

Vulnerability

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Abstract

This paper reviews research traditions of vulnerability to environmental change and the challenges for present vulnerability research in integrating with the domains of resilience and adaptation. Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt. Antecedent traditions include theories of vulnerability as entitlement failure and theories of hazard. Each of these areas has contributed to present formulations of vulnerability to environmental change as a characteristic of social-ecological systems linked to resilience. Research on vulnerability to the impacts of climate change spans all the antecedent and successor traditions. The challenges for vulnerability research are to develop robust and credible measures, to incorporate diverse methods that include perceptions of risk and vulnerability, and to incorporate governance research on the mechanisms that mediate vulnerability and promote adaptive action and resilience. These challenges are common to the domains of vulnerability, adaptation and resilience and form common ground for consistency and integration.

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1. Introduction

The purpose of this article is to review existing knowledge on analytical approaches to vulnerability to environmental change in order to propose synergies between research on vulnerability and on resilience of social-ecological systems. The concept of vulnerability has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to enhance well-being through reduction of risk. In this article, I argue that emerging insights into the resilience of social-ecological systems complement and can significantly add to a converging research agenda on the challenges faced by human environment interactions under stresses caused by global environmental and social change.

I review the precursors and the present emphases of vulnerability research. I argue that, following decades of vulnerability assessment that distinguished between process

and outcome, much exciting current research emphasizes multiple stressors and multiple pathways of vulnerability. This current research can potentially contribute to emerging resilience science through methods and conceptualization of the stresses and processes that lead to threshold changes, particularly those involved in the social and institutional dynamics of social-ecological systems.

Part of the potential convergence and learning across vulnerability and resilience research comes from a consistent focus on social-ecological systems. The concept of a social-ecological system reflects the idea that human action and social structures are integral to nature and hence any distinction between social and natural systems is arbitrary. Clearly natural systems refer to biological and biophysical processes while social systems are made up of rules and institutions that mediate human use of resources as well as systems of knowledge and ethics that interpret natural systems from a human perspective (Berkes and Folke, 1998). In the context of these social-ecological systems, resilience refers to the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organise and the

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capacity for adaptation to emerging circumstances (e.g. Carpenter et al., 2001; Berkes et al., 2003; Folke, 2006).

Vulnerability, by contrast, is usually portrayed in negative terms as the susceptibility to be harmed. The central idea of the often-cited IPCC definition (McCarthy et al., 2001) is that vulnerability is degree to which a system is susceptible to and is unable to cope with adverse effects (of climate change). In all formulations, the key parameters of vulnerability are the stress to which a system is exposed, its sensitivity, and its adaptive capacity. Thus, vulnerability research and resilience research have common elements of interest—the shocks and stresses experienced by the social-ecological system, the response of the system, and the capacity for adaptive action. The points of convergence are more numerous and more fundamental than the points of divergence.

The different formulations of research needs, research methods, and normative implications of resilience and vulnerability research stem from, I believe, the formulation of the objectives of study (or the system) in each case. As Berkes and Folke (1998, p. 9) point out, ‘there is no single universally accepted way of formulating the linkages between human and natural systems’. Other areas of research in the human–environment interaction (such as common property, ecological economics or adaptive management) conceptualize social-ecological linkages in different ways. The common property resource tradition, for example, stresses the importance of social, political and economic organizations in social-ecological systems, with institutions as mediating factors that govern the relationship between social systems and ecosystems on which they depend (Dolšak and Ostrom, 2003). Ecological economics, by contrast, links social and natural systems through analysis of the interactions and substitutability of natural capital with other forms of capital (human, social and physical) (e.g. the ‘containing and sustaining ecosystem’ idea of Daly and Farley, 2004). Adaptive management, by contrast, deals with the unpredictable interactions between humans and ecosystems that evolve together—it is the science of explaining how social and natural systems learn through experimentation (Berkes and Folke, 1998). All of these other traditions (and both vulnerability and resilience research in effect) seek to elaborate the nature of social-ecological systems while using theories with explanatory power for particular dimensions of human–environment interactions.

Evolving insights into the vulnerability of social-ecological systems show that vulnerability is influenced by the build up or erosion of the elements of social-ecological resilience. These are the ability to absorb the shocks, the autonomy of self-organisation and the ability to adapt both in advance and in reaction to shocks. The impacts and recovery from Asian tsunami of 2004, or the ability of small islands to cope with weather-related extremes, for example, demonstrate how discrete events in nature expose underlying vulnerability and push systems into new domains where resilience may be reduced (Adger et al.,

2005b). In a world of global change, such discrete events are becoming more common. Indeed, risk and perturbation in many ways define and constitute the landscape of decision-making for social-ecological systems.

I proceed by examining the traditions within vulnerability research including the fields of disasters research (delineated into human ecology, hazards, and the ‘Pressure and Release’ model) and research on entitlements. This discussion is complementary to other reviews that discern trends and strategies for useful and analytically powerful vulnerability research. Eakin and Luers (2006), Bankoff et al. (2004), Pelling (2003), Füssel and Klein (2006), Cutter (2003), Ionescu et al. (2005) and Kaspersen et al. (2005), for example, present significant reviews of the evolution and present application of vulnerability tools and methods across resource management, social change and urbanization and climate change. These build on earlier elaborations by Liverman (1990), Dow (1992), Ribot et al. (1996), and others (see the paper by Janssen et al. (2006) for an evaluation of the seminal articles).

Elements of disasters and entitlements theories have contributed to current use of vulnerability in the analysis of social-ecological systems and in sustainable livelihoods research. Livelihoods research remains, I argue, firmly rooted in social systems rather than integrative of risks across social-ecological systems. All these traditions and approaches are found in applications of vulnerability in the context of climate change. The remaining sections of the paper examine methodological developments and challenges to human dimensions research, particularly on measurement of vulnerability, dealing with perceptions of risk, and issues of governance. The paper demonstrates that these challenges are common to the fields of vulnerability, adaptation and resilience and hence point to common ground for learning between presently disparate traditions and communities.

2. Evolution of approaches to vulnerability

2.1. Antecedents: hazards and entitlements

A number of traditions and disciplines, from economics and anthropology to psychology and engineering, use the term vulnerability. It is only in the area of human–environment relationships that vulnerability has common, though contested, meaning. Human geography and human ecology have, in particular, theorized vulnerability to environmental change. Both of these disciplines have made contributions to present understanding of social-ecological systems, while related insights into entitlements grounded vulnerability analysis in theories of social change and decision-making. In this section, I argue that all these disciplines traditions continue to contribute to emerging methods and concepts around social-ecological systems and their inherent and dynamic vulnerability.

While there are differences in approaches, there are many commonalities in vulnerability research in the

environmental arena. First, it is widely noted that vulnerability to environmental change does not exist in isolation from the wider political economy of resource use. Vulnerability is driven by inadvertent or deliberate human action that reinforces self-interest and the distribution of power in addition to interacting with physical and ecological systems. Second, there are common terms across theoretical approaches: vulnerability is most often conceptualized as being constituted by a components that include exposure and sensitivity to perturbations or external stresses, and the capacity to adapt. Exposure is the nature and degree to which a system experiences environmental or socio-political stress. The characteristics of these stresses include their magnitude, frequency, duration and areal extent of the hazard (Burton et al., 1993). Sensitivity is the degree to which a system is modified or affected by perturbations.¹ Adaptive capacity is the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope.

There are, I believe, two relevant existing theories that relate to human use of environmental resources and to environmental risks: the vulnerability and related resilience research on social-ecological systems and the separate literature on vulnerability of livelihoods to poverty. Fig. 1 is an attempt to portray the overlap in ideas and those ideas, which are distinct from each other and is based on my reading of this literature.² Two major research traditions in vulnerability acted as seedbeds for ideas that eventually translated into current research on vulnerability of social and physical systems in an integrated manner. These two antecedents are the analysis of vulnerability as lack of entitlements and the analysis of vulnerability to natural hazards. These are depicted in the upper part of Fig. 1, with the hazards tradition delineated into three overlapping areas of human ecology (or political ecology), natural hazards, and the so-called 'Pressure and Release' model that spans the space between hazards and political ecology approaches.

Other reviews of vulnerability have come to different conclusions on intellectual traditions. Cutter (1996) and Cutter et al. (2003), for example, classify research into first, vulnerability as exposure (conditions that make people or places vulnerable to hazard), second, vulnerability as social condition (measure of resilience to hazards), and third, 'the integration of potential exposures and societal resilience

with a specific focus on places or regions (Cutter et al., 2003, p. 243). O'Brien et al. (2005) identify similar trends in 'vulnerability as outcome' and 'contextual vulnerability' as two opposing research foci and traditions, relating to debates within the climate change area (see also Kelly and Adger, 2000). These distinctions between outcome and processes of vulnerability are also important, though not captured in Fig. 1, which portrays more of the disciplinary divide between those endeavours which largely ignore physical and biological systems (entitlements and livelihoods) and those that try to integrate social and ecological systems.

The impetus for research on entitlements in livelihoods has been the need to explain food insecurity, civil strife and social upheaval. Research on the social impacts of natural hazards came from explaining commonalities between apparently different types of natural disasters and their impacts on society. But clearly these phenomena (of entitlement failure leading to famine and natural hazards) themselves are not independent of each other. While some famines can be triggered by extreme climate events, such as drought or flood, for example, vulnerability researchers have increasingly shown that famines and food insecurity are much more often caused by disease, war or other factors (Sen, 1981; Swift, 1989; Bohle et al., 1994; Blaikie et al., 1994). Entitlements-based explanations of vulnerability focussed almost exclusively on the social realm of institutions, well-being and on class, social status and gender as important variables while vulnerability research on natural hazards developed an integral knowledge of environmental risks with human response drawing on geographical and psychological perspectives in addition to social parameters of risk.

Vulnerability to food insecurity is explained, through so-called entitlement theory, as a set of linked economic and institutional factors. Entitlements are the actual or potential resources available to individuals based on their own production, assets or reciprocal arrangements. Food insecurity is therefore a consequence of human activity, which can be prevented by modified behaviour and by political interventions. Vulnerability is the result of processes in which humans actively engage and which they can almost always prevent. The theory of entitlements as an explanation for famine causes was developed in the early 1980s (Sen, 1981, 1984) and displaced prior notions that shortfalls in food production through drought, flood, or pest, were the principal cause of famine. It focused instead on the effective demand for food, and the social and economic means of obtaining it.

Entitlements are sources of welfare or income that are realized or are latent. They are 'the set of alternative commodity bundles that a person can command in a society using the totality of rights and opportunities that he or she faces' (Sen, 1984, p. 497). Essentially, vulnerability of livelihoods to shocks occurs when people have insufficient real income and wealth, and when there is a breakdown in other previously held endowments.

¹The generic meaning of sensitivity is applied in the climate change field where McCarthy et al. (2001) in the IPCC report of 2001 defines sensitivity and illustrates the generic meaning with reference to climate change risks thus: 'the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)'.

²The observations leading to Fig. 1 are confirmed to an extent by the findings of Janssen et al. (2006) on the importance of Sen (1981) as a seminal reference across many areas of vulnerability research and the non-inclusion of the present livelihood vulnerability literature.

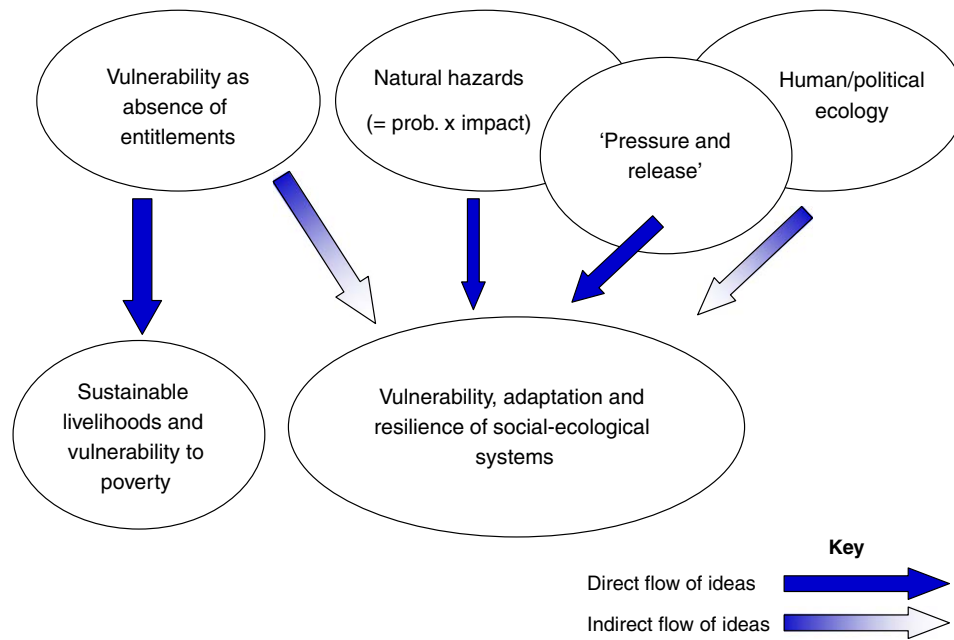


Fig. 1. Traditions in vulnerability research and their evolution.

The advantage of the entitlements approach to famine is that it can be used to explain situations where populations have been vulnerable to famine even where there are no absolute shortages of food or obvious environmental drivers at work. Famines and other crises occur when entitlements fail.

While the entitlements approach to analysing vulnerability to famine often underplayed ecological or physical risk, it succeeded in highlighting social differentiation in cause and outcome of vulnerability. The second research tradition (upper right in Fig. 1) on natural hazards, by contrast has since its inception attempted to incorporate physical science, engineering and social science to explain linkages between system elements.

The physical elements of exposure, probability and impacts of hazards, both seemingly natural and unnatural, are the basis for this tradition. Burton et al. (1978 and 1993) summarized and synthesized decades of research and practice on flood management, geo-hazards and major technological hazards, deriving lessons on individual perceptions of risk, through to international collective action. They demonstrated that virtually all types of natural hazard and all social and political upheaval have vastly different impacts on different groups in society. For many natural hazards the vulnerability of human populations is based on where they reside, their use of the natural resources, and the resources they have to cope.

The human ecology tradition (sometimes labelled the political ecology stream—Cutter, 1996) within analysis of vulnerability to hazards (upper right in Fig. 1) argued that the discourse of hazard management, because of a perceived dominance of engineering approaches, failed to engage with the political and structural causes of vulner-

ability within society. Human ecologists attempted to explain why the poor and marginalized have been most at risk from natural hazards (Hewitt, 1983; Watts, 1983), what Hewitt (1997) termed 'the human ecology of endangerment'. Poorer households tend to live in riskier areas in urban settlements, putting them at risk from flooding, disease and other chronic stresses. Women are differentially at risk from many elements of environmental hazards, including, for example, the burden of work in recovery of home and livelihood after an event (Fordham, 2003). Flooding in low-lying coastal areas associated with monsoon climates or hurricane impacts, for example, are seasonal and usually short lived, yet can have significant unexpected impacts for vulnerable sections of society.

Burton et al. (1993), from a mainstream hazards tradition, argued that hazards are essentially mediated by institutional structures, and that increased economic activity does not necessarily reduce vulnerability to impacts of hazards in general. As with food insecurity, vulnerability to natural hazards has often been explained by technical and institutional factors. By contrast the human ecology approach emphasizes the role of economic development in adapting to changing exogenous risk and hence differences in class structure, governance, and economic dependency in the differential impacts of hazards (Hewitt, 1983).

Much of the world's 'vulnerability as experienced' comes from perceptions of insecurity. Insecurity at its most basic level is not only a lack of security of food supply and availability and of economic well-being, but also freedom from strife and conflict. Hewitt (1994, 1997) argues that violence and the 'disasters of war' have been pervasive sources of danger for societies, accounting for up to half of all reported famines in the past century. While war and

civil strife often exacerbate natural hazards, the perceptions of vulnerability associated with them are fundamentally different in that food insecurity, displacement and violence to create vulnerabilities are deliberate acts perpetrated towards political ends (Hewitt, 1994, 1997).

In Fig. 1, I portray these two traditions of hazards research as being successfully bridged by Blaikie and colleagues (1994) in their ‘Pressure and Release’ model of hazards. They proposed that physical or biological hazards represent one pressure and characteristic of vulnerability and that a further pressure comes from the cumulative progression of vulnerability, from root causes through to local geography and social differentiation. These two pressures culminate in the disasters that result from the additive pressures of hazard and vulnerability (Blaikie et al., 1994). The analysis captured the essence of vulnerability from the physical hazards tradition while also identifying the proximate and underlying causes of vulnerability within a human ecology framework. The analysis was also comprehensive in seeking to explain physical and biological hazards (though deliberately omitting technological hazards). Impacts associated with geological hazards often occur without much effective warning and with a speed of onset of only a few minutes. By contrast, the HIV/AIDS epidemic is a long wave disaster with a slow onset but catastrophic impact (Barnett and Blaikie, 1994; Stabinski et al., 2003).

Blaikie et al. (1994) also prescribed actions and principles for recovery and mitigation of disasters that focussed explicitly on reducing vulnerability. The pressure and release model is portrayed in Fig. 1 as successfully synthesizing social and physical vulnerability. In being comprehensive and in giving equal weight to ‘hazard’ and ‘vulnerability’ as pressures, the analysis fails to provide a systematic view of the mechanisms and processes of vulnerability. Operationalising the pressure and release model necessarily involves typologies of causes and categorical data on hazards types, limiting the analysis in terms of quantifiable or predictive relationships.

In Fig. 1, a separate stream on sustainable livelihoods and vulnerability to poverty is shown as a successor to vulnerability as entitlement failure. This research tradition, largely within development economics, tends not to consider integrative social-ecological systems and hence, but nevertheless complements the hazards-based approaches in Fig. 1 through conceptualization and measurement of the links between risk and well-being at the individual level (Alwang et al., 2001; Adger and Winkels, 2006). A sustainable livelihood refers to the well-being of a person or household (Ellis, 2000) and comprises the capabilities, assets and activities that lead to well-being (Chambers and Conway, 1992; Allison and Ellis, 2001). Vulnerability in this context refers to the susceptibility to circumstances of not being able to sustain a livelihood: the concepts are most often applied in the context of development assistance and poverty alleviation. While livelihoods are conceptualized as flowing from capital

assets that include ecosystem services (natural capital), the physical and ecological dynamics of risk remain largely unaccounted for in this area of research. The principal focus is on consumption of poor households as a manifestation of vulnerability (Dercon, 2004). Given the importance of this tradition and the contribution that researchers in this field make to methods (see section below), it seems that cross-fertilization of development economics with vulnerability, adaptation and resilience research would yield new insights.

2.2. Successors and current research frontiers

The upper part of Fig. 1 and the discussions here portray a somewhat linear relationship between antecedent and successor traditions of vulnerability research. This is, of course, a caricature, given the influence of particular researchers across traditions and the overlap and cross-fertilization of ideas and methods. Nevertheless, from its origins in disasters and entitlement theories, there is a newly emerging synthesis of systems-oriented research attempting, through advances in methods, to understand vulnerability in a holistic manner in natural and social systems.

Portraying vulnerability as a property of a social-ecological system, and seeking to elaborate the mechanisms and processes in a coupled manner, represents a conceptual advance in analysis (Turner et al., 2003a). Rather than focusing on multiple outcomes from a single physical stress, the approach proposed by Turner and colleagues (2003a) seeks to analyse the elements of vulnerability (its exposure, sensitivity and resilience) of a bounded system at a particular spatial scale. It also seeks to quantify and make explicit both the links to other scales and to quantify the impact of action to cope and responsibility on other elements of the system (such as the degree of exposure of ecological components or communities). The interdisciplinary and integrative nature of the framework is part of a wider effort to identify science that supports goals of sustainability (e.g. Kates et al., 2001) and is mirrored in other system-oriented vulnerability research such as that developed at the Potsdam Institute for Climate Impacts Research (Schröter et al., 2005; Ionescu et al., 2005).

Integrative frameworks focused on interaction between properties of social-ecological systems have built on pioneering work, for example by Liverman (1990) that crucially developed robust methods for vulnerability assessment. In her work on vulnerability to drought in Mexico, Liverman (1990) argued for integrative approaches based on comparative quantitative assessment of the drivers of vulnerability. She showed that irrigation and land tenure have the greatest impact on the incidence of vulnerability to drought making collectively owned *ejido* land more susceptible. Thus, using diverse sources of quantitative data, this study showed the places and the people and the drivers within the social-ecological system that led to vulnerability.

Following in that tradition, Luers and colleagues (2003) utilize the Turner et al. (2003a) framework to also examine vulnerability of social-ecological systems in an agricultural region of Mexico and demonstrate innovations in methods associated with this approach. In recognizing many of the constraints they make a case for measuring the vulnerability of specific variables: they argue that vulnerability should shift away from quantifying critical areas or vulnerable places towards measures that can be applied at any scale. They argue for assessing the vulnerability of the most important variables in the causal chain of vulnerability to specific sets of stressors. They develop generic metrics that attempt to assess the relationship between a wide range of stressors and the outcome variables of concern (Luers et al., 2003). In their most general form:

$$\text{Vulnerability} = \frac{\text{sensitivity to stress}}{\text{state relative to threshold}} \times \text{Prob. of exposure to stress.}$$

The parameter under scrutiny here could be a physical or social parameter. In the case of Luers et al. (2003) they investigate the vulnerability of farming systems in an irrigated area of Mexico through examining agricultural yields. But the same generalized equation could examine disease prevalence, mortality in human populations, or income of households—all of which are legitimate potential measures within vulnerability analysis.

But other research presently argues that the key to understanding vulnerability lies in the interaction between social dynamics within a social-ecological system and that these dynamics are important for resilience. For example, livelihood specialization and diversity have been shown to be important elements in vulnerability to drought in Kenya and Tanzania (Eriksen et al., 2005). While these variables can be measured directly, it is the social capital and social relations that translate these parameters into vulnerability of place. Eriksen et al. (2005) show that women are excluded from particular high-value activities: hence vulnerability is reproduced within certain parts of social systems through deep structural elements. Similarly, Eakin (2005) shows for Mexican farmers that diversity is key to avoiding vulnerability and that investment in commercial high-yielding irrigated agriculture can exacerbate vulnerability compared to a farming strategy based on maize (that is in effect more sensitive to drought). It is the multi-level interactions between system components (livelihoods, social structures and agricultural policy) that determine system vulnerability.

Hence vulnerability assessment incorporates a significant range of parameters in building quantitative and qualitative pictures of the processes and outcomes of vulnerability. These relate to ideas of resilience by identifying key elements of the system that represent adaptive capacity (often social capital and other assets—Pelling and High,

2005; Adger, 2003) and the impact of extreme event thresholds on creating vulnerabilities within systems.

2.3. Traditions exemplified in vulnerability to climate change

Research on vulnerability applied to the issue of climate change impacts and risk demonstrates the full range of research traditions while contributing in a significant way to the development of newly emerging systems vulnerability analysis. Vulnerability research in climate change has, in some ways, a unique distinction of being a widely accepted and used term and an integral part of its scientific agenda. Climate change represents a classic multi-scale global change problem in that it is characterized by infinitely diverse actors, multiple stressors and multiple time scales. The existing evidence suggests that climate change impacts will substantially increase burdens on those populations that are already vulnerable to climate extremes, and bear the brunt of projected (and increasingly observed) changes that are attributable to global climate change. The 2003 European heatwave and even the impacts of recent Atlantic hurricanes demonstrate essential elements of system vulnerability (Poumadère et al., 2005; Stott et al., 2004; Kovats et al., 2005; O'Brien, 2006). Groups that are already marginalized bear a disproportionate burden of climate impacts, both in the developed countries and in the developing world.

The science of climate change relies on insights from multiple disciplines and is founded on multiple epistemologies. Climate change is, in addition, unusually focused on consensus (Oreskes, 2004) because of the nature of evidence and interaction of science with a highly contested legal instrument, the UN Framework Convention on Climate Change. Within climate change, therefore, the reports of the Intergovernmental Panel on Climate Change (IPCC) have become an authoritative source that sets agendas and acts as a legitimizing device for research. It is therefore worth examining primary research on vulnerability to climate change and its interpretation within the reports of the IPCC.

The full range of concepts and approaches highlighted in Fig. 1 are used within vulnerability assessments of climate change. O'Brien et al. (2005) argues that this diversity of approaches confuses policy-makers in this arena—research is often not explicit about whether it portrays vulnerability as an outcome or vulnerability as a context in which climate risks are dealt with and adapted to. The IPCC defines vulnerability within the latest assessment report (McCarthy et al., 2001) as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity'.

Vulnerability to climate change in this context is therefore defined as a characteristic of a system and as a

function of exposure, sensitivity and adaptive capacity. The IPCC reports make assertions as to the determinants of both vulnerability and adaptive capacity. For example, the 1996 report states that the determinants of adaptive capacity are directly correlated with measures of economic development (GDP per capita) (IPCC, 1996). Hence developing countries are asserted to be more vulnerable to climate change because among other things, of their ‘lack of institutional capacity’ (usually interpreted as a lack of capacity of government). This is an apparent paradox in the IPCC conclusions on vulnerability of regions. While developing countries are portrayed as ‘most vulnerable’ there is, at the same time, much evidence, from the Arctic to the Sahel, suggesting that communities and countries themselves have significant capacity to adapt latent in local knowledge and experience of coping with variability (e.g. Berkes and Jolly, 2001; Mortimore and Adams, 2001). The paradox derives from two faces of vulnerability—a state of ‘powerlessness and endangerment’ (cf. Hewitt, 1997) and the recognition of the ability of social-ecological systems to adapt to changing circumstances. O’Brien et al. (2005) explain this paradox by highlighting the separate epistemological positions on ‘vulnerability as outcome’ versus ‘contextual vulnerability’.

Thus, the IPCC headline policy statements on vulnerability of regions and systems do not reflect the richness and diversity of findings on causes and consequences of vulnerability to climate change and climate risks. Barnett (2006), for example, makes the linkages between armed conflict and vulnerability to climate change, an issue not addressed to date in IPCC reports. Barnett (2006) inverts the usual argument that climate change impacts may lead to armed conflict by demonstrating that violent conflict exacerbates climate change injustices and creates its own vulnerabilities to climate change. These include the paralysis of governments in post-conflict situations, such as in East Timor, to address and anticipate potentially significant impacts of environmental change. The unequal distribution of vulnerability to climate change is therefore exacerbated by pre-existing inequalities. Vulnerability research also allows for systematic investigation of the potential for pro-active adaptation and for system-wide changes well-being linked to ecosystems. Shröter et al. (2005) demonstrate how vulnerability to global change could result in loss of ecosystem services across Europe by combining spatially explicit models of water, climate and land use—they explicitly account for the multiple stressors that are inadequately handled in the climate change policy community to date (see also O’Brien and Leichenko, 2000).

This review of approaches demonstrates diverging conceptions of vulnerability due to the different epistemological positions of research traditions and because of differing objectives of research in these areas. Table 1 summarises both the objectives and some seminal contributions across the typology outlined in Fig. 1, distinguishing between the antecedent approaches to vulnerability to hazards and to entitlement failure and

their successors in distinct analysis of vulnerability to poverty, and in vulnerability of coupled social-ecological systems. The antecedent research from all traditions contributes to framing vulnerability to global change in two ways. First, it demonstrates that institutions adapt to environmental risk. Given resources and favourable circumstances, this adaptation will ultimately reduce the impact of perturbations on marginal sections of society and enhance resilience. Second, it shows that there is a close interdependence between environmental risk, the political economy of development and the resilience of systems.

3. Challenges and directions for vulnerability research

3.1. *Measuring vulnerability*

All research traditions reviewed above struggle to find suitable metrics for vulnerability. Vulnerability is a dynamic phenomenon often in a continuous state of flux both the biophysical and social processes that shape local conditions and the ability to cope are themselves dynamic (O’Brien et al., 2005). Measurement of vulnerability must therefore reflect social processes as well as material outcomes within systems that appear complicated and with many linkages that are difficult to pin down. Vulnerability is, therefore, not easily reduced to a single metric and is not easily quantifiable. While it is easy to recognize personally the feeling of vulnerability and perhaps to grasp the outcome of vulnerability in others in a similar situation, the translation of this complex set of parameters into a quantitative metric in many ways reduces its impact and hides its complexity (Alwang et al., 2001). This section outlines challenges in this area of vulnerability research highlighting significant advances in methods in vulnerability: significant challenges include developing metrics that incorporate both human well-being and recognize the relative and perceptual nature of vulnerability.

In the quantitative social sciences, particularly in the field of sustainable livelihoods, there has been significant recent attention to deriving metrics for vulnerability that are comparable across time and location to make them more tractable (Kamanou and Morduch, 2004; Alwang et al., 2001). Much of the research concerned with vulnerability to poverty comes from development economics and, in the search for tractability, often focuses on consumption of the poor as the key parameter. But since social-ecological systems are vulnerable to multiple stresses and vulnerability is manifest in various outcomes (not just material), there are, in effect, different thresholds on vulnerability informed by values and social context (Alwang et al., 2001). It is important nonetheless to provide consistent frameworks for measuring vulnerability that provide complementary quantitative and qualitative insights into outcomes and perceptions of vulnerability. Quantitative measures complement rich narratives of stakeholder-led or qualitative assessments of vulnerability in places and contexts (e.g. Luttrell, 2001; Winkels, 2004).

Table 1
Antecedent and successor traditions in vulnerability research

Vulnerability approach	Objectives	Sources
<i>Antecedents</i>		
Vulnerability to famine and food insecurity	Developed to explain vulnerability to famine in the absence of shortages of food or production failures. Described vulnerability as a failure of entitlements and shortage of capabilities.	Sen (1981); Swift (1989); Watts and Bohle (1993)
Vulnerability to hazards	Identification and prediction of vulnerable groups, critical regions through likelihood and consequence of hazard. Applications in climate change impacts.	Burton et al. (1978, 1993); Smith (1996); Anderson and Woodrow (1998); Parry and Carter (1994)
Human ecology	Structural analysis of underlying causes of vulnerability to natural hazards.	Hewitt (1983); O'Keefe et al. (1976); Mustafa (1998)
Pressure and Release	Further developed human ecology model to link discrete risks with political economy of resources and normative disaster management and intervention.	Blaikie et al. (1994); Winchester (1992); Pelling (2003)
<i>Successors</i>		
Vulnerability to climate change and variability	Explaining present social, physical or ecological system vulnerability to (primarily) future risks, using wide range of methods and research traditions.	Klein and Nicholls (1999); Smit and Pilifosova (2001); Smith et al. (2001); Ford and Smit (2004); O'Brien et al. (2004)
Sustainable livelihoods and vulnerability to poverty	Explains why populations become or stay poor based on analysis of economic factors and social relations.	Morduch (1994); Bebbington (1999); Ellis (2000); Dercon (2004); Ligon and Schechter (2003); Dercon and Krishnan (2000)
Vulnerability of social-ecological systems	Explaining the vulnerability of coupled human-environment systems.	Turner et al. (2003a, b); Luers et al. (2003); Luers (2005); O'Brien et al. (2004)

Research on mapping vulnerability increasingly attempts to validate and triangulate data to derive more robust measures for both policy analysis and intervention (Downing et al., 2001; Yohe and Tol, 2002; Haddad, 2005; Brooks et al., 2005). Such mapping most often involves cross-national or spatially mapped comparisons of indicators. A common critique of comparative statistical research, particularly focused on country-level analysis, is that it fails to capture the sub-national spatial and social differentiation of vulnerability and local conditions that mediate the capacity to adapt (Cutter et al., 2003).

There have been parallel advances in the spatial mapping of elements of vulnerability (e.g. O'Brien et al., 2004; Kaspersen et al., 2005; SEI, 2001; Schröter et al., 2005), particularly on multiple stressors to social-ecologic systems. In India, for example, both climate change and trade liberalization are changing the context for agricultural production. Some farmers are able to adapt to these changing conditions, including the discrete events such as drought and rapid changes in commodity prices. Other farmers may experience predominately negative outcomes from these simultaneous processes. O'Brien et al. (2004) modelled combined data on trade liberalization and on climate change risks at the district level in India, to show which districts most likely to be able to adapt to drier conditions and variability in the Indian monsoons, as well as respond to import competition and export opportunities resulting from liberalized agricultural trade. The results of this mapping showed higher degrees of adaptive capacity in districts located along the Indo-Gangetic Plains, and lower capacity in the interior parts of the country.

Similarly, the Stockholm Environment Institute (2001) identify hot-spots of vulnerability in the greater Mekong Sub-Region using maps of flood risk, future planned development of dams and other factors. Importantly, decision-makers and stakeholders interpreted the raw data to arrive at consensus maps.

These innovations in vulnerability methods attempt to capture the dynamics and spatial distribution of individual variables of concern and interactions between them (Luers, 2005; Polsky, 2004). However, specific variables do not necessarily measure vulnerability directly. Hence a leap of faith is required between vulnerability of a key variable (whether physical or social) and other elements such as ecosystem services or well-being. Unless the variable and causal links are well established, the relationship may not hold. This is, after all, a key finding of the entitlement failure explanations of vulnerability discussed above: vulnerability may result from failure of exchange, access, transfer, endowments or production. Assuming one of these factors control the system in advance can lead to wayward results. Hence focusing on physical production variables or social variables within a system, may not capture the issues that make individuals or localities vulnerable to multiple stresses. The remaining challenge is in combining measurement of aspects of vulnerability and thresholds within systems with explanations of whole-system vulnerability and the role of institutions and governance processes.

A generalized measure of vulnerability, building on both sustainable livelihoods and hazards traditions, needs to account for dynamics (what is vulnerable in one period is

not necessarily vulnerable in the next period) and account for the degree and severity of vulnerability. Appendix A outlines a set of generalized indicators that meet these criteria. Luers et al. (2003) and Luers (2005) highlight that, whatever the generalized form of vulnerability measure, there is an inescapable need for a threshold of risk, danger or harm. The measures of vulnerability severity discussed in Appendix A involve a measure of well-being that could be measured in a number of different ways. It could be objective material measures such indicators of mortality, income, wealth, or freedom from crime or access to education, depending on the nature of the vulnerability being measured. In addition, vulnerability as experienced could be measured directly through perceptions of those that are vulnerable.

Any meaningful threshold is, however, likely to be highly heterogeneous. Vulnerability is manifest in specific places at specific times: hence the determination of the threshold level of well-being that constitutes the threshold is not simply a proportional measure, the same for all sections of society. In addition, the choice of thresholds is based on values and preferences and hence is both institutionally and culturally determined. The measurement of vulnerability inevitably requires external judgments and interpretations of the thresholds of acceptable risk. The inescapability of a vulnerability threshold needs to be both made explicit and embraced in vulnerability methods. Thresholds that undermine system resilience, even in relatively well-understood ecological elements of a social-ecological system, are difficult to discern (Folke et al., 2004).

3.2. *Experiencing vulnerability and surprise*

A second challenge arises from the tension between objective and perceived elements of vulnerability and risk. As discussed above, there are good reasons why vulnerability research has focused on objective measures in interactions with scientific communities in geological hazards, risk research, climate change and land use change. But vulnerability may be differently perceived or experienced by the vulnerable themselves (Kasperson et al., 2005).

The experiential or perceptual dimensions of vulnerability are not easily measured. Perceptions of insecurity or of ‘things not being as they should be’ open up a whole new area of research, only touched on by environmental psychology. First, security and insecurity themselves are not easily measured (Kasperson and Kasperson, 2001). Second, the impacts of environmental change that create perceptions of insecurity themselves may not be obvious. Thus, as argued by O’Brien and colleagues (2005), more subtle impacts of environmental change may have a greater relevance to individuals and communities in terms of their perceived vulnerabilities—these iconic environmental changes are highly culturally specific. While Norwegians may be concerned with snow for skiing, English gardeners worry about the early arrival of spring, and indigenous

Inuit hunters feel uneasy because of the disappearance of summer sea ice (Riedlinger and Berkes, 2001).

Psychological research, for example, has provided empirical evidence that those who perceive themselves to be vulnerable to environmental risks, or who perceive themselves to be victims of injustice, also perceive themselves to be more at risk from environmental hazards of all types (Satterfield et al., 2004). Similarly, perceptions of barriers to actually adapting by the vulnerable do in fact limit adaptive actions, even when there are capacities and resources to adapt (Grothmann and Patt, 2005). This challenge, of incorporating the gamut of vulnerability as experienced now and dreaded for the future, suggests the need for novel methods in both the positivist and constructivist traditions.

The future is, of course, unknown. Trends in environmental change, technologies and other social and demographic processes make individuals and social systems are always vulnerable to surprise and susceptible to unforeseen consequences of action (Cutter, 2003; Schneider et al., 1998). While policy-makers always express surprise at events, many of these are predictable or at least ‘imaginable’. Yet vulnerability persists, due both to inherent unpredictability in some physical systems, but also because of ideological blocks to perceiving certain risks. Thus technological risks that create new vulnerabilities (from nuclear power to genetically modified agricultural crops) are ignored in the name of progress. If a goal of sustainable development is to eliminate risks to the most vulnerable, then this suggests that application of the precautionary principle should be central to decision processes.

3.3. *Governance implications of vulnerability*

A third challenge is that posed by vulnerability both for the analysis of governance and for the implementation of governance solutions to environmental change. Vulnerable people and places are often excluded from decision-making and from access to power and resources (Dow, 1992; Pelling, 2003; Adger, 2003; Stockholm Environment Institute, 2001). Hence policy interventions to reduce vulnerability need to be able to identify vulnerabilities within social-ecological systems, to recognize the mechanisms, which cause vulnerability in the first place, and to redress marginalization as a cause of social vulnerability. Further, policy interventions need to recognize the plurality of types of knowledge and of governance systems that are used throughout the world to manage risks and promote resilience (Ostrom, 2001; Brown, 2003). Vulnerability thereby challenges the design of good governance to promote resilience to minimize exclusion thereby reducing both the severity of perceived vulnerability and its structural causes.

Vulnerability is manifest at multiple scales (Turner et al., 2003a). Policy interventions that promote resilience therefore need to address the multi-level nature of vulnerability. At the local scale, adaptation to environmental risks often

reduces the vulnerability of those best able to mobilize resources, rather than the most vulnerable. In adapting to changing flood risk in Norway, for example, Næss et al. (2005) show just such an outcome in interplay between governance structures at local and national level. Municipalities, despite being an appropriate institutional level for adapting to new flood risk and having high legitimacy among those at risk, are stymied by agencies of central government seeking to shift and spread financial risks.

In many situations and examples it appears that the incidence of vulnerability within the social and natural systems is not central to decision-making and adaptive action. As a result, adaptive actions often reduce the vulnerability of those best placed to take advantage of governance institutions, rather than reduce the vulnerability of the marginalized, or the undervalued parts of the social-ecological system (Adger et al., 2005a). Integrating principles of equity with the identification of vulnerability is therefore an important element of adaptation decision-making. Dow et al. (2006), for example, argue that Rawlsian principles of justice provide a firm foundation for action to reduce vulnerability to environmental change, while Adger (2004) argues that rights-based justice rules can also make avoidance of vulnerability central to public policy—rights to a safe environment without inherent vulnerabilities are part of cosmopolitan and universal human rights. These issues are discussed in detail in Adger et al. (2006). Given the insights into marginalization and the experience of vulnerability highlighted in the section above, equity within decision-making processes is as important as equity in outcome in reducing vulnerability.

International action on climate change provides examples of how vulnerability challenges governance structures for adaptation. Adaptation is now discussed explicitly within the mechanisms of the Climate Change Convention and there are funds and strategies targeted at the most vulnerable countries. One example is the development of National Adaptation Plans of Action (NAPAs) that will help to prioritize adaptive needs. NAPAs are being implemented by around fifty Least Developed Countries. The guidelines for the preparation of NAPAs seek to ensure that the voices and priorities of vulnerable communities are incorporated into national adaptation planning and are reflected in decisions taken at the international level. The fairness of national adaptation planning under the Convention will, however, ultimately depend on national systems of governance, political and institutional cultures and democratic traditions. A review of NAPA planning processes in Bangladesh shows that effective participatory planning for climate change requires functioning democratic structures. Where these are absent, planning for climate change is little more than rhetoric (Huq and Khan, 2006).

The notion that fair adaptation is that which reduces vulnerability of the most vulnerable links governance to vulnerability assessment. Implementation of vulnerability-focused action, however, requires resolution of both what

constitutes vulnerability, and a full account of the authority by which those assessments are made. Inclusion of vulnerable sections of society and representation of vulnerable social-ecological systems within decision-making structures is an important and highly under-researched area.

4. Conclusions

I have reviewed divergent methods and epistemologies in vulnerability research. The diversity and apparent lack of convergence over time are, in many ways, a reflection of the divergent objectives of the research and the phenomena being explained (see also Janssen et al. (2006) on its networks). But this diversity, I argue is a strength and sign of vitality, not a weakness, of vulnerability research. The review of antecedent and current research in the first part of the paper has nevertheless highlighted generic features of vulnerability. These are the resources available to cope with exposure, the distribution of these resources (both social and natural) across the system, and the institutions that mediate resource use and coping strategies. Where institutions fail to plan for hazards or for changing social conditions and risks, system vulnerability can be exacerbated. A comprehensive theory of vulnerability to global change therefore needs to account for a range of risks, thresholds and institutional responses and resources, given that vulnerability will manifest itself differently at different scales (Kasperson and Kasperson, 2001).

But vulnerability research, if it is to contribute to wider debates on resilience and adaptation faces significant challenges, in measurement, in handling perceptions of risk, and in governance. The challenges for human dimensions research include those of measuring vulnerability within a robust conceptual framework, addressing perceptions of vulnerability and risk, and of governance. All these challenges are common to the domains of vulnerability, adaptation and resilience. They relate fundamentally to the relationship between vulnerability and both social resilience and the resilience of the ecosystems on which human well-being ultimately depends. Given that a key element of socio-ecological resilience is the ability to adapt to new circumstances (Carpenter et al., 2001), a theory of adaptation would explicitly incorporate the formation, persistence and causes of vulnerability.

Resources to reduce vulnerable in times of crisis are largely latent in social institutions. They are, in effect, short-term adjustments to stresses associated with present day variability; are usually involuntary; and almost invariably lead to a different subsequent state of vulnerability to future risks. But are such actions a part of adaptation to long-term trends? In other words, is there a distinction between coping and adapting? Adaptation does not necessarily entail changes in system boundaries in order to build resilience. And in the same fashion, adaptation strategies that include radical change of resource use (in location, economics or significant land

use change for example) may not necessarily be a symptom of a lack of resilience.

Ultimately insights through newly emerging interdisciplinary understanding of vulnerability and resilience demonstrates the co-evolutionary nature of social and natural systems—resilient ecosystems and resilient societies can better cope with external physical as well as socio-political stresses. The policy implications of vulnerability and resilience are profound and contested. Policies and strategies, which reduce vulnerability and promote resilience change the status quo for many agencies and institutions and are frequently resisted. Despite the limitations of theory, data, and methods outlined in the sections above, enough is known about vulnerability and resilience in most circumstances to provide robust information to decision-makers (Kasperson et al., 2005). The challenges for research are consistency (the interlocking of explanations of cause and effect between disciplines) between vulnerability, adaptation and resilience, and to present the rationale for reducing vulnerability in terms of benefits and sustainability for all.

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Appendix A. A generalized measure of social vulnerability

Given the relative nature of vulnerability, a generalized measure needs not only to incorporate an objective material measure of vulnerability but also to capture relative vulnerability, and severity in its distribution. The vulnerability of any system is not simply a matter of the number of elements of the system or individuals in a population who are vulnerable through being exposed to stresses associated with environmental change or not having adaptive capacity. Rather a generalized measure needs to account for the severity of the vulnerability and the measure needs also to be sensitive to redistribution of risk within vulnerable populations. Many of these challenges have been tackled in measures of vulnerability to poverty: in that domain vulnerability also examines issues of well-being, relative versus absolute change and transient versus persistent states.

A vulnerability measure focused on human well-being therefore incorporates material aspects and outcomes of vulnerability. If the outcomes of vulnerability were

exclusively economic and could be measured in income terms then a measure of vulnerability could collapse to a measure of relative poverty. But the entitlements theory of Sen (1981) and contributions to risk and vulnerability analysis (e.g. Sarewitz et al., 2003; Cannon, 1994) have argued that vulnerability is not the same as poverty. Therefore a vulnerability measure needs to incorporate well-being defined broadly.

A second necessary condition for a vulnerability measure is that it accounts for the temporal dynamics dimensions of risk – whether vulnerability is a transient phenomenon associated with exposure to particular risks, or is a chronic state. In vulnerability, assessment based exclusively on measuring, a key parameter is the mobility of incomes that measures whether the poor can escape from their vulnerable state over time. Similarly, the risk of becoming vulnerable needs be measured.

A third issue in vulnerability measures is the ability to account for the distribution of vulnerability within the vulnerable system. Take an example of livelihoods of farmers and beach-front property owners in a coastal area all of whom are vulnerable from the risk of coastal flooding. Say the farmers acted to reduce (but not eliminate) their vulnerability through hard coastal defenses that changed coastal processes and displace the risk of flooding down the coast such that the owners of beach-front coastal properties were now more vulnerable than previously. A vulnerability measure should be sensitive to this changed distribution of risk (property owners more vulnerable, farmers less vulnerable) even if the total vulnerable population remains the same.

A generalized measure of vulnerability that satisfies all of the criteria set out above, should therefore be able to identify the proportion of the population that are vulnerable, be sensitive to distribution of vulnerability within the population and to the severity of the vulnerability (distance from threshold). The ‘population’ in this case refers to the systems over which vulnerability is measured and could be a population of communities, individuals or ecosystems. Such a set of indicators (V_α) would be defined (based on the Foster et al. (1984) generalised poverty measures) as follows:

$$V_\alpha = \frac{1}{n} \left[\sum_{i=1}^q (W_0 - W_i/W_0)^\alpha \right],$$

where V_α is the vulnerability indicator, W_i the well-being of individual i ; W_0 the threshold level of well-being representing danger or vulnerability; n the total number of individuals (whether households, farms, settlements or whatever); q the number of individuals above the vulnerability threshold; α the sensitivity parameter and individuals are ordered from bottom to top (W_1 is more vulnerable than W_2 and so on).

Well-being (W) in these measures refers to general relative positive elements of parts of the social-ecological system (i) rather than necessarily human well-being.

Table A1
A class of vulnerability measures and their intuitive interpretation

Measure		Explained as:
Proportional vulnerability	$V_0 = q/n$	The proportion of the relevant population (individual components of a system) that are classed as vulnerable. This is a 'headcount' indicator. This does not account for the degree of vulnerability of the individual.
Vulnerability gap	$V_1 = \frac{1}{n} \left[\sum_{i=1}^q (W_0 - W_i/W_0)^1 \right]$	The aggregate scope of vulnerability measured in well-being terms: the summed distance of well-being for each individual from the vulnerability threshold level of well-being. Action to reduce vulnerability could focus either on reducing the number of individuals that cross the threshold or the scale of their vulnerability.
Vulnerability severity	$V_2 = \frac{1}{n} \left[\sum_{i=1}^q (W_0 - W_i/W_0)^2 \right]$	The severity of vulnerability is measured by weighting the distribution of the vulnerability gap within the vulnerable population. The greater the vulnerability is skewed towards the most vulnerable, the greater the severity.

These generalized measures do not account explicitly for the dynamic nature of vulnerability, however, unless V , the vulnerability indicator, is a composite vector of exposure and adaptive capacity. Nevertheless, the measures in Table A1 are, in effect, classes of vulnerability indicators, where the choice of type of indicator depends on the purpose of the measure or the type of intervention required. The resulting different indicators (proportional vulnerability, vulnerability gap, and vulnerability severity) and their explanations are outlined in Table A1. Thus when α is set at zero, $V_0 = q/n =$ proportion of population vulnerable. In other words P_0 focuses on the number of individuals that are vulnerable (as a proportion of the population of people, communities, locations or farms for example). When $\alpha = 1$, V_1 is an aggregate vulnerability gap measure: the number of individuals vulnerable times the extent of their vulnerability (distance from the threshold level W_0). Where α is set at greater than 1 (V_2) the distribution of vulnerability becomes more important. V_α is the weighted sum of the distance of individual well-being from the level that constitutes vulnerability (W_0) where the vulnerability distance gaps themselves are the weights. V_2 is in effect a measure of Vulnerability Severity.

References

- Adger, W.N., 2003. Social capital, collective action and adaptation to climate change. *Economic Geography* 79, 387–404.
- Adger, W.N., 2004. The right to keep cold. *Environment and Planning A* 36, 1711–1715.
- Adger, W.N., Winkels, A., 2006. Vulnerability, poverty, and sustaining well-being. In: Atkinson, G., Dietz, S., Neumayer, E. (Eds.), *Handbook of Sustainable Development*. Elgar, Cheltenham.
- Adger, W.N., Arnell, N.W., Tompkins, E.L., 2005a. Successful adaptation to climate change across scales. *Global Environmental Change* 15, 77–86.
- Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R., Rockström, J., 2005b. Social-ecological resilience to coastal disasters. *Science* 309, 1036–1039.
- Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), 2006. *Fairness in Adaptation to Climate Change*. MIT Press, Cambridge.
- Allison, E.H., Ellis, F., 2001. The livelihoods approach and management of small-scale fisheries. *Marine Policy* 25 (5), 377–388.
- Alwang, J., Siegel, P.B., Jorgensen, S.L., 2001. *Vulnerability: A View from Different Disciplines*. Discussion Paper Series No. 0115. Social Protection Unit, World Bank, Washington DC.
- Anderson, M.B., Woodrow, P.J., 1998. *Rising From the Ashes. Development Strategies in Times of Disaster*. Intermediate Technology Publications, London.
- Bankoff, G., Frerks, G., Hilhorst, D. (Eds.), 2004. *Mapping Vulnerability: Disasters Development and People*. Earthscan, London.
- Barnett, J., 2006. Climate change, insecurity and injustice. In: Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), *Fairness in Adaptation to Climate Change*. MIT Press, Cambridge, MA, pp. 115–129.
- Barnett, A., Blaikie, P., 1994. AIDS as a long wave disaster. In: Varley, A. (Ed.), *Disasters, Development, and Environment*. Wiley, Chichester, pp. 139–162.
- Bebbington, A., 1999. Capitals and capabilities: a framework for analysing peasant viability, rural livelihoods and poverty. *World Development* 27, 2021–2044.
- Berkes, F., Folke, C., 1998. Linking social and ecological systems for resilience and sustainability. In: Berkes, F., Folke, C. (Eds.), *Linking Social and Ecological Systems*. Cambridge University Press, Cambridge, pp. 1–25.
- Berkes, F., Jolly, D., 2001. Adapting to climate change: social-ecological resilience in a Canadian Western Arctic community. *Conservation Ecology* 5 (2), 18 (online) www.consecol.org/Journal/vol5/iss2/.
- Berkes, F., Colding, J., Folke, C. (Eds.), 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press, Cambridge.
- Blaikie, P., Cannon, T., Davis, I., Wisner, B., 1994. *At Risk: Natural Hazards, People's Vulnerability and Disasters*. Routledge, London.
- Bohle, H.G., Downing, T.E., Watts, M.J., 1994. Climate change and social vulnerability: toward a sociology and geography of food insecurity. *Global Environmental Change* 4, 37–48.
- Brooks, N., Adger, W.N., Kelly, P.M., 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change* 15, 151–163.
- Brown, K., 2003. Three challenges for a real people-centred conservation. *Global Ecology and Biogeography* 12, 89–92.
- Burton, I., Kates, R.W., White, G.F., 1978. *The Environment as Hazard*. Guilford, New York.
- Burton, I., Kates, R.W., White, G.F., 1993. *The Environment as Hazard*, Second ed. Guilford, New York.
- Cannon, T., 1994. Vulnerability analysis and the explanation of natural disasters. In: Varley, A. (Ed.), *Disasters, Development, and Environment*. Wiley, Chichester, pp. 13–30.

- Carpenter, S.R., Walker, B.H., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? *Ecosystems* 4, 765–781.
- Chambers, R., Conway, G., 1992. Sustainable rural livelihoods: practical concepts for the 21st century, IDS Discussion paper 296, Institute of Development Studies, University of Sussex, Brighton, UK.
- Cutter, S.L., 1996. Vulnerability to environmental hazards. *Progress in Human Geography* 20, 529–539.
- Cutter, S.L., 2003. The vulnerability of science and the science of vulnerability. *Annals of the Association of American Geographers* 93, 1–12.
- Cutter, S.L., Boruff, B.J., Shirley, W.L., 2003. Social vulnerability to environmental hazards. *Social Science Quarterly* 84, 242–261.
- Dercon, S. (Ed.), 2004. *Insurance Against Poverty*. Oxford University Press, Oxford.
- Dercon, S., Krishnan, P., 2000. Vulnerability, seasonality and poverty in Ethiopia. *Journal of Development Studies* 36 (6), 25–53.
- Daly, H.E., Farley, J., 2004. *Ecological Economics: Principles and Applications*. Island Press, Washington, DC.
- Dolšák, N., Ostrom, E. (Eds.), 2003. *The Commons in the New Millennium: Challenges and Adaptations*. MIT Press, Cambridge.
- Dow, K., 1992. Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. *Geoforum* 23, 417–436.
- Dow, K., Kasperson, R.E., Bohn, M., 2006. Exploring the social justice implications of adaptation and vulnerability. In: Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), *Fairness in Adaptation to Climate Change*. MIT Press, Cambridge, MA, pp. 79–96.
- Downing, T.E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y., Stephen, L., 2001. *Vulnerability Indices: Climate Change Impacts and Adaptation*. UNEP Policy Series. UNEP, Nairobi.
- Eakin, H., 2005. Institutional change, climate risk, and rural vulnerability: cases from Central Mexico. *World Development* 33, 1923–1938.
- Eakin, H., Luers, A.L., 2006. Assessing human and biophysical vulnerability to global environmental change. *Annual Review of Environment and Resources* 31, in press.
- Ellis, F., 2000. *Rural Livelihood Diversity in Developing Countries*. Oxford University Press, Oxford.
- Eriksen, S., Brown, K., Kelly, P.M., 2005. The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. *Geographical Journal* 171, 287–305.
- Folke, C., 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16 (3), 253–267.
- Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C.S., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology and Systematics* 35, 557–581.
- Ford, J.D., Smit, B., 2004. A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. *Arctic* 57, 389–400.
- Fordham, M., 2003. Gender, disaster and development: the necessity for integration. In: Pelling, M. (Ed.), *Natural Disasters and Development in a Globalizing World*. Routledge, London, pp. 57–74.
- Foster, J., Greer, J., Thorbecke, E., 1984. A class of decomposable poverty measures. *Econometrica* 52, 761–766.
- Füssel, H.-M., Klein, R.J.T., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change*, in press.
- Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environmental Change* 15, 199–213.
- Haddad, B.M., 2005. Ranking the adaptive capacity of nations to climate change when socio-political goals are explicit. *Global Environmental Change* 15, 165–176.
- Hewitt, K., 1983. The idea of calamity in a technocratic age. In: Hewitt, K. (Ed.), *Interpretations of Calamity from the Viewpoint of Human Ecology*. Allen and Unwin, Boston, pp. 3–32.
- Hewitt, K., 1994. When the great planes came and made ashes of our city: towards an oral geography of the disasters of war. *Antipode* 26, 1–34.
- Hewitt, K., 1997. *Regions of Risk: A Geographical Introduction to Disasters*. Longman, Harlow.
- Huq, S., Khan, M., 2006. Equity in national adaptation programs of action (NAPAs): the case of Bangladesh. In: Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), *Fairness in Adaptation to Climate Change*. MIT Press, Cambridge, pp. 181–200.
- Intergovernmental Panel on Climate Change, 1996. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Summary for Policy Makers*. World Meteorological Organisation, Geneva.
- Ionescu, C., Klein, R.J.T., Hinkel, J., Kumar, K.S.K., Klein, R., 2005. *Towards a Formal Framework of Vulnerability to Climate Change*. NeWater Working Paper 2, Potsdam Institute for Climate Impact Research, Potsdam.
- Janssen, M.A., Schoon, M.L., Ke, W., Börner, K., 2006. Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. *Global Environmental Change* 16 (3), 240–252.
- Kamanou, G., Morduch, J., 2004. Measuring vulnerability to poverty. In: Dercon, S. (Ed.), *Insurance Against Poverty*. Oxford University Press, Oxford.
- Kasperson, J.X., Kasperson, R.E. (Eds.), 2001. *Global Environmental Risk*. Earthscan and UNU Press, London.
- Kasperson, R.E., Dow, K., Archer, E., Caceres, D., Downing, T., Elmqvist, T., Eriksen, S., Folke, C., Han, G., Iyengar, K., Vogel, C., Wilson, K., Ziervogel, G., 2005. Vulnerable people and places. In: Hassan, R., Scholes, R., Ash, N. (Eds.), *Ecosystems and Human Well-being: Current State and Trends*, vol. 1. Island Press, Washington, DC, pp. 143–164.
- Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore III, B., O’Riordan, T., Svedin, U., 2001. *Environment and development: sustainability science*. *Science* 292, 641–642.
- Kelly, P.M., Adger, W.N., 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47, 325–352.
- Klein, R.J.T., Nicholls, R.J., 1999. Assessment of coastal vulnerability to climate change. *Ambio* 28, 182–187.
- Kovats, R.S., Campbell-Lendrum, D., Matthies, F., 2005. Climate change and human health: estimating avoidable deaths and disease. *Risk Analysis* 25, 1409–1418.
- Ligon, E., Schechter, L., 2003. Measuring vulnerability. *Economic Journal* 113, C95–C102.
- Liverman, D.M., 1990. Drought impacts in Mexico: climate, agriculture, technology, and land tenure in Sonora and Puebla. *Annals of the Association of American Geographers* 80, 49–72.
- Luers, A.L., 2005. The surface of vulnerability: an analytical framework for examining environmental change. *Global Environmental Change* 15, 214–223.
- Luers, A.L., Lobell, D.B., Sklar, L.S., Addams, C.L., Matson, P.A., 2003. A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change* 13, 255–267.
- Luttrell, C., 2001. *An Institutional Approach to Livelihood Resilience in Vietnam*. Ph.D. Thesis, School of Environmental Sciences, University of East Anglia, Norwich.
- McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge.
- Morduch, J., 1994. Poverty and vulnerability. *American Economic Review* 84, 221–225.
- Mortimore, M.J., Adams, W.M., 2001. Farmer adaptation, change and ‘crisis’ in the Sahel. *Global Environmental Change* 11, 49–57.
- Mustafa, D., 1998. Structural causes of vulnerability to flood hazard in Pakistan. *Economic Geography* 74, 289–305.

- Næss, L.O., Bang, G., Eriksen, S., Vevatne, J., 2005. Institutional adaptation to climate change: flood responses at the municipal level in Norway. *Global Environmental Change* 15, 125–138.
- O'Brien, K., 2006. Are we missing the point? Global environmental change as an issue of human security. *Global Environmental Change* 16, 1–3.
- O'Brien, K.L., Leichenko, R.M., 2000. Double exposure: assessing the impacts of climate change within the context of economic globalisation. *Global Environmental Change* 10, 221–232.
- O'Brien, K.L., Leichenko, R., Kelkar, U., Venemad, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., West, J., 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change* 14, 303–313.
- O'Brien, K.L., Eriksen, S., Schjolden, A., Lygaard, L., 2005. What's in a word? Interpretations of vulnerability in climate change research. *Climate Policy*, submitted for publication.
- O'Keefe, P., Westgate, K., Wisner, B., 1976. Taking naturalness out of natural disasters. *Nature* 260, 566–567.
- Oreskes, N., 2004. The scientific consensus on climate change. *Science* 306, 1686.
- Ostrom, E., 2001. Vulnerability and polycentric governance systems. *IHDP Update* 3/01, 1–4.
- Parry, M., Carter, T., 1994. *Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach*. Earthscan, London.
- Pelling, M., 2003. *The Vulnerability of Cities: Natural Disasters and Social Resilience*. Earthscan, London.
- Pelling, M., High, C., 2005. Understanding adaptation: what can social capital offer assessments of adaptive capacity? *Global Environmental Change* 15, 308–319.
- Polsky, C., 2004. Putting space and time in Ricardian climate change impact studies: agriculture in the US Great Plains, 1969–1992. *Annals of the Association of American Geographers* 94, 549–564.
- Poumadère, M., Mays, C., Le Mer, S., Blong, R., 2005. The 2003 heat wave in France: dangerous climate change here and now. *Risk Analysis* 25, 1483–1494.
- Ribot, J.C., Magalhães, A.R., Panagides, S.S. (Eds.), 1996. *Climate Variability, Climate Change and Social Vulnerability in the Semi-arid Tropics*. Cambridge University Press, Cambridge.
- Riedlinger, D., Berkes, F., 2001. Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record* 37, 315–328.
- Sarewitz, D., Pielke, R., Keykhan, M., 2003. Vulnerability and risk: some thoughts from a political and policy perspective. *Risk Analysis* 23, 805–810.
- Satterfield, T.A., Mertz, C.K., Slovic, P., 2004. Discrimination, vulnerability, and justice in the face of risk. *Risk Analysis* 24, 115–129.
- Schneider, S.H., Turner II, B.L., Garriga, H.M., 1998. Imaginable surprise in global change science. *Journal of Risk Research* 1, 165–185.
- Schröter, D., Cramer, W., Leemans, R., Prentice, I.C., Araujo, M.B., Arnell, N.W., Bondeau, A., Bugmann, H., Carter, T.R., Gracia, C.A., de la VegaLeinert, A.C., Erhard, M., Ewert, F., Glendining, M., House, J.I., Kankaanpää, S., Klein, R.J.T., Lavorel, S., Lindner, M., Metzger, M.J., Meyer, J., Mitchell, T.D., Reginster, I., Rounsevell, M., Sabate, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M.T., Thonicke, K., Thuiller, W., Tuck, G., Zaehle, S., Zierl, B., 2005. Ecosystem service supply and vulnerability to global change in Europe. *Science* 310, 1333–1337.
- Sen, A.K., 1981. *Poverty and Famines: An Essay on Entitlement and Deprivation*. Clarendon, Oxford.
- Sen, A.K., 1984. *Resources, Values and Development*. Blackwell, Oxford.
- Smith, K., 1996. *Environmental Hazards: Assessing Risk and Reducing Disaster*, Second ed. Routledge, London.
- Smit, B., Pilifosova, O., 2001. Adaptation to climate change in the context of sustainable development and equity. In: McCarthy, J.J., Canziani, O., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability*. IPCC Working Group II. Cambridge University Press, Cambridge, pp. 877–912.
- Smith, J.B., Schellnhuber, H.-J., Mirza, M.M.Q., 2001. Vulnerability to climate change and reasons for concern: a synthesis. In: McCarthy, J.J., Canziani, O., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability*. IPCC Working Group II. Cambridge University Press, Cambridge, pp. 914–967.
- Stabinski, L., Pelley, K., Jacob, S.T., Long, J.M., Jennifer, L., 2003. Reframing HIV and AIDS. *British Medical Journal* 327, 1101–1103.
- Stockholm Environment Institute, 2001. *Strategic Environmental Framework for the Greater Mekong Subregion: Integrating Development and Environment in the Transport and Water Resource Sectors*. Stockholm Environment Institute and Asian Development Bank, Stockholm.
- Stott, P.A., Stone, D.A., Allen, M.R., 2004. Human contribution to the European heatwave of 2003. *Nature* 432, 610–614.
- Swift, J., 1989. Why are rural people vulnerable to famine? *IDS Bulletin* 20 (2), 8–15.
- Turner II, 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., 2003a. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences US* 100, 8074–8079.
- Turner II, B.L., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Hovelsrud-Broda, G.K., Kasperson, J.X., Kasperson, R.E., Luers, A., Martello, M.L., Mathiesen, S., Naylor, R., Polsky, C., Pulsipher, A., Schiller, A., Selin, H., Tyler, N., 2003b. Illustrating the coupled human-environment system for vulnerability analysis: three case studies. *Proceedings of the National Academy of Sciences US* 100, 8080–8085.
- Watts, M., 1983. On the poverty of theory: natural hazards research in context. In: Hewitt, K. (Ed.), *Interpretations of Calamity for the Viewpoint of Human Ecology*. Allen and Unwin, Boston, pp. 231–262.
- Watts, M.J., Bohle, H.G., 1993. The space of vulnerability: the causal structure of hunger and famine. *Progress in Human Geography* 17, 43–67.
- Winchester, P., 1992. *Power, Choice and Vulnerability: A Case Study in Disaster Management in South India*. James and James, London.
- Winkels, A., 2004. *Migratory Livelihoods in Vietnam: Vulnerability and the Role of Migrant Livelihoods*. Ph.D. Thesis, School of Environmental Sciences, University of East Anglia, Norwich.
- Yohe, G., Tol, R.S.J., 2002. Indicators for social and economic coping capacity: moving toward a working definition of adaptive capacity. *Global Environmental Change* 12, 25–40.