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Opening Editorial for Special Issue

Assessing Vulnerability to Climate Change in Dryland Livelihood Systems: Conceptual Challenges and Interdisciplinary Solutions

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INTRODUCTION

Over 40 % of the Earth's land surface are drylands (encompassing arid, semi-arid and dry sub-humid climatic zones) that are home to around 2.5 billion people (Millennium Ecosystem Assessment 2005). Livelihood sustainability in drylands is threatened by a complex and inter-related range of social, economic, political, and environmental, changes that present significant challenges to researchers, policy-makers and, above all, rural land users (Reynolds et al. 2007). Concerns over dryland degradation (often termed desertification) have been widely reported and recognised by the UN ever since the Sahelian droughts of the late 1960s (United Nations Environment Program 1997). It is increasingly recognized that changes in soil fertility and ecosystem processes are a pressing form of dryland degradation (Stocking 2003, Stringer 2008) and that these have coincided with changes in the institutional and social regimes under which drylands are managed. Key institutional and socio-economic changes include the breakdown of traditional land tenure systems (Toulimin and Quan 2000), a reduced ability to move livestock across the landscape (Lane 1998) and shifts towards cash cropping of a narrow range of commodities (Whiteside 1998).

Dynamic (often termed non-equilibrium) ecological and environmental change models (e.g.Dougill et al. 1999, Joubert et al. 2008) suggest that climate change induced drought events may push dryland systems to cross biophysical thresholds, causing a long-term drop in agricultural productivity due to either changes in soil fertility or shifts between ecological states. The scientific consensus with regard to future climate change is that the proportion of dryland areas affected by droughts is likely to increase (Intergovernmental Panel on Climate Change 2007a). Sub-Saharan African drylands have been specifically highlighted as particularly vulnerable due to their low adaptive capacity and sensitivity to the projected changes (Callaway 2004, Intergovernmental Panel on Climate Change 2007b). However, a similar combination of climate and socio-economic pressures are being observed in North Africa (Christensen 2007, Thomas 2008), Asia (Lioubimtseva et al. 2005, Cruz et al. 2007) and Latin America (Eakin and Wehbe 2009). Considerable uncertainty remains about how future climatic changes will affect drylands. This is especially important given biosphere-climate and socio-economic feedbacks (Sitch et al. 2007) and it is imperative that new and interdisciplinary research agendas are developed focused on livelihood security in these dynamic, complex, and risk-prone environments (Reed et al. 2008). Specifically, research is needed to explore how development strategies and other socio-economic changes help livelihoods become more resilient and robust at a time of growing climatic risk and uncertainty (Thompson and Scoones 2009).

As a result, the overarching goal of this special issue is to conduct a structured comparison of how livelihood systems in seven different dryland regions are changing in their vulnerability to climate change. In doing so, this collection of this special issue has three objectives.

1. To make an empirical contribution to our understanding of how these types of socio-ecological systems are vulnerable to climate change.
2. To make a theoretical contribution to climate change impacts research by testing and refining an analytic framework through which to assess vulnerability.
3. To provide methodological insight into the strengths and weaknesses of using tools from different disciplines and the ways they can best be combined for more accurate assessments of dryland system vulnerability.

In introducing these issues, the purpose of this editorial is to provide an overview of the two main intellectual challenges of this work, namely: (1) how to conceptualize vulnerability to climate change in coupled social-ecological systems; and (2) the methodological challenges of anticipating trends in vulnerability in dynamic environments. Having addressed these two challenges, this editorial will close with a short précis of the case studies provided in this special issue.

CONCEPTUALIZING VULNERABILITY TO CLIMATE CHANGE IN COUPLED SOCIAL-ECOLOGICAL SYSTEMS

The first challenge in presenting a consistent analysis of seven different case studies was to establish a common theoretical understanding of vulnerability. The literature on vulnerability is a vast corpus of material spanning a wide range of disciplines including disaster management, risk analysis, engineering, ecology, and sociology (Adger 2006). This body of literature also includes a range of case studies such as preparedness to tropical storms (Tompkins 2005) and the effects of sea level rise (Adger 1999). Taken together, this research suggests that the social and ecological context in which climatic problems occur is likely to be as important (if not more so) than the climatic shock itself (Watts and Bohle 1993, Turner et al. 2003, Ericksen 2008). This observation has been confirmed by qualitative historic case studies that show even relatively small environmental problems can cause significant consequences depending on socio-economic constraints (Comenetz and Caviedes 2002, Fraser 2003) as well as by quantitative work on the socio-economic factors that make grain harvests sensitive to rainfall anomalies (Fraser et al. 2008, Simelton et al. 2009).

More specifically, effort has been invested in modelling crop production under different climate scenarios (Challinor et al. 2009). It is clear from this work that farm management (e.g. choice of crops), along with ecological features (e.g. soil fertility), will have a large influence on whether or not weather-related shocks affect yields (Smit and Skinner 2002, Challinor 2009). One implication of this work is that different agro-ecosystems react differently to similar climatic problems. Therefore, for this special issue, each vulnerability assessment includes an explicit agro-ecological dimension that explores the ability of specific dryland agro-ecosystems to tolerate climatic extremes while still remaining productive.

Economic modellers have also contributed to this field by showing that even rural livelihoods, which rely on agriculture for income as well as subsistence, depend on much more than just biophysical factors. For example, Mendelsohn and Reinsborough (2007) find that 39% of the variations in average crop failure can be explained by variations in climate and soil implying that socio-economic and institutional/political factors could account for much of the other 61% of crop failure. While these results are based on North American data, they broadly confirm work on livelihood diversification, land management and biodiversity done in Africa (Blocka and Webb 2001, Unruh 2001). To account for these other factors, Sen's work on food security, which focuses on "freedom" and "capability" at the household scale, is particular useful (1981, 2000). In brief, if households have access to a range of different resources then they will likely have the capacity to adapt to a problem. For example, a rural household with extensive friends or other social relations may be able to maintain yields without outside institutional help during a drought, for example under traditional systems of moving cattle between regions (Reed et al. 2008). A family with less social capital may not have the resources to accomplish this. Sen's work, which provides a theoretical foundation for understanding such capabilities, has given rise to the "sustainable livelihoods approach", a set of methodological tools that are used to explore how households deploy “capital assets” to maintain livelihoods during shocks (Scoones 1998). Capital assets include: social capital (e.g. networks of friends and relations), human capital (a person’s health and education), financial capital (income or savings), physical capital (the built infrastructure) and natural capital (ecological features such as soil quality or forests) (Bebbington 1999). In addition, a sustainable livelihood analysis also examines broader contextual questions such as the household’s exposure to shocks (e.g. floods or droughts) and trends such as environmental or population change and chronic disease threats. Therefore, each vulnerability assessment in this special issue includes an explicit evaluation of the socio-economic context based on a sustainable livelihoods approach.

Finally, the literature also suggests that researchers interested in vulnerability must assess institutional processes. For example, de Waal (1997) provides a critical exploration of the role of the international community in providing famine relief while Ostrom et al. explore the role of institutions at a more local scale (Ostrom et al. 1999, Ostrom 2001). The importance of institutions in determining vulnerability to climate change was illustrated in 1991-2 when an “apocalyptic” drought in southern Africa caused grain yields in ten states to drop 56% below normal years and 17-20 million people were exposed to starvation (Green 1993). Despite the magnitude of the problem, a combination of national and international policy helped avert disease and death in countries with functioning governments. Therefore, understanding whether livelihoods are vulnerable to climate change also involves assessing the institutions that are working in society that allow for a collective response to a problem. This builds on Scott’s (2001) idea that institutions include the groups that create the norms and rules that direct behaviour. Consequently, each vulnerability assessment in this special issue also involves an institutional dimension that includes exploring what groups within a society have power and are able to mobilize political attention.

In summary, to draw these bodies of literature together, each vulnerability assessment in this special issue has three distinct but overlapping components. Each includes: (1) an assessment of changes in the agro-ecosystem that provides the livelihoods, thus providing insight into the ability of each agro-ecosystem to remain productive during an environmental problem; (2) an evaluation of changes in the socio-economic affluence of different groups within the livelihood system, thus providing insight into those groups that may not have the capacity to adapt themselves; and (3) an exploration of the institutional capability, thus providing insight into which regions have the potential to mobilize effective relief in the case of a crisis.

These three factors can be heuristically depicted as a three dimensional space diagram where each of these factors represents one dimension (Figure 1). For each case study, if, over time, data show that the agro-ecosystem is becoming less able to remain productive during an environmental problem, that households are losing socio-economic assets, and institutions have a diminishing capacity to respond to a crisis, then this could be plotted into this space as a trend towards the top, back, and right corner of the figure (corner 8). Such a trend would imply that the livelihood system within the case study was becoming more vulnerable to climate change and that a comparatively small environmental problem may have a larger impact on livelihoods. It is important to note, however, that how each of these three key components is determined will vary depending on the scale and socio-economic and ecological context. As such, the specific indicators chosen to represent these three broad categories are specific to each case.

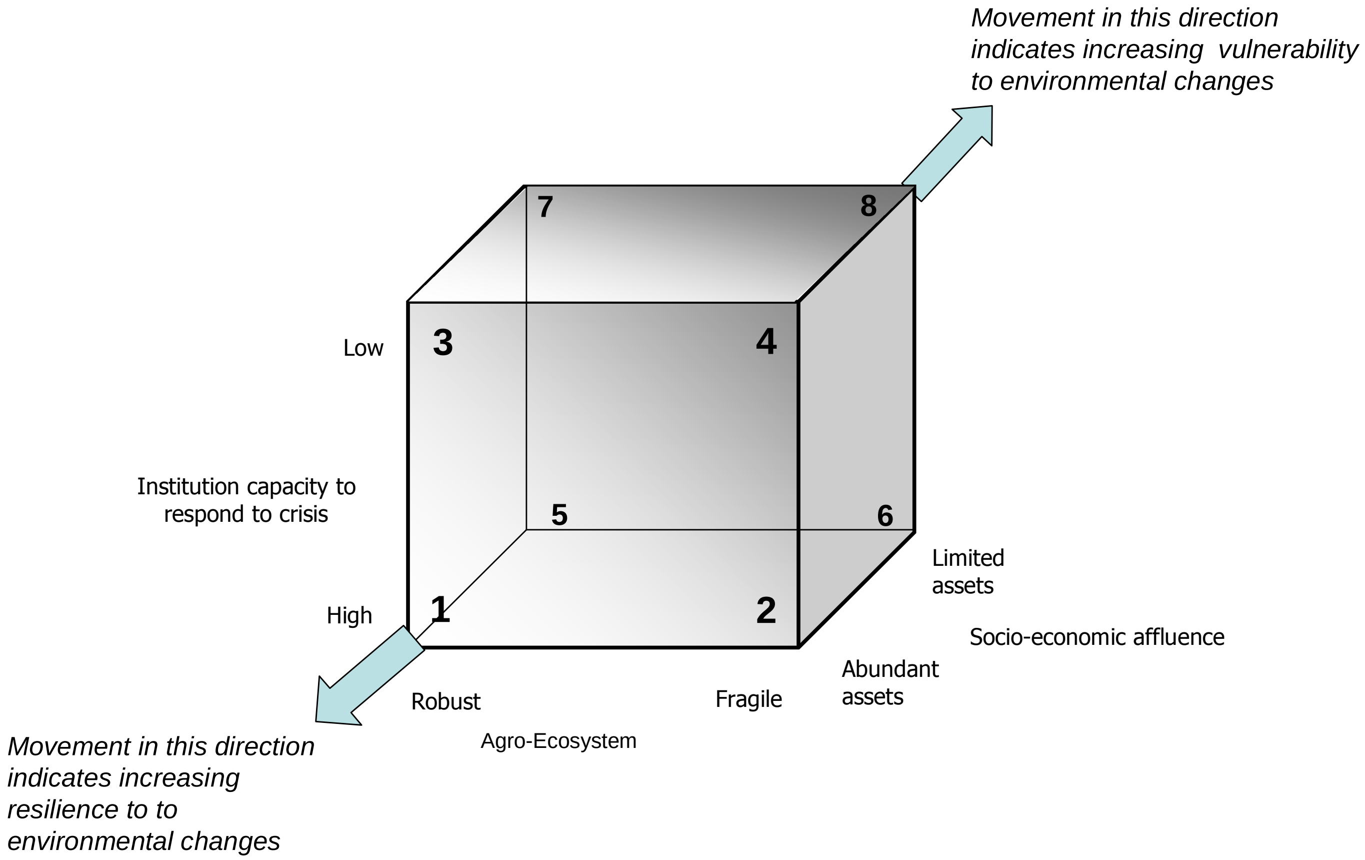

Figure 1. Generic vulnerability framework made up of three dimensions the literature suggests are important in assessing vulnerability: (1) agro-ecosystem resilience that measures the extent to which the agro-ecosystem can tolerate climatic shocks and remain productive; (2) socio-economic affluence that measures the extent to which households will have access to the assets needed to maintain livelihoods in the event of an environmental shock; and (3) institutional capacity that measures the extent to which institutions in society will provide effective crisis relief.

METHODOLOGICAL APPROACHES TO ANTICIPATE TRENDS IN VULNERABILITY

The second intellectual challenge was to find a consistent yet flexible set of steps to be used in each case study. As mentioned earlier, the academic literature is full of examples of formal quantitative models being used to understand systems and to predict how climatic changes will impact on agricultural production and livelihoods (Lobell et al. 2008). Trying to understand complex social-ecological phenomena using quantitative tools has a long intellectual tradition and dates back at least to Thomas Malthus. Mathematical models were used in early attempts to anticipate the Earth's future in light of rising population, overuse of resources and pollution (Meadows and Club of Rome. 1972). This approach has benefits in that it uses our technological ability to model complex interactions between large numbers of variables and vast amounts of data.

There are, however, problems with mathematical modelling approaches. Many forecasts of complex social ecological systems made over the past 20 years have proven wrong (Sterman 2002). One possible reason for this is that formal mathematical modelling lends itself more readily to modelling biophysical relations that are comparatively simple and more predictable than socio-economic relations. The chapter on agriculture by Working Group II of IPCC's fourth assessment report is illustrative. It provides an excellent survey of how crops respond to moisture stress, carbon dioxide fertilization and elevated temperatures (Easterling et al. 2007). The chapter is far less complete when it comes to understanding the people who produce these crops. The section on adaptive capacity, for example, is just a few short paragraphs and discusses how the impact of climate change on food production will depend on local socio-economic context. The actual projections made in the chapter do not include any human dimension. This is a critical omission as it is these human-less projections that provide the evidence for climate change policy. This problem was highlighted by Hulme (2007) who stated*:*

> *…the construction of narratives around global warming remain strongly tied to roots within the natural sciences … which claims both global reach and universal authority. (pg. 5)*

What Hulme refers to as a "global reach and universal authority" of the natural sciences has given this community – and the atmospheric modellers in particular – more power when it comes to translating their research into policy advice. For example, the current emphasis on promoting bioenergy has the potential to re-shape livelihood systems in much of the developing world (Mol 2007). This policy itself, however, can be argued as partly a result of the way that the discourse on climate change has emerged out of the climate modelling tradition and the rarely-spoken assumption that since greenhouse gases are the problem, removing them must be the solution. These challenges to mathematical models need to be seen in a broader academic context of post-modernism in the social sciences. For the last 40 years, there has been a significant emphasis amongst many sociologists and anthropologists on discourse theory and how an individual's position or background shapes their perceptions of everything from the landscapes they find aesthetically pleasing (Fraser and Kenney 2000, Suckall et al. 2009) to their perceptions of risks that they face (Tansey and O'Riordan 1999). One conclusion of this work is that scientific pursuits are never as objective or impartial as may be claimed but rather are socially constructed (Wynne 1992). The message that many social scientists take from this is that we must be highly critical of any theory (or model) because they may reveal more about the author of the theory than the "real" world. As a result, many social scientists are sceptical of formal mathematical modelling and have rejected attempts to use these tools.

A different type of modelling has emerged that tries to address some of these concerns. Called mediated modelling, it is a cluster of approaches that that tries to capture complex system dynamics by drawing on a range of different types of input (including qualitative stakeholder and expert opinions) to help management and policy-making. Rather than attempting to reduce uncertainty through ever more accurate prediction, mediated modelling attempts to flexibly incorporate potential feedbacks and different assumptions, to investigate and prepare for the uncertainties that are fundamental within complex systems. Sometimes this approach also uses formal computer models to challenge the implicit or 'mental models' of policy makers (Lane 2007), whilst also having the capacity to critically examine the assumptions within formal models. The goal is for a range of experts, policy makers, or other stakeholders to participate in an exercise designed to uncover the complex relations within a dynamic system. This allows for the creation of a model of the system that can be tested to provoke a re-examination of primary assumptions, at which point the underlying mental models are more easily discovered. Such discovery can facilitate deep learning and may lead to significant policy reform that is more robust to uncertainty than policy revised purely on technical or scientific grounds.

Mediated approaches to create system dynamics models have been applied in a variety of group model building exercises (for example, see: Van den Belt 2004, Dougill et al. 2006). Such examples provide a series of generic steps that help a group of people (both researchers and local stakeholders / land managers) to first develop a common conceptual model of how a dynamic system (such as a livelihoods system) works, and then provides guidance on how to formalize this conceptual model into a deterministic computer model (Volpe and Voss 2005). Regardless of the details of the different approaches, each approach generally involves bringing a team of people together to create a narrative or story of how a system works. Narratives are then turned into conceptual models or flow charts (sometimes called causal loop diagrams or mental maps) of the system that is of concern to the participants. This conceptual modelling phase exposes key relationships, makes feedbacks explicit, and helps identify where there are key gaps in the knowledge of the important relations. Conceptual models also help to show where there are key drivers that may affect overall system functioning and can help to identify where potential thresholds / tipping points occur that are likely to trigger rapid system changes (Reed et al. 2008).

The logic here is that everyone has a mental model underlying their thinking. A conceptual model, built through a group exercise, imperfectly reflects and synthesizes the underlying mental models of the participants. Developing conceptual models, therefore, is a useful exercise in itself in that it enables group problem solving and produces heuristic devices that incorporate a variety of different types of information. Conceptual models have been used to point the way towards future research and can help stakeholders articulate hypotheses that need to be tested. Generally speaking, this is the approach used through the "soft systems methodology" that guides groups to analyse and solve management problems (Checkland and Winter 2006). Many proponents of this methodology (especially those from sociological, anthropological and development studies traditions) stop at the stage of a diagrammatic conceptual model rather than exploring additional information that can be gained by quantifying relationships within the models. This is because expressing relations in the conceptual model mathematically can take years of specialized field work and invariably involves making assumptions about how variables are mathematically related to each other.

As such, formal predictive models create only crude predictions. This problem led Sterman to argue that results of models are inevitably wrong but that formal (predictive) models can still be useful as a way of exploring the dynamic consequences of what one assumes at the conceptual modelling stage (Sterman 2002, Epstein 2008).

Despite these concerns about turning mental models into mathematical models, a number of scholars argue that using mathematics to create different simulations of the future is necessary. One reason for this is that in the absence of formal quantification, simple causal loop diagrams can be misleading because they obscure the "stock and flow structures" that drive many complex systems. Stock and flow structures occur where a stock of a resource changes over time. For example, this might be land that is converted from forest to tilled agricultural land that then turns into degraded land. This sort of dynamic is poorly captured through causal loop diagrams, and the nature of stocks and flows makes it necessary to express relations mathematically so that modellers can run simulations of the future and observe how stocks may change under different scenarios. Therefore, Richardson (1986) suggests that people wishing to use system dynamics to analyze complex phenomena should either avoid causal loop diagrams or only use them to accompany expository writing that can be elaborated on through mathematical simulations. Homer and Oliva (2001) build on this by arguing that one cannot draw reliable inferences from complex causal maps without formal simulation. Furthermore, not defining the relationships between components mathematically means that we forego attempts to identify and quantify connections often unseen by stakeholders. This is important since neurological and psychological studies show the human brain is ill-equipped to comprehend complex connections or to accurately predict thresholds, emergent properties or feedbacks (Sterman 1992, 2002).

This brief discussion on dynamic system modelling highlights two things. First, there is a growing awareness that dynamic systems modelling is useful as a way of creating a 'rich picture' that brings together a range of information to describe a problem. Second, there is a disagreement over whether to use system dynamics as a qualitative or quantitative tool. In many important ways, this disagreement is related to the value of causal loop diagrams as a stand-alone policy tool or whether they need to be accompanied by formal mathematical simulations. A compromise is offered by Wolstenholme (1999) who states that while:

> *… formal, quantitative models are essential for understanding the dynamics of complex systems, the need for quantification is relative and depends on the purpose of analysis, which, in turn, is related to the methods used and the audience addressed. … [The] true power of system dynamics to address problem solving lies in a judicious blend and intertwining of both qualitative and quantitative ideas, aimed at addressing as broad an audience as possible whilst remaining sufficiently rigorous to be useful." (p. 422).*

In practical terms, Wolstenholme is proposing that key relations within a causal loop diagram should be formally expressed and calibrated with actual data. Where this is not possible, relations can be merely estimated as generic functions (e.g. linear, logistic, step, ramp, exponential), using expert opinion to create a heuristic learning devise that can be used to create simulations of the future and identify uncertainty. The results of this sort of model are not prescriptive and do not claim to "predict the future." While such attempts are still fraught with conceptual, philosophical and methodological challenges, this approach offers a way of using mathematical simulation as a learning device. In a world of imperfect knowledge and uncertain answers, dynamic systems modelling offers a rapid, transparent and systematic approach to capture and use stakeholder knowledge to better understand how complex systems might work.

The articles in this special issue will not resolve these discussions. Rather, we use a combination of mediated dynamic systems modelling approaches to explore some of the tensions. More specifically, we synthesized approaches into four generic methodological steps and then used the case studies to explore different elements within these four steps:

1. To use expert opinion and published socio-economic and environmental data to establish a background narrative that describes the livelihood system and its social, institutional and ecological context (see section two above);
2. To refine the narrative and establish a conceptual model of the livelihood system focusing on the three dimensions of vulnerability in Figure 1;
3. To conduct a three part qualitative vulnerability analysis of each livelihood system to show how the three dimensions of vulnerability (agro-ecological, household assets, and institutional factors) had changed through time; and
4. To conduct a quantitative vulnerability analysis where key relations in the conceptual model were expressed numerically. This enabled different policy simulations to be run that helped the establishment of hypotheses about which elements of the system would be most influential in changing future vulnerability.

Each case study in this special issue emphasizes different aspects of these steps. Some focus more on the critical construction of the narrative (Crane and Sallu et al.). Others focused more on the construction of the conceptual model and the qualitative vulnerability analysis (Sendzimir et al., Ravera et al., and Quinn et al.). Only two (Manez et al. and Dougill et al.) used mathematical modelling to create future scenarios. In doing this, our goal is to shed some light onto the strengths and weaknesses of using these different approaches and reflect on these in the closing editorial.

OVERVIEW OF CASE STUDIES

The first two case studies are the most rooted in the qualitative social science tradition. This first paper (Crane) describes the relevance of ideological aspects of culture (especially values and systems of meaning) to vulnerability, resilience and adaptation. In particular, this article shows how cultural ideologies shape experience of, and adaptive responses to, climate change. This is based on research in central Mali where subsistence niches have historically been closely linked with distinct ethnicities. The second case study (Sallu et al.) explores the resilience and vulnerability of livelihoods in two remote communities in rural Botswana over the last 30 years and draws on field data sources that include oral histories, livelihood surveys, ecological surveys, and documented evidence of environmental, socio-economic and institutional change. This paper identifies a broad range of activities that combine to create a range of different household livelihood portfolios and uses this information as a way of assessing how these livelihood activities have changed over time.

The third, fourth and fifth case studies emphasise conceptual modelling to explore changing vulnerability to climate change. Quinn et al. investigate how local communities cope with and adapt to multiple stresses, including water scarcity, in rural semi-arid South Africa. These authors construct system diagrams and narratives to examine the relationships and interactions between ecological conditions, institutions at different scales and local communities to understand local adaptive capacity. Ravera et al. assess the vulnerability caused by changes of agropastoral food systems in the semiarid mountain region in northern Nicaragua, an area that has displayed ecological and social resilience to environmental instabilities. Sendzimir et al. examine the causal mechanisms that link ecological, economic and socio-political processes, both within and across scales, in the surprising re-greening of the Sahel in south-central Niger over the past two decades. Both the multi-layered structure and its dynamism challenge understanding of this complex adaptive system where national and international policies along with international and regional NGOs supported farmers in efforts to increase climatic resilience in this livelihood system.

The final two case studies emphasize the creation of formal future scenarios by describing relations in the conceptual models using a formal mathematical tool. Manez et al. focus on one of the poorest regions in the EU, a region of Southern Portugal where the traditional farming system is rainfed and combines cattle raising with cultivation of cereals in traditional *montado* systems. During the 20th century, the intensification of cereal cultivation and later the population exodus has radically changed this landscape and affected its capacity to cope with the threats of climate change. Dougill et al. use causal loop diagrams to simulate the dynamics of key pastoral system variables for the Kalahari of southern Botswana to establish basic future scenarios from a series of hypotheses, including that policy targeting socio-economic factors may be more effective at reducing drought vulnerability than policies targeting environmental best management.

Lastly, in the closing editorial, we compare all seven case studies, reflect on commonalities and differences, and evaluate the vulnerability framework applied as well as the integration of different methods.

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