivers, leading to the concentration of pollutants in stream water to levels that may be toxic for use in agriculture (Confalonieri et al., 2007). The livelihood and wider economic consequences of this for irrigated agricultural systems may be significant.

The yields of many of the world's most important crops are dependent upon pollinators, representing approximately 35% of global food production (Klein et al., 2007). The estimated value of crop pollination globally is around €153 billion annually (Gallai et al., 2009). Given the sensitivity of many insects to small changes in temperature, climate change is likely to interact with a number of other processes to negatively impact upon plant-pollinator interactions (Kjøhl et al., 2011), including interactions with invasive species (Memmott and Waser 2002; Bjerknes et al., 2007), pesticide use (Kearns et al., 1998; Kremen et al., 2002), land-use changes such as habitat fragmentation (Steffan-Dewenter and Tscharntke 1999; Mustajarvi et al. 2001; Aguilar et al. 2006) and agricultural intensification (Tscharntke et al. 2005; Ricketts et al. 2008). Where these interactions lead to the extinction of wild pollinator species, this could significantly constrain the production of many crops, compounding the effects of land degradation on livelihoods.

There have been few studies of the likely effects of climate change and land degradation on cultural services. MA (2005a) considered trends in what they called cultural identity, cultural heritage, spiritual services, inspirational services, aesthetic services, recreation and tourism. Under the heading of "cultural identity", MA (2005a) discussed the trend towards sedentarising nomadic groups around the world. Following Hardin's (1968) conception of the Tragedy of the Commons, there was a belief that communal systems of livestock management were leading to land degradation, and that nationalization or privatization of rangelands could lead to more sustainable management. However, Hardin was in fact referring to open access regimes, which were *de facto* created when national institutions took over the management of rangelands. In many cases, privatization of rangelands had similar effects, with limited improvements in the sustainability of rangeland management (and in some cases worsened degradation due to the inability to extend forage range during drought after fencing (e.g. Perkins, 1996 and Mulale et al., 2014 in Botswana). The fencing of communal grazing land also significantly limits the capacity of the system to adapt to droughts, which are predicted to become more frequent and severe in many semi-arid rangelands (Reed et al., 2007; Nori et al., 2008; Stringer et al., 2009). An alternative, more appropriate solution to the tragedy of the commons (Hardin, 1968) in many locations may be to revert to common property regimes. Ostrom (1999) shows how (well designed and implemented) common property regimes are more likely to foster innovative solutions to the challenges of land degradation and climate change, whilst preventing further alienation of commonly-held rangeland resources by wealthy individuals (Taylor, 2004).

Spiritual benefits may be derived from particular landscapes and landscape features, such as sacred or holy places (e.g. sacred groves, mountains or waterfalls) or species of plants or animals (e.g. used in ceremonies) (MA, 2005a). Spiritual benefits may also be derived from the journeys or pilgrimages to these holy sites, through landscapes that imbued with meaning by the experiences of those who have passed before them (Frey, 1998). In some cases, veneration for particular species or places has afforded protection against over-use or degradation, e.g. the protection of endangered plant species including

rare herbs and medicinal plants in sacred groves by Meghalaya tribal communities in northeast India, in an otherwise degraded forest environment (Tiwari et al., 1998), and taboos leading to the retention of *Boscia albitrunca* (Shepherd's Tree) in degraded semi-arid savannah in southern Africa (Reed et al., 2007). *B. albitrunca* retains valuable forage all year round, and is a valuable asset during drought, providing opportunities to adapt to climate change (Reed et al., 2014).

Kenter et al. (2014) take this a step further to argue for a link between the aesthetic qualities of particular locations or landscape features and spiritual experience, pointing to evidence that aesthetic and spiritual experiences can be co-emergent. They argue that aesthetic valuing of nature overlaps with spiritual values such as reverence and caring, and stand in opposition to the commodification and degradation of the natural environment. Some of these considerations lay behind the development of the European Landscape Convention, which came into force in 2004. Its goal is to protect and reflect "*European identity and diversity, the landscape is our living natural and cultural heritage, be it ordinary or outstanding, urban or rural, on land or in water.*"

Although some studies have found an aesthetic preference for natural environments in good ecological condition, compared to degraded ecosystems (e.g. Ulrich, 1986), it is important to recognize that many of the aesthetic characteristics consistently appreciated by humans have nothing to do with ecological condition, for example depth of view, openness and the presence of water (Tveit et al., 2006). As a result, local populations may come to appreciate the aesthetic value of exotic invasive species and oppose their removal (Genovesi, 2005). Aesthetic perceptions also vary between cultures and over time. For example, Western perceptions of wilderness have changed from attitudes of indifference and hostility until the seventeenth century (which still persist in some cultures) to a more romantic notion of wilderness associated with beauty and freedom (Nash, 2014).

3.4 Feedbacks between climate change and land degradation in regions affected by DLDD

There is evidence that land degradation contributes towards climate change, while climate change can exacerbate land degradation (Cowie et al., 2011). There are a number of important, but poorly understood feedbacks between climate change and land degradation in regions affected by DLDD, which are likely to mediate the interactions and impacts of these two processes on livelihoods. Principal among these are feedbacks between:

1. Climate change, land degradation and carbon sequestration and storage in the soils and vegetation of regions affected by DLDD. Local, regional and global climate patterns are strongly affected by land cover conditions. Moreover, land degradation also affects the organic carbon and nitrogen cycles, altering emissions of organic carbon and nitrogen from soils to the atmosphere and as such affecting the climate itself. Nevertheless, there are still important knowledge gaps regarding the impact of land degradation and specifically soil erosion on the overall carbon budget, especially

regarding possible stabilization mechanisms after erosion and increased inputs of organic carbon to the soil (e.g. Boix-Fayos et al., 2014).

2. Feedbacks between climate change and land degradation-induced changes in vegetation cover and type and local and global climate. Locally, this may lead to changes in regional atmospheric circulation, leading to drier conditions at particular times of year. Globally, changes in the reflectivity (or "albedo") of land as a result of these changes in vegetation cover, may dampen the effects of global climate change.
3. There may also be feedbacks between the effects of climate change and land degradation on biodiversity and the provision of a range of ecosystem services, which may further exacerbate land degradation and compromise capacities to adapt to climate change and maintain sustainable livelihoods.

Whether directly via the loss of ecosystem service provision or indirectly through impacts on the climate system, each of these feedbacks has the potential to reduce livelihood opportunities. It is therefore important to better understand these feedbacks in order to better understand threats and opportunities for livelihoods and develop strategies that can enable livelihood adaptation.

Feedbacks with carbon in vegetation and soil

Greenhouse gas emissions associated with the loss of soil and vegetation are the key mechanism through which land degradation contributes towards climate change (MA, 2005a). This relationship represents a potential feedback loop, where land degradation leads to climate change, which in turn worsens land degradation. Dryland soils alone, which are particularly vulnerable to degradation, contain more than a quarter of all of the organic carbon stores in the world and nearly all the inorganic carbon (MA, 2005a). The loss to the atmosphere of organic carbon held in the drylands could therefore have significant consequences for the global climate system (Kirschbaum, 2006; Heimann and Reichstein, 2008). Indeed, it is already estimated that around 300 million tons of carbon are lost to the atmosphere from drylands as a result of land degradation every year; equivalent to around 4% of total global emissions from all sources combined (MA, 2005a; Neely et al., 2009). Conversely, restoration of degraded drylands could sequester 12–20 PgC globally over 50 years, if a range of Sustainable Land Management practices were successfully applied at a global scale (Lal, 2001, 2004; Suleimenov and Thomas, 2007; Thomas, 2008). Thomas (2008) concluded: "*these estimates are admittedly crude but highlight the magnitude of the potential benefits that can be achieved globally through a focus on SLM*". In reality, sequestration will be limited by low net primary productivity and the limited capacity of many dryland soils for stabilizing organic matter (Kimetu et al., 2009; Neely et al., 2009). Moreover, feedbacks between climate change, land degradation and losses of carbon from soil and vegetation are highly likely, given the number of mechanisms through which soil carbon may lost to the atmosphere as a result of both climate change and land degradation. Key mechanisms driving this feedback are:

- Enhanced soil respiration under climate warming
- Drought-induced wildfire
- Land use and management practices leading to a reduction in carbon sequestration and storage by soils and vegetation and/or losses of GHGs from soil and vegetation, including wind and water erosion of soils, over-grazing and over-harvesting (including deforestation)

Climate warming of 2.4°C is predicted to increase soil respiration by around 20% under conditions of sufficient moisture (Norby et al., 2007). For example, climate warming has been blamed for a 2% per annum loss of carbon from carbon-rich soils in England and Wales over the last 50 years (Bellamy et al., 2005). Although respiration losses may be lower in reality (e.g. due to acclimatization of the soil microbial community – see section 2.3.2), climate warming is likely to lead to a progressive loss of soil carbon to the atmosphere, where it can contribute towards future climate change. At the same time, soil carbon plays a critical role in the provision of many ecosystem services linked to plant production, which in turn support rural livelihoods. In drylands particularly, soil carbon has been linked to increased resilience to climate variability and change (Cowie et al., 2011). This is in part because soil carbon enhances, amongst others, infiltration of water and the retention of moisture in soils, improving water availability to plants.

Carbon losses from vegetation due to fire under climate change are likely to be most significant in dryland scrublands and forests, which are currently mainly used for livestock grazing (Howden et al., 1999; MA, 2005a). An increased incidence and severity of droughts could increase the likelihood of wildfires (Lindner et al., 2010). The likely impacts of drought on forests has been projected for several regions (e.g., Amazon, Europe; Cox et al., 2004; Schaphoff et al., 2006; Scholze et al., 2006), showing impacts on forest net ecosystem productivity and wildfire risk, with the potential for a positive feedback to climate change through the release of carbon to the atmosphere and influences on regional climate. In some places a lack of fire can have important negative consequences for ecosystem functioning as the seeds of some plants depend on fire to break their dormancy and allow them to grow. However, there is also evidence that wildfires can lead to long-term land degradation, because the removal of vegetation cover makes soils more susceptible to erosion (Hobbs and Norton, 1996). Where the dominant tree species are already at the margins of their climatic range, there is an increased probability under climate change that wildfire may lead to a shift to a new ecological state, possibly dominated by grass or shrubs, which may store less carbon than the previous state (Dougill et al., 1999; Suding et al., 2004). Depending on the extent to which the new state can meet land user objectives, this may or may not constitute land degradation.

Land use and management play a significant role in the release of carbon from soils and vegetation. Net carbon losses occur when carbon sequestration by vegetation and soils decrease and/or removal of carbon from vegetation and soils increases (Cowie et al., 2011). For example, deforestation, heavy grazing and conversion from perennial to annual plants in rangelands, release carbon stored in above-ground and below-ground biomass to the atmosphere. Regular

cultivation of soils can reduce soil carbon unless it is replaced e.g. via addition of manures, or the retaining of residues (Cowie et al., 2006). Grazing-induced land degradation has been estimated to emit as much as 100 million tonnes of CO_2 per year globally in drylands alone (FAO/LEAD 2006).

Feedbacks with vegetation cover

Both climate change and land degradation can lead to a reduction in biomass and vegetation cover. Climate-induced changes to vegetation cover are typically in response to reduced water availability due to increasing aridity linked to changing precipitation regimes, combined with increased water use due to increased evapotranspiration under increased temperatures. Soils with low vegetation cover are then more susceptible to erosion, with threshold vegetation cover depending on slope, soil type and erosivity of rainfall (for water erosion) or wind-speeds (for wind erosion). Although the CO_2 fertilisation effect is predicted to increase water-use efficiency of plants, water-use efficiency is compromised in degraded land (Snyman, 1998; Prince et al., 1998; Diouf and Lambin, 2001), thus reducing any compensating effect in these areas. Although there is little certainty over likely changes in average wind-speeds under climate change (IPCC, 2007) an increase in the incidence and severity of extreme weather events is predicted, including a highly likely increase in the frequency, intensity, and/or amount of heavy precipitation (especially at mid-latitudes), a highly likely increase in the frequency and/or duration of extremely hot weather (or "heat waves") and likely increases in intensity and/or duration of drought (IPCC, 2013).

Human-induced changes to vegetation cover are typically due to over-exploitation of resources, for example due to over-grazing or over-cultivation (also due to reduced fallow periods). Together, increases in extreme weather events and human-induced land degradation processes are likely to lead to a loss of vegetation cover across many parts of the world. Thomas (2008) suggests that this combination of effects might be felt particularly acutely where annual rainfall lies between 500–750mm, because extreme weather events are likely in these regions, and vegetation cover is unlikely to be sufficient to protect soils from the effects of these events. Soil loss may lead to further land degradation, where this leads to a loss of ecosystem resilience, increasing the likelihood that the system will be unable to regain its former state after the extreme event (Thomas, 2008).

There are two types of feedback linked to this. First, these changes may alter regional climates due to changes in dust fluxes (Hardy, 2003; Prospero and Lamb, 2003; Lioubimtseva and Adams, 2004) and high-pressure circulation anomalies that can result in drier conditions at particular times of year (McGuffie et al., 1995; Sud et al., 1996; Archer and Tadross, 2009). The second type of feedback relates to increase in the reflectivity or "albedo" of the land surface when vegetation cover is removed, leading to possible effects on surface evapotranspiration and heat and moisture fluxes. This in turn may affect local, regional and possibly global, atmospheric circulation, leading to a negative feedback to the climate system (Thomas, 2008).

Feedbacks with biodiversity

Climate change and land degradation have similar effects on biodiversity, leading to the simplification of ecosystems and an increased abundance of generalist species at the expense of specialists (Clavel et al., 2010). Indeed, recent literature includes loss of biodiversity as a form of land degradation (Haines-Young and Potschin, 2010). Climate change will have a number of indirect impacts on biodiversity, for example, shifts in the timing and success of reproduction (Forchhammer et al., 1998; Crick and Sparks, 1999; Winkler et al., 2002), changes in the availability and suitability of habitats and niches (Visser and Both, 2005), changes in the way species use habitats, e.g. nest and shelter site selection (Telemeco et al., 2009) and changes in survival rates (Chamaille-Jammes et al., 2006). Climate change will directly affect the distribution of species, as the location of climatic zones to which they are adapted generally move polewards and towards higher altitudes (Meynecke, 2004; Penman et al., 2010). This shift in climatic zones will also mean there is likely to be a declining number of habitats and specialist niches, leading to the replacement of specialist species with generalists (MA, 2005a). The CO_2 fertilisation effect is likely to lead to changes in plant species composition, for example favouring nitrogen-fixing and C4 species (see section 2.3.2; MA, 2005a; Thomas, 2008). In areas made more susceptible to fire due to climate change and land degradation, species composition is likely to shift towards pyrophytic species, capable of withstanding fire, leading to an overall reduction in biodiversity (Neilson et al. 1998). The mix of species likely to gain a competitive advantage will therefore depend on the assemblage of species exposed to climate change in any given location, so it is difficult to predict how these changes in diversity might affect the provision of ecosystem services, and hence impact upon livelihoods. Canziani et al. (1998) suggested dryland species might be less sensitive to climate change because they are already well adapted to climate extremes. However, it is clear that this poorly understood feedback is likely to present significant challenges to those whose livelihoods depend on biodiversity (MA, 2005a).

3.5 Key vulnerabilities to the interactive effects of land degradation and climate change in regions affected by DLDD

This chapter has considered how interactions between climate change and land degradation are likely to affect a range of different ecosystem services, notably provisioning services, with consequent impacts on livelihoods and human wellbeing. It is difficult to anticipate how specific ecosystems and populations are likely to be affected by climate change and land degradation, given the many uncertainties and feedbacks that have been identified in this chapter.

Furthermore, two important features of drylands that further complicate constraints of climate change and DLDD are: (1) unlike mesic systems, drylands are pulsed systems for multiple resources, especially for water; and (2) dryland systems often rely upon resource subsidies from surrounding areas. These features occur for both natural and human-managed dryland ecosystems. The

pulsed nature of natural drylands are well documented (e.g. Schwinning et al., 2004 and rest of special issue Oecologia 141(2)), and management activities often are directed towards mitigating pulsed resource availability (e.g. livestock wells) or subsidizing resources (e.g. irrigation systems). The pulsed nature of drylands means that climate change and DLDD interactive effects will be a function of deviations from current climate/management regimes, and the subsidy nature of drylands means that climate change and DLDD interactive effects also will depend on the ability of surrounding systems to continue to export resources.

However, using the conceptual and methodological frameworks described in the previous chapter (Figures 3 and 4), it is possible to identify a number of key vulnerabilities to the combined effects of climate change and land degradation at a more generalised, global level. First, it is important to recognize that exposure to climate change varies globally, with different regional projections of changes in temperature, rainfall and sea-level rise. Likewise, different regions are exposed to different types and levels of land degradation, and it is impossible to assess the vulnerability of populations and ecosystems to either climate change or land degradation solely on the basis of these differing levels of exposure to climate change and land degradation. However assessments of current and likely future exposure to climate change and land degradation can provide an important basis for assessing the sensitivity of social-ecological systems to those changes. In particular, areas already experiencing land degradation are likely to be exposed to potentially damaging interactions with climate change, where extreme weather events such as increased droughts or heavy rainfall events exacerbate wind or water erosion and (with unchanged agricultural practices) contribute towards the further reductions in biomass or physical and chemical degradation of soils. Further research is needed to combine assessments of land degradation and climate change impacts, to better understand the extent to which different ecosystems and populations around the world are likely to be exposed to important combinations of changes resulting from both processes. However, the full extent to which this exposure to risks from climate change and land degradation leads to negative impacts on ecosystems and populations, can only be understood by considering the relative sensitivity of different systems to the interactions between climate change and land degradation.

Assessing the sensitivity of ecosystems and populations to the combined effects of climate change and land degradation is in part a biophysical challenge. It is necessary to understand how land degradation processes such as water and wind erosion and physical (e.g. compaction and sealing) and chemical (e.g. soil organic matter loss and salinization) degradation of soils might interact with changes in soil temperature, precipitation (amount, intensity and patterns), humidity, atmospheric CO_2 concentrations and evapotranspiration rates. Given the high temperatures and limited rainfall already experienced in drylands, these regions are likely to be particularly sensitive to the effects of climate-induced changes in temperature and moisture, combined with degradation-induced reductions in soil organic matter, biomass and soil fertility. These processes may in some cases be self-reinforcing, leading to feedbacks between

climate change and land degradation, for example when land degradation via the loss of terrestrial carbon stores from soils and vegetation leads to climate warming, or when the albedo effect of degradation-induced reductions in vegetation cover leads to climate cooling or other local climatic effects. Similarly, the dual effects of climate change and land degradation may have impacts on biodiversity that may further exacerbate land degradation, compromise the provision of ecosystem services and limit capacities to adapt to climate change. It is therefore important to focus research on identifying ecosystems and areas where these feedbacks are most likely to occur, to identify options for climate mitigation and adaptation and achieving land degradation neutrality.

Assessing sensitivity to the interactions between climate change and land degradation is also in part a social science challenge. First, assessing the sensitivity of ecosystems and human populations to climate change and land degradation requires both scientific and locally-held knowledge. By definition, land degradation must be assessed in relation to the objectives of those using the land, and locally-held knowledge is usually necessary to appreciate the full effects of climate change on livelihoods and human wellbeing. Collecting and analyzing qualitative data from local communities can be time-consuming and expensive. However, the costs of doing this versus the costs of inaction need to be evaluated.

Second, in addition to considering the sensitivity of ecosystems to these processes, it is necessary to understand the sensitivity of livelihoods to the combined effects of climate change and land degradation. The sustainable livelihoods approach (Carney, 1998; Scoones, 1998) provides a framework for analysing both the key components that make up livelihoods and the contextual factors that influence them, which may make a household or community more or less sensitive to the effects of a changing climate and land degradation (Eakin and Luers, 2006). Climate change and land degradation have the potential to disrupt established ecological and land use systems, which in turn may lead to the failure of food and water supplies, and the failure of livelihoods. This may in turn then limit the adaptive capacity of households when they are faced with other perturbations or stresses.

Finally, moving to the final elements of the conceptual and methodological frameworks outlined in Figure 3 and 4, any assessment of vulnerability to climate change and land degradation must consider the adaptive capacity of the ecosystems and human populations under consideration. This is the topic of the next chapter.

4. Responses

Given the likely sensitivity of ecosystems and human populations to interactions between climate change and land degradation, reviewed in the previous chapter, it is essential to devise ways of mitigating these effects whilst achieving land degradation neutrality. Some level of adaptation[15] will also be necessary, in response to current impacts, and continued likely changes arising from the effects of future GHG emissions and increases in global population (IPCC, 2014). The MA (2005b) defines responses generically as "*human actions, including policies, strategies, and interventions, designed to respond to specific issues, needs, opportunities, or problems*." It is important to view responses in the context of perceived needs relating to the maintenance of ecosystems and populations exposed to DLDD, and the improvement of human well-being.

Climate change mitigation typically involves "*an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases*" (IPCC, 2001). To achieve land degradation neutrality, mitigation of land degradation typically involves prevention of land degradation, restoration or rehabilitation of partly degraded land and reclamation of severely degraded land, e.g. via reforestation or remediation of soils damaged by processes such as erosion or salinization (Aronson and Alexander, 2013; Grainger, 2014). Many of these mitigation responses also enhance the capacity of ecosystems and people to adapt to the dual effects of climate change and land degradation. As such, there is typically a blurring between mitigation and adaptation options that tackle both processes. Following the conceptual frameworks described in the previous chapter, this chapter therefore focuses on options that can increase the adaptive capacity (and hence resilience) of ecosystems and populations experiencing climate change and land degradation.

4.1 Approaches to adaptation

In order for people to adapt to climate change and land degradation, they first need to perceive that something is changing, second, assess their options in light of their capabilities (the resources they have available to adapt) and third, mobilise their latent adaptive capacity to enact their adaptation decision. Successful adaptations may be viewed as those actions that decrease vulnerability and increase resilience overall, in response to a range of immediate needs, risks and aspirations (van Aalst et al., 2008), and which do not lock people into particular pathways or trajectories, or erode their future adaptive capacity.

Adaptation may be autonomous (ongoing, incremental changes to existing systems with current knowledge and technologies to cope with pressures arising from climate change and land degradation), reactive (to climate change and land degradation as they occur) or planned/anticipatory (proactive adaptations that can either adjust or transform systems at broader scales in

[15] Adaptation is defined by IPCC (2014) as "*reductions in risk and vulnerability through the actions of adjusting practices, processes and capital in response to the actuality or threat of climate change*".

advance of anticipated changes in climate change or land degradation) (Schneider et al., 2000; Smith and Lenart, 1996; Tol et al., 1998; Howden et al., 2010). Due to the focus on learning from past and current adaptations to climate variability and extremes, most adaptation work has tended to focus on reactive adaptation, rather than anticipatory, planned or pro-active adaptation (Reed et al., 2013a). However, the use of planned strategies has been shown to enhance adaptation in many contexts (IPCC, 2007).

Adaptation can occur at a range of scales, from field-scale (e.g. changes in cropping or livestock systems, through the implementation of agroecology and climate smart agriculture approaches to cropping systems) to the implementation of policy at national and international scales (e.g. National Adaptation Programmes of Action under UNFCCC and National Action Programs under UNCCD). The value of autonomous adaptations at local scales, based on locally-held knowledge, is increasingly being recognized, but there is also recognition that effective adaptation will also require planned changes in institutional arrangements and policies to create an enabling environment for future adaptation at broader spatial scales (Stringer et al., 2009; IPCC, 2014).

Béné et al. (2012) identify three types of adaptation: coping, adjustment and transformation. Coping is a short-term, reactive response to reduce immediate risks from climate change and drought to livelihoods. Adjustment is more commonly a planned response to longer-term climatic change and land degradation processes, and may require changes to rules, processes, structures and institutions that enable the (livelihood) system to continue functioning (Stringer et al., in press). Transformation involves more fundamental changes to the social-ecological system of the governance arrangements that mediate change in the system (Klein et al., 2014).

Adaptation strategies and sustainable management of agro-ecosystems cannot be developed without looking at the biophysical and sociocultural interactions and interdependencies between different ecosystems. Therefore, there is a need for a holistic approach considering both agriculture and (semi) natural (surrounding) ecosystems and their positive and negative interactions. Even if there are no apparent biophysical interactions, sociocultural factors and land use in one ecosystem may determine the outcomes of sustainable land management in another ecosystem. In that sense, not only provisioning services but also regulating, supporting and cultural services need to be taken into consideration. Only by looking at the system as a whole can we identify possible trade-offs and design most effective, efficient and sustainable adaptation measures.

Adaptation needs may be classified as biophysical and environmental, social, institutional, and knowledge exchange and resource needs (Burton et al., 2006; IPCC, 2014):

- Biophysical and environmental: there is a need to enable natural systems to adapt to the pressures of climate change and land degradation, so they can continue to provide essential ecosystem services, such as freshwater, food and climate regulation.

- Social: social needs for adaptation to the effects of climate change and land degradation vary geographically, with gender and age, and with socio-economic status. Poverty and persistent inequality underpin vulnerability to both processes, particularly for rural populations more dependent on natural resources.
- Institutional: adaptation is needed of the formal and informal institutions that constrain and shape social behaviour and the institutional rules that affect negotiation and the performance of power (Pelling et al., 2008; McGuire and Sperling 2008). Such adaptations to institutions have the potential to facilitate cross-scale solutions to climate change and land degradation, establish incentives and in other ways promote adaptation, and establish protocols for making and acting on decisions to adapt to climate change and land degradation (Adger et al., 2005; Thomalla et al., 2006; Compston, 2010). For instance, the implementation of 'Payments for Ecosystem Services' policies can be effective engines for behavior change (Lapeyre and Pirard, 2013).
- Knowledge exchange and access to resources: successful adaptation depends on availability and access to information, and access to technology and financial resources, from micro-finance to international financial mechanisms to facilitate adaptation to climate change and land degradation (Yohe and Tol, 2001; Adger, 2006; Eakin and Lemos, 2006; Smit and Wandel, 2006; World Bank, 2010). As part of this, there is a need for the private sector to enable adaptation by managing their internal risks and engaging with civil society and Government initiatives (Khattri et al., 2010), and through Payments for Ecosystem Services schemes that deliver benefits to businesses while paying for adaptations such as agroforestry or soil management techniques that deliver climate regulation or other ecosystem services (Reed et al., 2015). There is a need to enhance knowledge exchange about adaptation options for climate change and land degradation, for example combining systems such as the World Overview of Conservation Approaches and Technologies (WOCAT), and the UNCCD's various knowledge management mechanisms with systems related to climate adaptation[16], and exploiting the diffusion of mobile phone technologies to raise awareness, monitor and alert land managers to changes in climate and land degradation, and increase social capital by enabling sharing of knowledge about adaptations to climate change and land degradation.

In many cases, these adaptations may be informed (or triggered) by assessments of land degradation risks or climate forecasts (McKeon et al., 2009). In some cases adaptation may enhance opportunities from climate change, for example by being able to exploit longer growing seasons through cropping adaptations (IPCC, 2014 WGIIAR5 Ch7). There are, however, a range of barriers to adaptation which could be addressed by changes in infrastructure, markets, access to credit, better animal health services and more

[16] For example The European Climate Adaptation Platform (Climate-ADAPT) (http://climate-adapt.eea.europa.eu) or the UNCBD's Climate Adaptation Database (http://adaptation.cbd.int)

effective systems for knowledge sharing (Howden et al., 2008; Kabubo-Mariara, 2009; Mertz et al., 2009; Silvestri et al., 2012; IPCC, 2014).

It is also important to recognise the potential for maladaptation. This will be explored in the final section of this chapter. One way of avoiding maladaptation is to identify 'no-regret', 'low regret' or 'win-win' adaptation options. 'No-regret' options should be implemented irrespective of climate change and land degradation, and are considered to be politically and economically feasible under a range of possible future climates. 'Low regret' options are cost-effective and low-risk responses to climate change and land degradation with relatively large benefits for vulnerable sectors, geographical regions or populations. 'Win-win' options are those that contribute to adaptation but also have wider social, environmental or economic policy benefits, including mitigation benefits (de Bruin et al., 2009; Stringer et al., in press). The final section of this chapter considers whether it may be possible to develop 'triple-win' options that provide opportunities for both mitigation and adaptation of climate change and land degradation.

While climate change is now the global focus, neglecting natural climate variability in land management may sometimes be a precursor to land degradation, which is then exacerbated when long-term climate change occurs. Conversely, if land managers are prepared for short-term climate variability, something they themselves can do with improved land management, they are then better prepared for long-term climate change. Much of the funding spent on 'adaptation' to climate change is focusing exactly on what has been the focus of combating desertification a decade or two earlier. However, how to enhance implementation of climate change adaptation to help tackle desertification at the ground level remains a challenge (Seely & Montgomery, 2011).

4.2 Options for simultaneously adapting to climate change and land degradation

A range of adaptation options have the potential to tackle land degradation and climate change simultaneously, and may therefore be able to mitigate some of the interactions between these two processes and protect livelihoods and human wellbeing. These include:

Adaptation of cropping systems

There is already evidence that farmers are adapting to climate change by changing cultivation and sowing times, crop cultivars and species, and marketing arrangements (Fujisawa and Koyabashi; 2010, Olesen et al., 2011; IPCC, 2014). Whilst the previous section considered the potential for SLM to prevent land degradation, many SLM options are already being used to adapt to the effects of land degradation, e.g. to adapt to soil degradation: for instance, agroecology and agroforestry techniques, such as intercropping with leguminous woody species, allow access to nutrients deeper in the soil profile, whilst simultaneously reducing the effects of erosion and increasing levels of soil fertility higher up the soil profile; on-farm production and use of organic

materials (compost, vermicompost, biochar and other by-products) can improve soil fertility; the use of different types of biofertilizers can increase plant nutrients mobilization, nitrogen fixation and demineralization; and adaptation of the tillage system (including no-till and conservation tillage) can improve the soil quality. The benefits of such practices nevertheless have to be carefully evaluated in relation to labour costs, as well ensuring there are no detrimental effects in terms of moisture or light availability.

Adaptation of livestock systems

In many cases, livestock systems are already highly adapted to climate variability, and provide a valuable means of adapting to future climate change, often drawing on locally-held knowledge to inform adaptation decision making. A range of adaptations to livestock systems can enable adaptation to both land degradation and climate change (IPCC, 2014), including:

- altering stocking rates to match changes in forage production in response to climate change and/or land degradation;
- adjusting the management of herds and water points in response to changing seasonal and spatial patterns of forage production under climate change and inter-annual trends in forage production due to land degradation;
- managing diet quality (using dietary supplements, legumes, choice of introduced pasture species and pasture fertility management) to maintain herds under climate change and/or land degradation;
- more effective use of rotational grazing systems;
- managing the encroachment of woody shrubs spreading on productive rangeland;
- using livestock breeds or species that are better suited to new conditions as a result of climate change and/or land degradation;
- increased provision of shade from trees to reduce heat stress in livestock though the adoption of silvopastoral systems that can also reduce erosion rates and provide fodder for livestock during drought;
- enabling migratory pastoralist activities (though this has to be carefully managed to avoid exacerbating land use conflicts);
- monitoring and managing the spread of livestock and rangeland pests, weeds and diseases; and
- improved soil and water management.

Climate-smart agriculture

Adaptation of cropping and livestock systems should be considered within the emerging concept of climate-smart agriculture (CSA), as defined and presented by FAO at the Hague Conference on Agriculture, Food Security and Climate Change in 2010. It integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars:

- sustainably increasing agricultural productivity and incomes;
- adapting and building resilience to climate change;
- reducing and/or removing greenhouse gases emissions, where possible.

CSA is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change. The magnitude, immediacy and broad scope of the effects of climate change on agricultural systems create a compelling need to ensure comprehensive integration of these effects into national agricultural planning, investments and programs. The CSA approach is designed to identify and operationalise sustainable agricultural development within the explicit parameters of climate change.

Ecosystem-based adaptations

Some adaptations that use biodiversity and ecosystem services to enable adaptation to climate change may also be able to enable adaptation to the effects of land degradation. For example, wetland restoration may be able to provide water resources for livestock and cropping systems, whilst creating a buffer to climate-induced flood risks (Huntjens et al., 2010; Jones et al., 2012). Green infrastructure, such as green roofs, porous pavements and urban wildlife corridors, can reduce soil-sealing whilst improving storm water management, reducing flood risk in cities, and moderating the heat-island effect (IPCC, 2014 WGIIAR5 Ch14). Ecosystem-based adaptations such as these have the potential to simultaneously enable adaptation to climate change and land degradation, whilst in many cases also protecting and enhancing biodiversity.

Income diversification measures

Where climate change and/or land degradation threatens current livelihood strategies, it may be possible to diversify into new sources of income to support livelihoods

Sustainable land management

There are a range of adaptations to soil and water management practices that can enhance adaptation to both climate change and land degradation, for example building terraces or other structures that can reduce erosion and tackle land degradation whilst also mitigating downstream flood risk as a result of changes in rainfall patterns under climate change. These options are considered in more detail in the rest of this section.

It is now widely acknowledged that sustainable land management[17] (SLM) can simultaneously tackle land degradation, reduce net greenhouse gas emissions and contribute towards the conservation of biodiversity, thereby contributing towards the goals of all three Rio Conventions; the UNCCD, CBD and UNFCCC (Thomas, 2008; Cowie et al., 2011). Whether these 'wins' can be achieved whilst still protecting food production, livelihoods, social equity, economic viability and cultural values depends on the ways in which they are enacted and require a delicate balance to be reached. There are a range of SLM technologies[18] that can be used within an overall SLM approach. These technologies need to be viewed in the context of their socio-cultural and policy environment, which may enable or hinder their development and adoption. Rather than attempting to provide an overview of SLM, this section focuses on how SLM might be able to mitigate interactions between climate change and land degradation.

SLM technologies typically attempt to maintain a protective biological surface cover (e.g. living plants or mulches), good soil structure and adequate levels of soil organic matter (Thomas, 2008). As a result, such measures also typically reduce GHG emissions from agriculture. Thomas (2008: 597) therefore argues that "*maintaining a cover over the ground and developing a better stewardship of the flora and fauna will help prevent and reverse land degradation, increase the resilience of ecosystems to climatic and human-induced stresses and thereby contribute to the conservation of biodiversity and mitigation of climate change*." Increasing soil carbon enhances infiltration and moisture retention, and therefore may improve water availability for crops and forage during drought (Cowie et al., 2011).

In this way, SLM can help avoid the feedback between climate change and land degradation via changes in vegetation and soil carbon stocks, described in Section 3.4.1. Rather than losing carbon to the atmosphere due to land degradation, and contributing towards climate change, SLM can build resilience for climate change by increasing soil organic matter (Aguilera et al., 2013), and it has been argued that SLM at a global scale has the potential to sequester and store significant amounts of carbon, thereby helping mitigate climate change (Lal, 2004; 2007). SLM practices can also directly link to the feedback between climate change and land degradation that is mediated through losses of vegetation cover, described in Section 3.4.2. Rather than losing biomass and vegetation cover, which can lead to regional climatic changes (including drier conditions at particular times of year), SLM maintains biomass and vegetation cover, and so contributes towards stable regional climates. Although SLM would of course reduce the albedo-based cooling effect of land degradation at a global scale, this would be offset to an unknown extent by its carbon sequestration benefits. Finally, certain SLM technologies also have the potential

[17] Defined as ''the use of land resources including soil, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and ensuring their environmental functions'' (Liniger and Critchley 2007:10)

[18] Defined as the ''agronomic, vegetative, structural and/or management measures that prevent and control land degradation and enhance productivity in the field'' (Liniger and Critchley 2007:10)

to mitigate biodiversity-mediated feedbacks between climate change and land degradation. For example cover crops and mulches can have benefits for plant diversity and create habitats for arthropods (Andersen et al., 2013; Bryant et al., 2013; Scopel et al., 2013; Licznar-Małańczuk, 2014).

SLM technologies often evolve through local traditional practices and incremental experimentation rather than being taken up on the basis of scientific evidence (Berkes et al., 2000). SLM technologies are also often suited to particular biophysical or socio-cultural contexts (Liniger and Critchley 2007). These factors make it complex to effectively promote the adoption of these technologies and scale up SLM from field to regional and national scales (Stringer and Reed, 2007). Other barriers to the adoption of SLM technologies include for example, the cost of introducing or maintaining the technology; availability of labor to implement it; local traditions and cultural factors; or logistical challenges such as distance to markets (Stringer et al., in press). These complications make it imperative to combine locally-held knowledge on SLM technologies with scientific testing and validation, so that local technologies and knowhow can gain greater policy credence and be more widely applicable across contexts (Raymond el al., 2010; Stringer et al., 2014). Despite the challenges associated with achieving SLM, there are already a wide range of technologies available and there is growing awareness of the constraints that are preventing more widespread uptake. These will be considered later in the chapter.

4.3 Learning to adapt using locally-held and scientific knowledge

There is a danger that adaptations based on scientific knowledge alone may not be suitable for the socio-cultural context in which they are needed, and this may significantly limit their uptake and effectiveness. By combining scientific understanding of adaptation options with local, contextual knowledge, it may be possible to develop adaptations based on generations worth of experiential knowledge, which can help refine adaptations. Locally-held knowledge can provide a wealth of adaptation options based on previous experience and exposure to climate change and land degradation processes (Dixon et al., 2014). For example, traditional methods of water harvesting, making use of local topographic and soil characteristics, or using architectural innovations to condense atmospheric water (e.g. stone heaps, dry walls, little cavities, and depressions in the soil), can successfully enable plants to overcome periods of drought and improve productivity (Biazin et al., 2012). Inca traditions of crop diversification, raised bed cultivation, agroforestry, weather forecasting and water harvesting are still used today in the southern Andes (Goodman-Elgar, 2008; McDowell and Hess, 2012).

Locally-held knowledge is typically context-specific, and may have limited potential for being used elsewhere, but it is often highly relevant and acceptable within the socio-political and biophysical context in which it was developed (Raymond et al., 2010). This kind of knowledge is typically highly dynamic, and involves learning from local experimentation and incorporating

ideas from other areas (for example observed during seasonal or temporary migrations) (Mazzucato and Niemeijer, 2000). Local, experiential knowledge has informed responses to past climate variability and land degradation, leading to claims that these knowledge systems can help to foster learning and livelihood resilience in the face of future climate and land degradation risks (Stringer et al., 2009). However, little work has been done to assess the extent to which locally-held knowledge can inform future adaptations. In particular, there are concerns that the future may see extremes that exceed those that have been experienced in the past, reducing the utility of locally-held knowledge (Speranza et al., 2010; Kalanda et al., 2011; McDowell and Hess, 2012).

This supports the need for scientific approaches to play a key role in generating new adaptations to climate change and land degradation, using some of the methods and modelling techniques mentioned in the methodological framework that is described in Chapter 2. Science can provide certain kinds of information that can be difficult to capture through locally-held knowledge alone, for example, providing data at spatial and temporal scales that would otherwise not be possible to consider. By elucidating the processes through which climate change and land degradation impact upon livelihoods, scientific evidence can identify potential system feedbacks and unanticipated impacts that can inform the development of adaptation options (Reed et al., 2011).

Although adaptations based on scientific knowledge are typically more widely applicable, with a greater potential for use in different contexts, they may have limited social acceptance. It is therefore essential to link different knowledge systems to foster adaptation, putting scientific findings alongside local knowledge, recognizing each as valid (whether formally codified or not), and scrutinizing each with equal rigour (Berkes and Folke, 2002; Raymond et al., 2010; Stringer et al., 2014). In this way, scientific evidence may be questioned and perhaps rejected in favor of adaptations based on local experience that are more profitable, less risky or more culturally acceptable. Such context sensitivity is vital in instances where behavioural changes are needed (see Section 4.4). In cases where local approaches are perceived to be failing, it is important to distinguish cases where the technologies work but need a more enabling political or socioeconomic environment from those cases where more appropriate technologies may need to be developed (MA, 2005b).

4.4 Overcoming barriers to adaptation

The extent to which individuals, households and communities can adapt their livelihoods in response to climate change and land degradation, may be restricted by a range of obstacles. Barriers to adaptation can arise from a variety of sources, for example: a lack of available options to substitute one form of capital for another (e.g. due to a limited asset base, limited agro-ecosystem capacity or limited market access); limited political capacity to enact strategies to support adaptation; high levels of institutional inertia and rigidity; lack of access to information about adaptation options (including poor agricultural extension services); or financial constraints (including lack of access to credit) (Bryan et al., 2009; Deressa et al., 2009; Kabubo-Mariara,

2009; de Bruin and Dellink, 2011, Quinn et al., 2011; Silvestri et al. 2012). Other barriers can be cognitive in nature, linked to a lack of perceived risk, a lack of perceived agency and a sense of powerlessness, or the social norms that influence behaviour within particular socio-cultural settings (MA, 2005b), or a lack of /limited incentives to change behaviour. For example, opportunities for women to diversify into new livelihood activities could be restricted due to particular cultural or religious expectations (Stringer et al., in press).

An important barrier to adoption of adaptation measures is due to a lack of awareness, lack of available knowledge and differences in perception of problems and solutions to the impacts from climate change and land degradation by different stakeholders. The fact that land degradation and climate change are generally slow, creeping and complex processes often hampers fast adoption of adaptation measures by stakeholders who may perceive other more urgent priorities. Social attitudes that increase land degradation and climate change effects and that should require the reinforcement of the combined actions of institutional polices and social awareness of perceived risk are well explained by the causes of wildfire. In the Mediterranean area this is one of the major environmental threats for many decades. Despite policies to mitigate their incidence and impacts, forest fires are mostly human-caused (voluntary, arson, or involuntary, negligence). Along the history, temporal trends of wildfire causes are invariant with rates around 50%, or more, with no particular trend to mitigate in recent times: this may be an indicator of the difficulties to activate policies to raise social awareness and mitigate the impact of wildfires (Meddour-Sahar et al., 2013).

There is increasing empirical evidence that well-designed participatory processes may help to solve this as these processes often lead to social learning, increased trust between stakeholders and ownership over problems and solutions. This makes that decisions taken in participatory processes are more likely to be accepted and implemented (Reed, 2008; de Vente et al., in review).

As an example, the Regional Landcare Facilitator (RFL) program is an initiative of the Department of Agriculture of Australia. This four year program funds Regional Landcare Facilitators located in each of the 56 natural resource management regions across Australia where they support Landcare (a unique grass-roots movement that started in the 1980s through initiatives to tackle degradation of farmland, public land and waterways) and production groups to adopt sustainable land management practices and to protect Australia's landscape. The Natural Resource Management PlaceStories Project provides members with a powerful digital storytelling and communication digital platform to help natural resource managers to document and report on their natural resource management work and projects, monitor and evaluate management activities; share successes and key learnings with others, promote effective practices, and communicate and collaborate online (see: http://placestories.com/project/8169).

Other barriers and limitations are associated with a range of adaptation options and contexts. Broadly speaking, adaptation options work within the constraints of the capital assets available to the individual, household or community. So for

example, agricultural intensification may be a relevant adaptation to climate change and land degradation in some areas, but will be limited by natural capital in terms of the soil nutrients or water that is available. However, it may be possible to draw upon human capital to develop rainwater harvesting techniques to overcome water shortages or to use financial capital to purchase fertiliser. In other areas where population densities are low, extensification may be considered as an adaptation option. However, this may be constrained by human capital if there is not sufficient labour to herd animals (Stringer et al., in press). Where adaptations depend on the use or substitution between capital assets, it is necessary to understand how this asset base is likely to be affected by climate change and land degradation, in order to understand future adaptive capacity (Reed et al., 2013a). It is also necessary to understand how climate change and land degradation is likely to influence people's ability to access or substitute between assets.

Following this approach, Reed et al. (2013a) characterise adaptation decisions as a choice between: i) adopting adaptations based on new ways of using or substituting between existing assets; or ii) developing new assets. In some cases, opportunities to develop new assets and associated livelihood options may arise as a consequence of climate change, for example cultivating new crops. Although these adaptations may have been tried elsewhere, they are innovations in a new context or environment or for a different social group. As such, it may be useful to think about the evaluation of adaptation options as an innovation-decision, in which the perceived relative advantage, trialability, compatibility, observability, complexity and adaptability of different options are evaluated against each other and current practice (c.f. Rogers, 1995). The literature on social learning and the diffusion of innovations emphasises that such decisions are evaluated in a social context. For example, people's decisions are influenced by others to whom they are socially tied. Social networks, in other words, influence how individuals learn and consequently make decisions (Prell et al., 2009). This happens for a number of reasons: social psychology and social network analysis research shows that individuals tend to adapt their views to those around them as a way to decrease cognitive dissonance (Homans, 1950; Friedkin, 1998; Ruef et al., 2004; Skvoretz et al., 2004).

Adaptation may also be constrained by institutional and structural barriers, for example linked to land tenure, or globalised processes of 'land grabbing' which limit access to the natural resource base (i.e. large-scale acquisition of arable land by foreign companies or governments, typically for cash crops) (Stringer et al., in press). For example, the 'Land Policy Initiative' (http://www.uneca/lpi) aims to ensure that all land users have equitable access to land and security of land rights to boost sustainable development in Africa. National policies can both incentivise and act as barriers to adaptation, for example incentivising the production of certain crops, and so simplifying the agro-ecosystem and limiting future adaptation options (Dixon et al., 2014). Such policy decisions can create 'path dependencies' and 'lock-in' effects, which further limit future adaptation (Bailey and Wilson, 2009; Wilson, 2014). For example Freier et al. (2012) describe how despite predicted decreases in rainfall, pastoralists in semi-arid Morocco still chose livelihoods based on

livestock, and were more likely to abandon nomadic lifestyles, even though this would increase pressure on available land and water resources, and reduce resilience. Equally, informal institutional barriers may limit the range of adaptive options that are considered to be acceptable, if adaptation options are not compatible with prevailing social norms and customs. As such, many adaptations require a certain degree of behavioural change.

Adaptations that require behavioural change within individuals, households, communities or institutions are often linked to transformative adaptation (Stringer et al., in press). Behavioural adaptations often require changes from a previous or current activity or way of doing an activity to a new one. Short-term behavioural changes can sometimes be top-down, and shaped by prevailing institutions and laws, by, for example, restricting access to certain areas to allow ecosystem recovery following drought. Such changes may be effective in improving the long-term ecosystem state and allowing vegetation recovery, but can have inequitable and unjust implications for some groups over the short and medium term – particularly those whose livelihoods depend solely on access to those areas.

Long-term behavioural changes can include adopting new agricultural techniques, switching to growing different crops, or changing planting and/or harvesting calendars. However, these kinds of household level changes often also require wider institutional support. For example, while a household may recognize the need to plant earlier and mobilise the financial capital necessary to hire a tractor to prepare the soil earlier than is usually the case, unless the institutions responsible for making tractors available have sufficient accessible machinery to meet changing timings of demand, the household will be unable to enact their adaptation decision (Simelton et al., 2013). This kind of scenario is particularly problematic when several households decide to undertake the same adaptation at the same time, placing unexpected new demands on particular institutions. Such relations between adaptation practice and broader institutional factors demonstrate the importance of appropriate policy instruments and governance models in enacting adaptive capacities.

Reed et al. (2013a) argue that adaptation decisions are influenced by the aspiration level of the decision-maker. This views livelihood decisions as aiming for a satisfactory outcome (defined by an aspiration level) rather than necessarily the optimal outcome (a process sometimes called "satisficing"; Simon, 1955; 1956). If livelihoods are sensitive to climate change, a reduction in assets may be deemed acceptable to an actor with a low aspiration level who would perceive no need to adapt. However, the same reduction in assets may stimulate a search for adaptive options by the same actor if their aspiration levels were higher. Different adaptation options may be necessary to meet different aspiration levels. In this context, adaptation may be used to improve rather than simply maintain livelihoods in the face of future change (Ziervogel et al., 2006). If livelihood outcomes are no longer deemed satisfactory, then a search commences for livelihood adaptation options, which are evaluated against individual decision rules.

Limited research to date has sought to examine the links between the adaptations taking place on the ground and the support for adaptation provided within policy. Stringer et al. (2009) examined local adaptations as well as policy adaptations as outlined in National Action Programmes to combat desertification and National Communications to the UNFCCC in three countries in sub-Saharan Africa. Their research found that there are some overlaps in terms of the types of adaptations in policy and practice, but that these are largely coincidental rather than the result of the active incorporation of local adaptations within policy planning. Similar to other research (e.g. Kalaba et al., 2014), a need for mainstreaming adaptation within policy is recognised, in order to avoid duplication of efforts. A lack of mainstreaming also increases the risk of negative externalities and to prevent policies from undermining the success of other policies and strategies in other sectors. Policy lock-ins are also important as existing strategies are reinforced over time, such that resistance to change can develop. Policies have further been criticised for their lack of consideration of social and cultural factors. For example, in some countries, micro-credit schemes have been proposed as an important policy mechanism to address shortages of financial capital at key points in the agricultural calendar when people require the purchase of agricultural inputs. However, many rural people are disinclined to engage in such schemes, particularly where it would require them to use cattle as collateral.

To overcome these challenges, there is a need to bring together top down policy approaches across key livelihood sectors, with bottom up adaptations that are already taking place on the ground. This could help people to enact the successful adaptations that they would choose to employ, and which are already tailored to the realities of the local livelihood and social-cultural context. It is nevertheless important to recognise that not all adaptation options are compatible with one another and what is a successful adaptation at one scale could undermine adaptation options at larger scales. Further research is needed to help inform policy support such that these kinds of trade-offs are reduced.

Payments for Ecosystem Services (PES) can be powerful instruments for overcoming obstacles to SLM adoption and other ecosystem-friendly behaviours (Pirard et al., 2010). When designed as asset-building instruments (i.e. paying farmers conditional to the adoption of new farming, or other natural resource use, techniques), PES may assist rural communities, especially poorest and most vulnerable ones, with start-up physical and financial capital, as well as training, in order for these to adopt new and sustainable strategies. Without such technical and financial assistance during the start-up phase, farmers would not modify their strategies even if this behaviour change is in any case beneficial to them in the longer term (by stopping land degradation, soil loss of productivity and climate change). Such PES instruments, as already implemented currently, include for example PES schemes for stimulating adoption of silvopastoral conservation practices in Costa Rica, Nicaragua, and Colombia (Garbach et al., 2012).

So far, the focus has been on complementarities between adaptation options for both climate change and land degradation. However, it is also necessary to evaluate potential trade-offs between adaptations, so that complementary bundles of adaptations can be implemented together, avoiding maladaptation and reducing vulnerability to both climate change and land degradation. A variety of techniques has been developed for systematically selecting adaptation options (e.g. de Bruin et al., 2009; Ogden and Innes, 2009; Füssel, 2009). However, these techniques have many limitations, as they are typically not able to account for many of the barriers reviewed in this section (Smith et al., 2009), and most economic techniques struggle to capture non-market costs and benefits, which can be considerable (IPCC, 2014 WGIIAR5 Ch 14).

Evidence from studies of adaptations to past and current climate variability and extremes show that adaptation options are rarely adopted singly (e.g. Reid and Vogel, 2006; Stringer et al., in press). Instead, bundles of complementary adaptation options are adopted together, overlapping in time and space, in an attempt to address the multiple outcomes of climate change and land degradation. However, not all adaptation options are necessarily compatible with one another, and it is important to investigate in advance the likely effects of combining different adaptations to climate change and land degradation. For example, coupling models such as Agent-Based Models with biophysical (e.g. soil erosion) and climate models, it is possible to model which adaptation options are likely to be adopted where (e.g. Fleskens et al., 2013). Reed et al. (2013b) developed adaptation options on the basis of combined land degradation and climate scenarios and considered likely consequences for biodiversity, and Ceccarelli et al. (2014) developed a range of land degradation (principally land abandonment and soil sealing) and climate change scenarios. However, there have been few attempts to consider how climate and land degradation adaptation options might interact in space and time. Such an analysis would facilitate the development of complementary bundles of options to reduce the vulnerability of ecosystems and populations to both climate change and land degradation, whilst considering likely effects on biodiversity. Evidence presented in this chapter suggests that it is in theory possible to develop adaptations to both climate change and land degradation, which can in many cases have benefits for biodiversity. Ecosystem-based approaches and SLM have particular potential in this regard. It may therefore be possible in future to develop 'triple-win' options that enable adaptation to climate change, land degradation and biodiversity (Suckall et al., 2014).

4.5 Synthesis

This chapter has considered how adaptive capacity may be enhanced to retain the integrity of ecosystems in regions affected by DLDD and maintain sustainable livelihoods in the face of the interactive effects of climate change and land degradation. It has reviewed different approaches to adaptation, including: autonomous, reactive and planned/anticipatory adaptation; coping, adjustment and transformation; and win-win versus no-regret and low-regret adaptation options. It has considered a range of barriers to adaptation, and the potential for maladaptation. It has assessed adaptation needs in relation to

climate change and land degradation, in terms of biophysical and environment, social, institutional, and information, capacity and resource needs.

The chapter has considered options for simultaneously adapting to climate change and land degradation, including the adaptation of cropping and livestock systems, ecosystem-based adaptation such as green infrastructure, and sustainable land management. It may be possible through SLM to address a number of the feedbacks between climate change and land degradation identified in Chapter 3. SLM may be able to help mediate the feedback between climate change and land degradation via changes in vegetation and soil carbon stocks. Rather than losing carbon due to land degradation, a number of SLM techniques are able to build soil organic matter and sequester significant amounts of carbon, thereby helping mitigate climate change. SLM practices also directly link to the feedback between climate change and land degradation that is mediated through losses of vegetation cover. Certain SLM technologies also have the potential to mitigate biodiversity-mediated feedbacks between climate change and land degradation.

There is a danger however, that adaptations based on scientific knowledge alone may not be suitable for the socio-cultural context in which they are needed, and this may significantly limit their uptake and effectiveness. By combining scientific understanding of adaptation options with local, contextual knowledge, it may be possible to develop adaptations based on generations´ worth of experiential knowledge, which can help refine adaptations. It is therefore necessary to consider the benefits and drawbacks of both locally-held and scientific knowledge for the development of adaptations to climate change and land degradation.

Finally, the chapter has considered how barriers to adaptation may be overcome. Barriers to adaptation may arise from a lack of available options to substitute one form of capital for another, low political capacity to enact strategies to support adaptation, high levels of institutional inertia and rigidity, lack of access to information about adaptation options, or financial constraints. Other barriers can be cognitive in nature, linked to a lack of perceived risk, a lack of perceived agency and a sense of powerlessness, low aspirations, or the social norms that influence behaviour within particular socio-cultural settings.

Once these barriers have been overcome, it is necessary to evaluate potential trade-offs between adaptations, so that complementary bundles of adaptations can be implemented together, avoiding maladaptation and reducing vulnerability to both climate change and land degradation. It is argued that ecosystem-based approaches and SLM have the potential to simultaneously enable adaptation to climate change and land degradation, whilst in many cases protecting or enhancing biodiversity; what may be considered 'triple-win' adaptation options.

5. Monitoring and evaluation

This chapter considers how best to monitor and evaluate interventions to enhance the capacity of ecosystems and populations to adapt to climate change and land degradation. Decision-makers, from landowners and managers, to regional, national and international stakeholders, need to be able to effectively evaluate response options and monitor their success or failure, so that responses can be refined in future. This is important because the complex linkages within and between social-ecological systems mean that the effects of different responses may have unexpected consequences for linked ecosystems and populations, and the ecosystem services they depend upon. When evaluating the suitability and effectiveness of adaptations to both climate change and land degradation, it is important to consider likely effects on ecosystem processes and ecosystem services, and how these then impact upon livelihoods.

It is also essential to assess the socio-cultural context in which these adaptations might be used, for example, considering the skills and resources required to implement them, their cultural acceptability and their compatibility with existing institutional arrangements, for example land tenure systems. Understanding the likely consequences of different response options is highly complex, and can only be done in collaboration with those who may use those options. For this reason, co-operation between members of the policy and research community with practitioners and local communities is important to fully consider the likely implications of different response options and to be able to appropriately use monitoring data to refine future responses.

This chapter therefore starts by reviewing approaches for monitoring and evaluating the interactive effects of climate change and land degradation, considering both current and likely future effects. It then considers how decision-makers may assess different response options. Finally, it considers ways of enabling more effective knowledge exchange and participation between policy-makers, researchers, practitioners and local communities.

5.1 Monitoring and evaluating current effects of land degradation and climate change

Following the conceptual framework described in Chapter 2, where ecosystems and populations are exposed and sensitive to climate change and land degradation, there are a number of potential interactions that may occur between these two processes that may impact upon livelihoods and human wellbeing. Understanding these sensitivities is essential to identify appropriate adaptations that may reduce the vulnerability of these ecosystems and populations to the interactive effects of climate change and land degradation. Monitoring and evaluation is also essential to determine the effectiveness of adaptations, so that they can be refined where necessary to enhance resilience. As described in the methodological framework in Chapter 2, there are three broad approaches to monitoring: i) direct measurements; ii) proxy

measurements or indicators; and iii) model-based approaches. Each of these approaches has a number of benefits and drawbacks.

Direct measurements are the most accurate approach, but can be extremely costly and time-consuming. The accuracy of direct measurements makes it possible to reliably compare ecosystem processes and the provision of ecosystem services between locations and over time, providing a detailed account of changes as they occur, with the ability to interpret the likely causes of those changes via understanding of the underlying processes driving change. Although sampling regimes are typically used to represent systems and reduce the number of measurements required, the level of investment required is typically beyond the reach of landowners and managers, and not feasible at scales relevant to regional, national or international stakeholders. For example, the heterogeneity of soil characteristics typically requires a high sampling frequency, and laboratory testing is required to accurately measure many of these characteristics. Similarly, directly measuring the impacts of climate change and land degradation on livelihoods typically requires household surveys, which may be feasible at a village-level, but which become time-consuming and costly at broader spatial scales.

For these reasons, proxy measurements or indicators are often used to represent changes in ecosystem processes and services, and assess their likely impacts on livelihoods. By definition, indicators will only ever be an approximation or indication of change, and may sometimes provide misleading guidance for decision-makers. It is therefore typically necessary to monitor and triangulate data between a range of different indicators to reliably assess the effects of climate change and land degradation (Reed et al., 2006, 2011). It has been claimed that indicators tend to provide few benefits to landowners and managers, who as a consequence rarely apply them (Carruthers and Tinning, 2003; Innes and Booher, 1999). Partly, this is because indicators are usually developed by experts, and applied without engaging effectively with local communities and other decision-makers (Riley, 2001). As a result, the UNCCD stresses the need for local communities to participate in all stages of project planning and implementation, including the selection, collection and monitoring of indicators (WCED, 1987; UNCCD, 1994; Corbiere-Nicollier et al., 2003). To do this, the methods used to collect, apply and interpret indicators must be easily used by non-specialists. To achieve widespread uptake, indicators must also be clearly linked to the needs, priorities and goals of the decision-makers who need to use them. In the hands of local communities, regional and national decision-makers affected by climate change and land degradation, indicators have the potential to enhance the overall understanding of environmental and social challenges and empower decision-makers to respond appropriately without having to rely on external experts (Reed et al., 2006). Indicators have the potential to provide spatial comparisons, if a core set of indicators can be used to compare progress in different locations. This can be done at local and international scales, though at these broader spatial scales, indicators tend to be based more on scientific rather than local knowledge (Reed et al., 2011). At COP11, the UNCCD adopted a set of six "progress indicators" (two indicators for each of the convention's strategic objectives),

which will be used in reporting to the convention in 2016 (via the performance review and assessment of implementation system, PRAIS) and linked to National Action Programmes (Decision 22/COP.11). The approach uses readily available data and attempts to link global level reporting with monitoring data from local and national scales. The approach combines qualitative and quantitative data and emphasizes stakeholder participation, and integrates effects on human well-being with effects on ecosystem services using the DPSheIR (Driving Force, Pressure, State, human and environmental Impact and Response) framework.

Model-based approaches have the potential to assess relationships between multiple variables, many of which may be indicators, checked or "validated" against direct measurements. As such, models are particularly well-suited to assessing the likely interactions between climate change and land degradation. Chapter 3 reviews evidence from a number of models that have considered how different aspects of climate change may interact with or exacerbate land degradation. Section 5.2 considers how model-based approaches compare to alternative approaches for assessing likely future climate change and land degradation.

In reality, a combination of direct measurements, indicators and models is likely to be required to understand the complex interactions between climate change and land degradation and monitor their effects. Indeed, some processes are related to size (scale) and the combination of environmental components that may be altered by both land degradation and climate change, and that finally will be reflected in a particular system's response, will probably require different strategies for direct measuring. For example, the multi-scale study applied to Barranc de Carraixet in Eastern Spain (Pascual Aguilar et al., 2010) shows that, at slope scale, the hydrological response at small experimental plots (320 m^2) is relatively high to the number of rainfall events, while the number decrease considerably when measuring at small watershed size of 17 ha, requiring a greater rainfall threshold, or inexistent concentrated flow when measuring at a basin size of 128 km^2.

Reed et al. (2011) and Hessel et al. (2014) suggest a hybrid framework building on approaches developed by UN Food & Agriculture Organisation's Land Degradation Assessment in Drylands (LADA), the World Conservation Approaches and Technologies (WOCAT) programme and the Dryland Development Paradigm (DDP), which was applied internationally through the EU-funded DESIRE project. Although focused on monitoring land degradation and SLM, the framework is equally applicable to monitoring the effects of climate change, and interactions between climate change and land degradation. Following this framework, indicators would be developed and used to monitor climate change, land degradation and adaptation responses, enabling local communities and regional decision-makers to collect, analyse and act on monitoring results. Models would then be used to upscale assessments to national and international scales, to inform decision-makers at this scale about likely challenges and policy response options. Direct measurements would be used in the development and testing of indicators, and to calibrate models to new context and validate their outputs.

5.2 Assessing likely future effects of climate change and land degradation

The complex and uncertain interactions that are likely to take place between land degradation and climate change make it difficult to predict what the future may hold for the parts of the world that will be affected. However, to develop appropriate responses in policy and in practice, it is necessary to understand the type, direction and magnitude of the challenges that these processes will create. These responses might be as much about harnessing benefits from the challenges posed by land degradation and climate change: as Louis Pasteur said, "*chance favours only the prepared minds*". Broadly, there are three ways we can anticipate the future and set out policies and strategies that can move us closer to the future we want: prediction; visioning; and scenarios (Reed et al., 2013c). This section therefore considers the benefits and drawbacks of each of these approaches in the context of anticipating likely interactions between climate change and land degradation.

5.2.1 Predictive approaches

Through history, people have effectively used cues from their environment to predict environmental change over relatively short time-scales, for example predicting the weather from perceptible drops in atmospheric pressure or storm clouds on the horizon, or predicting the onset of rains after drought before any storm clouds are visible by looking for buds on certain species of trees. However, it is only relatively recently that mathematical models have enabled us to predict anything over longer time horizons and to assign confidence levels to our projections. Now with increasing computer power, these models are capable of depicting ever more complex processes.

For example, IPCC (2014) created 900 mitigation scenarios based on large-scale, integrated models, including a range of technological, socioeconomic, and institutional trajectories. Detailed outputs from these models, and their links to land degradation, are reviewed in Chapter 3. These models link human systems (including energy, land use and economy) with the physical processes of climate change, to identify cost-effective mitigation outcomes. However, IPCC (2014: 10) warns that "*they are simplified, stylized representations of highly-complex, real-world processes, and the scenarios they produce (…) can differ considerably from the reality that unfolds*".

This is because all models are essentially simplified representations of reality. They seek to represent real-world processes as logically and realistically as possible, but they are abstractions of reality. Given the huge range of possible variables, interactions and feedback loops in any socio-ecological system, models concerned with climate change and land degradation processes have to focus on the most important components of the system that is being modelled. These would typically be the aspects that explain most of the change or variability that the system exhibits. In this sense, building a model is a bit like painting a portrait. A skilled portrait painter can represent their subject deftly with a few brush strokes, and although somewhat abstracted from reality when compared to a photograph, the subject is instantly recognisable to the viewer.

The painter could add many more brush strokes to more accurately represent the subject's face, but it is unlikely to do much to increase their recognisability. The more abstract the portrait, the wider the variety of ways it can be interpreted by those who view it.

Model builders face the same challenge: to build up their 'portrait' of the system with no more components and interactions than are necessary to represent the way it functions. However, if the model becomes too abstract or simplified, it may not adequately represent the complexity of the real system. When this happens, it can sometimes mean that the results are misleading. As different modellers focus on different aspects of the system, and represent processes in different ways, so discrepancies appear between competing models, which fuel uncertainty, and cloud decision-making.

Often, future predictions are sought using increasingly powerful computer models that couple or integrate elements of socio-economic and environmental systems (Prell et al., 2007). Partly, the goal is to more precisely represent real-world systems, where people are part of the environment in which they live – like a portrait painter zooming out from their subject to depict them as part of a landscape or event, for example riding horseback through a landscape or as part of a battle scene. But these integrated models also have the potential to help us understand how humans are likely to behave in response to environmental change, and in turn understand how their actions will alter the course of those environmental changes.

There is evidence that people are already adapting to the twin challenges of climate change and land degradation and have been doing so for millennia (e.g. Stringer et al., 2009), and these adaptations will themselves mediate the consequences of climate change and land degradation. Only by understanding how people are likely to react to these challenges, can we realistically anticipate the nature of the challenges we will face. However, by casting the net this wide, the number of potential variables that must be considered starts to mushroom, and difficult decisions must be made about where to focus modelling activity. To use the portrait metaphor again, rather than just trying to depict a single person, it is like trying to accurately render an entire city of people's faces in a single portrait along with their interactions with each other and surroundings – some level of abstraction and simplification is inevitable.

Ultimately, given the enormous complexity and dynamism of coupled socio-economic and environmental systems, computer models can offer a number of very *precise* insights into the ways that they may respond to climate change and land degradation, but they may be precisely wrong. With their numerical outputs, statistical probabilities and maps, there is a danger that such models present an illusion of certainty to decision-makers. The danger of this is that those who attempt to use predictive models to prepare for the future focus on preparing only for the future that the model predicted. In doing so, they may neglect to prepare for a range of equally plausible futures that may in fact come to pass. Therefore, if the model turns out to be wrong, they find themselves unprepared and less likely to be able to adapt rapidly and effectively for the future that they find themselves in.

5.2.2 Visioning approaches

An alternative to predicting the effects of climate change and land degradation is to envision idealised futures and then consider how these futures might be realised in the context of climate change and land degradation. "Visioning" and "back-casting" exercises are an increasingly popular way for decision-makers to prepare for the future (Wilson, 1992; Dreborg, 1996; Manning et al., 2006). These involve a structured, group process of envisioning desirable future states, and then working back to the present day, to think about the actions or conditions that would be necessary to achieve the vision.

Although visioning processes can be a powerful and creative way of getting diverse groups of people to plan for the future together, some groups within society have more power than others to pursue their vision for the future, which inevitably raises issues of equity and distributional justice (Konow, 2003). There is also another problem: most of us are simply not that ambitious or imaginative. This is known as the "status quo bias". When asked what they would like the future to look like, most people look around themselves, and say "this" (Samuelson and Zeckhauser, 1988). There are a few people who have radical visions for the future, but since they are in a minority, their vision is likely to be unpopular with the majority. For example, many have argued that marginal agricultural land should be abandoned (or at least managed less intensively) as a way of reversing land degradation and increasing resilience to climate change (e.g. Scherr, 1999). However, proponents of "re-wilding" are deeply unpopular with land managers and many others who value the ecosystem services currently associated with agricultural landscapes. For example, some warn that intensification of agriculture and climate change may limit that extent to which abandoned land returns to its original vegetation state (Cramer et al., 2008), and others argue that land abandonment is in fact a major form of land degradation in its own right (e.g. Cerdà, 1997; Bajocco et al., 2012). There are also fears relating to impacts on wildfires and the spread of invasive species (Benayas et al., 2007; Cramer et al., 2008).

5.2.3 Scenario-based approaches

Scenarios represent an alternative to prediction and visioning. As Kay (1989) suggests, "*the best way to predict the future is to invent it*". This may be as much about anticipating "nightmare" scenarios that no-one would want to happen, as it is about envisioning ideal futures we want to pursue. By developing scenarios, we can explore what different people's visions of the future might be like, and be prepared for whatever happens. Scenario development (or scenario "analysis" or "planning") is a therefore a "*systematic method for thinking creatively about dynamic, complex and uncertain futures, and identifying strategies to prepare for a range of possible outcomes*" (Reed et al., 2013c).

The wider the range of different plausible scenarios we develop and prepare for, the more likely we are to prepare for something close to what actually happens and be able to adapt effectively. Even if the future turns out to be quite different, the process of thinking about how we might adapt to a range of different futures may still help us adapt more effectively than if we hadn't

prepared. For example, by preparing for the effects of gradual land abandonment or "re-wilding" of marginal agricultural land, we may also be prepared for a range of other futures that have similar effects, for example the emergence of a new, untreatable animal or crop disease that leads to much more rapid land abandonment than we had previously anticipated.

Scenarios concerned with climate change and land degradation are often the domain of modellers, who try and understand how different scenarios might play out on the basis of their process-based understanding of the systems under consideration. Scenarios may however combine both quantitative and qualitative information, including the hopes and fears of the people who live and work in the system that is being studied. There is a normative argument that the people whose futures are being discussed should be involved in the scenario development process. There is also a pragmatic argument that by involving stakeholders in scenario development, it may be possible to anticipate and prepare for a far wider range of plausible futures than could be done by researchers alone (Reed et al., 2013c).

Stakeholder engagement in scenario development can provide as many benefits for the stakeholders who participate as it does for those who wish to develop the scenarios. Kok et al. (2007) and Walz et al. (2007) argue that involvement in scenario development may empower participants through the co-generation of new and useful knowledge with researchers, by communicating existing knowledge in a way that can be easily understood, and by increasing participants' capacity to use this knowledge. Stakeholder involvement can provide a wealth of relevant locally-held knowledge that might otherwise be missed, and this information may also lead to more pragmatic benefits. In particular, it may be possible to expand the breadth and depth of scenarios, enhancing the logic, internal consistency and validity of the scenarios (Walz et al., 2007). In a context where there was conflict between citizens and planning authorities in Denmark, Tress and Tress (2003) argued that involving stakeholders in scenario development built trust and increased the acceptance of planning decisions by local residents, whilst giving planners access to community knowledge that enabled them to produce better plans.

5.3 Assessing response options

As described above, when evaluating the appropriateness and effectiveness of adaptations to both climate change and land degradation, it is important to consider effects on ecosystem processes and ecosystem services, and how these then impact upon livelihoods, and hence poverty. It is also important to understand the political, institutional, economic and social-technical context in which adaptations may be developed or implemented, to ensure responses are relevant and likely to be adopted and applied effectively (MA, 2005b).

The Millennium Ecosystem Assessment (MA, 2005b) proposed a three-stage assessment process. First it is necessary to identify constraints to adaptation and other response options. Second, trade-offs and synergies associated with different options need to be assessed, evaluating and comparing options in relation to multiple dimensions, focusing on compatibility or conflict between

different policy objectives. Third, on this basis it is then possible to select adaptation or other response options. The following sub-sections use this framework to consider the role that political and institutional, economic and socio-technical factors are likely to play in creating constraints and trade-offs for adaptation. Methods are then covered for assessing the characteristics of adaptations that may make them more or less likely to be adopted. It concludes by considering methods for monitoring adaptation.

5.3.1 Political and institutional factors

The development and implementation of response options is likely to be significantly hindered if they face political opposition. It is therefore important to consider the political environment within which responses are being developed. Specifically, it is necessary to consider how adaptation options are likely to be perceived by different political actors (including politicians and stakeholders with political interest) in relation to their interests. Stakeholder analysis techniques can be used to assess the relative interest and power of these different actors, and can be used to develop engagement strategies to better understand their interests and consider ways of altering adaptations to make them more politically acceptable (Grimble et al., 1995, 1997; Reed et al., 2009). It is important however to avoid using such techniques to prioritise the interests of the powerful at the expense of marginalized, disempowered voices within society, particularly when these groups may be most vulnerable to the effects of climate change and land degradation (Reed, 2008; Reed et al., 2009). The extent to which it will be possible to empower these groups in the development of adaptation options will depend on the political structures of the nation state[19] to which they belong, and wider governance structures that shape access to and management of natural resources, including formal governance institutions such as farming co-operatives and informal mechanisms such as behavioural norms within communities of interest (Wenger, 2000).

A range of institutional factors can constrain adaptation options and result in trade-offs or synergies (MA, 2005b). Principal among these is capacity for environmental governance. This depends partly on the capacity for individual institutions to govern natural resources, and partly on the interactions between relevant institutions and their collective capacity as a network of actors, underpinned by certain principles, norms and decision-making procedures (Krasner, 1983). Capacity for collaboration at these scales can be constrained by the different knowledge bases and understandings of climate change and land degradation, making it challenging to reconcile different perspectives and priorities (Reed et al., 2011). Incentives for collaboration may also be lacking. Where institutions lack skills, information and resources to implement adaptations, the response to climate change and land degradation may fail to protect vulnerable ecosystems and populations. For example, data needs to be collected on the implementation of response options, for example via National

[19] MA (2005b:76) define a nation state as "*a combination of actors and institutions, encompassing manifold activities that include everything from political fundraisers, legislative committee hearings, and consultative meetings, to policy implementation on the ground*".

Action Plans (UNCCD) and National Adapatation Programmes of Action (UNFCCC), and appropriate skills and resources are necessary to track progress, and to inform and enable further action.

However, it is possible to build institutional capacity by increasing or pooling access to information, skills and resources. International institutional capacity has grown in recent years through the implementation of, and increasing collaboration between, the Rio Conventions. The effectiveness of international institutions in enabling effective responses to the combined effects of climate change and land degradation depends on the extent to which individual states comply with their commitments under these Conventions (Brown-Weiss and Jacobson, 1998; Chasek et al., 2011; Cowie et al., 2011). Compliance with international Conventions is more likely if those Conventions and the institutions that manage them are perceived to be legitimacy of these international institutions and their associated governance mechanisms (Franck, 1990; Brown-Weiss and Jacobson, 1998). The effectiveness and perceived legitimacy of the Rio Conventions and their associated institutions may be enhanced through more effective collaboration between the Conventions and adequate financing (MA, 2005b; Akhtar-Schuster et al., 2011; Requier-Desjardins et al., 2011).

At a national scale, there is a danger that institutional mechanisms addressing climate change and land degradation are largely top-down in nature, "*being pushed by outside [international] interests*" (Dalal-Clayton and Bass, 2009). Top-down institutional structures may not address the needs of those who are actually affected by climate change and land degradation, and may lead to the development of costly solutions that are not adjustable to local contexts and do not effectively reduce vulnerability to climate change or land degradation (Akhtar-Schuster et al., 2011). Political commitment is needed to create an enabling environment for adaptation (Leftwich, 1994). MA (2005b) suggest that to achieve effective adaptation, the national policy environment needs to: be pluralist, enabling multiple interests and ideologies to be represented; and have a clear separation between executive, legislative, and judicial functions, so that decision-making processes can be fully accountable and transparent; and have included environmental policy goals. National institutions are often constrained by a lack of scientifically validated national monitoring and reporting, the results of which are rarely available in politically accessible formats (Akhtar-Schuster et al., 2011). National financial constraints and insufficient legal frameworks and regulations may further limit institutional capacity for adaptation (Dalal-Clayton and Bass, 2009; Akhtar-Schuster et al., 2011).

At a local level, communities have varying capacities for environmental governance, which may enable or hinder adaptation to climate change and land degradation. The capacity for local institutions to enable effective adaptation depends upon: *(1) perceived local benefits from cooperating; (2) clearly defined rights and boundaries for any natural resources implicated in the response; (3) knowledge about the state of those resources, including for example their extent, accessibility, and potential for regeneration; (4) small size of user groups; (5) low degree of heterogeneity of interests and values within user groups; (6) long-term,*

multilayered interaction across the communities and other governing institutions involved; (7) simple, unambiguous rules and adaptable management regimes; (8) graduated sanctions as punishment; (9) ease of monitoring and accountability; (10) conflict resolution mechanisms; (11) strong, effective local leadership; and (12) congruence with the wider political economy within which those communities function (quoted from MA, 2005b).

5.3.2 Economic factors

It is necessary to assess the economic effectiveness of responses on a number of levels, and from a range of perspectives. At national and international scales, it is important to demonstrate the cost-effectiveness of programmes of responses to climate change and land degradation, to justify funding from public sources. At the level of individuals and local communities considering response options, cost-effectiveness will be considered in relation to alternative livelihood strategies, opportunity costs and the financial and other benefits associated with any given option. The value of different adaptations may be considered at a number of different levels, from the 'contextual value' of an option in a livelihood context (which may be measured via value indicators including money) to more deeply-held 'transcendental values'. Different response options will be valued differently be different groups within society, depending on the extent to which they are consistent with these more deeply-held values.

A range of approaches exist for the valuation of adaptation options, each of which capture some or all of the elements of Total Economic Value[20] (TEV) (IUCN/TNC/World Bank, 2004; Christie et al., 2008). These valuation techniques consider the value of adaptation options in terms of their relative contribution towards different elements of TEV. As such, valuation techniques typically consider the extent to which adaptations may increase an individual's welfare through direct provision of a good (e.g. food, fuel, or recreational use of natural areas), or indirectly through its contribution towards benefits such as the regulation of water and carbon cycles (Pimm et al., 1995; Fromm, 2000). People may also consider the value of adaptations in terms of cultural ecosystem services, e.g. through spiritual or non-use ("passive-use") benefits (such as those derived from cultural values or the knowledge that biodiversity is being protected for future generations to enjoy).

Direct valuation methods typically determine the physical effects of environmental change (such as climate change and land degradation) and measure the monetary value of changes in ecological function and the provision of ecosystem services. Indirect methods assign a monetary value to environmental change, based on production factors affecting the prices of the products (Requier-Desjardins et al., 2011). Some methods are more suited to capturing the value of adaptation options than others. Cost benefit analysis for example, compares the likely impacts of climate change and land degradation

[20] This comprises both use values that accrue directly or indirectly to those who use (or wish to have the option to use) environmental resources (Bateman et al., 2002) and non-use values that reflects the value individuals attach to environmental resources even if they do not use them, for example the value of simply knowing that these resources exist or the value of preserving them for future generations (Krutilla, 1967; Smith, 1987 and Cameron, 1992).

with the benefits of adaptation (whether direct or indirect) by translating likely impacts and adaptation benefits into monetary values, to assess whether responses are likely to be cost-effective and generate greater social wellbeing (Requier-Desjardins et al., 2011). Revealed preference techniques might be more suitable to capturing use values (e.g. the travel cost method which uses the costs of travelling to a biodiversity-rich area to assess the recreation value of that area; Navrud and Mungatana, 1994). On the other hand, stated preference techniques would be more suited to the capture of non-use values (e.g. contingent valuation of how much people are willing to pay to protect an endangered species (Christie, 2007)).

Although environmental valuations have been used widely to assess adaptations to environmental change in both academic and policy-making communities (e.g. Arrow et al., 1993), there has been debate over the validity of these methods (Sagoff, 1988; Diamond and Hausman, 1993; Bate, 1994; Gowdy, 2004). There is also growing evidence that monetary valuations of ecosystem services economic are in any case seldom actually used by decision-makers when designing policies, projects and instruments on the ground (Laurans et al., 2013). There are concerns about how to adequately capture multiple and complex preferences (Spash, 1993; Spash and Hanley, 1995), especially where there are intergenerational rights involved (Bromley, 1995; Hubacek and Mauerhofer, 2008). There has also been recent debate about the way in which values should be elicited. In neoclassical economics, the focus is usually on the expressed preferences of individuals, which are then aggregated and fed into cost-benefit analysis. However, it has also been suggested that people can express preferences as individuals, as individuals in a group setting, or as a group (Clark et al., 2000). Indeed Kenter et al. (2014) found evidence of significant differences between aggregated individual values and values expressed through group deliberative processes. As such, traditional economic analyses can fail to capture the shared, cultural and plural values associated with different adaptation options, given the range of ecosystem services that may be affected by climate change and land degradation. In particular, deeply-held, cultural values and beliefs that may be shared across a community, and widely divergent preferences that may be placed on the same ecosystem state by different communities (e.g. bush encroachment for cattle versus goat farmers), can easily be omitted (Kenter et al., 2015).

Rather than simply converting the costs and benefits of land degradation and SLM to monetary units, it is important to recognise that people hold different types of values, ranging from attitudinal values or preferences for one type of land management over another, to deeper held ethical or 'transcendental' values and beliefs (Kenter et al., 2015). People also play different roles within a single society. This means they may hold different values depending on whether they are asked as an individual land manager or a member of their local community or interest group, or as a consumer versus a citizen. There is also evidence that values around nature are not pre-formed, and are often implicit, and that people may therefore need to form values through deliberation with others.

Kenter et al. (2014) show how deliberative processes can inform values, as well as bring out the shared and cultural transcendental values, beliefs and meanings that shape individual values. Deliberative processes also allow participants to consider issues of fairness, risk and uncertainty more explicitly, and consider the medium- and long-term impacts of a decision. For this reason, mixed method and participatory approaches to environmental valuation are growing in popularity, which combine monetary valuation tools (such as Cost-Benefit Analysis and Deliberative Monetary Valuation) with non-monetary valuation tools (such as Multi-Criteria Evaluation or Matrix Ranking) (Wegner & Pascual 2011; Parks and Gowdy 2012; Kenter et al., 2014). In this way, it is argued that it may be possible to more robustly and fairly assess the social impacts of adaptation options, as well as their economic impacts, informed by locally-held knowledge and the context in which climate change and land degradation occurs (Farber et al., 2002; Bebbington et al., 2007; Fujiwara and Campbell 2011; Parks and Gowdy 2012). Best practices in stakeholder participation and deliberation are considered in Section 5.7.

5.3.3 Social-technical factors

Many early adaptation studies assumed that adaptation was primarily a function of available technology and technical knowledge (Burton et al., 2002; van Aalst et al., 2008). However, these top-down approaches failed to consider local socio-technical constraints to the development and implementation of adaptations (e.g. access, cost and the necessary skills), or the influence of local socio-cultural contexts on adaptation choices (van Aalst et al., 2008). Innovation may be particularly important in the development of adaptation options that can simultaneously enable adaptation to climate change and land degradation. Innovation in this context means "*an idea, practice, or object that is perceived as new by an individual or other unit of adoption*" (Rogers 1995: 11).

A large body of work exists to evaluate, refine and disseminate innovative adaptation options. Much of this work has focussed on agricultural innovations and soil and water conservation. Rogers (1995) describes adoption as a five step "innovation-decision process" in which farmers: i) gain knowledge of an innovation; ii) seek information about the likely consequences of adoption and form an attitude towards it; iii) decide to adopt or reject the innovation; iv) implement the innovation; and v) confirm their innovation decision by seeking reinforcement, and discontinue it if exposed to conflicting experiences and messages. Rogers (1995) also identified five key perceived characteristics of innovations that determine their adoption potential: relative advantage, trialability, compatibility, observability and complexity. The most significant of these for adoption are usually high relative advantage, high compatibility and low complexity (Tornatzky and Klein, 1982). Reed (2007) added adjustability: the extent to which an innovation can be adjusted to meet dynamic, and sometimes unforeseen user demands and specifications. Furthermore, Reed (2007) integrated the innovation-decision process with the sustainable livelihoods framework, suggesting that the need to innovate was stimulated by farmer needs and aspirations, which in turn were influenced by their changing endowment and access to capital assets. At the same time, the perceived risk

associated with an innovation is negatively related to its rate of adoption. Perceived risk is the degree to which economic, social, physical, and functional risks are perceived as being associated with the innovation (Slovic, 1987). Risk perception is influenced by the interaction of individual psychological, social and other cultural factors, and the subsequent behavior of individuals and groups may further affect the way these risks are perceived (Kasperson et al., 1988; Kasperson and Kasperson, 2005). These sorts of approaches stand in contrast to traditional economic approaches, which tend to assume that people have complete knowledge of the system within which they are adapting, and apply this knowledge through economically rational behaviour to optimise profits (Ellis, 1988; Parker et al., 2008). However, diffusion theory has been criticised for being used as a highly structured and top-down tool that tends to be used by the powerful to influence others. It also assumes that well-connected social networks exist through which innovations can diffuse, which is not always the case (Reed et al., 2013a).

Partly in reaction to this, there is now growing interest in the role that social learning might play in developing and diffusing adaptations to climate change. Reed et al. (2010) argue that to be considered "social learning", a process must: (1) demonstrate that some depth of conceptual change or change in understanding has taken place in the individuals involved; (2) demonstrate some degree of breadth for this change to go beyond individuals and become situated within wider social groups within society; and (3) occur through social interactions and processes between actors within a social network. Such learning is typically accompanied by individual and group reflection about adaptations, and iterative attempts to apply what is learned, making incremental changes to the socio-ecological system (Forester 1999; Daniels and Walker 2001; Schusler and Decker 2003; Keen and Mahanty 2006). Pelling *et al*. (2008) argue that adaptive behaviour is by definition a form of learning. As such, they argue that it is essential to understand the processes through which people learn how to be adaptive. Drawing on social learning theory, they propose that to develop innovative adaptation options and permit their wider diffusion, it is necessary for institutions to create "spaces" in which individuals and groups can experiment, communicate, learn and reflect on new ideas. It should be noted that since social learning takes place through interaction within social networks, the network characteristics can hinder or promote the development and dissemination of adaptation options (Pelling and High, 2005). For example, social networks may rapidly diffuse effective and socially acceptable adaptations but social norms or traditional taboos may prevent the adoption of other adaptations (Reed et al., 2013a).

5.3.4 Monitoring adaptation

Despite an extensive literature on monitoring climate change and land degradation processes and impacts, attention has only recently moved to monitoring adaptations to these processes (Carpenter et al., 2006; Schwilch et al., 2011). Although there have been many assessments highlighting successful adaptation to climate change and land degradation (e.g. by UNEP, 2002; FAO, 2002; GM-CCD – Reij and Steeds, 2003; IWMI – Penning de Vries et al., 2008;

and UNFCCC, 2010) these have typically been snapshots in time, and have seldom involved long-term monitoring (Hedger et al., 2008; Prowse and Sniltveit, 2010; Schwilch et al., 2011). Ultimately, the goal is to provide information about the effects of adaptation and other responses to climate change and land degradation on livelihoods and human wellbeing. Given the mechanisms through which climate change and land degradation are likely to interact with one another (reviewed in Chapter 3), this is likely to involve monitoring changes in ecosystem processes and the provision of ecosystem services, as well as socio-economic assessments that can demonstrate links between adaptation, livelihoods and wellbeing. When adaptation monitoring does happen, it is typically done (informally) by land managers, or by external experts (often extension services), but there are few documented methods for monitoring adaptation responses in the academic literature (Schwilch et al., 2011).

Although not designed to monitor the effectiveness of adaptation over time, land capability assessments (Helms, 1992) have formed the basis for some adaptation assessments, given their ability to assess changes in the productive potential of the land in relation to soil quality, land use and climate. For example, land capability models have been used to assess the likely productivity of agricultural land under climate change scenarios and hence the types of land uses and crops that may be grown in future (Brown et al., 2008, 2011). In some cases, these models have been linked to soil erosion models to consider how such adaptations might interact with land degradation processes (e.g. Reed et al., 2013b). As such, with appropriate data sources, it may be possible to use techniques based on land capability assessment to monitor the extent to which adaptations to climate change and land degradation maintain the productivity of land for agriculture, and hence in theory support livelihoods.

Where it is possible to monitor the effects of climate change and land degradation via remote sensing, it may be possible to monitor the extent to which response options mitigate or reverse these effects (Buenemann et al., 2011). Remote sensing has been used to monitor the provision of many ecosystem services, including: provisioning services (e.g. land cover, biological productivity, and water quality and quantity via products such as GlobCover and Afri-Cover); regulating services (e.g. climate variables such as temperature, diseases and evapotranspiration); supporting services (e.g. nutrient cycling and soil characteristics such as soil organic matter, soil moisture, surface roughness, texture, moisture, and salinity) (Buenemann et al., 2011); and cultural services (e.g. 'wild' land mapping; Carver et al., 2012, 2013). However determining causality would normally require more detailed, field-level biophysical and socio-economic assessments, given wide range of other factors that could account for any changes.

More local-scale methods for monitoring adaptation have been developed recently by the LADA[21] and DESIRE[22] projects in collaboration with WOCAT[23].

[21] http://www.fao.org/nr/lada/
[22] http://www.desire-project.eu

Although these projects focussed primarily on monitoring SLM practices, this is a key adaptation to both climate change and land degradation (see Section 4.2) and the approach could in principle be easily extended to monitoring the biophysical and socio-economic effects of other response options. The WOCAT methodology at the local level involves:

1. assessing local case studies of successful response options and their local spread and adoption;
2. using a standardized framework that enables comparison and transferability beyond the local scale;
3. inclusion of socio-economic as well as biophysical aspects;
4. use of the knowledge of both specialists and land users as data sources, backed up (triangulated) by scientific data where possible; and
5. simultaneously using the same tools for both (self-) evaluation and for knowledge sharing (based on Schwilch et al., 2011).

This is done at local level using two questionnaires, on specific SLM technologies (physical practices and management measures that control land degradation and enhance productivity) and broader approaches to SLM (which enable the implementation, adjustment and uptake of these technologies), which feed into an online database. Importantly, the WOCAT tools enable self-evaluation by land managers, which can inform and refine their practice, as well as being applicable by external assessors.

The use of standardised methods and indicators creates the possibility of comparing progress between locations internationally, and integrating information about the success of response options at multiple scales, from local to international (Schwilch et al., 2011). Reed et al. (2011) suggest that a nested approach in which indicators would be developed at local levels, relevant to monitoring adaptations in different contexts, but with a core set of indicators monitored across contexts to enable cross-scale comparisons and global-scale monitoring. Linked to this the UN-INWEH's KM:Land[24] project developed an online Learning Network for SLM practitioners to accompany an indicator system for monitoring the impact of SLM projects funded by the UN's Global Environment Facility that can compare progress between projects internationally.

Adaptation indicators may be process-based (to help measure progress and enhance adaptation) or outcome-based (measuring the effectiveness of interventions). The characteristics of effective indicators are universal, and can be broadly grouped under criteria relating to their robustness[25] and ease of

[23] https://www.wocat.net
[24] http://www.comap.ca/kmland/
[25] e.g. they should be accurate, free from bias, reliable and consistent over space and time, assess trends over time, provide early warnings, be verifiable and replicable, provide timely information and be measured in relation to relevant targets or baselines.

use[26] (Reed et al., 2006). Effective indicators for assessing adaptation need to consider: the effectiveness (extent to which objectives are achieved); flexibility (to account for the uncertainty of climate change and land degradation processes, and the evolving knowledge base); equity (across sectors, regions and societies); efficiency (to address agreed acceptable levels of risk); and sustainability (including partnership-building and community engagement) of adaptation interventions (Hedger et al., 2008). Indicators may be developed to cover thematic areas (e.g. by sector (such as agriculture), habitat (e.g. forest) or issue (e.g. food security)), and may be developed to represent adaptation processes such as policy and planning processes, capacity development and awareness raising.

Developing indicators at local or project scales is relatively straightforward, and can often use existing indicators and datasets from established monitoring systems. Indeed, Spearman and McGray (2011) argue that indicators should normally be developed during project design and linked to objectives to ensure progress can be monitored. They go on to propose a six-step process for developing a monitoring and assessment system for an adaptation project:

1. Describe the adaptation context: conducting a climate change and land degradation vulnerability or risk assessment early in the design process can help practitioners to understand how ecosystems and human populations are likely to be affected by climate change and land degradation, that the adaptation intervention might be able to address;
2. Identify the contribution to adaptation: identify ways an intervention can contribute towards adaptive capacity, specific adaptation actions, and sustained development;
3. Form an adaptation hypothesis: to evaluate the validity of specific approaches to adaptation, practitioners can formulate an adaptation hypothesis for each of the expected outcomes of their intervention;
4. Create an adaptation 'theory of change': to illustrate the relationship between an intervention's components, expected results, and assumptions about factors that might affect its likelihood of achieving success;
5. Choose indicators and set a baseline: indicators may be characterised by type of outcome and should link to a baseline from which progress can be measured;
6. Use the adaptation monitoring and evaluation system: its implementation needs to involve flexibility and learning, via regular feedback and engagement with partners.

In any case, monitoring and assessment of adaptation responses should be carried out through robust impact evaluation (IE) methods which scientifically measure the causal effect of a specific adaptation intervention *vis-à-vis* a credible counterfactual scenario and seek to understand the conditions under

[26] e.g. they should be easily measured, make use of available data, have social appeal and resonance with users, be cost-effective and rapid to use, provide clear and unambiguous information, be limited in number and be easily accessible to decision-makers.

which effects arise. In such a robust IE, building on the adaptation 'theory of change', one needs to rule rival explanations of the outcomes of the program (adaptation response and associated designed instrument, e.g. a payment scheme for environmental services) so that evaluators can attribute impacts specifically to the program. Such types of IE, including quasi-experimental methods and randomized controlled trials, have been developed in the health, education and development sectors and more recently in the field of conservation (Ferraro & Hanauer, 2014). This could be applied in the field of responses to vulnerability to land degradation and climate change. In turn, this would efficiently inform policy-makers about what works and what does not.

However, monitoring of adaptation policies and national, cross-sectoral adaptation programmes is more complex. In particular, there are challenges establishing cause and effect in adaptation interventions and accounting for unintended consequences. There are rarely baselines or historical trends, from which progress may be inferred, and more generally there tends to be limited sharing of relevant information across stakeholder groups, levels and sectors (Hedger et al., 2008; Prowse and Sniltveit, 2010). Nevertheless, Frankel-Read et al. (2009:285) suggest that monitoring and evaluation of adaptation at these broader scales is possible, and should: *identify links between development and climate change; focus the scope of adaptation on key sectors, themes or issues (without limiting integration among them); identify processes, institutions and capacities to strengthen system-wide adaptive capacity; identify adaptation practices/behaviours related to development outcomes (including the actors involved and the change sought); identify adaptation measures necessary to reduce climate-related [and land degradation] risks; incorporate climate hazard and capacity/vulnerability factors; and balance quantitative, qualitative and narrative monitoring and evaluation tools to enable triangulation.*

Some general lessons can however be derived for monitoring adaptation to climate change and adaptation. Given the nature of climate change and land degradation processes and the types of feedbacks that may occur between these two processes, monitoring and evaluation needs to consider both biophysical and socio-economic changes arising from adaptations. There are a number of biophysical indicators that may be monitored cost-effectively via remote-sensing at broad spatial scales. However, field-based measurements are likely to be necessary to interpret this data, and to establish cause and effect. Although field-based measurements of biophysical indicators are time-consuming and expensive, it may in some cases be possible to develop indicators that can be used by land managers to inform their adaptation practice, which can also be reported and used at broader spatial scales. By taking a nested approach to indicator development, it may be possible to develop locally relevant indicators around a core set of indicators that can enable cross-scale comparisons. Even with more detailed field-based data, it may be difficult to directly attribute changes to adaptation interventions. Socio-economic (often qualitative) data is also essential to triangulate and supplement biophysical data, in order to understand whether observed changes in biophysical variables (e.g. increase vegetation cover and biomass) may be considered to be sustainable (e.g. if the vegetation is palatable to

livestock) or further worsening land degradation (e.g. if the vegetation represents encroachment by unpalatable species). Such data is also necessary to understand changes in natural capital (which may be observed using biophysical indicators) in the context of changes in other capital assets (e.g. financial, physical, human or social capital), to interpret the overall impact of interventions on livelihoods and wellbeing. Finally, if the goal of adaptation is to promote sustainable livelihoods and human wellbeing, then there is a strong normative argument for engaging affected communities in monitoring, so that adaptations may be refined using local knowledge and made more relevant to local needs and priorities (Abbot and Guijt, 1997; Reed et al., 2006). This is the subject of the following section.

5.4 Improving co-operation and knowledge exchange for monitoring and assessment of adaptation options

Understanding, adapting to and monitoring the interactions between climate change and land degradation requires the integration of many types of knowledge, from: local to generalized; informal to formal; novice to expert; tacit and implicit to explicit; and traditional and local to scientific and universal (Raymond et al., 2010). Improved co-operation and knowledge exchange is needed between scientists and men and women in local communities, technical advisors, administrators and policy makers. Fundamentally, this is a challenge of using, and in some cases integrating, very different types of knowledge. In doing so, it may be possible to enhance the robustness of policy decisions designed to reduce the vulnerability of ecosystems and human populations to the interactions between climate change and land degradation, and develop response options that are more appropriate to the needs of local communities and can protect their livelihoods and wellbeing.

5.4.1 How does knowledge exchange operate?

Knowledge exchange (KE) can be defined as generating, sharing, and using knowledge through various methods appropriate to the context, purpose, and participants involved (Fazey et al., 2013). KE activities range from simple transfer of information, to management of knowledge through computerised systems (Raman et al., 2011; Warner et al., 2011), through to wider, complex multi-way interactions and exchange of expertise, such as in adaptive co-management (Shepherd et al., 2010; Leys and Vanclay, 2011). They can also occur in formal organised, designed and intentional ways or as informal implicit processes and social learning (Fazey et al., 2013). Perceptions of about what knowledge is considered to be relevant and legitimate are influenced by what knowledge is understood to be; how it is shared between those who might use it; how it is translated and/or transformed as it is shared and created; and the social context in which people produce and learn about new knowledge (Hofer, 2000; Jasanoff, 2003; Fazey et al., 2013; Cook et al., 2013).

Knowledge is created not just through the act of doing research, but also through social interactions and the exchange of different expertise and ways of knowing between those involved, which is also influenced by other contextual factors (Meagher et al., 2008; Morton, 2012). In individuals, learning and knowledge creation also occurs through complex relationships between tacit and explicit knowledge, including through socialisation (tacit to tacit), externalisation (tacit to explicit), combination (explicit to explicit) and internalisation (explicit to tacit) (Nonaka et al., 2000). Learning and knowledge can also spread beyond individuals to groups and other social scales (Reed et al., 2010). KE activities can therefore enhance knowledge sharing, use and contribute to diverse outcomes operating at different levels, including: (1) changes in understanding (e.g. in knowledge, attitudes or ways of thinking) (Kirshbaum, 2008) (conceptual impacts); (2) changes to actual on-ground impacts (e.g. improvements in human or ecological health) (Gross and Lowe, 2009; Crawford et al., 2010) as a result of the implementation of new policies and practices (instrumental impacts); (3) capacity building impacts (Meagher et al., 2008); (4) attitudinal or cultural impacts (Meagher et al., 2008); and (5) process-oriented outcomes (e.g. engagement, trust, relationships, sustainability of activities) (Heylings and Bravo, 2007; de Vente et al., under review) (sometimes referred to as "enduring connectivity" impacts) (Meagher et al., 2008). These impacts may be potential, in progress (or "interim") or achieved (Meagher et al., 2008).

The creation and sharing of knowledge is essentially a social process (Jasanoff, 2003) where the majority of what people learn and the beliefs they hold stem from interactions with other people, whether informally through conversation with those in their social network or via formal relationships, such as with teachers and mentors (Bandura, 1977; Sutherland et al., 2004; Reed et al., 2010). Even learning from written material is socially mediated, as what people learn about and trust is influenced by the society and the culture in which they are embedded (Bandura, 1977). As such, the knowledge an individual gains through engaging with research is a product of an individual's previous experience and practices, interactions, and a reflection of the cultural, social, and institutional structures of the society within which they live (Bourdieu 2001, cited in Contandriopoulos et al., 2010). Consequently, the extent to which the generation of new knowledge through research becomes embodied in policy or practice is often more dependent upon the quality of the relationships of those involved than it is upon the quality of the research itself (Reed et al., 2014). The social context therefore mediates the transformation of information into knowledge, and whether and how it is subsequently shared and acted upon by others (Albaek, 1995; Bourdieu 1980, 1994 cited in Contandriopoulos et al., 2010).

Knowledge creation therefore needs to be understood in relation to its timeliness, access and relevance, and how this knowledge is shaped by other factors, such as group dynamics, legislation and institutions (Heylings and Bravo, 2007; Meagher et al., 2008). A key and often overlooked aspect is the role of power, which influences whose voices get heard and how knowledge is created or used (Chambers, 1997; Fazey et al., 2013; Williams et al., 2003; Reed, 2008). While there are many conceptualisations of power in social theory, they

all generally refer to the various means by which individuals and groups act and their implications for human agency (Gaventa, 1980; Valorinta et al., 2011; Hat, 2012; Avelino and Rotmans, 2009). This includes status, positional, and social power, such as that mediated through pressure groups or differences in formal educational status that prevent equal participation of disadvantaged groups (Ingram and Stern, 2007). It can also include power as a "distribution of knowledge", which operates through both individual and collective action (Foucault and Gordon, 1980; Barnes, 1983). Social processes can also affect the quality of outcomes (Connick and Innes, 2003). For example, collaborative ventures with multi-stakeholder interests can produce considerable quantities of 'new' knowledge but not necessarily knowledge of quality (e.g. whether it is valued or likely to be used over long time-scales). Such qualities may only emerge when there has been considerable focus on social processes that build trust, mutual respect, legitimacy and collaborative capacity and are more widely accepted when these processes have also considered the role of power (Chambers, 1997; Connick and Innes, 2003; Kuper et al., 2009).

Partnership building is one way to achieve long-term collaboration between different stakeholders and researchers. Partnerships are typically affected by contextual factors such as geography (e.g. determining infrastructure, subsidies and legislation), economics (e.g. size of partners), culture (e.g. finding partners with compatible values), and the existence of mutual interdependencies (e.g. technical knowledge) (Ziggers and Trienekens, 1999). Key factors in successful partnerships include: identifying clear benefits for all participants, having a good strategic fit for all partners, the involvement of management at all levels, and organisational flexibility (Hughes, 1994). For example, the UNCCD Secretariat has a "partnership framework" that seeks to build public-private partnerships on the basis of a number of clearly identified shared values and principles[27]. Developing partnerships between the Secretariat and key stakeholders is also one of the operational objectives of the UNCCD's Comprehensive Communication Strategy[28], which aims to raise the profile and influence of soils and land in national and international policy arenas. The UNCCD's "mini-guide to building partnerships"[29] compares partnership building to farming, proposing four phases: "preparing the field" (identifying stakeholders, context and barriers to developing a common vision); "sowing the seeds" (scoping objectives, identifying shared priorities, setting roles and responsibilities, assessing power dynamics and building relevant skills and expertise); "weeding and tending the growing plants" (needs assessment, strategy development, co-ordination, monitoring and evaluation); and "harvesting" (institutionalizing partnerships, maintaining linkages, reporting progress and achieving continuity). Dyer et al. (2013) build on this from experience developing "climate compatible development" in sub-Saharan Africa, to propose that good practice in partnership building should also ensure

[27] http://www.unccd.int/en/about-the-convention/the-bodies/the-cop/cop11/Pages/Call-for-interests-in-the-UNCCD-secretariat-and-the-private-sector-partnership.aspx
[28] http://www.unccd.int/Lists/SiteDocumentLibrary/convention/css.pdf
[29] http://www.unccd.int/Lists/SiteDocumentLibrary/Partnerships/Mini_Guide.pdf

projects are appropriate and relevant to local needs, by engaging communities from the outset.

Achieving partnerships and knowledge exchange across multiple scales, from local to international is still a significant challenge. There are increasing calls for environmental policy decisions to be based on research evidence and monitoring at a variety of scales (e.g. UNCCD, 1994; Sutherland et al., 2004; Pullin et al., 2004; MA, 2005; Reid et al., 2006; WOCAT, 2007; Jessop et al., 2008). Studies of science-policy communication have tended to focus on the perceptions of researchers e.g. surveys of authors publishing in conservation journals about whether they perceive their recommendations have been implemented (Flaspohler et al., 2000; Ormerod et al., 2002). Few studies have focused on the perceptions of those responsible for using this evidence in decision-making, or analysed the pathways through which research evidence and monitoring data reaches policy makers, or if is transformed or blocked by the involved actors (Knight et al., 2008; Spierenburg, 2012). Evidence can often be distorted as it is passed from person to person through social networks, and is sometimes misappropriated to achieve the goals of special interest groups. Robust evidence may be overlooked and more flimsy findings may gain traction with decision-makers who do not always have the time or expertise to critically interrogate its theoretical, methodological or empirical basis. Instead it is often easier to trust evidence on basis of the trustworthiness of its source, whether that be the quality of the journal it is published in or the credentials of the person who communicates it.

This is complicated further by the highly fractured nature of the current knowledge base across different institutions and academic disciplines, combined with structural and procedural barriers that prevent the flow of knowledge between those who are monitoring land degradation and climate change at different scales (Reed et al., 2013d). With limited co-ordination of monitoring activities or integration of data across scales, those working at national and international levels are rarely able to tap into the data and expertise held by those who manage the land. In turn, land managers rarely see the benefits of national and international monitoring programmes (Reed et al., 2006). However, if knowledge about monitoring and assessment can be managed more effectively, it may be possible to provide a more robust evidence-base that can support more sustainable land management policies and practices to tackle land degradation and climate change (Raymond et al., 2010). Scientific literature provides valuable evidence, and a means of generating certain types of data from monitoring and evaluation, but if we are to capture the dynamic, context-dependent and value-laden nature of land degradation, we cannot overlook the equally valuable but often unrecognised knowledge of local knowledge and the contributions of the NGOs, CBOs and Civil Society Organisations that work with them. To achieve knowledge exchange across scales, it will be necessary to better understand the structure of the social and organizational networks that exist around those generating and using knowledge about land degradation and climate change. In this way, it may be possible to identify knowledge brokers and boundary organisations that can efficiently exchange knowledge between communities of actors who

would otherwise have little communication with one another. Partly, this is being addressed by increasing efforts to share knowledge between those involved in the implementation of the Rio conventions (see Chapter 1), but key challenges remain in facilitating knowledge exchange between actors operating at international and local scales. More research is needed to understand the barriers to communication and knowledge exchange, and how these might be overcome in future.

5.4.2 Key groups that need to exchange knowledge about climate change and land degradation

Given the complexity and knowledge gaps around the links between climate change and land degradation that have been highlighted in this report, it is essential to pool knowledge from different sources to better understand the processes involved, the likely response options and to be able to effectively monitor responses. Partly knowledge exchange needs to be facilitated through the development of cross-institutional initiatives and mechanisms for evidence-based policy, including Science-Policy Interfaces like the IPCC, IPBES, and the newly established Science Policy Interface (SPI) and Scientific Knowledge Brokering Portal for the UNCCD, and assessments like the Millennium Ecosystem Assessment and the Land Degradation and Restoration Assessment (see Akhtar-Schuster et al. (2011) and Chasek et al. (2011) for more detailed discussions of opportunities for horizontal knowledge management at national and international levels).

Partly, knowledge exchange needs to be facilitated between local communities, civil society and policy makers at national and international scales. The UNCCD grew out of a recognition that the top-down, science-led technology transfer paradigm was inadequate for combating desertification. It was argued that by tapping into local and traditional knowledge, more complete information could lead to more robust solutions to environmental problems. Compared to the other Rio Conventions, the UNCCD affords the most attention to the participation of civil society and local communities in its text. However, there is no formal mechanism to ensure local and traditional knowledge is taken into account in UNCCD processes and negotiations. Locally-held knowledge has typically entered the international UNCCD process via: i) participation of local communities representatives in the process via CSOs such as Non-Governmental Organisations, farmers associations, unions and local authorities (though each have relatively little power in the policy arena and do not necessarily represent the diversity of local knowledge in their constituencies); and ii) national UNCCD processes such as NAP consultations, UNCCD national reporting processes, and National Coordinating Bodies (knowledge from the local level can be included in National Reports to be submitted to the CRICs and COPs, or can be taken along in negotiations by the representatives of Parties). However, there is no stock-taking mechanism for national reports to gather relevant experiences and knowledge and present it in a practical way for upscaling and/or dissemination. Current pathways depend largely on the willingness of individuals and Parties to take this knowledge into account (DESIRE/DryNet/eniD, 2008).

Knowledge exchange also needs to be facilitated between researchers and stakeholders affected by climate change and land degradation. By combining scientific knowledge with locally-held knowledge through participatory research, it may be possible to enable enhanced adoption of innovations that can enable adaptation in different social and environmental contexts. Local populations are often well placed to collect data and take part in monitoring and evaluation.

5.4.3 Best practice in stakeholder participation

Climate change and land degradation are highly complex processes, affecting many different stakeholders at different scales. Traditional top-down approaches to environmental challenges such as climate change and land degradation often face serious problems when it comes to implementation (Cramb et al., 1999; Knill and Lenschow, 2000). Often, these problems can be attributed to the lack of ownership over the process amongst those who have the power to implement decisions (e.g. state actors or affected citizens and land owners), leading to low rates of acceptance. This may then lead to these groups delaying or preventing the implementation of decisions, in order to preserve their interests.

Attempts to tackle these processes, and the interactions between them, therefore require engagement with diverse, and often conflicting stakeholder priorities, especially where response options lead to trade-offs between different ecosystem services. Often, this is a trade-off between short-term provisioning services (e.g. crop and animal production or extractive uses of forests) upon which the resource-dependent poor often depend for their livelihoods, versus the protection and enhancement of regulating and supporting services (such as nutrient cycling and soil formation), which have the potential to reverse land degradation and enhance resilience to climate change.

Participatory approaches are often sought to address these conflicts. Indeed, it has been claimed that more bottom-up, participatory approaches to tackling climate change and land degradation have the capacity to reduce conflict, build trust and facilitate learning amongst stakeholders, who are then more likely to support adaptation in the long term (e.g. Beierle, 2002; Reed, 2008). However, participatory approaches by definition seek and value a plurality of views, rather than seeking a single evidence-based solution. Taking a participatory approach, scientific evidence therefore becomes one of many lines of arguments in a multi-stakeholder discourse about different options for responding to the effects of climate change and land degradation. The very nature of participation means that conflicts of interest will be made explicit and brought to the fore, and local knowledge will be evaluated alongside scientific knowledge.

If stakeholder participation is conducted effectively, it may be possible to evaluate and consider these different sources of knowledge equally, and facilitate decisions that are supported by the majority of stakeholders. However, there are many examples of participatory approaches to climate

change and land degradation failing to deliver the intended beneficial environmental or social outcomes. It is often unclear why different participatory processes in different contexts often lead to such different outcomes. Despite many local case studies of participatory approaches to climate change and land degradation adaptation, there have been few attempts to generalise from these experiences to explain how and why participatory approaches sometimes work, and sometimes are ineffective and exacerbate local conflicts (de Vente et al., under review).

First, it should be noted that there are a number of contexts in which participation may not be appropriate, for example: where there is widespread apathy and disengagement among stakeholders, making it difficult to mobilise participation; where there is an autocratic culture (i.e. with little decision making autonomy for individuals) e.g. in former communist states (Stringer et al., 2009); where there are significant power imbalances between participants; or where some or all participants do not really have decision-making power (Reed, 2008; de Vente et al., under review). However, assuming that it is appropriate to opt for a participatory approach, then it is essential to spend time designing the process effectively. It is possible to identify three good practice principles for the design of participatory processes for tackling climate change and land degradation from the bottom-up. These principles are derived from a literature review by Reed (2008) and a subsequent empirical analysis of case studies by de Vente et al. (under review).

The right people

A diverse group of well-informed people from different backgrounds is likely to provide the most relevant and innovative ideas. There are two tasks that need to be performed: identifying the right people for inclusion in the participatory process; and actually getting these people engaged.

First, it is necessary to identify the most relevant individuals and organisations, who can represent the full range of interests in the decision-making process. For issues like climate change and land degradation, these stakeholders may operate at local, national and international levels, and it is therefore important to define the scale at which participation is sought. Where multiple scales are sought it may be necessary to facilitate different processes at these different scales, given the likely differences in location (and hence travel distances) between stakeholders, and their different interests in the issues. If the focus is on only one scale, it is still often important to be aware of and link to stakeholder interests at different scales, to ensure options emerging from the process are viable. If key parties are missing from the participatory process, then they are likely to question the legitimacy of the process and potentially block progress towards implementing outcomes. If possible, once representation has been achieved, it can be useful to consider whether the right people have been invited from the organisations that are represented. If these people do not have decision-making power and have to refer any decision back to their superiors, it will be difficult to reach any agreement as part of the participatory process. Finally, where possible, trying to target a few representatives who are known for being innovative and creative can help the

participatory process achieve creative solutions to climate change and land degradation.

Second, it is necessary to actually bring these people into the participatory process. A participatory process that has identified all the key players but fails to engage them is likely to lead to biased outcomes with low acceptance and implementation. Partly this is about effective communication, and making involvement attractive and easy for all participants. For some participants, this may be about practical considerations (e.g. avoiding meetings at certain times of day or certain seasons) or financial or other types of incentives (e.g. payments for participation, offering meals and opportunities to network). For many participants, they simply need to believe there is a high probability that engaging in the process will lead to direct benefits (e.g. access to land, compensation etc). By working through existing trusted contacts and networks, it may be possible to reach and convince potential participants who may not otherwise have been contacted and involved.

The right atmosphere

Creating an open and respectful environment needs to start at the very beginning and continue throughout people's engagement with the process. There is little point in having the right people engaged in the process if some dominate and others feel powerless to speak. Working with a professional, independent mediator can help create the right atmosphere, enabling everyone to have an equal say. They can manage conflicts as they arise, and they often have tools that can get lots of information from people very quickly, for them to think about critically together.

The methods that a mediator employs can go a long way towards creating an atmosphere of trust. For example, methods must be adapted to the socio-cultural context of the participatory process e.g. avoiding methods that require participants to read or write in groups that might include illiterate participants. Depending on the power dynamics of the group, methods may need to be employed that rebalance power between participants to avoid marginalising the voices of the less powerful. There is evidence that actors who are marginalised during decision-making can delay or prevent implementation through litigation.

Making it relevant

Finally, it is important to make the participatory process as relevant as possible for all participants. Partly this is about the content and focus of the participatory process, and how this focus is derived. Partly it is about the perceived credibility of the process, and the likelihood that it will lead to beneficial change. If participants do not perceive that the process has credibility to affect the issues that concern them, then they will view it as irrelevant and not engage with it. Negotiating a set of ambitious but achievable goals with all participants from the outset can help demonstrate that their participation is likely to make a real difference. If the goals are developed through dialogue (making trade-offs where necessary) between participants, they are more likely to take ownership of the process, partnership building will be more likely, and

the outcomes are more likely to be more relevant to stakeholder needs and priorities, motivating their ongoing active engagement.

Once the content and focus of participation has been negotiated and agreed by all parties, the approach to participation needs to be made as relevant as possible to all participants. For example, language can sometimes be used to erect barriers between different groups who each have their own exclusive vocabulary, so it is important to try and use language that is familiar and impartial to all parties. When dealing with complex, intangible concepts (such as biodiversity), it may be necessary to focus on aspects that are more tangible to participants (such as indicator species that have known uses for humans).

5.5 Synthesis

This chapter has considered how best to monitor and evaluate interventions to enhance the capacity of ecosystem and populations to adapt to climate change. The goal is to enable decision-makers to effectively evaluate and then monitor the success of response options, so that responses can be improved in future. In addition to monitoring and evaluating effects of response options on ecosystem processes and services, it is essential to assess the socio-cultural context in which adaptations might be implemented, and to evaluate and monitor the effects of those adaptations on livelihoods and human wellbeing. For this reason, co-operation between members of the policy and research community with practitioners and local communities is important to fully consider the likely implications of different response options and appropriately use monitoring data to refine future responses.

The chapter has considered approaches to monitoring and evaluating current effects of land degradation and climate change. It has considered the benefits and drawbacks of direct measurements, proxy measures (or indicators) and model-based approaches. It concludes that a combination of these approaches is most appropriate for understanding the complex interactions between climate change and land degradation and monitoring their effects. A number of hybrid frameworks and approaches now exist that can enable this combined approach.

Given the complex and uncertain interactions that are likely to take place between land degradation and climate change, it is difficult to predict how different social and ecological systems around the world are likely to be affected by the combined effects of climate change and land degradation. The chapter considered how predictive, visioning and scenario-based approaches may enable policy-makers to better anticipate the likely interactions between land degradation and climate change in future.

The chapter then considered how responses to the interactive effects of climate change and land degradation may be assessed, considering the political, institutional, economic and social-technical context in which adaptations may be developed or implemented, to ensure responses are relevant and likely to be adopted and applied effectively. It then reviewed methods for monitoring the success of adaptation interventions.

Given types of interactions likely to occur between climate change and land degradation in future, monitoring and evaluation needs to consider both biophysical and socio-economic changes arising from adaptations. There are a number of biophysical indicators that may be monitored cost-effectively via remote-sensing at broad spatial scales. However, field-based measurements are likely to be necessary to interpret this data, and to establish cause and effect. Even with more detailed field-based data, it may be difficult to directly attribute changes to adaptation interventions. Socio-economic (often qualitative) data is therefore essential to triangulate and supplement biophysical data, in order to understand whether observed changes in biophysical variables may be considered to be sustainable or are further worsening land degradation. Such data is also necessary to understand changes in natural capital in the context of changes in other capital assets, to interpret the overall impact of interventions on livelihoods and wellbeing.

If the goal of adaptation is to promote sustainable livelihoods and human wellbeing whilst retaining ecosystem integrity, then there is a strong normative argument for engaging affected communities in monitoring, so that adaptations may be refined using local knowledge and made more relevant to local needs and priorities. Understanding, adapting to and monitoring the interactions between climate change and land degradation requires the integration of many types of knowledge, from: local to generalized; informal to formal; novice to expert; tacit and implicit to explicit; and traditional and local to scientific and generalized. Given the number of knowledge gaps around the links between climate change and land degradation highlighted in this report, it is essential to pool knowledge from different sources to better understand the processes involved, the likely response options and to be able to effectively monitor responses. Knowledge exchange needs to be facilitated through the development of cross-institutional initiatives and mechanisms for evidence-based policy, including Science-Policy Interfaces like the IPCC, IPBES, and the newly established Science Policy Interface (SPI) for the UNCCD, and assessments like the Millennium Ecosystem Assessment and the Land Degradation and Restoration Assessment. Knowledge exchange also needs to be facilitated between local communities, civil society and policy makers at national and international scales, and between researchers and stakeholders affected by climate change and land degradation. By combining scientific knowledge with traditional and local knowledge through participatory research, it may be possible to enable enhanced adoption of innovations that can enable adaptation in different social and environmental contexts.

Attempts to tackle these processes, and the interactions between them, therefore require engagement with diverse, and often conflicting stakeholder priorities, especially where response options lead to trade-offs between different ecosystem services. Often, this is a trade-off between short-term provisioning services (e.g. crop and animal production or extractive uses of forests) versus the protection and enhancement of regulating and supporting services (such as nutrient cycling and soil formation), which have the potential to reverse land degradation and enhance resilience to climate change.

Participatory approaches are often sought to address these conflicts, and may be able to reduce conflict, build trust and facilitate learning amongst stakeholders, who are then more likely to support project goals and implement decisions in the long term. However, participatory approaches seek and value a plurality of views, rather than seeking a single evidence-based solution. Taking a participatory approach, scientific evidence therefore becomes one of many lines of arguments in a multi-stakeholder discourse about different options for responding to the effects of climate change and land degradation. There are certain contexts where it is not appropriate to seek engagement with stakeholders. Where participation is appropriate, it is important to design participatory processes in relation to known good practice principles. These relate principally to the appropriate representation of stakeholder interests, the management of power dynamics, and the relevance of the process to stakeholder needs and priorities.

6. Conclusion

This impulse report is designed to inform debate at the 3rd UNCCD scientific conference, which will be held during the 4th special session of the Committee on Science and Technology (CST S-4) of the UNCCD. The conference aims to provide new scientific insights and recommendations to policy makers about how to assess the vulnerability of land to climate change and current capacities to adapt. The conference is expected to help combat desertification and land degradation, and reduce the impacts of drought by: i) better anticipating the impacts of climate change on land degradation and desertification; ii) identifying sustainable and adaptive methods of using ecosystems to reduce poverty and achieve sustainable development; and iii) identifying pathways towards a land degradation neutral world. To reach these outcomes, the conference is organized around three major challenges. This report provides initial answers and additional questions in relation to each of these challenges:

1. **Diagnosis of constraints:** how to best characterize and understand the vulnerability and adaptive capacities of ecosystems (in particular agro-ecosystems) and populations in affected regions, including regions newly susceptible to the consequences of climate change?

2. **Responses:** how to build efficiently on available knowledge, success stories and lessons learnt to promote implementation of better adapted, knowledge-based practices and technologies?

3. **Monitoring and assessment:** what are the appropriate monitoring and assessment methods available to evaluate the effectiveness of these practices and technologies that provide improved insights on whether or how their implementation should be scaled up?

Although it is well recognized that climate change and land degradation present major challenges to livelihoods and human wellbeing, little attention has been paid to the way climate change may combine with land degradation in future, to create new and potentially unexpected challenges. The likely impacts of climate change and land degradation have typically been examined separately, and in isolation from their socio-economic and governance contexts. Although this approach has been widely critiqued (e.g. Blaikie et al., 1994; Bohle, 2001; Hilhorst and Bankoff, 2004; Reed et al., 2011), there have been few attempts at more integrated assessments. This report is one of the first attempts to consider how the land management, policy and research communities can work together to better anticipate, assess, and adapt to the combined effects of climate change and land degradation. It has taken an interdisciplinary and integrated approach to climate change and land degradation as interlinked concepts that have both biophysical and human drivers, impacts and responses.

As such, the likely effects and most appropriate response options can only be determined by considering both biophysical and socio-economic data, interpreted in relation to qualitative (and often subjective) information about the livelihood strategies of those affected. This is because land degradation can only be defined in relation to the objectives of those using the land (Warren,

2001), so one form of environmental change might represent degradation to one land user, whilst it may represent a livelihood opportunity to another. This may present an even greater social science challenge if definitions of land degradation are extended to cover any medium- or long-term, permanent decline in the provision of ecosystem services more generally, including cultural services (Reed et al., 2015).

The report has identified a number of important knowledge gaps and questions under each of the three challenges that will be addressed in the conference.

Diagnosis of constraints

- How to best characterize and understand the vulnerability and adaptive capacities of ecosystems (in particular agro-ecosystems) and human populations in affected regions, including regions newly susceptible to the consequences of climate change?
- Which disciplines need to be brought together to enable a holistic assessment of vulnerability and adaptive capacity? What common terminology and definitions should be used for the issue?
- What methodologies can capture the temporal and spatial dynamics of vulnerability and adaptive capacity? To what extent can temporal and spatial analogues be used to identify possible trajectories of vulnerability?
- How might the effects of climate change be moderated by interactions with other future social-ecological trends and drivers of change to make ecosystems and populations less vulnerable to land degradation?
- What trade-offs might exist between climate adaptation options in terms of their effects on ecosystem service provision and land degradation? Are there complementary bundles of adaptation options that can reduce trade-offs and create win-wins for both climate change and land degradation?
- How are cultural factors likely to shape adaptation options and influence their uptake, and how might the implantation of these adaptation options influence the provision of cultural ecosystem services?
- Are there currently unused ecosystem services that may be combined with existing assets to provide new livelihood options that can increase resilience to climate change and land degradation?
- At what spatial scale do vulnerability maps provide the most useful information to decision makers whilst at the same time retaining richness of information?
- What steps can be taken to deliver a more equitable distribution of adaptive capacity across different social-ecological systems? What preventative measures can be undertaken to prevent the erosion of adaptive capacity?
- How climatic drivers can prevent or speed up the land degradation and how to reach LDN in the changing climate?
- Can a LDN approach be considered as a climate change adaptation strategy?

Responses

- How to build efficiently on available knowledge, success stories and lessons learnt, to promote implementation of better adapted, knowledge-based practices and technologies?
- How do knowledge exchange activities, social relations and power shape the way knowledge is shared and created?
- What are the challenges associated with managing knowledge exchange at different organisational and spatial scales?
- How do contextual conditions (e.g. political, structural and funding) and the way knowledge is understood and framed influence the way knowledge exchange strategies are developed within international policy programmes such as UNCCD?
- What are the processes and mechanisms through which knowledge exchange activities (at these different scales) generate beneficial outcomes for the ecosystems and human populations that are affected by climate change and land degradation?
- How do different research (disciplinary) and decision-making contexts influence the likelihood that knowledge exchange delivers beneficial outcomes for ecosystems and human populations?
- What formats should knowledge and information take to enable widespread sharing of success stories across areas with comparable conditions?
- How can scientists and other stakeholders co-evaluate and jointly communicate success stories and adaptations?
- What drives the discontinuation of sustainable practices and technologies (and what incentives and disincentives need to be in place to promote continued adoption)?
- What actions need to be taken to assess the applicability of success stories in other locations? What analyses of cultural dimensions of practices and technologies are required?
- How to reach LDN, taking into account different national, regional and local peculiarities?

Monitoring and assessment

- What are the new monitoring and assessment methods available to evaluate the effectiveness of sustainable practices and technologies that provide improved insights on whether or how their implementation should be scaled up?
- How can we reconcile results from the monitoring of slow and fast variables?
- What are the most important variables to monitor interactions and feedbacks between climate change and land degradation?

- What resolution and frequency of monitoring provides optimal information to decision makers for important variables linked to climate change and land degradation?
- How can we identify the thresholds (temporal and spatial) at which adaptive practices and technologies may become maladaptive, such that their spread should be discouraged?
- How can we use modelling and mapping approaches to prioritise spatial areas for in-depth monitoring and assessment?
- Against what criteria should the success of practices and technologies be evaluated and who should decide?
- What resources are needed and how do the costs of monitoring (action) fare against the costs of not monitoring (inaction) over short, medium and long time frames?
- How to monitor and evaluate LDN at global, national and local levels?

Despite a number of known uncertainties and gaps in our knowledge about links between climate change and land degradation, it is possible to draw some broad conclusions about the vulnerability of ecosystems and populations, adaptation needs and methods needed to monitor and evaluate interactions between and responses to these processes:

1. Areas already experiencing DLDD are likely to be exposed to potentially damaging interactions with climate change, given the range of land degradation processes that could be exacerbated by increased droughts and heavy rainfall events. Given the high temperatures and limited rainfall already experienced in drylands, these regions are likely to be particularly sensitive to the effects of climate-induced changes in temperature and moisture, combined with degradation-induced reductions in soil organic matter, biomass and soil fertility.
2. These processes may in some cases be self-reinforcing, leading to feedbacks between climate change and land degradation, for example when land degradation via the loss of terrestrial carbon stores from soils and vegetation leads to climate warming, or when the albedo effect of degradation-induced reductions in vegetation cover leads to climate cooling or other local climatic effects. Similarly, the dual effects of climate change and land degradation may have impacts on biodiversity that may further exacerbate land degradation, compromise the provision of ecosystem services and limit capacities to adapt to climate change.
3. In addition to considering the sensitivity of ecosystems to these processes, it is necessary to understand the sensitivity of livelihoods to the combined effects of climate change and land degradation. Climate change and land degradation have the potential to disrupt established ecological and land use systems, which in turn may lead to the failure of food and water supplies, with consequent impacts upon livelihoods. This may in turn then limit the adaptive capacity of households when they are faced with other perturbations or stresses.

4. Despite many barriers to adaptation and the potential for maladaptation, there are a number of response options to enhance adaptive capacity and retain resilient ecosystems and populations in regions affected by DLDD. Ecosystem-based approaches and sustainable land management techniques and approaches have the potential to simultaneously enable adaptation to climate change and land degradation, whilst in many cases protecting or enhancing biodiversity; what may be considered 'triple-win' adaptation options. Importantly, many of these adaptations have the potential to help avoid significant feedbacks between climate change and land degradation.

5. Decision-makers need to be able to effectively monitor and evaluate the success of response options, to provide feedback that can refine adaptations and enhance the capacity of ecosystems and populations to adapt to climate change and land degradation. In addition to monitoring and evaluating effects of response options on ecosystem processes and services, it is essential to assess the socio-cultural context in which adaptations might be implemented, and to evaluate and monitor the effects adaptations on livelihoods and human wellbeing.

6. There are a number of biophysical indicators that may be monitored cost-effectively via remote-sensing at broad spatial scales. However, field-based measurements are likely to be necessary to interpret this data, and to establish cause and effect. Even with more detailed field-based data, it may be difficult to directly attribute changes to adaptation interventions. Socio-economic (often qualitative) data is therefore essential to triangulate and supplement biophysical data, in order to understand whether observed changes in biophysical variables may be considered to be sustainable or are further worsening land degradation.

7. Adaptation to climate change and land degradation will require engagement with diverse, and often conflicting, stakeholder priorities and perspectives. Participatory approaches may be able to reduce conflict, build trust and facilitate learning amongst stakeholders, who are then more likely to co-develop and implement effective adaptations in the long term. However, it is important to design participatory processes to effectively represent stakeholder interests, manage power dynamics, and be relevant to stakeholder needs and priorities.

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ABOUT THE CONFERENCE

http://3sc.unccd.int

The 3rd UNCCD international scientific conference on "Combating desertification/land degradation and drought for poverty reduction and sustainable development: the contribution of science, technology, traditional knowledge and practices" is held from 9 to 12 March 2015 in Cancún (Mexico), during the 4th special session of the Committee on Science and Technology (CST S-4) of the United Nations Convention to Combat Desertification (UNCCD).

The conference aims to attract the widest possible range of scientific, local and traditional knowledge that can be harnessed to achieve poverty reduction and sustainable development in areas susceptible to desertification, land degradation and drought.

One of the major challenges facing delegates to the conference is the development of new scientific insights and recommendations to policy makers with regards to the assessment of vulnerability of socio-ecosystems to climate change and current and future capacities to adapt.

The conference addresses three major challenges:

- **Diagnosis of constraints:** How to best characterize and understand the vulnerability and adaptive capacities of ecosystems (in particular agro-ecosystems) and populations in affected regions, including regions newly susceptible to the consequences of climate change?
- **Responses:** How to build efficiently on available knowledge, success stories and lessons learnt to promote implementation of better adapted, knowledge-based practices and technologies?
- **Monitoring and assessment:** What are the new monitoring and assessment methods available to evaluate the effectiveness of these practices and technologies that provide improved insights on whether or how their implementation should be scaled up?

The conference is expected to contribute to the combat against desertification and land degradation and to addressing the impact of drought, through delivering the following outcomes:

- Better anticipation and prevention of the impact of climate change on land degradation and desertification through capacity building;
- Identification and promotion of sustainable and adaptive methods of using ecosystems to reduce poverty and environmental degradation while achieving sustainable development;
- Identification of pathways towards land-degradation neutrality: by way of reducing degradation processes and scaling up restoration activities, the objective is to maintain and improve the quantity and quality of productive land.