



Surveys

Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options[☆]



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ABSTRACT

Experts working on behalf of international development organisations need better tools to assist land managers in developing countries maintain their livelihoods, as climate change puts pressure on the ecosystem services that they depend upon. However, current understanding of livelihood vulnerability to climate change is based on a fractured and disparate set of theories and methods. This review therefore combines theoretical insights from sustainable livelihoods analysis with other analytical frameworks (including the ecosystem services framework, diffusion theory, social learning, adaptive management and transitions management) to assess the vulnerability of rural livelihoods to climate change. This integrated analytical framework helps diagnose vulnerability to climate change, whilst identifying and comparing adaptation options that could reduce vulnerability, following four broad steps: i) determine likely level of exposure to climate change, and how climate change might interact with existing stresses and other future drivers of change; ii) determine the sensitivity of stocks of capital assets and flows of ecosystem services to climate change; iii) identify factors influencing decisions to develop and/or adopt different adaptation strategies, based on innovation or the use/substitution of existing assets; and iv) identify and evaluate potential trade-offs between adaptation options. The paper concludes by identifying interdisciplinary research needs for assessing the vulnerability of livelihoods to climate change.

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1. Introduction

The impacts of future climate change on many ecosystem services¹ are uncertain, but it is clear that those who depend most on natural resources are likely to be most severely affected (e.g., African Development Bank et al., 2003; Burton et al., 2002; Simms et al., 2004). Although the challenges of climate change may seem distant and marginal compared to poverty

alleviation and economic development in the developing world, there is a growing recognition that poverty and the impacts of climate change are closely interconnected, e.g., impacting upon land availability (due to sea-level rise), water availability for rain-fed agriculture and reducing production in fisheries due to the emergence of new diseases and other factors (Schipper and Lisa, 2007). It is also recognised that both these issues are inextricably linked to land degradation and sustainable land management (UNCCD, 1994). Unless we can better understand what the future might hold and how to prepare for it, we could see major disruptions to ecosystem services that could threaten existing livelihoods and further increase the vulnerability of the poor to climatic and other future changes, e.g., related to globalisation (Davidson et al., 2003; O'Brien et al., 2007). This presents a challenge for experts working on behalf of international development organisations, who need better tools to assist land managers in developing countries maintain their livelihoods, as

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¹ Defined as “the benefits people obtain from ecosystems” (Millennium Ecosystem Assessment, 2003: 38).

climate change puts pressure on the ecosystem services that they depend upon. However, existing analytical frameworks struggle to deal with the complex interactions between climate change and other existing or future stresses, or to explain how vulnerability may be mediated by new adaptations to climate change. Theory is also split over how these adaptations are likely to emerge and how they are likely to be adopted by the sorts of communities in the developing world that often make their livelihoods from a highly dynamic and heterogeneous resource-base.

Although the sustainable livelihoods framework (Carney, 1998; Scoones, 1998) offers many useful insights, it also has a number of limitations (e.g., Small, 2007), and has rarely been used to assess the vulnerability of rural livelihoods to climate change. This paper therefore explores synergies between this and other widely used analytical frameworks, with the goal of developing an integrated framework for assessing livelihood vulnerability to climate change. To do this, we first describe and compare a number of relevant analytical frameworks. Next, we draw these together into a novel integrated analytical framework. We then use this framework to identify research needs and relevant methods by development practitioners and others to operationalise the framework. The paper draws on case study research from southern Africa, where the challenge of tackling climate change in combination with poverty, land degradation and loss of biodiversity, is particularly acute.

2. Analytical Frameworks to Understand Livelihood Vulnerability to Climate Change

There are many different interpretations of the concept of vulnerability in relation to climate and other environmental changes (e.g., Adger, 2006; Bohle et al., 1994; Downing et al., 2005; Holling, 1986; IPCC, 2001a, 2001b; Kasperson et al., 1995; Kelly and Adger, 2000; Smit and Wandel, 2006; Wisner et al., 2004). Whilst there is little consensus about its precise meaning (Gallopín, 2006), the concept 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 perturbations, which are major spikes in some kind of pressure (e.g., hurricane and sudden global economic crisis), 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 the system of study (Kasperson et al., 2005; Turner et al., 2003). Vulnerability also does not always have negative connotations, and can be expressed as a positive, such as the degree to which a social group can emerge from poverty (Gallopín, 2006).

Despite numerous interpretations, the literature consistently considers vulnerability of any system to be a function of three elements: exposure to a hazard; sensitivity to that hazard, and the capacity of the system to cope, adapt or recover from the effects of those conditions (Smit and Wandel, 2006). Exposure is the degree, duration, and/or extent in which the system is in contact with, or subject to, the disturbance (Kasperson et al., 2005); sensitivity is the degree to which a system is modified or affected by a disturbance (Gallopín, 2006); and the capacity to respond (also known as adaptive capacity) is the ability of a system to cope or recover from the disturbance (Smit and Wandel, 2006). Gallopín (2006) gives an example of the effects of flooding on a community where the most precarious homes are hit harder by a flood than the more solid ones (sensitivity); the poorest households are often located in the places most susceptible to flooding (exposure); and families with greater resources are in better position to repair water damage or move elsewhere (adaptive capacity). The combination of the three elements therefore determine the degree to which a household, community, or system is vulnerable to changing climatic conditions. These elements are usually incorporated into vulnerability assessments in one way or another (e.g., IPCC, 2001a, 2001b; Metzger and Schroter, 2006).

There are many approaches to assessing vulnerability to climate change (e.g., Fussel and Klein, 2006; IPCC, 2001a, 2001b; Metzger and

Schroter, 2006). Fussel and Klein (2006) suggest four stages assessing vulnerability to generate more effective adaptation policies: initial impact assessment (evaluation of the potential effects of climate change scenarios which affect the degree of exposure of the system being assessed); first and second generation vulnerability assessments (evaluation of climate impacts in terms of their relevance for society and consideration of potential and feasible adaptive capacity); and adaptation policy assessments (evaluations to provide specific recommendations to planners and policy-makers). At the scale of local communities, vulnerability assessments typically involve ethnographic methods to identify and document the conditions or risks people have to deal with, cataloguing how they have adapted to previous perturbations. This may then be combined with information from other researchers and policy analysts to help identify future exposures and sensitivities and the ways that it may be possible to help communities plan for or respond to these conditions (Smit and Wandel, 2006).

Vulnerability assessments do often take into account livelihoods and/or the factors that are likely to constrain or influence the way in which adaptation may occur. However, as yet there has been no framework proposed to specifically analyse the vulnerability of livelihoods to climate change per se, or that integrates different analytical frameworks to help understand different aspects of vulnerability to climate and other types of changes and the interactions between these drivers of change. To do this, the rest of this paper therefore integrates a number of commonly used analytical frameworks that have not previously been brought together: sustainable livelihoods, ecosystem services, diffusion theory, social learning, adaptive management and transitions management. Each of the frameworks contribute in different ways to a more holistic and comprehensive approach to assessing and reducing the vulnerability of livelihoods to climate change. In the following sections, each framework is described and compared in turn, pairing frameworks that contain the most conceptual overlap, and moving from frameworks that consider vulnerability at micro-scales to meso- and macro-scales. The final part of this section then compares and integrates the insights that emerge from this analysis, as the basis for the integrated framework that is proposed in the following section of the paper.

2.1. Sustainable Livelihoods Framework and Ecosystem Services

The sustainable livelihoods framework is particularly relevant to understand vulnerability to climate change because it provides a framework for analysing both the key components that make up livelihoods and the contextual factors that influence them. Both of these relate closely to the elements that make a household or community more sensitive or exposed to the effects of a changing climate and affect their ability to cope with environmental change (Eakin and Luers, 2006). There is, for example, a growing appreciation of the links between climate change and poverty, which explores how livelihoods might be affected (Ziervogel et al., 2006). Climate change can disrupt established ecological and land use systems, which in turn can compromise food and water supplies, which in turn impact upon livelihoods. For example, changes in seasonality may determine whether wetlands become affected by salinisation, rendering the soil infertile (Jin, 2008). Through the impacts of climate change on ecosystem services, livelihood options can be reduced and poverty increased. This then has further impacts on the adaptive capacity of households when they are faced with other perturbations or stresses.

The sustainable livelihoods framework is based on understanding people's access to assets that typically include natural, human, social, physical and financial capital. Other assets are increasingly being used in such analyses, such as information, cultural/traditional and institutional assets (e.g., Cochrane, 2006; Otero, 2008). Access to these assets are then analysed in relation to the context of that livelihood (e.g., climate, demography, history and macro-economic conditions), institutional and social processes (e.g., organisational arrangements and land tenure), and the livelihood strategies that are used (combinations of

activities people choose to undertake to achieve their livelihood goals). Interventions to reduce poverty can then be based on an improved understanding of the livelihoods they are designed to protect and enhance, and the interacting factors that influence them. Although all capital assets are substitutable in the sustainable livelihoods framework (see below), proponents of “strong sustainability” approaches argue that for a livelihood to be truly sustainable, it must maintain critical levels of natural capital (Ekins et al., 2003). However, this tends to be overlooked in the sustainable livelihoods framework, which tends to focus on people’s access to capital assets and the resulting flow of services they can benefit from, rather than considering the overall stocks of those assets and associated services.

There are a number of ways in which the sustainable livelihoods approach may be used in climate change vulnerability analyses. First, the framework provides the basis for understanding how livelihood strategies can build adaptive capacity to enable people to better cope with change, and diversify their activities to increase resilience to unforeseen future change. The framework, for example, helps explain how livelihoods adapt to shocks, seasonality and economic or resource trends, and how their vulnerability may be reduced, for example through building social capital, increasing the flow of information about new technologies or by improving access rights to alternative grazing areas during drought (Adger, 2003; Kelly and Adger, 2000; Smit and Pilifosova, 2001; Yohe and Tol, 2002; Ziervogel et al., 2006). The asset-based framework helps identify ways capital can be used to cope in the short term, or ways capital can be used to prepare for future problems (e.g., financial capital to purchase crop insurance) and/or how capital assets can be substituted to adapt to changing circumstances (e.g., substituting natural for social capital by moving cattle to unaffected areas during drought and allowing relatives to use milk and keep calves). Complementary bundles of adaptation strategies based on available assets that provide livelihood options can therefore be developed using overlapping combinations and/or substitutions of capital assets.

Second, the framework recognises that different stakeholders are affected by climate change in different ways and have different capacities to adapt, depending on their reliance on and access to capital assets (e.g., Carr, 2008; Ziervogel et al., 2006). As a result, participatory, people-centred and action research approaches are often used in sustainable livelihoods research and practice to build adaptive capacity to different and dynamic livelihood contexts (e.g., Ashley, 2000; Small, 2007).

Third, the framework emphasises the need to address the underlying causes of weak adaptive capacity, such as the inability to access inequitably distributed resources (Kelly and Adger, 2000). This recognises that it is often access to capital assets that is most limiting to livelihoods, rather than the total stock of an asset that is theoretically available. To alter access to these assets may require adaptation of the formal and informal institutions that constrain and shape social behaviour and the institutional rules that affect negotiation and the performance of power (McGuire and Sperling, 2008; Pelling et al., 2008). Such adaptations to institutions have the potential to facilitate cross-scale solutions (Adger et al., 2005; Stringer et al., 2009; Thomalla et al., 2006).

Despite these characteristics, there have been few attempts to use the sustainable livelihoods framework to assess vulnerability to climate change. An exception is Reid and Vogel (2006), who used the framework with small-scale farmers in South Africa. The research showed that whilst periods of drought and floods always occurred in the study region, it was not only the stresses associated with climate that were undermining community and household adaptive capacity and local development. Instead, other factors, including institutional organisation, access to information and governance in the area were also reducing the ability of farmers to secure sustainable livelihoods in the context of climate change. The study highlighted the complexity and variability in the factors driving responses and adaptations to risk, including those associated with climate. The

authors found that the use of the sustainable livelihoods framework helped them to understand the multiple stressors that governed the flow of the various assets ‘in’ and ‘out’ of communities, which they argued was essential for developing effective regional and global climate change initiatives (Reid and Vogel, 2006).

Although the sustainable livelihoods framework has been widely adopted by donors and NGOs in relation to development (e.g., Carney, 1999; IUCN, 2007; ODI, 2000; UNDP, 1999), there are a number of general criticisms. These include its inability to capture the dynamism in capital assets over time, the high levels of resourcing and skills required to implement the framework on the ground, and insufficient attention to the often complex ecological consequences of livelihood adaptations (Ashley, 2000; Small, 2007).

In addition to these concerns, the focus on capital assets in the sustainable livelihoods framework emphasises stocks of assets, rather than the flow of services that those assets provide. This is particularly important for natural capital, as the flow of services may change substantially in response to climate change, without necessarily altering overall stocks of natural capital. For example, whilst increased drought would deplete carbon stocks in peatlands, increased precipitation may increase fluxes of the Greenhouse Gas methane to the atmosphere without depleting carbon stocks (Clark et al., 2010). Similarly, it may be possible to maintain timber stocks in a forest under climate change by under-planting with exotic species that are better adapted to the future climate, but this may lead to a loss of provisioning and cultural services from the forest, e.g., non-timber forest products, biodiversity and recreational benefits. This distinction between stocks of natural capital and flows of ecosystem services is particularly pertinent to developing world contexts where livelihoods are often highly dependant on provisioning services.

The ecosystem services framework provides a way to analyse the vulnerability of livelihoods to changes in both stocks and flows of natural capital. This framework groups ecosystem services as: supporting services (necessary for the production of other ecosystem services, e.g., soil formation, photosynthesis and nutrient cycling); provisioning services (ecosystem products, e.g., food, fibre and water); regulating services (including process such as climate stabilisation, erosion regulation and pollination); and cultural services (non-material benefits from ecosystems, e.g., spiritual fulfilment, cognitive development and recreation) (Millennium Ecosystem Assessment, 2003). This body of work emphasises the dependence of human well-being on natural capital. Although it aims to conceptualise the “complex links between ecosystems and human wellbeing” (p34), it only covers natural capital and does not consider the role of adaptation strategies based on human, physical, social or financial capital to protect human well-being in the face of future change. In response to this, Turner and Daily (2008) developed an ecosystem services-based decision support process that attempts to consider the social, economic and politico-cultural context of ecosystem services. They recognise that different stakeholders are likely to value ecosystem services differently, and emphasise the importance of stakeholder perceptions, property rights and institutions in the management of ecosystem services. This in turn stresses the need for participatory approaches and community-based governance over ecosystem service management.

If, as the ecosystem services framework suggests, livelihoods are ultimately dependent on ecosystem services derived from stocks of natural capital, then a sustainable livelihood must maintain critical stocks of natural capital (Ekins et al., 2003). This suggests that to assess the viability of adaptation options, it is necessary to determine whether they threaten critical levels of natural capital and the long-term viability of associated ecosystem services. Indicators with thresholds have been developed for a range of ecosystem services to date (e.g., Lu and Chang, 1998; Schroder et al., 2004), and using a chosen climatic base-line, they could be adjusted and used to help ensure that adaptation does not simply put off or create new problems. For example, adaptations that involve agricultural intensification may

increase diffuse pollution of water courses – something which is currently being measured by a number of indicators with thresholds (e.g., trends in nutrient concentration levels) under the Water Framework Directive in Europe.

2.2. Social Learning and the Diffusion of Innovations

Early adaptation studies applied climate scenarios based on down-scaled global circulation models to determine likely impacts, and assumed that adaptation was a function of available technology and knowledge (Burton et al., 2002; van Aalst et al., 2008). However, these top-down approaches failed to consider local constraints to the adoption of adaptation technologies (e.g., access, cost and the necessary skills), or the influence of local socio-economic, cultural and political contexts on adaptation choices (van Aalst et al., 2008). In response to this, more bottom-up approaches started to identify locally relevant adaptations through engagement with stakeholders, for example UNDP's (2005) Adaptation Policy Frameworks for Climate Change. Much of this work focussed on investigating how people and systems respond and adapt to past and current climate variability and extremes (e.g., Adger, 2003; Adger et al., 2005; Berkhout et al., 2006; Conway et al., 2005; Kahn, 2003; Mortimore and Adams, 2001). However, the uncertainty of future climate change calls into question the assumption that past and current practice will be relevant under future conditions (Adger et al., 2003). For this reason, there is increasing interest in international knowledge exchange between land managers, so that communities experiencing new conditions due to climate change can learn from those elsewhere who have for generations adapted to such climatic conditions (Raymond et al., 2010; Reed et al., 2011, in press; WOCAT, 2007). To facilitate this knowledge exchange, it is essential to know about the sensitivity of adaptive land management practices to climate variability and climate extremes. This requires proper assessment and documentation, such as is being carried out by the World Overview of Conservation Approaches and Technologies (WOCAT, 2007). However, although existing strategies are likely to have benefits under moderate climate change in some systems, there may be limits to their effectiveness under more rapid and severe climate change (Howden et al., 2007), or when combined with other underlying pressures, such as armed conflict or the expansion of built infrastructure. For example, Stringer et al. (2009) propose reducing institutional barriers to the traditional “mafisa” livestock movement system in southern Africa, to facilitate movement to non-affected areas during drought via social networks. However, if the predictions of Thomas et al. (2005) are correct, the currently stable Kalahari dunefield will gradually remobilise over this century due to increasing aridity and livestock production on any scale will become unviable. Fig. 2a and b shows typical images of cattle herding and dune encroachment in the SW Kalahari, Botswana. Although this is an extreme example, it emphasises the need to innovate in addition to building on past and current adaptations.

Innovation may be particularly important in the development of adaptation options that can simultaneously reduce poverty and vulnerability to climate change. 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). Innovative adaptation options may include new ways of using and/or combining existing capital assets, for example transporting livestock and well water to ungrazed pasture on a daily basis (Reed, 2007). Alternatively, innovation may focus on the realisation of untapped capital assets, including the realisation of new ecosystem services. For example, planting deep-rooted Shepherd trees (*Boscia albitrunca*; Fig. 2c) on Kalahari rangeland that has been cleared after bush encroachment could enhance livelihoods and reduce vulnerability to climate change by providing year-round tree fodder for livestock whilst enhancing biodiversity and carbon storage (*B. albitrunca* is the deepest rooting tree in the world, reaching up to 68 m; Canadell et al., 1996). In this context, climate regulation through carbon storage is a currently untapped ecosystem service that could

finance this sort of ecological restoration through access to funds from carbon markets. Equally, by monetising and measuring carbon in this way, it may be possible to also account for losses of carbon from the system (e.g., losses of soil carbon) due to climate change or inappropriate management.

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 adaptability: the extent to which an innovation can be adapted 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 behaviour of individuals and groups may further affect the way these risks are perceived (Kasperson and Kasperson, 2005; Kasperson et al., 1988). 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). Although diffusion theory offers a number of benefits to assessing the suitability of potential adaptations, like many forms of vulnerability assessment it has been criticised for being a highly structured and top-down tool that tends to be used by the powerful to influence (or perhaps even manipulate) others. It also assumes that well-connected social networks exist through which innovations can diffuse, which is not always the case.

Given the role of social structures in mediating the exchange of knowledge and behaviour change, there is now growing interest amongst the research and development communities 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 (Daniels and Walker, 2001; Forester, 1999; Keen and Mahanty, 2006; Schusler and Decker, 2003). 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 adapt. 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

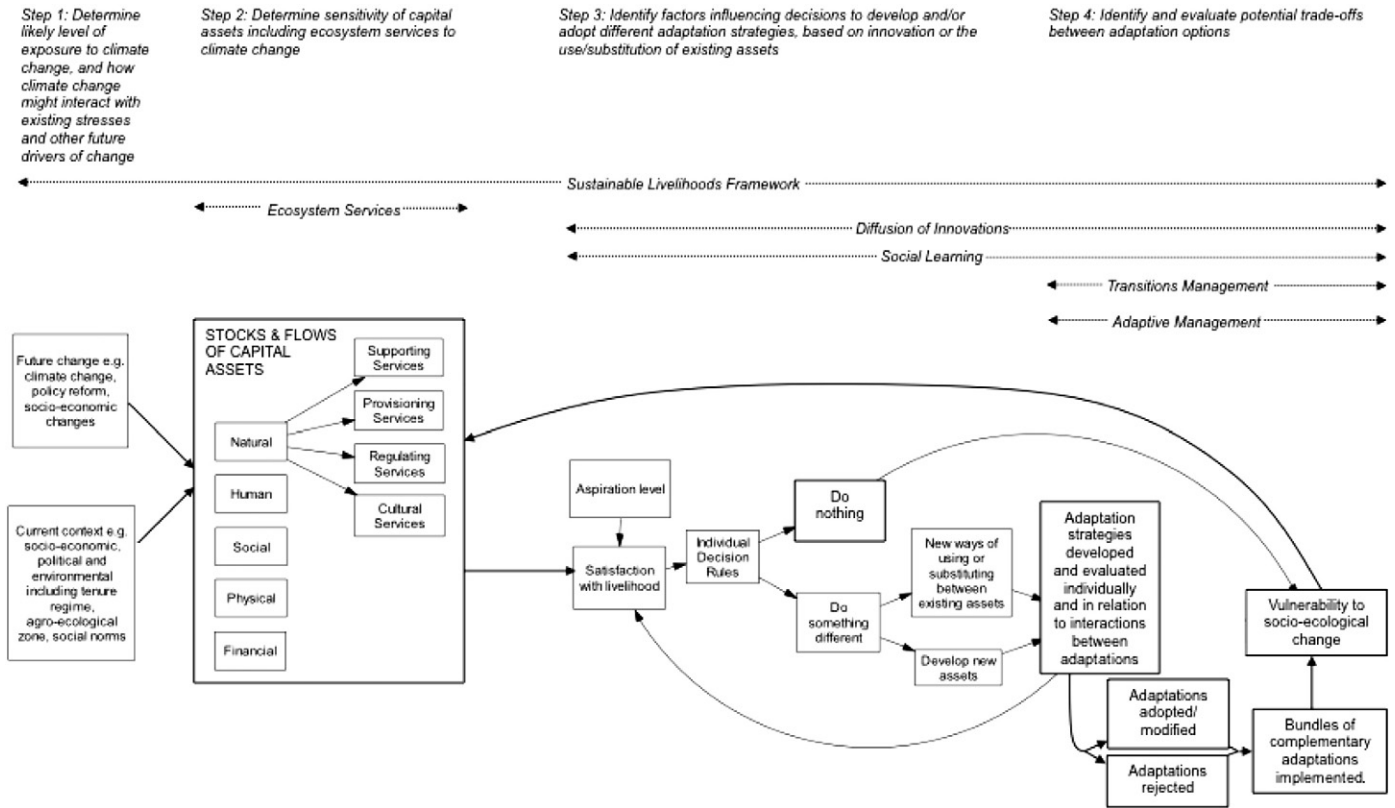


Fig. 1. An integrated analytical framework for analysing livelihood vulnerability to climate change.

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, certain characteristics of social networks can hinder or promote the development and dissemination of adaptation options (Pelling and High, 2005; Prell and Bodin, 2011). 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. Literature on the role of social networks in facilitating social learning about adaptations suggests an important role for knowledge brokers who bridge a number of generally disconnected social networks and can facilitate the spread of ideas from one social group to another (Prell and Bodin, 2011). By framing innovations in ways that are more readily understood and adopted by others in their social network, these key individuals can facilitate more a bottom-up diffusion of innovations than is typically seen in approaches following diffusion theory.

2.3. Transitions Management and Adaptive Management

Until now, the scale of analysis for the analytical frameworks that have been discussed has been primarily at the micro-scale of households and individuals. Transitions management and adaptive management view adaptation to climate change at meso- and macro-scales, in the wider context of the socio-ecological and political systems within which livelihoods operate. The transitions management literature considers adaptation to climate change as a transition towards a more sustainable socio-ecological system (Rip and Kemp, 1998). Building on diffusion theory, such a transition may be stimulated through innovation (as new adaptations arise) and managed through environmental policy. Policy options are appraised through a process of “experimentation” that evaluates the capacity for new adaptation options to create “transition pathways” towards a system that is less vulnerable to climate change. These macro-scale policy experiments typically involve collaboration between technology developers, industrial partners, local

authorities and community groups, and are designed to test the socio-technical feasibility and social acceptability of proposed transition paths. This policy-making process is designed to be participatory, where a small group of innovative stakeholders can learn together (in a “transitions arena”) about future opportunities (van der Brugge and van Raak, 2007). The transitions management framework has been used successfully in Dutch environmental policy (Kemp and Rotmans, 2005; Rotmans et al., 2001), and has the potential to develop and embed new adaptations to climate change within national policy, for application at broad spatial scales. However, transitions management has been criticised for ignoring the influence of changing contexts as systems move along transition paths, and down-playing the role of power relations in the policy-making process (Kern and Smith, 2007; Smith et al., 2005).

Transitions management shares a number of similarities with experimental and participatory approaches to decision-making in adaptive management (Foxon et al., 2009). Adaptive management views climate change in the context of dynamic, self-organising complex socio-ecological systems (Bavington, 2002; Levin, 1992). It acknowledges the limits to predictability (Levin, 1999), and accepts that knowledge about social and ecological systems is both uncertain and pluralistic (Carpenter and Gunderson, 2001). This in turn, has led to an emphasis on learning, as adaptations are tested through experimentation at meso-scales, and results inform subsequent decisions and further experimentation where necessary (Clark et al., 2001; Holling, 1978; Stringer et al., 2006; Walters, 1986). This literature suggests that systems move through distinct phases of development (the “adaptive cycle”) in which periods of growth are often followed by periods of re-organisation, in which triggers (such as a slowly changing climate or faster changing variables such as extreme weather events or pest/disease outbreaks) may lead to a collapse of the current system (Berkes et al., 2002). The ensuing phase is characterised by high levels of uncertainty and unpredictability, in which space is created for innovation. This in turn may then lead to growth once more, but in a



Fig. 2. Typical images from the Kalahari of a) cattle making their way through *Acacia mellifera* thorn bushes to a cattle post and borehole to access drinking water; b) dune encroachment; and c) Shepherd's tree (*Boscia albitrunca*) in SW Kgalagadi District, Botswana.

different form to the social–ecological system that preceded it. Crucially, in the context of this paper, if this process of re-organisation was triggered by climate change, the new system should be well adapted to the new climatic regime, though it will likely be vulnerable to some other future perturbation, which may lead to the adaptive cycle repeating once more.

Both adaptive management and transitions management emphasise multi-stakeholder participation in the development of adaptation options, drawing on evidence that participation may enhance the quality and durability of environmental decisions, and potentially leads to better informed policy options, by drawing on a wider knowledge base (Reed, 2008). In contrast to the sustainable livelihoods framework, adaptive management and transitions management emphasise adaptation to climate change over time and over multiple spatial scales.

Adaptive management emphasises the iterative process of experimentation in which those who adapt, learn from their experience and refine their adaptations over time. Transitions management takes a long-term view of adaptation, managing long-term transitions towards systems that are less vulnerable to climate change through the development and implementation of adaptation measures (including necessary institutional change), scaling up from small-scale experiments to societal levels. One of the benefits of transitions management is the way in which it institutionalises participation and learning by doing within the policy-making process. Although transitions management has been widely applied in the Netherlands, its application elsewhere has been more limited. However, there may be other ways to institutionalise lessons from both transitions management and adaptive management, to reduce vulnerability to climate change. For example, Scott

et al. (2013) show how spatial planning may be used to integrate and operationalise many of the concepts arising from literature on transitions management and adaptive management, alongside the ecosystem services framework. Spatial planning, it is argued may be able to draw on lessons from the past to consider multiple futures, engaging multiple stakeholders from local to national scales, in decisions about landscape governance, which could reduce vulnerability to climate change.

2.4. Synthesis

In summary, despite its shortcomings, the sustainable livelihoods framework offers a structured space in which to integrate and organise complementary theories and concepts about livelihood vulnerability to climate change. Natural capital from the livelihoods framework can be considered both as stocks of capital and flows of ecosystem services that may be affected differently by climate change. The effectiveness of climate change adaptation options may be measured by looking at the sensitivity of natural capital (and associated ecosystem services) and other capital assets, to the levels of climate change a system is exposed to. If a sustainable livelihood is built on maintaining critical levels of natural capital and associated ecosystem services, then the long-term viability and sustainability of adaptations may be measured by looking at their effect on natural capital and ecosystem service provision. However, adaptations based on past and existing responses to climate variability and change may have limited success under future conditions that have not been previously experienced. Innovation will therefore be necessary to develop adaptations that can reduce vulnerability to the twin challenges of climate change and poverty in the developing world. This may involve identifying and realising untapped ecosystem services or using existing assets and services in new ways.

A range of theories and concepts can help understand how such innovations are evaluated, refined and disseminated within livelihood strategies. For example, diffusion theory explores the way people make decisions about the adoption of innovative adaptations. Social learning helps explain how people learn about innovative adaptations in their social context, and how people learn about adaptations through interactions with those in their social network. Adaptive management addresses some of the perceived weaknesses of transitions management, and supports multi-stakeholder decision-making through iterative experiments to explore how adaptive options might play out in the socio-ecological system at multiple temporal and spatial scales. Rather than seeking to understand how adaptations are adopted and diffused through socio-ecological systems, transitions management seeks to identify transition pathways along which these systems can be actively transformed towards more sustainable futures. Adaptive management and transitions management show how livelihood strategies from livelihoods analysis (which are usually focused on the household scale) can be evaluated, refined and replicated to achieve adaptation at meso- and macro-scales.

This then takes adaptation into the realm of governance, where it is possible to recognise that many ecosystem services are in fact “common goods” that it is impossible to prevent people competing for, as part of the livelihood strategies. As Ostrom et al. (1999) and others have shown, the cooperative behaviour necessary to protect critical levels of natural capital depends on human motivation, rules governing use, and resource characteristics. Devising effective governance systems is akin to a co-evolutionary race in which the rules governing resource use are able to evolve with changing socio-ecological conditions. A set of rules crafted to fit one set of socio-ecological conditions may erode as social, economic and technological developments increase the potential for human damage to ecosystems and to the biosphere itself. Further, humans devise ways of evading rules. Thus, successful commons governance requires that rules evolve. Devising ways to sustain the Earth’s ability to support diverse life, including a reasonable quality of life for humans, involves making decisions under uncertainty,

complexity and substantial biophysical constraints as well as conflicting human values and interests.

3. An Integrated Analytical Framework

Despite the rich development and application of theories from disparate disciplines to understand the vulnerability of livelihoods to climate change, there has so far been little attempt to integrate insights from these different discourses. Given the clear complementarities between many aspects of the frameworks that have been reviewed so far, the following section attempts to carry out this integration. The goal is to develop an integrated analytical framework, from which new methodological approaches and insights can be derived, to better understand and reduce the vulnerability of livelihoods to climate change. Fig. 1 combines insights from each of the frameworks described in the previous section into an integrated analytical framework. The framework may be used as a diagnostic tool by development practitioners and others who need to appreciate levels of livelihood vulnerability to climate change. Following the definition of vulnerability in the introduction to Section 2, we consider adaptive capacity to be integral to determining vulnerability, hence the second two steps in the framework consider factors influencing the adoption of different adaptation strategies and the range of adaptation options that are available. Therefore, in addition to offering a “diagnosis” for the vulnerability of livelihoods to climate change, the proposed analytical framework should help development practitioners identify “treatments” that can help households and communities adapt effectively to the challenges they are likely to face in future. The following four broad steps can be identified:

1. Determine the likely level of exposure to climate change, and how climate change might interact with existing stresses and other future drivers of change;
2. Determine the sensitivity of stocks of capital assets and flows of ecosystem services to climate change;
3. Identify adaptation options and factors influencing decisions to develop and/or adopt different adaptation strategies, based on innovation or the use/substitution of existing assets; and
4. Identify and evaluate potential trade-offs between adaptation options.

The following sections explore each of these steps in turn.

3.1. Determine Climate Change Exposure and Interactions with Existing/Future Stresses

It is now well recognised that climate variability and change are just two of many current stresses on rural livelihoods (e.g., HIV/AIDS, land degradation and demographic change). However, little attention has been paid to the way that the effects of climate change may be cumulative or may combine with other changes in the future, to create new and potentially unexpected challenges (van Aalst et al., 2008). Ziervogel et al. (2006) suggest that focussing exclusively on climate change adaptation could divert attention from more urgent development needs if it emerges that other drivers play a more significant role in sustaining rural livelihoods. Thomas and Twyman (2005) argue that there is nothing “special” about climate change adaptation in comparison with adaptation to other changes. They draw on examples of past adaptation to changing policy amongst Inuit and Kalahari hunter-gatherer societies to show how adapting to policy change may be as important as adapting to climate change to maintain livelihoods. They also show that similar adaptation strategies may effectively address both challenges. Building on this, Fig. 1 starts by combining the effects of climate change and other future changes on livelihoods.

However, the likely impacts of climate change have usually been examined in isolation from other existing biophysical, socio-economic or policy contexts. Although this approach has been widely critiqued (e.g., Blaikie et al., 1994; Bohle, 2001; Hilhorst and Bankoff, 2004), there have been few attempts at more integrated approaches, or “second generation vulnerability assessments” as Fussler and Klein (2006) call them. O'Brien and Leichenko (2000) and Leichenko and O'Brien (2002) combined exposure to ‘double’ risk factors, to show that climate change and globalisation further aggravated stress in a region. Various other existing stresses have been identified that are likely to increase vulnerability in combination with climate change through impacts on capital assets, for example weakening social ties, land degradation and lack of access to information (e.g., Aysan, 1993; Scoones, 2004). These ongoing stresses are part of the wider socio-economic, political and environmental context in which livelihoods are made. For example, institutional regimes (including land tenure systems) and social norms (including taboos) influence people's access to capital assets that could form a basis for their livelihood. Sen (1981) declared that, “no famine has ever occurred in a functioning democracy”, arguing that democracy may ensure a fairer distribution of resources. Others have built on this, arguing that democracies are more likely to fund social services for the poor that could, for example, acting as a safety net during drought (see Ross (2006) for a review). This biophysical, socio-economic and policy context is analogous to the “transforming structures and processes” in the sustainable livelihoods framework. The assets used in any livelihood strategy depend on the contextual factors that determine access to them, e.g., the existence of extensive private grazing reserves means little to a communal pastoralist who does not have access rights. These contextual factors also determine the level of asset endowment, e.g., in terms of environmental context, semi-arid rangelands will provide less forage per unit area than temperate grasslands. As such, these are grouped under “current context” in parallel with “future change” as inputs that determine availability of capital assets in Fig. 1.

Although there is extensive research about how current environmental, socio-economic and policy contexts influence livelihoods, there have been few attempts to consider how future contexts might combine with climate change to influence future access to livelihood assets and adaptation strategies. Research needs to identify likely future trends and allow for unexpected scenarios (arising from “non-linear” behaviour) that might combine with the effects of climate change in particularly noteworthy ways. Such information will enable stakeholders to identify and prepare for futures in which climate change combines with other key drivers to produce important challenges for livelihoods.

3.2. Determine Sensitivity of Capital Assets and Ecosystem Services to Climate Change

Rather than considering the effects of climate change on livelihoods as a function of the effects on natural capital and ecosystem services (e.g., as done by IPCC, 2001a, 2001b), the sustainable livelihoods framework recognises that climate change can directly affect livelihoods and vice versa. This may occur indirectly through effects of climate change on natural capital and knock-on effects on physical, human, social and financial capital. However, climate change may also directly affect these other assets, e.g., weakening social networks through heat and disease-vector related illness and mortality, or rendering physical infrastructure (e.g., existing flood defences) obsolete. In this way, the livelihoods framework recognises the diverse range of likely effects on different livelihoods at a household scale, rather than assuming similar effects of climate change across specific agro-ecosystems or homogeneous communities (c.f., van Aalst et al., 2008).

Sustainability indicators offer one way of quantifying the sensitivity of capital assets to climate change (Reed et al., 2006). They can be used in a quantitative manner, accurately measuring indicators in

relation to empirically determined thresholds and baselines (e.g., long-term monitoring of specific pollutants against agreed limits in water courses). Alternatively, indicators can be used more qualitatively by stakeholders to evaluate the effects of climate change and monitor progress towards livelihood goals (e.g., observing the appearance of indicator species and changing land management accordingly). Reed (2008) and Reed et al. (2013a) show how local and scientific knowledge can be integrated to develop empirically robust indicators that can be used easily and effectively by local stakeholders to monitor change. Crucially, sustainability indicators can not only monitor ongoing effects of climate change on livelihoods, but also enable stakeholders to monitor the effectiveness of the adaptation options they adopt. Feedback from indicator-based assessments can then be used as a basis for modifying adaptations or adopting alternative adaptations (Reed et al., 2006). For example, improved rangeland management is proposed as an adaptation to climate change in Botswana's National Action Plan under the United Nations Framework Convention on Climate Change (Stringer et al., 2009), and a wide range of sustainability indicators have been developed (e.g., focusing on vegetation change, livestock health and soils) that can be used by local communities to monitor the success of this form of adaptation (Reed et al., 2008).

This feedback between adaptation strategies and capital assets is captured by the arrow between vulnerability to socio-ecological change and capital assets in Fig. 1. The long-term viability of adaptation strategies will depend upon the way that adaptations affect capital assets, including stocks of natural capital and the subsequent flow of ecosystem services. Using sustainability indicators representing each of the capital assets and a range of ecosystem services, it should be possible for development practitioners and others to gain a holistic understanding of the likely effects of adaptation strategies on these assets and services.

3.3. Identify Factors Influencing Decisions to Develop/Adopt Adaptations

Many adaptations to climate change depend on using capital assets in different ways, or substituting between capital assets. It is therefore essential to understand how climate change is likely to affect this asset base in order to understand how it will influence future adaptive capacity (see previous section). It is also necessary to understand how climate change is likely to influence people's ability to access or substitute between assets. However, this is only one way of assessing adaptive capacity. To better understand the factors influencing future adaptation strategies, it is essential to better understand the decision-making processes through which people choose to adapt.

By assessing the sensitivity of livelihood assets to climate change, the livelihoods framework provides an analytical construct for assessing the need and capacity for people to adapt their livelihoods under future change. The perceived need to adapt to climate and other socio-ecological change is based on: i) the sensitivity of the livelihood to climate change (the link between capital assets and satisfaction with livelihood in Fig. 1); and ii) the aspiration level of the person making the livelihood (which may vary between different components of a person's livelihood). 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 a livelihood is not particularly sensitive to climate change, then there is little need to adapt to climatic drivers (it may still be necessary to adapt to other changes, for example in policy). This is represented by the “do nothing” option in Fig. 1. If the livelihood is 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 (this would also lead to “doing nothing”). In this case, the livelihood is not vulnerable to the sorts of socio-ecological changes that are likely under future climate change (the arrow between “do nothing” and “vulnerability to socio-ecological change” makes this

link). 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 households no longer deem livelihood outcomes satisfactory, then they are likely to start searching for livelihood adaptation options, which each individual within the household will evaluate against their decision rules. Fig. 1 simplifies this as a choice between: i) adopting adaptations based on new ways of using or substituting between existing assets; or ii) developing new assets. Fig. 1 shows how these adaptations are evaluated against the decision rules held by different individuals, including an evaluation of each adaptation and the likely interactions between adaptations (Section 3.4). In some cases, opportunities to develop new assets and associated livelihood options may arise as a consequence of climate change, for example cultivating biofuels. 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 (Fig. 1; c.f. Reed, 2007; Rogers, 1995). The literature on social learning and the diffusion of innovations emphasises the fact 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 (Cross and Parker, 2004; Friedkin, 1998; Homans, 1950; Mark, 2003; Ruef et al., 2003; Skvoretz et al., 2004; Snijders, 2005). Individuals feel uncomfortable having relationships with others with whom they disagree, and will therefore modify their views (or the relationship) accordingly. In a more general sense, as individuals interact with one another over time, they mutually learn from one another, influence one another, and tend to become more similar in their views (Burt, 2001; Davidson-Hunt, 2006; Raffles, 2002; Valente and Davis, 1999). People's decisions are also determined by their capacity to use adaptations (e.g., access to technology, skills, and resources) (e.g., UNEP, 1998, 2001). Although there have been attempts to incorporate such criteria in the evaluation of adaptations (e.g., Ziervogel et al., 2006), it is difficult to incorporate the way preferences for adaptations differ between actors and change over time in response to multiple factors.

For this reason, complex models of human behaviour are increasingly being developed to understand how individuals evaluate options and make decisions in their social context. Emergent behaviours can appear when a number of simple agents operate in an environment, forming more complex behaviours as a collective. The complex behaviour is not a property of any individual, nor can they easily be predicted or deduced from behaviour in the lower-level entities: they are irreducible. For example, landscape architects often will not route the pavements connecting a complex of buildings. Instead they will let usage patterns emerge and then place pavement where pathways have become worn in. Agent-based models mimic emergent behaviours by simulating the actions and interactions of autonomous individuals in a social network (this can be based on empirical inputs from interviews), and can be used to simulate likely adoption of different adaptations to climate change in a community or wider social network (e.g., Berman et al., 2004; Bharwani et al., 2005; Schneider et al., 2000). Although many agent-based models are theoretical in nature, using hypothetical decision-rules, it is possible to derive decision-rules from field-based data (e.g., Chapman et al., 2009; Reed et al., 2013b) statistically derived decision rules from interviews with land

managers. This is important because first generation impact assessments (e.g., Schneider and Chen, 1981) did not account for the likelihood that people would adapt and so modify the actual effects of future climate change (Rosenberg, 1992). Agent-based approaches recognise that such behaviour is not necessarily "optimising" or "rational". This is particularly important in environments that are naturally exposed to a high degree of climate variability, where variation can mask more gradual trends and delay adaptive responses, or lead to maladaptation due to "false starts" (Schneider et al., 2000: 204). Agent-based models are able to capture adaptation to climate variability in addition to climate change, as shown in work by Bharwani et al. (2005) and Ziervogel et al. (2006) investigating responses to forecasts as an adaptation to climate variability over time.

3.4. Evaluate Potential Trade-offs Between Adaptations

Finally, before adaptations are implemented, development practitioners may wish to evaluate potential trade-offs between adaptations, so that complementary bundles of adaptations can be implemented together, to reduce vulnerability to climate change.

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 (to climate change as it occurs), rather than anticipatory or planned adaptation (to reduce vulnerability to future climate change) (Schneider et al., 2000; Smith and Lenart, 1996; Tol et al., 1998). However, the use of planned strategies has been shown to enhance adaptation (IPCC, 2007). Anticipatory adaptation may be focused solely on climate change, or may also be justified for other reasons (e.g., poverty alleviation); the latter is sometimes referred to as "no-regrets" adaptation (Smith and Lenart, 1996; Tol et al., 1998). Anticipatory adaptation responses are undertaken by either public (e.g., governments) or private agents (e.g., farmers) with diverse objectives (Adger et al., 2005).

Anticipatory adaptation options can be evaluated through the sort of generic principles that are usually applied to policy appraisal, for example seeking to promote legitimate, effective, equitable, efficient and legitimate action (Adger et al., 2005). Therefore any evaluation of adaptation options should be user and context-specific, and based on the objectives of each group. Various methodologies have been proposed to help evaluate adaptation options. These include the use of economic and bio-physical models (e.g., Carter, 1996), which enable the integration of economic, social and environmental objectives. By coupling models such as agent-based models with biophysical and climate models, it is possible to model which adaptation options are likely to be adopted where, and consequently how they may mitigate the effects of climate change (Chapman et al., 2009; Podesta et al., 2008). They have the capacity to identify the key socio-economic characteristics that drive agents to adopt different adaptations in different geographical areas. They can also be used to investigate the likely effects of policy interventions and other future scenarios on the uptake of specific adaptations.

Evidence from studies of adaptations to past and current climate variability and extremes shows that adaptation options are rarely adopted singly (e.g., Reid and Vogel, 2006; Stringer et al., 2009). 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 for socio-ecological systems. However, not all adaptation options are necessarily compatible with one another, and an important final step is to investigate in advance the likely aggregate effects when anticipatory adaptations are combined. For example, planting biofuels may be a relevant adaptation to maintain income under a changing climate, but may not be compatible with adaptations designed to increase food security. On the other hand, planting woody biofuels on degraded rangeland (that can support little else) might avoid such a trade-off. In this way, it should be possible to facilitate the development of complementary bundles of options to reduce

livelihood vulnerability to climate change that reduce trade-offs and enhance synergistic benefits for poverty alleviation.

4. Conclusions

The analytical framework proposed in this paper is not unique to climate change; it should be possible to apply it to understand the vulnerability of livelihoods to a wide range of socio-ecological shocks and changes. It should also be possible to use this integrated framework to identify and target no-regrets anticipatory climate change adaptation options. This framework explains livelihood vulnerability to climate change through: i) the sort of integrated scenarios proposed in Section 3.1; ii) that play out in people's livelihoods through the changing availability of capital assets (Section 3.2); iii) take account of the complex, context-specific factors that influence the development and adoption of adaptations by different individuals (Section 3.3); and iv) consider potential trade-offs between potential adaptation options.

To properly evaluate the proposed framework, interdisciplinary, field-based research is necessary. Focusing on climate change, such research needs to understand how potential effects of climate change might be modulated by interactions with other future socio-ecological changes. Scenarios that combine climate change with multiple other likely drivers of change do not currently exist but are essential to enable poor societies to adapt effectively. By better understanding how individuals are likely to behave in response to such scenarios, it may be possible to develop adaptation strategies that can achieve more widespread uptake. Research also needs to investigate trade-offs between adaptation options to enhance understanding of their aggregate effects on ecosystem services. This will allow the development of complementary bundles of adaptation options that reduce trade-offs and enhance synergistic benefits for poverty alleviation and ecosystem service conservation. Although it is clear that cultural factors will shape adaptation options and influence their uptake, less is understood about the effect of climate adaptation strategies on the flow of cultural ecosystem services. Finally, research is needed to identify and evaluate currently untapped ecosystem services that may be combined with existing assets to provide new livelihood options that can reduce poverty whilst also increasing resilience. Although adaptation strategies often involve substitution between assets to sustain livelihoods (e.g., liquidating natural capital like forests to generate financial capital), innovative adaptation and poverty alleviation options may also emerge by exploiting hitherto untapped assets (e.g., enhancing natural capital in the form of carbon stocks by marketing the carbon sequestration potential of new adaptation options).

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References

- Adger, W.N., 2003. Social aspects of adaptive capacity. In: Smith, J.B., Klein, R.J.T., Huq, S. (Eds.), *Climate Change, Adaptive Capacity and Development*, 29–49. Imperial College Press, London.
- Adger, W.N., 2006. Vulnerability. *Global Environmental Change – Human and Policy Dimensions* 16, 268–281.
- Adger, W.N., Huq, S., Brown, K., Conway, D., Hulme, M., 2003. Adaptation to climate change in the developing world. *Progress in Development Studies* 3, 179–195.
- Adger, W.N., Arnell, N.W., Tompkins, E.L., 2005. Successful adaptation to climate change across scales. *Global Environmental Change* 15, 77–86.
- African Development Bank, Asian Development Bank, UK DfID, DGIS Netherlands, European Commission DG for Development, BMZ German, OECD, UNDP, UNEP, World Bank, 2003. *Poverty and Climate Change. Reducing the Vulnerability of the Poor through Adaptation*. Department for International Development.
- Ashley, C., 2000. *Applying Livelihood Approaches to Natural Resource Management Initiatives: Experiences in Namibia and Kenya* ODI Working Paper 134. Overseas Development Institute, London.
- Aysan, Y., 1993. Keynote paper: vulnerability assessment. In: Merriman, P., Browitt, C. (Eds.), *Natural Disasters: Protecting Vulnerability Communities*. Telford, London.
- Bavington, D., 2002. Managerial ecology and its discontents: exploring the complexity of control, careful use and coping in resource and environmental management. *Environments* 30, 3–21.
- Berkes, F., Colding, J., Folke, C., 2002. *Navigating Social–Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press.
- Berkhout, F., Hertin, J., Gann, D.M., 2006. Learning to adapt: organisational adaptation to climate change impacts. *Climatic Change* 78 (1).
- Berman, M., Nicolson, C., Kofinas, G., Tetlich, J., Martin, S., 2004. Adaptation and sustainability in a small Arctic community: results of an agent-based simulation model. *Arctic* 57, 401–414.
- Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R., Ziervogel, G., 2005. Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B – Biological Sciences* 360, 2183–2194.
- Blaikie, P.M., Cannon, T., Davies, I., Wisner, B., 1994. *At Risk: Natural Hazards, Peoples Vulnerability and Disasters*. Routledge, London.
- Bohle, H., 2001. Vulnerability and criticality: perspectives from social geography. *IHPD Update* 2 1. 3–5.
- Bohle, H.G., Downing, T.E., Watts, M.J., 1994. Climate change and social vulnerability: the sociology and geography of food insecurity. *Global Environmental Change* 4, 37–48.
- Burt, R., 2001. Structure Holes versus Network Closure as Social Capital. *Social Capital: Theory and Research*. In: Lin, K.C.N., Burt, R. (Eds.), Aldine de Gruyter, New York, pp. 31–56.
- Burton, I., Huq, S., Lim, B., Pilifosova, O., Schipper, E.L., 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy* 2, 145–159.
- Canadell, J., Jackson, R.B., Ehleringer, J.B., Mooney, H.A., Sala, O.E., Schulze, E.-D., 1996. Maximum rooting depth of vegetation types at the global scale. *Oecologia* 108, 583–595.
- Carney, D. (Ed.), 1998. *Sustainable Rural Livelihoods: What Contribution Can We Make?* Department for International Development, London.
- Carney, D., 1999. *Livelihood Approaches Compared*. DfID, London.
- Carpenter, S.R., Gunderson, L.H., 2001. Coping with collapse: ecological and social dynamics in ecosystem management. *Bioscience* 51, 451–457.
- Carr, E.R., 2008. Between structure and agency: livelihoods and adaptation in Ghana's Central Region. *Global Environmental Change – Human and Policy Dimensions* 18, 689–699.
- Carter, T.R., 1996. Assessing climate change adaptations: the IPCC guidelines. In: Smith, J.G., Bhatti, N., Menzhulin, G., Benioff, R., Budyko, M.I., Campos, M., Jallow, B., Rijsberman, F., Dixon, R.K. (Eds.), *Adapting to Climate Change: An International Perspective*. Springer, New York, pp. 27–43.
- Chapman, D.S., Termansen, M., Jin, N., Quinn, C.H., Cornell, S.J., Fraser, E.D.G., Hubacek, K., Kunin, W.E., Reed, M.S., 2009. Modelling the coupled dynamics of moorland management and vegetation in the UK uplands. *Journal of Applied Ecology* 46, 278–288.
- Clark, W.C., Jager, J., van Eijndhoven, J., Dickson, N., 2001. *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain*. MIT Press, Cambridge, MA.
- Clark, J.M., Bottrell, H., Evans, C.D., Monteith, D.T., Bartlett, R., Rose, R., Newton, R.J., Chapman, P.J., 2010. The importance of the relationship between scale and process in understanding long-term DOC dynamics. *Science of the Total Environment* 408, 2768–2775.
- Cochrane, P., 2006. Exploring cultural capital and its importance in sustainable development. *Ecological Economics* 57, 318–330.
- Conway, D., Allison, E., Felstead, R., Goulden, M., 2005. Rainfall variability in East Africa: implications for natural resources management and livelihoods. *Philosophical Transactions of the Royal Society A – Mathematical Physical and Engineering Sciences* 363, 49–54.
- Cross, R.L., Parker, A., 2004. *The Hidden Power of Social Networks: Understanding How Work Really Gets Done in Organizations*. Harvard Business School Press, Boston, Mass.
- Daniels, S.E., Walker, G.B., 2001. *Working Through Environmental Conflict: The Collaborative Learning Approach*. Praeger, Westport, CT.
- Davidson, O., Halsnaes, K., Huq, S., 2003. The development and climate nexus: the case of sub-Saharan Africa. *Climate Policy* 3, S97–S113.
- Davidson-Hunt, I., 2006. Adaptive learning networks: developing resource management knowledge through social learning forums. *Human Ecology* 34, 593–614.
- Downing, T.E., Patwardhan, A., Klein, R.J.T., Mukhala, E., Stephen, L., Winograd, M., Ziervogel, G., 2005. Assessing vulnerability for climate adaptation. In: Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E., Huq, S. (Eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*. Cambridge University Press, Cambridge.
- Eakin, H., Luers, A.L., 2006. Assessing the vulnerability of social–environmental systems. *Annual Review of Environment and Resources* 31, 365–394.
- Ekins, P., Simon, S., Deutsch, L., Folke, C., De Groot, R., 2003. A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecological Economics* 44, 165–185.
- Ellis, F.M., 1988. *Peasant Economics*. Cambridge University Press, Cambridge.
- Forester, J., 1999. *The Deliberative Practitioner*. MIT Press, Cambridge, MA.

- Foxon, T., Reed, M.S., Stringer, L.C., 2009. Governing long-term socio-ecological change: what can resilience and transitions approaches learn from each other? *Environmental Governance & Policy* 19, 3–20.
- Friedkin, N.E., 1998. *A Structural Theory of Social Influence*. Cambridge University Press, New York.
- Fussler, H.M., Klein, R.T.J., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change* 75, 301–329.
- Gallopin, G.C., 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change – Human and Policy Dimensions* 16, 293–303.
- Hilhorst, D., Bankoff, G., 2004. Introduction: mapping vulnerability. In: Bankoff, G., Frerks, G., Holhorst, T. (Eds.), *Vulnerability, Disasters, Development and People*. Earthscan, London, pp. 1–24.
- Holling, C.S., 1978. *Adaptive Environmental Assessment and Management*. Wiley, New York, USA.
- Holling, C.S., 1986. The resilience of terrestrial ecosystems, local surprise and global change. In: Clark, W.C., Mtmn, R.E. (Eds.), *Sustainable Development of the Biosphere*. Cambridge University Press, Cambridge, pp. 292–317.
- Homans, G.C., 1950. *The Human Group*. Routledge and Kegan Paul, London.
- Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H., 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104, 19691–19696.
- IPCC (Intergovernmental Panel of Climate Change), 2001a. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge.
- IPCC (Intergovernmental Panel of Climate Change), 2001b. *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.
- IPCC (Intergovernmental Panel of Climate Change), 2007. *Fourth Assessment Report, Working Group II Report on Impacts*. Working Group II Report on Impacts, Assessment and Vulnerability.
- IUCN (The World Conservation Union), 2007. *Theme on Sustainable Livelihoods*. International Conservation Union, Gland, Switzerland (http://www.iucn.org/themes/ceesp/Wkg_grp/SL/SL.htm).
- Jin, C., 2008. Biodiversity dynamics of freshwater wetland ecosystems affected by secondary salinisation and seasonal hydrology variation: a model-based study. *Hydrobiologia* 598, 257–270.
- Kahn, M.E., 2003. Two measures of progress in adapting to climate change. *Global Environmental Change* 13, 307–312.
- Kasperson, J.X., Kasperson, R.E., 2005. The social contours of risk. Volume I: Publics, Risk Communication & the Social Amplification of Risk. Earthscan, Virginia.
- Kasperson, R.E., Renn, O., Slovic, P., Brown, H., Emel, J., Goble, R., Kasperson, J., Ratick, J., 1988. The social amplification of risk: a conceptual framework. *Risk Analysis* 8, 177–187.
- Kasperson, J., Kasperson, R., Turner, B., 1995. *Regions at Risk*. United Nations University Press ([Online]. [Accessed 29/12/04]. Available on World Wide Web at: <http://www.unu.edu/unupress/unupbooks/uui14re/uui14re00.htm>).
- Kasperson, J.X., Kasperson, R.E., Turner II, B.L., Schiller, A., Hsiel, W.H., 2005. *Vulnerability to global environmental change*. In: Kasperson, J.X., Kasperson, R.E. (Eds.), *Social Contours of Risk*. Earthscan, London.
- Keen, M., Mahanty, S., 2006. Learning in sustainable natural resource management: challenges and opportunities in the Pacific. *Society and Natural Resources* 19, 497–513.
- Kelly, P.M., Adger, W.N., 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47, 325–352.
- Kemp, R., Rotmans, J., 2005. The management of the co-evolution of technical, environmental and social systems. In: Weber, Matthias, Hemmelskamp, Jens (Eds.), *Towards Environmental Innovation Systems*. Springer Verlag, Berlin.
- Kern, F., Smith, A., 2007. *Restructuring energy systems for sustainability? Energy transition policy in the Netherlands*. SPRU, University of Sussex, Brighton, UK, Sussex Energy Working Paper.
- Leichenko, R., O'Brien, K., 2002. The dynamics of rural vulnerability to global change: the case of southern Africa. *Mitigation and Adaptation Strategies for Global Change* 7, 1–18.
- Levin, S.A., 1992. The problem of pattern and scale in ecology. *Ecology* 73, 1943–1967.
- Levin, S., 1999. *Fragile Dominion*. Perseus Books, Reading, MA, USA.
- Lu, C.H., Chang, J.S., 1998. On the indicator-based approach to assess ozone sensitivities and emissions features. *Journal of Geophysical Research – Atmospheres* 103, 3453–3462.
- Mark, N.P., 2003. Culture and competition: homophily and distancing explanations for cultural niches. *American Sociological Review* 68, 319–345.
- McGuire, S.J., Sperling, L., 2008. Leveraging farmers' strategies for coping with stress: seed aid in Ethiopia. *Global Environmental Change – Human and Policy Dimensions* 18, 679–688.
- Metzger, M.J., Schroter, D., 2006. Towards a spatially explicit and quantitative vulnerability assessment of environmental change in Europe. *Regional Environmental Change* 6, 201–216.
- Millennium Ecosystem Assessment, 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. World Resources Institute, Washington, DC.
- Mortimore, M.J., Adams, W.M., 2001. Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change* 11, 49–57.
- O'Brien, K., Leichenko, R., 2000. 'Double exposure': assessing the impacts of climate change within the context of economic globalisation. *Global Environmental Change* 10, 221–232.
- O'Brien, K., Eriksen, S., Schjolden, A., Nygaard, L.P., 2007. What's in a word? Conflicting interpretations of vulnerability in climate change research. *Climate Policy* 7, 73–88.
- Odero, K.K., 2008. Information capital: 6th asset of sustainable livelihood framework. *Discovery and Innovation* 18, 83–91.
- Ostrom, E., Burger, J., Field, C., Norgaard, R., Policansky, D., 1999. Revisiting the commons: local lessons. *Global Challenges Science* 284, 278–282.
- Overseas Development Institute (ODI), 2000. *Sustainable Livelihoods Working Paper Series*. Overseas Development Institute, London.
- Parker, D.C., Hessel, A., Davis, S.C., 2008. Complexity, land-use modeling, and the human dimension: fundamental challenges for mapping unknown outcome spaces. *Geoforum* 39, 789–804.
- Pelling, M., High, C., 2005. Understanding adaptation: what can social capital offer assessments of adaptive capacity? *Global Environmental Change* 15, 308–319.
- Pelling, M., High, C., Dearing, J., Smith, J., 2008. Shadow spaces for social learning – a relational understanding of adaptive capacity to climate change within organizations. *Environment and Planning A* 40, 867–884.
- Podesta, G., et al., 2008. Interactions between changing climate and technological innovations in agricultural decision-making: implications for land use and sustainability of production systems: Project Description. Unpublished Research Proposal.
- Prell, C., Bodin, O. (Eds.), 2011. *Social Networks and Natural Resource Management*. Cambridge University Press.
- Prell, C., Hubacek, K., Quinn, C., Reed, M.S., 2009. 'Who's in the network?' When stakeholders influence data analysis. *Systemic Practice and Action Research* 21, 443–458.
- Raffles, H., 2002. Intimate knowledge. *International Social Science Journal* 173, 25–35.
- Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M., Evely, A.C., 2010. Integrating local and scientific knowledge for environmental management: from products to processes. *Journal of Environmental Management* 91, 1766–1777.
- Reed, M.S., 2007. Participatory technology development for agroforestry extension: an innovation–decision approach. *African Journal of Agricultural Research* 2, 334–341.
- Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. *Biological Conservation* 141, 2417–2431.
- Reed, M.S., Fraser, E.D.G., Dougill, A.J., 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics* 59, 406–418.
- Reed, M.S., Dougill, A.J., Baker, T., 2008. Participatory indicator development: what can ecologists and local communities learn from each other? *Ecological Applications* 18, 1253–1269.
- Reed, M.S., Evely, A.C., Cundill, G., Fazey, I., Glass, J., Laing, A., Newig, J., Parrish, B., Prell, C., Raymond, C., Stringer, L.C., 2010. What is social learning? *Ecology and Society* 15 (4), r1 ([online] URL: <http://www.ecologyandsociety.org/vol15/iss4/resp1>).
- Reed, M.S., Buenemann, M., Athlopheng, J., Akhtar-Schuster, M., Bachmann, F., Bastin, G., Bigas, H., Chanda, R., Dougill, A.J., Essahli, W., Evely, A.C., Fleskens, L., Geeson, N., Glass, J.H., Hessel, R., Holden, J., Ioris, A., Kruger, B., Liniger, H.P., Mphinyane, W., Nainggolan, D., Perkins, J., Raymond, C.M., Ritsema, C.J., Schwilch, G., Sebege, R., Seely, M., Stringer, L.C., Thomas, R., Twomlow, S., Verzaandvoort, S., 2011. Cross-scale monitoring and assessment of land degradation and sustainable land management: a methodological framework for knowledge management. *Land Degradation & Development* 22, 261–271.
- Reed, M.S., Fazey, I., Stringer, L.C., Raymond, C.M., Geeson, N., Ioris, A., Kruger, B., Phillipson, J., Prell, C., Quinn, C.H., Seely, M., van der Werff, J., Ten Bosch, M., Akhtar-Schuster, M., Vergunst, P., 2013. Knowledge management for land degradation monitoring and assessment: a conceptual framework. *Land Degradation & Development* (in press).
- Reed, M.S., Fazey, I., Stringer, L.C., Raymond, C.M., Akhtar-Schuster, M., Begni, G., Bigas, H., Brehm, S., Briggs, J., Bryce, R., Buckmaster, S., Chanda, R., Davies, J., Diez, E., Essahli, W., Evely, A., Geeson, N., Hartmann, I., Holden, J., Hubacek, K., Ioris, I., Kruger, B., Laureano, P., Phillipson, J., Prell, C., Quinn, C.H., Reeves, A.D., Seely, M., Thomas, R., van der Werff Ten Bosch, M.J., Vergunst, P., Wagner, L., 2013a. Knowledge management for land degradation monitoring and assessment: an analysis of contemporary thinking. *Land Degradation & Development* 24, 307–322.
- Reed, M.S., Hubacek, K., Bonn, A., Burt, T.P., Holden, J., Stringer, L.C., Beharry-Borg, N., Buckmaster, S., Chapman, D., Chapman, P., Clay, G.D., Cornell, S., Dougill, A.J., Evely, A., Fraser, E.D.G., Jin, N., Irvine, B., Kirkby, M., Kunin, W., Prell, C., Quinn, C.H., Slee, W., Stagl, S., Termansen, M., Thorp, S., Worrall, F., 2013b. Anticipating and managing future trade-offs and complementarities between ecosystem services. *Ecology and Society* 18 (1), 5. <http://dx.doi.org/10.5751/ES-04924-180105>.
- Reid, P., Vogel, C., 2006. Living and responding to multiple stressors in South Africa – glimpses from KwaZulu-Natal. *Global Environmental Change* 16, 195–206.
- Rip, A., Kemp, R., 1998. *Technological change*. In: Rayner, S., Malone, E.L. (Eds.), *Human Choices and Climate Change*. vol. 2. Battelle Press, Columbus, Ohio.
- Rogers, E.M., 1995. *Diffusion of Innovations*, 4th edition. The Free Press, New York.
- Rosenberg, N.J., 1992. Adaptation of agriculture to climate change. *Climatic Change* 21, 385–405.
- Ross, M., 2006. Is democracy good for the poor? *American Journal of Political Science* 50, 860–874.
- Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: transition management in public policy. *Foresight* 3, 15–31.
- Ruef, M., Aldrich, H.E., Carter, N.M., 2003. The structure of founding teams: homophily, strong ties, and isolation among U.S. entrepreneurs. *American Sociological Review* 68 (2), 195–222.
- Schipper, E., Lisa, F., 2007. *Climate Change Adaptation and Development: Exploring the Linkages*. Tyndall Centre Working Paper 107. Tyndall Centre for Climate Change Research, University of East Anglia and South East Asia START Regional Centre, Norwich, UK and Bangkok, Thailand.
- Schneider, S.H., Chen, R.S., 1981. Carbon dioxide warming and coastline flooding: physical factors and climatic impact. *Annual Review of Energy* 5, 107.
- Schneider, S.H., Easterling, W.E., Mearns, L.O., 2000. Adaptation: sensitivity to natural variability, agent assumptions and dynamic climate changes. *Climatic Change* 45, 203–221.

- Schroder, J.J., Scholefield, D., Cabral, F., Hofman, G., 2004. The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. *Environmental Science & Policy* 7, 15–23.
- Schusler, T.M., Decker, D.J., 2003. Social learning for collaborative natural resource management. *Society and Natural Resources* 15, 309–326.
- Scoones, I., 1998. Sustainable Rural Livelihoods: A Framework for Analysis IDS Working Paper 72. Institute of Development Studies, Brighton.
- Scoones, I., 2004. Climatic change and the challenge of non-equilibrium thinking. *IDS Bulletin* 3, 114–119.
- Scott, A.J., Carter, C.E., Larkham, P., Reed, M., Morton, N., Waters, R., Adams, D., Collier, D., Crean, C., Curzon, R., Forster, R., Gibbs, P., Grayson, N., Hardman, M., Hearle, A., Jarvis, D., Kennet, M., Leach, K., Middleton, M., Schiessel, N., Stonyer, B., Coles, R., 2013. Disintegrated development at the rural urban fringe: re-connecting spatial planning theory and practice. *Progress in Planning* 83, 1–52.
- Sen, A., 1981. *Poverty and Famines*. Clarendon Press, Oxford.
- Simms, A., Magrath, J., Reid, H., 2004. *Up in Smoke?* International Institute for Environment and Development New Economics Foundation, London (38 pp.).
- Simon, H.A., 1955. A behavioral model of rational choice. *Quarterly Journal of Economics* 69, 99–118.
- Simon, H.A., 1956. Rational choice and the structure of the environment. *Psychological Review* 63, 129–138.
- Skvoretz, J., Fararo, T.J., Agneessens, F., 2004. Advances in biased net theory: definitions, derivations, and estimations. *Social Networks* 26, 113–139.
- Slovic, P., 1987. Perception of risk. *Science* 236, 280–285.
- Small, L.A., 2007. The sustainable rural livelihoods approach: a critical review. *Canadian Journal of Development Studies* 28, 27–38.
- Smit, B., Pilifosova, O., 2001. Adaptation to climate change in the context of sustainable development and equity. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge, UK, pp. 77–912.
- Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change – Human and Policy Dimensions* 16, 282–292.
- Smith, J.B., Lenart, S.S., 1996. Climate change adaptation policy options. *Climate Research* 6, 193–201.
- Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable sociotechnical transitions. *Research Policy* 34, 1491–1510.
- Snijders, T.A.B., 2005. Models for Longitudinal Network Data Models and Methods in Social Network Analysis. In: Carrington, P., Scott, J., Wasserman, S. (Eds.), Cambridge University Press, New York (Chapter 11).
- Stringer, L.C., Dougill, A.J., Fraser, E.D.G., Hubacek, K., Prell, C., Reed, M.S., 2006. Unpacking “participation” in the adaptive management of social–ecological systems: a critical review. *Ecology and Society* 1 (2), 39 ([online] URL: <http://www.ecologyandsociety.org/vol11/iss2/art39/>).
- Stringer, L.C., Reed, M.S., Dougill, A.J., Twyman, C., 2009. Local adaptations to climate change, drought and desertification: insights to enhance policy in southern Africa. *Environmental Science & Policy* 12, 748–765.
- Thomalla, F., Downing, T., Spanger-Siegfried, E., Han, G.Y., Rockstrom, J., 2006. Reducing hazard vulnerability: toward a common approach between disaster risk reduction and climate adaptation. *Disasters* 30, 39–48.
- Thomas, D.S.G., Twyman, C., 2005. Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Global Environmental Change* 15, 115–124.
- Thomas, D.S.G., Knight, M., Wiggs, G.F.S., 2005. Remobilization of southern African desert dune systems by twenty-first century global warming. *Nature* 435, 1218–1221.
- Tol, R., Fankhauser, S., Smith, J.B., 1998. The scope for adaptation to climate change: what can we learn from the impact literature? *Global Environmental Change* 8, 109–123.
- Tornatzky, L.G., Klein, K.J., 1982. Innovation characteristics and innovation adoption-implementation — a meta-analysis of findings. *IEEE Transactions on Engineering Management* 29, 28–45.
- Turner, R.K., Daily, G.C., 2008. The ecosystem services framework and natural capital conservation. *Environmental and Resource Economics* 39, 25–35.
- Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A., 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America* 100, 8074–8079.
- UNCCD, 1994. *United Nations Convention to Combat Desertification* United Nations, Geneva.
- United Nations Development Programme (UNDP), 1999. *Sustainable Livelihoods Concepts, Principles, and Approaches to Indicator Development*. UNDP (Available from: <http://www.undp.org/sl>).
- United Nations Development Programme (UNDP), 2005. *Adaptation Policy Frameworks for Climate Change. Developing Strategies, Policies and Measures*. Cambridge University Press, Cambridge, UK and New York, NY.
- United Nations Environment Programme (UNEP), 1998. *Handbook on Methods for Climate Impact Assessment and Adaptation Strategies*. In: Feenstra, J., Burton, I., Smith, J., Tols, R. (Eds.), United Nations Environment Program Institute for Environmental Studies, Amsterdam.
- United Nations Environment Programme (UNEP), 2001. *Assessing Human Vulnerability to Environmental Change: Concepts, Issues, Methods and Case Studies. A Report on Work in Progress*. United Nations Environment Program, Nairobi.
- Valente, T.W., Davis, R., 1999. Accelerating the diffusion of innovations using opinion leaders. *The Annals of the American Academy of Political and Social Science* 566, 55–67.
- van Aalst, M.K., Cannon, T., Burton, I., 2008. Community level adaptation to climate change: the potential role of participatory community risk assessment. *Global Environmental Change* 18, 165–179.
- van der Brugge, R., van Raak, R., 2007. Facing the adaptive management challenge: insights from transition management. *Ecology and Society* 12 (2), 33 ([online] URL: <http://www.ecologyandsociety.org/vol12/iss2/art33/>).
- Walters, C.J., 1986. *Adaptive Management of Renewable Resources*. McMillan, New York, USA.
- Wisner, B., Blaikie, P., Cannon, T., Davis, I., 2004. *At Risk: Natural Hazards, People's Vulnerability and Disasters*, 2nd ed. Routledge, London.
- WOCAT, 2007. In: Liniger, H., Critchley, W. (Eds.), *Where the Land is Greener: Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide*. CTA, Wageningen, The Netherlands (Co-published by CTA, FAO, UNEP and CDE).
- Yohe, G., Tol, R., 2002. Indicators for social and economic coping capacity — moving toward a working definition of adaptive capacity. *Global Environmental Change* 12, 25–40.
- Ziervogel, G., Bharwani, S., Downing, T.E., 2006. Adapting to climate variability: pumps, people and policy. *Natural Resources Forum* 30, 294–305.