Assessing vulnerabilities to the effects of global change: an eight step approach[1]

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Abstract

In the recent years, global environmental change research has seen increased attention to the concept of vulnerability. There have been a growing number of vulnerability assessments, but relatively little discussion on appropriate and common methods. Here we propose a methodology to guide vulnerability assessments of coupled human-environment systems towards a common objective: informing the decision-making of specific stakeholders about options for adapting to the effects of global change. We suggest five criteria vulnerability assessments must at least possess to achieve this objective. They should have a knowledge base from various disciplines and stakeholder participation, be place based, consider multiple interacting stresses, examine differential adaptive capacity, and be prospective as well as historical. Based on these criteria, we present a general methodological guideline of eight steps. To examine whether these eight steps, if attentively coordinated, do in fact achieve the criteria, and in turn satisfy the objective of the assessment, we discuss two case studies. We expect most readers to identify some of the steps as part of their well-established disciplinary practices. However, they should also identify one or more steps as uncommon to their research traditions. Thus taken together the eight steps constitute a novel methodological framework. We hypothesize that if researchers employ this methodological framework, then the products of the research will (1) achieve the objective of preparing stakeholders for the effects of global change on a site-specific basis, and (2) further the "public good" of additional insights through cross-study comparisons of research projects designed according to common principles.

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1 Introduction

Scientists, policy-makers, and the general public are increasingly aware that global patterns of environmental degradation are putting people at risk (Kasperson and Kasperson, 2001). These threats are global in both systemic (e.g., climate change due to greenhouse gas emissions) and cumulative terms (e.g., localized but widespread land degradation due to intensive agriculture) (Turner et al., 1990). People are also facing social and economic transformations (e.g., the breakup of the Soviet Union) that may amplify or dampen the importance of the environmental challenges. To minimize the potential harm associated with global changes, people and societies need an accurate assessment of the *vulnerability* of the coupled human-environment systems in which they operate, and associated adaptation opportunities and constraints. It is a common (if implicit) theme in the growing discussion that the concepts and methodologies for global change vulnerability assessments represent a new research frontier (e.g., Cutter, 1996; NRC, 1999; Downing, 2000; Kelly and Adger, 2000; Kasperson, 2001; McCarthy et al., 2001; Parry, 2001; Turner et al., 2003a). Yet it is unclear exactly how vulnerability assessments differ in conceptual and/or methodological terms from previous research on impacts and adaptation.

The point of departure for this paper is a workshop held in October 2002 on the topic of methods and models for vulnerability assessments and discussions within two research projects, the Environmental Vulnerability Assessment (EVA) based at the Potsdam Institute for Climate Impact Research (PIK; http://www.pik-potsdam.de) and the Research and Assessment Systems for Sustainability (RASSP) based at Harvard University (http://sust.harvard.edu). Over the last ten years, researchers have both highlighted the need for vulnerability assessment over extant approaches (e.g. impact assessment), and discussed particular ways of conducting it (e.g., Riebsame 1989; Carter et al., 1994; Klein et al., 1999; Smit et al., 1999; Klein and Maciver 1999; Downing et al. 2001; Kasperson, 2001; Ahmad and Warrick 2001; Jones 2001; Smit and Pilifosova 2001; Smith et al. 2001; Walker et al., 2002). A growing number of place-based vulnerability assessments, several of which we have participated in, have answered this call. However, to date the discussion on methods has focused more on particular techniques as opposed to an overarching methodological framework for guiding and integrating the entire analysis. Such an integrative framework is essential to the success of global change vulnerability assessments, because these analyses necessarily span multiple disciplines and require many years and attentive coordination to conduct. For these reasons we offer here an overarching, general methodological framework for global change vulnerability assessments. This framework is not meant to be a rigid prescription of specific techniques. Instead, we argue for a general methodological approach that when implemented in specific cases will guide vulnerability assessments towards a common end, even if the particular techniques employed vary from case to case.

This paper is organized as follows: In Section 2, we develop a set of criteria that defines global change vulnerability assessments, and propose a set of research steps that we believe to be necessary to satisfy these criteria. In Section 3, we discuss two studies with regard to whether they satisfy the criteria defining global change vulnerability assessments, analysing the consequences of neglected methodological steps. In Section 4, we briefly introduce some emerging vulnerability assessments against which to evaluate our proposed methodology further. We then show how a common methodology may create a "public good", as facilitated by a number of initiatives, for which we give examples.

2 Describing Vulnerability

2.1 Definitions and Objective

Vulnerability is typically described to be a function of three overlapping elements: *exposure*, *sensitivity*, and *adaptive capacity*[2] (Turner et al., 2003a). For example, agricultural vulnerability to climate change is described in terms of not only *exposure* to elevated temperatures, but also crop yield *sensitivity* to the elevated temperatures and the ability of farmers to *adapt* to the effects of that sensitivity, e.g. by planting more heat-resistant cultivars or by ceasing to plant their current crop altogether. Global change *vulnerability* is the likelihood that a specific coupled human-environment system will experience harm from exposure to stresses associated with alterations of societies and the environment, accounting for the process of adaptation. The term *coupled human-environment system* is used to highlight the fact that human and environmental systems are not separable entities but part of an integrated whole. *Global change vulnerability assessments* include not only the analysis of vulnerability but also the identification of specific options for stakeholders to reduce that vulnerability. *Stakeholders* are people and organizations with specific interests in the evolution of specific human-environment systems. Given these definitions, we assert that the general *objective* of global change vulnerability assessments is to inform the decision-making of specific stakeholders about options for adapting to the effects of global change (see also Stephen and Downing, 2001). In this way global change vulnerability assessments link directly with the broader aim of sustainable development and sustainability science, where successful research is measured not only by scientific merit but also by the usefulness of the resulting products and recommendations (Kates et al., 2001; Clark and Dickson, 2003).

2.2 The Roots of Vulnerability Assessment

Global change vulnerability assessments are the product of three streams of research, each of which dates from at least the 1960s. Even though these traditions overlap in motivation, concepts, and methods, it is useful to contrast them with vulnerability analysis in the following ways. The first two traditions, impact assessments and risk/hazards research, generally focus on the multiple effects of a single stress. Studies in these traditions might examine the environmental or social effects of, in the former case, constructing a highway in a given location, or in the latter case, hurricane landfall patterns. These traditions differ in that impact assessments tend to underemphasize, relative to risk/hazards research, the processes by which society can inadvertently amplify the impacts of a stress, or enact anticipatory adaptations designed to reduce the importance of the impacts. Third, food security studies generally focus on the multiple causes of a single effect, namely hunger or famine. Such research demonstrates that hunger is not, as is sometimes portrayed, the necessary and inevitable consequence of a single cause, such as drought, but instead the contingent and often avoidable result of multiple causes, such as the co-occurrence of political marginalization with the environmental stress (e.g., Garcia, 1981; Downing, 1991; Böhle et al., 1994; Ribot et al., 1996).

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[2] The terms *resilience* and *adaptive capacity* are often used synonymously. We prefer the term *adaptive capacity* to *resilience* because it suggests the possibility of change. Resilience, as defined by the Third Assessment Report of the IPCC (McCarthy et al., 2001), is "the amount of change a system can undergo *without changing state*". In contrast, the capacity to adapt can be determined by the system's ability to *change into a state* that is less vulnerable than before.

The emerging field of global change vulnerability assessment draws heavily from these three research streams. Thus the novelty of global change vulnerability assessments is not so much the development of new conceptual domains but the integration across these three traditions. Global change vulnerability assessments are based on a special concern for future trends in human sources of change (cf. impact assessments), for multiple and unintended consequences associated with the social amplification of risk (cf. risk/hazards assessments), and for adaptation constraints associated with multiple and interacting stresses (cf. food security assessments). Inspection of the seminal studies in these literatures (e.g., Kates, 1985; Kasperson et al., 1988) suggests that all of these conceptual dimensions have been identified as important, even if "vulnerability" as defined here was not used as an organizing principle. This is also true for the related and blossoming literature on the process of adaptation to the effects of climate change (e.g., Smithers and Smit, 1997; Kandlikar and Risbey, 2000; Schneider et al., 2000). However, this increasingly comprehensive cataloging of concepts has not been matched with an overarching methodological framework for guiding the assessment of the concepts.

2.3 Five Criteria for Vulnerability Assessments to Satisfy

There are several detailed descriptions of the conceptual and theoretical underpinnings of vulnerability research (see, e.g., Dow, 1992; Böhle et al., 1994; Cutter, 1996; Ribot et al., 1996; Golding, 2001; White et al., 2001; Kasperson et al., 2003; Turner et al., 2003a). Based on the shared experiences of and discussions among workshop participants and project partners, we propose the following set of five minimal criteria that global change vulnerability assessments should satisfy, to achieve the objective outlined above (section 2.1).

- *The knowledge base engaged for analysis should be varied and flexible*: The need to engage any and all relevant academic disciplines is a direct consequence of examining coupled human-environment systems rather than human or environmental systems in isolation (Turner and Meyer, 1991). However, this criterion goes beyond the standard call for interdisciplinary research. Scientists should collaborate with stakeholders to learn their perspective, knowledge and concerns in depth. It is furthermore imperative to engage indigenous, or local, knowledge – despite difficulties in testing such information within a scientific framework.
- *Vulnerability assessments should be "place-based", with an awareness of the nesting of scales*: In this context, a "place" generally means a study area that is small relative to study areas commonly discussed in climate change impacts reports (e.g., a village or group of villages instead of a country or group of countries). The scale of the vulnerability studies needs to match the scale of decision-making of the collaborating stakeholders. Whatever the boundaries chosen for a vulnerability assessment, the analysis should be aware of the nesting of scales, i.e. it should include processes operating at other spatial scales when important (e.g., NRC, 1999, 2001; Easterling and Polsky, forthcoming).
- *The global change drivers examined should be recognized as multiple and interacting*: Communities rarely face only one challenge at a time – the interaction of multiple trends may give rise to an amplification of risk (Kasperson et al., 1988; NRC, 1999; O'Brien and Leichenko, 2000). Climate change goes along with changes in atmospheric CO_2 concentration, which are coupled to socio-economic development which goes along with land use changes, and ultimately all of these drivers interact and affect processes within

the human-environment system (e.g. crop yields). The perceived importance of a single driver depends on the stakeholder perspective and on the time scale evaluated.

- *Vulnerability assessments should allow for differential adaptive capacity*: The abilities of all people in a given place to adapt are rarely homogeneous. Some individuals or social classes will likely be better equipped to cope with specific stresses than others. Moreover, even though people can be expected to try to respond to global change, sometimes their adaptation options are constrained by inadequate resources (including information) or political-institutional barriers. Differential adaptation profiles can account for the possible combinations of adaptation constraints and opportunities for a given case, and how these factors may vary both between and within populations.
- *The information should be both prospective and historical*: Implicit in any vulnerability assessment is an important role for both historical and prospective analyses. However, in global change research, when the historical component is thorough, the prospective component is often under-developed, or *vice versa*. To achieve the stated objective, both components should be thoroughly explored.

2.4 Proposed Methodology for Global Change Vulnerability Assessments: Eight Steps

We propose a set of eight steps for conducting vulnerability assessments that should lead to achieving the objective by satisfying the five criteria presented in the previous section. Our guidelines to assess vulnerability of human-environment systems are rooted in previous ideas. For example, a comprehensive set of guidelines to assess climate change impacts and evaluate adaptation strategies is available (Carter et al. 1994, Parry and Carter 1998) and has been reviewed from a coastal adaptation perspective (Klein et al. 1999). Some additional methodological elements have been proposed, such as the consideration of the interaction between multiple stresses, public involvement and non-technical (i.e. economic, legal and institutional) aspects of adaptation. These elements are accounted for in the guidelines to manage the resilience in socio-ecological systems proposed by Walker and co-workers (Walker et al. 2002). The objective of the eight step guidelines for vulnerability assessment presented here is to expand the discussion in that literature to include an appreciation of the full range of disciplinary perspectives and analyses required. As such, we expect most readers to identify some of the steps as self-evident and part of their well-established disciplinary practices. However, most readers should also identify one or more steps as uncommon to their research traditions. In this way, taken together the eight steps constitute a novel methodological framework (Figure 1).

When we speak of *modeling* in the context of vulnerability assessment, we mean a formalized attempt to describe a system. This will start with a conceptual or causal model, but is planned to lead to a numerical representation which allows processing of time series data. For vulnerability assessment, the role of numerical modeling is the projection of future states of a system. We break down our eight methodological steps into two broad classes: those that take place prior to modeling (1-3), and those that take place as part of the modeling and modeling refinement process (4-8). This distinction is, of course, artificial. Modeling and analysis for successful vulnerability assessment involves all the work necessary to create a useful representation of the system, and must therefore involve all of those steps. However, it is also possible to build an internally consistent model without engaging the first three steps. Such a model could answer specific questions about the system but would not necessarily respond to stakeholder needs, as demanded by the vulnerability perspective (Kates et al., 2001; Clark and Dickson, 2003; Turner et al., 2003a).

(Figure 1 about here)

2.4.1 Coordinating the Steps

In general, the tasks in each of the boxes in Figure 1 should be performed sequentially, reading top to bottom. However, we recognize that in practice, research and assessment will often be characterized by overlaps and iterations, so that any pre-ordained notion of "sequence" is likely to be violated early and often. The spiral next to the steps suggests the fluid nature of the research and assessment process. These eight steps constitute a methodology for research unto themselves, even though each individual step is intentionally vague about which specific method(s) may be helpful for completing each step. The specific methods appropriate for conducting a given global change vulnerability assessment will depend on the details of each project.

It is not likely that conducting these eight steps can be accomplished by a single researcher alone – an interdisciplinary team is better suited for the complexity of the task. Continuous communication and the development of a common vision of the researchers is crucial for the success of the team effort. We hope to provide a starting point for this by clearly stating the goal of global change vulnerability assessment, i.e. to inform the decision-making of specific stakeholders about options for adapting to the effects of global change (section 2.1). What is more, we wish to stress that the success of the research team will depend on attentive coordination. Coordination is an essential and complex scientific task, since the coordinator, or coordinating team must understand, communicate and balance the constituent disciplines, methods and results, as well as the overall research, communication and dissemination process. Attempting to do an interdisciplinary assessment without a coordinator a bit like cooking without a chef. While the importance and necessity of scientific coordination is increasingly understood, the scientific community is slow at rewarding the skills needed to successfully coordinate large interdisciplinary teams (Campbell 2003). The team structure of the vulnerability assessment project should be designed carefully, naming responsibilities clearly and appointing a coordinator and a steering committee supported by all researchers.

2.4.2 Steps Prior to Modeling

Step 1: Define study area together with stakeholders

A proper vulnerability assessment is more than a report or a product, it is an evolving social process by which scientists and stakeholders enter into a dialogue (Farrell et al., 2001). Such dialogues are necessary to yield a product that is both likely to be used (Fischhoff, 1995) and useable, i.e., information that is credible, salient, and legitimate for decision-makers (Cash et al., 2003). In the process of selecting the study area, it is essential to meet with stakeholders from the very beginning. Stakeholders should be included at this stage because they are the people who will ultimately have to take actions based on any information the assessment produces. Defining the study area includes choosing a scale by drawing artificial boundaries around the coupled human-environment system of interest. This scale is chosen according to the specific purpose of the vulnerability assessment. The place chosen will be the main focus of the study, with an awareness that processes at smaller and larger scales may matter for the understanding of its vulnerability.

Step 2: Get to know place over time

Once the study area has been selected together with stakeholders, it is essential to develop knowledge of the stakeholders, the ecosystem services they value and why, and the drivers of vulnerability. To understand the management options available, it is necessary to distinguish vulnerability drivers over which they may have control (e.g., use of their own land) from those beyond control (e.g., use of other people's land). It is easy to underestimate both the importance and difficulty of understanding the subtleties of local environmental, institutional, and political systems. Much of what is important does not exist in written form, but is expressed only in verbal communication. Actions for this step include conducting a literature survey for previous research in the place, and in neighboring or similar places. Where possible, researchers should also contact the authors of those studies, to obtain details meaningful for the vulnerability assessment that may have remained unreported in the original work. Most importantly, researchers need to spend significant time in the study area. They need to understand the community by interviewing as many people as possible from the full spectrum of social standings, and by interacting with them in different settings, from formal meetings to discussion over food to playing on their football teams or attending their poetry readings. Researchers should not stop at the boundaries of the chosen place but go beyond to explore nearby areas that are most likely to have direct influences on the place.

Step 3: Hypothesize who is vulnerable to what

As researchers get to know the place, they should focus their inquiry by hypothesizing which stresses (and interactions among stresses) pose a risk of harm to which people and the environmental services on which they depend. Researchers will likely already have preliminary hypotheses based on their interactions with stakeholders in Steps 1 and 2, but it is important to focus and formalize the hypotheses to be explored before the modeling commences in the subsequent steps. In this way researchers can avoid the major pitfall of global change vulnerability assessment: trying to analyze too much. The inter-disciplinary, holistic and cross-scale nature of global change vulnerability assessment suggests that everything is connected to everything else and that therefore everything should be analyzed. Forgetting to focus, we may soon be sacrificing meaningful depth for excessive breadth. Therefore it is necessary at this point of the assessment to also focus on subgroups among all possible stakeholders. This focusing process will be based on the understanding of the tools available to the research team as well as budget and time constraints. Other criteria justifying the focus on a particular subgroup of stakeholders may be of the following nature: the focus group is perceived as the most vulnerable social group and therefore of greatest concern; the focus group belongs to the main sector of the study region; the focus group has funded the study; or the focus group is studied for purpose of comparison to previous studies of the same group. In any event, the criteria underlying the focusing process of the study need to be clearly communicated.

2.4.3 Steps that Involve Modeling

Step 4: Develop a causal model of vulnerability

A causal model of vulnerability describes the factors, as well as the form and strength of the interactions linking these factors that lead to vulnerability. The vulnerability model will include factors related to elements outside the system, such as the local effects of global climate change, as well as factors related to elements within the system, such as local power relationships. Such a model may highlight possible opportunities for reducing future vulnerabilities through adaptations, even before these possibilities become realities (Liverman, 2001). Researchers can orient the causal model in one of two ways: starting with a set of causes and examining their consequences, or starting with set of consequences and examining their causes. In either case, the models are likely to have both qualitative and quantitative elements. Diagrams and flow charts, showing how changes in one or more variables lead to changes in others, can be used even where mathematical functions describing system dynamics are not specified. Stakeholders should be invited to participate in developing these models, both to improve the models and to ensure that everyone understands the inevitably complicated final product (Waltner-Toews et al., 2003). Researchers should not underestimate the ability of stakeholders to think quantitatively, provided they are guided through the process (Patt, 2001). Here, an examination of the vulnerability of indigenous Lapp people in Norway whose livelihood depends on reindeer herding is instructive: the causal model of vulnerability involves intensified overgrazing due to limited forage as a result of changes in snow quality (O'Brien et al. 2003, in press) and will also involve specific government policies on ruminant production and species protection (McCarthy et al. 2003, submitted). This specific, place-based causal model achieves the specificity missing (by design) from the general causal models of global change vulnerability presented elsewhere (e.g., Böhle et al., 1994; Turner et al., 2003a).

Step 5: Find indicators for the elements of vulnerability

It is important to develop a place-based set of indicators relating to exposure to global change drivers, and the associated sensitivities and adaptive capacities of the human-environment system[3]. However, there is no universally applicable metric for vulnerability or its components. For instance, a given economic indicator (e.g., GDP per capita) may reflect different processes for a study in the United States (US) than for a study in Senegal. Consequently, the methods for evaluating and then projecting the indicators (Steps 6 & 7) may vary between the two studies (e.g., a computable general equilibrium model may provide good projections of GDP per capita for the US, but a different approach may be required in the case of Senegal). In general, the same indicator may not necessarily be used to answer the same research questions in different places. Whatever indicators and associated methods are chosen, they must be not only scientifically sound and meaningful, but also understandable by stakeholders. The indicators should also be spatially explicit so that they can be mapped. While some of the data needed to support the indicators are likely to be published, much is known only locally. Finding quantitative indicators for adaptive capacity that capture the insights of a detailed qualitative analysis is often difficult and may sometimes be impossible. Researchers should state where they have omitted a particular indicator from their causal model because of their inability to quantify the indicator, and how this could bias model results.

Step 6: Operationalize model(s) of vulnerability

The indicators of exposure, sensitivity and adaptive capacity should be weighted and combined to produce a measure of vulnerability. This should be achieved by applying the causal model of vulnerability developed in step 4. In some cases it may be possible to operationalize the causal vulnerability concept into a single numerical model that will run with the indicators as input variables. Typically, however, there will be several models, each describing parts within our causal model of vulnerability. For example, ecosystem models driven by input data describing

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[3] See Downing et al. (2001) for a comprehensive review of indicators in this context.

exposure to global change drivers may yield indicators of sensitivity of a certain part of the human-environment system. Other models of the same system may yield the adaptive capacity of a specific group of stakeholders. In such cases, the relevant indicators may be combined into a measure of vulnerability by straightforward overlaying of maps (e.g. a map of sensitivity to exposure overlaid with an adaptive capacity map), or more complex methods such as geographically weighted regressions (e.g., Fotheringham et al., 1998) or qualitative differential equations (e.g., Petschel-Held et al., 1999). The minimum claim in the process of formalizing and operationalizing the causal model of vulnerability is that the resulting model(s) should be able to handle time series data. This allows for models of a wide range of complexities and favors computer based approaches even when combining qualitative and quantitative information.

Throughout the vulnerability assessment, researchers should strive for credibility and transparency, if stakeholders are to make decisions based on the results. Ideally, all models used in the assessment should be validated using data based on observations. For the credibility of combined vulnerability measures (and by extension, of the associated projections; see Step 7), researchers should validate the vulnerability results by comparing them with the intuitions of stakeholders, historical examples of exposure to stress, and case studies from similar systems in other places. For transparency, stakeholders should be able to view the maps of not only the composite vulnerability measures but also of the constituent indicators, i.e. exposure, sensitivity, adaptive capacity (Downing et al., 2001). In this way loci of high vulnerability can be interactively explored to identify the factors contributing to that vulnerability and to identify management options.

Step 7: Project future vulnerability

The projection of vulnerability should be based on a range of scenarios of the values for the relevant driving variables, be they climatic, socio-economic, biogeochemical, etc. This set of scenarios should demonstrate the full range of likely trends in the driving variables, as determined by expert panels. An example of this approach is the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC-SRES) (Nakicenovic and Swart, 2000) which depict a range of qualitatively different future directions consisting of a comprehensive set of narratives, defining the local, regional and global socio-economic driving forces of environmental change (e.g. demography, economy, technology, energy, and agriculture). The SRES scenarios are structured in four major families, each of which emphasizes a different set of social and economic ideals, ranging from regional to global development, and from economically to environmentally orientated futures. The SRES scenarios provide quantitative estimates of greenhouse gas and aerosol emissions from energy use, industrial activities and land use. The likely responses of the atmosphere to these emission estimates were described in the IPCC Third Assessment Report (McCarthy et al., 2001), and are further translated into quantitative scenarios of changing drivers and impacts by various institutions and projects, e.g. the IMAGE 2.2 implementation of the SRES scenarios (IMAGE team, 2001). The SRES scenarios have been criticized for the assumptions about environment, economy, and environment-economy interactions underlying those projections. Nevertheless, the SRES scenarios are a crucial step toward standardisation and comparability in global change research, providing a base for future improvements. Competing visions of “future worlds” (e.g. Raskin et al., 2002; Warwick et al., 2003), add to the continuous process of improving, refining and reinventing standardized and quantifiable global change scenarios. Naturally any projection into the future is a difficult and contentious task and needs continuous improvement as the projected future unfolds.

In general, the assumptions underlying any projection used in the vulnerability assessment should be examined closely and outlined explicitly. The uncertainties associated with these projections should be explicitly communicated, especially for those dimensions where the uncertainty itself is uncertain or unknowable. Therefore it is important to analyze multiple scenarios in a systematic way to cover the full range of possible futures that experts envision. How far the vulnerability assessment should project into the future should be decided with stakeholders to correspond to the time horizons of their management decisions. Stakeholders may also propose specific scenarios or assumptions to underlie the scenarios in order to test different management options. This aspect of comparing different outcomes of decision-making resembles multi criteria analysis, cost benefit analysis, and cost effectiveness analysis in the context of policy analysis, in that it examines the different states of a variable of concern (e.g. beauty, hunger, money, some other measure of welfare) under multiple decisions and policies (adaptations), including the base case, of taking no specific action (no adaptation). This resemblance is of course real, and indeed vulnerability analysis is a parallel to these other forms of analysis.

Step 8: Communicate vulnerability creatively

The communication of the modeled vulnerabilities should encourage a two-way flow of information between researchers and stakeholders. Discussing the uncertainty associated with the assessment's results is part of this information flow. Assessments that deny uncertainty may do more than fail to have an impact on stakeholders – they may compromise credibility of scientific support in decision-making. In the communication process, communicators should anticipate that stakeholders may have difficulties interpreting probabilistic information but will be able to do so given adequate time and support (Patt, 2001). They may have difficulties comparing possible gains and losses (Kahneman and Tversky, 1979) and reacting to anticipated future events (Loewenstein and Elster, 1992). Long-term involvement of stakeholders throughout the assessment will help overcome these difficulties. We recognize that by putting step eight on communication at the "end" of our proposed set of steps, we risk making the impression that communication in vulnerability assessments can be left for last. In fact, creative, sustained communication between stakeholders and analysts is crucial for and implicit in all steps listed here. Research on 'advocacy coalitions' has shown that social learning often takes place in networks of actors from government, non-governmental organisations, the private sector and the scientific community (Sabatier and Jenkins-Smith 1999). Such coalitions can be formed during long term dialogue processes throughout the vulnerability assessment, but not during a one-day stakeholder workshop at the end of a research process. We therefore wish to stress the importance of establishing robust, bi-directional communications.

The value of this stakeholder-driven approach goes beyond guiding further scientific inquiry. Such direct stakeholder engagement also increases the likelihood that the decision-makers will find subsequent research salient, credible, and legitimate, insofar as the underlying assumptions are derived in part from their observations (Cash et al., 2003). Moreover, this type of research product provides immediate educational benefits in a process of social learning for all participants, including researchers. In processes of social learning it remains an open question how not only experience (e.g. of a catastrophic event) but also new scientific discoveries come to be incorporated in action programmes (Clark 2002). Therefore a combination of state-of-the-art tools for stakeholder involvement – such as interactive computer models and focus groups (Kasemir et al. 2003) – should be used to discover and develop learning mechanisms for effective environmental management and policy making. Quantitative and qualitative descriptions of the vulnerability assessment's results should be provided, using a variety of media. For example, in a multi-media CD-ROM, Fox (2002) relates selected perspectives on recent environmental changes by stakeholders in two Inuit communities in Arctic Canada. This interactive medium integrates interview video clips, maps, drawings, text and photos. We wish to encourage teams to communicate with stakeholders creatively, informed by the large literature from the field of risk communication and the growing literature on stakeholder involvement and dialogue evaluation. At the same time, courage for creative communication can be sustained by the awareness that stakeholder dialogue is a dialogue between real people, which we practice from the beginning of our lives. When policies create major aspects of the reality they are supposed to shape, attempts to define long-term strategies once and for all will miss their target (Jaeger et al. 2001). Therefore communication needs will not end with the end of the vulnerability assessment, but be part of society's struggle to develop learning mechanisms for sustainable well-being in a changing world.

3 Evaluating the Usefulness of the Proposed Eight Step Approach

In Section 2 we proposed a general objective for global change vulnerability assessments, five information criteria that such assessments should satisfy to achieve the objective, and eight analytical steps for satisfying the criteria. In this section, we analyse the usefulness of the proposed steps. Two global change research projects are reviewed to support our earlier claim that there is a meaningful (if subtle) distinction between global change vulnerability assessments on the one hand, and impacts, risk/hazards and food security studies on the other hand.

3.1 Adaptation in Economic Terms: the US Great Plains

We begin with a recent example from the impacts and risk/hazards research traditions, a study of agricultural climate change impacts in the US Great Plains (Polsky, 2002). This study uses Ricardian land-use theory to evaluate the importance of climate in the determination of agricultural land values relative to other important factors (e.g., population density, soil quality). A spatial econometric regression model is used to estimate the statistical relationship between current climate and land values (i.e., the economic value of climate controlling for the other factors). The objective is to use the estimated relationships as a proxy for understanding the possible economic impacts of climate change, by applying a hypothetical climate change to the estimated historical relationships. For the study region of 446 counties, the model is estimated six times, once each for the years 1969, 1974, 1978, 1982, 1987 and 1992.

Even though all of the components of vulnerability are examined – exposure, sensitivity, adaptive capacity – the study does not satisfy all five criteria discussed in Section 2 because it does not follow all eight steps in Figure 1. The study satisfies the criteria of having a place-based focus, in that the modeling (steps 4-7) to test the hypotheses (step 3) is explicitly multi-scale: effects are specified for the macro-scale (the region as a whole; n=446 counties), for the meso-scale (two sub-regions; n_1=209, n_2=237); and for the micro-scale (many sets of small numbers of counties, $n \approx 7$ on average) (Polsky and Munroe, forthcoming). Moreover, the model explicitly accounts for multiple stresses, as social, edaphic and climatic variables are specified. However, the study did not analyze multiple standardized future scenarios (step 7). Furthermore, this study did not engage stakeholders at any stage of the analysis, so parts or all of steps 1, 2, 3 and 8 are not pursued. For these reasons, this study does not fully satisfy the criterion of diverse knowledge base, even though the study area is selected based on a careful review of the literature, and basic principles from both natural and social science are incorporated in the models. The criteria of analyzing differential adaptive capacity and projecting global change drivers into the future using a scenario framework are partially satisfied. Climate sensitivities are inspected for differences across the region, but these sensitivities are based on a stylized and unrealistic assumption about adaptive capacity. A future climate change is applied to the estimated historical climate sensitivities, but only a single (equilibrium, not transient) scenario of climate change is considered, and no changes in other important conditions are explored. Furthermore, there was no attempt to validate the models, owing to the fact that such validations are difficult to conduct. Thus as a result of not engaging stakeholders or exploring a range of adaptation and global change scenarios, the study by Polsky (2002) cannot fully achieve the objective of vulnerability assessments. In particular, there is little opportunity for the results of the analysis to support enhanced adaptations.

3.2 Vulnerability and Climate Variability in Zimbabwe

The food security research tradition is represented here by the Zimbabwe Forecast Applications (ZFA) project, an effort to explore how to reduce the sensitivity of Zimbabwean agriculture to inter-annual climate variability through the distribution of seasonal climate forecasts. The ZFA project consists of researchers in four villages conducting annual climate forecast workshops, in which they work with stakeholders to develop a local agricultural strategy that responds to that year's forecast. Later in the year, the researchers survey people in those villages, as well as in nearby villages where no workshops took place, to see if the additional information promoted adaptations. The ZFA project grew out of an attempt to understand the usefulness of seasonal climate forecasts to subsistence farmers (Patt and Gwata, 2002), and whether adaptive behavior is facilitated by increasing the detail of forecasts (Patt, 2001). Thus although ZFA researchers have not been specifically concerned assessing vulnerability as defined in this paper, the purpose of this project is consistent with that of global change vulnerability assessments: to understand how an information system can promote adaptation to the effects of global change.

Researchers have achieved Steps 1 and 2 by spending extensive time in the villages and interacting with stakeholders throughout the entire process. Consequently, the ZFA project satisfies the criteria of engaging a flexible knowledge base, in a place-based study, although the cross-scale linkages (namely to the national policy-makers) is weak. This weakness is in part by design, as researchers do not want bureaucratic concerns to compromise the independence of the researchers in the field. ZFA researchers have achieved Steps 3-5 by building a causal model of exposure, sensitivity and adaptation to climate variability and change. The causality of this very specific case of vulnerability is simplified: lack of rain results in crop failure, which results in hunger. Adapting by understanding the seasonal forecast and planting less sensitive crops may reduce hunger. In this region, agricultural fields are highly sensitive to climatic stress and adaptive capacity of the farmers is low, due to the tight range of their options and the poor infrastructure. The ZFA project bypasses quantitative operationalization of the resulting vulnerability (step 6), and takes high vulnerability of the subsistence farmers as a given fact. Based on the simple causal model and on seasonal climate forecasts, projections over the next season are made, which is the time frame of the decision making of the stakeholders (step 7). The project then concentrates on enhancing adaptive capacity by careful communication of the forecasts including uncertainty in interactive and repeated workshops (step 8). The ZFA does not satisfy the criterion of examining multiple stresses, but concerns itself solely with climate change and variability. This may in part be justified by the overwhelming influence of this factor. It may also be sadly justified to take socio-economic conditions at this place, e.g. poverty and inequity, as a given constant that will not change within the time frame of the study. Nevertheless, soil quality may be a factor that needs to be taken into account, especially when irrigation becomes an option to enhance adaptive capacity. However, in most cases irrigation is simply not an option, justifying to neglect the factor of soil quality because the precipitation pattern becomes the overwhelming driving variable for agricultural yield. The ZFA does not examine differential adaptive capacity, but assumes equal adaptive capacity within its specific group of stakeholders, i.e. subsistence farmers. Researchers should consider the opportunity within the ZFA to examine the influence of gender, social status and other factors on adaptive capacity differences within and between the case study village areas, especially since the researchers have made an effort to include stakeholders into the workshops regardless of gender or position. The ZFA project performs at least partly each of our proposed eight steps, except for step six, the quantification of vulnerability. Here the project takes a simplified approach, bypassing especially any sophisticated model of sensitivity, e.g. agricultural crop yield. Exposure to multiple stresses is not taken into account. Here the project would gain from collaboration with agricultural scientists and modelers. The range of possible adaptive behavior is limited, but well discussed with stakeholders. The vulnerability model implicit in the study does neither encompass all relevant risks nor all possible adaptation options. Nevertheless, the ZFA project has been successful so far in that farmers begin to consider seasonal forecasts and their inherent uncertainty in their decision-making due to careful communication (Patt and Gwata, 2002). Farmers who attend the workshops were more likely to change decisions on the basis of the forecasts than those farmers who had heard the forecast through non-participatory channels (e.g. radio). ZFA researchers are currently testing whether taking the advice actually resulted in higher yields and a less vulnerable life than in the village where no climate forecast workshops were held.

4 Discussion

The success of a vulnerability assessment is measured by scientific validity of its results and its usefulness to stakeholders (Kates et al., 2001; Clark and Dickson, 2003).Usefulness to stakeholders alone is not a sufficient sign of success, nor is scientific validity. The objective of global change vulnerability assessment is to inform the decision-making of specific stakeholders about options for adapting to the effects of global change. We developed a set of five criteria that vulnerability studies must at least possess if they are to achieve this objective. They should have a flexible knowledge base rooted in various disciplines and stakeholder participation, be place-based, consider multiple interacting stresses, examine differential adaptive capacity between and within populations, and be prospective as well as historical. By supposing a methodology of eight steps in global change vulnerability assessments we have tried to give a guideline that will lead to successful assessments, if the steps are attentively coordinated. To examine whether these steps do in fact achieve the criteria, and in turn satisfy the purpose of the assessment, we discussed two case studies. From these case studies the impression emerges that following the steps would improve the ultimate success of the research by better satisfying the five criteria. However, it is too early to tell whether this enhances the success of the vulnerability studies. We can hypothesize that in the case of the Great Plains project, greater engagement with stakeholders would improve the usability of the research results. In case of the ZFA project, action has been taken by local decision-makers to reduce their vulnerability, but the success of this action has not yet been shown.

We suggest that global change studies that address vulnerability may fail to inform the decision-making of specific stakeholders about options for adapting to the effects of global change, because they omit one or more of the eight steps. Of course not achieving this goal does not mean those studies are not useful for other purposes. We cannot prove that our methodology will bring success. There are few self-proclaimed global change vulnerability studies against which to evaluate the proposition. However, a thorough test of the usefulness of the methodological guidelines presented here should be possible in coming years. We are aware of several studies that will be well positioned to test and further develop the proposed methodology. At least four of these assessments are described elsewhere. Turner et al. (2003b) describe research on the Southern Yucatán Peninsular Region, Mexico and the Yaquí Valley, Mexico; Liverman and Meredith (2002) describe research on the US Southwest; and Finan and Nelson (2001) describe research on Northeast Brazil. Surely there are more projects that deserve mention; we will briefly describe only two more relevant projects.

The ATEAM project (Advanced Terrestrial Ecosystem Analysis and Modeling, http://www.pik-potsdam.de/ateam) explores where in Europe people may be vulnerable to the loss of particular ecosystem services, associated with the combined effects of climate change, land-use change, and atmospheric pollution. The “place” selected for this vulnerability assessment is large relative to the studies discussed in this paper thus far: the fifteen European Union countries plus Norway and Switzerland. Stakeholder interactions are an integral and ongoing part of this assessment, and consist of numerous small-scale meetings for sector-specific decision-makers; personal communications at meetings and via telephone, CD-ROMs and email; and a targeted system of web pages providing continuously updated information and a data exchange platform. A framework of models of different parts and aspects of the human-environment system is used. Some 20 different scenarios of global change are input to the models, to translate the global changes into changes in ecosystem services and into changes in society's macro-scale adaptive capacity. Results will be mapped onto a 16 x 16 km grid for 4 time slices over the next 100 years, and distributed and discussed within and outside the stakeholder network. The project is currently in the final third of is lifetime.

The AVS project (Arctic Vulnerability Study; http://sust.harvard.edu/avs) is designed to assess the vulnerability of selected Arctic human-environment systems to multiple and interacting social and environmental stresses. The AVS will examine three sets of stresses in particular for ways in which adaptations at local, regional and global scales can reduce associated vulnerabilities, for roughly the period 1980-2020. Plans for research to commence in the coming years include study sites in five locales, one each in Norway, Greenland, Canada, Alaska, and Russia. Based on stakeholder dialogues and background research, the AVS research team (consisting of natural and social scientists and local stakeholders) has hypothesized three sets of stresses to be important in determining vulnerability in this region: variability and change in climate; environmental pollution, focusing on heavy metals and persistent organic pollutants; and trends in human and societal development. Models will be developed, together with stakeholders, for the purpose of projecting relevant measures of future climate, pollution concentrations, and social conditions. For example, researchers will use emerging statistical downscaling techniques (e.g., Benestad, 2001) to provide local-scale climate projections of the climate variables that are most relevant to stakeholders. This common, broad organizing framework is designed to permit cross-site comparisons for distinguishing generalizable lessons from particular circumstances.

These and other projects will give insights on the usefulness of the eight step methodology for vulnerability assessments proposed here. The methodology will hopefully be a starting point for further development as we gain experience in this fairly new field. A common methodology should lead to common practice for the purpose of facilitating additional insights through cross-study comparisons. If such additional insights or generalizations emerge, a "public good" is created, i.e. insights from one assessment may be applied by other vulnerability researchers with little additional effort. The creation of such a "public good" is facilitated by a number of national and international initiatives. For example, the HERO project (Human-Environment Regional Observatory; http://hero.geog.psu.edu/) is designed to create the infrastructure for supporting and coordinating vulnerability assessments across study sites in the US. The Millennium Ecosystem Assessment (MA) is a global initiative linking researchers performing integrative assessments all over the world (http://www.millenniumassessment.org) in the context of vulnerability to impaired ecosystem services, or 'human well-being and nature'. By reaching out directly to stakeholders in countries and regions the MA shares its expertise at different scales, promotes multisectoral dialogue, brings the assessment closer to regional and national priorities and concerns, and supports the work of the international conventions it serves. The MA interacts with stakeholders from the government, civil society, indigenous organizations, business associations to develop regional and national user networks. A third example of initiatives facilitating the creation of a "public good" in vulnerability research is the Intergovernmental Panel on Climate Change, which has sponsored at least two efforts to produce suites of standardized future scenarios (discussed briefly in Step 7). The SRES (Special Report on Emission Scenarios; http://ipcc-ddc.cru.uea.ac.uk/) is designed to generate standardized and consistent projections of greenhouse gas emissions. The TCGIA (Task Group on Scenarios for Climate Impact Assessment; http://sres.ciesin.columbia.edu/tgcia) serves the same function for other variables, such as population and GDP. Such efforts are crucial to advance beyond individual case studies to common lessons that can inform stakeholder decision-making beyond the end of the assessment. We need to continuously support local communities to take over the never ending task of assessing impacts and risks of global change and the consequences for themselves, their social, environmental and economic well-being.

5 Conclusion

The goal of this paper is not to offer a rigid prescription for conducting global change vulnerability assessments. Instead, we argue for a general methodological approach that when implemented in specific cases will guide vulnerability assessments towards a common end, even if the particular techniques employed vary from case to case. We hypothesize that if researchers employ the methodological framework presented here, then the products of the research will (1) achieve the objective of preparing stakeholders for the effects of global change on a site-specific basis, and (2) further the "public good" of additional insights through cross-study comparisons of research projects designed according to common principles. This goal of producing generalizable insights into the processes that amplify and dampen vulnerability is especially important. Because in-depth, place-based vulnerability assessments require sustained, long term research efforts, researchers cannot possibly provide – on a timely basis – site-specific projections of imminent vulnerabilities and associated solutions for all communities that need these products. Generalizable insights can be gained by testing the methodology put forward in this paper.

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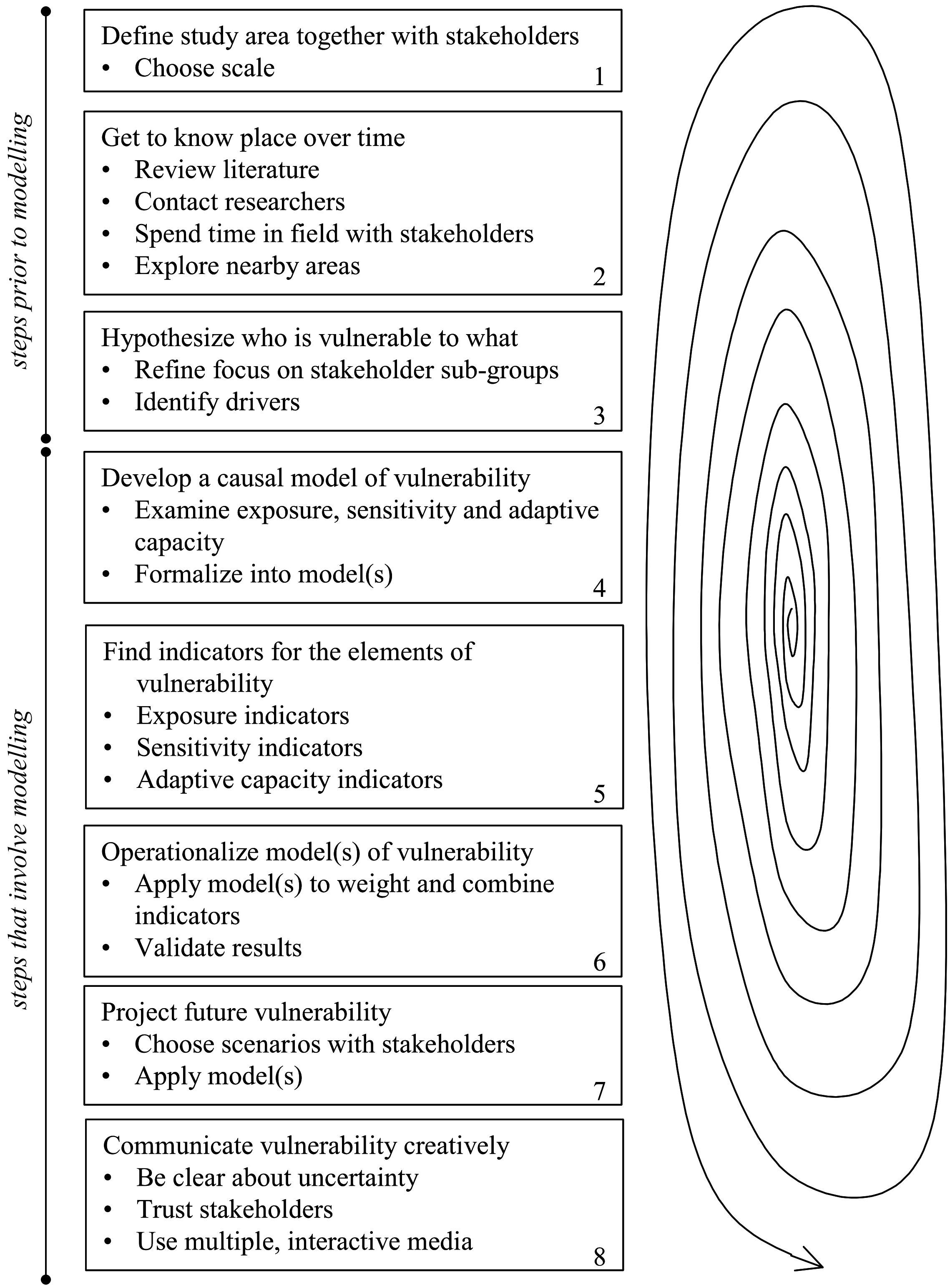

Figure 1. An eight step methodology for global change vulnerability assessments.

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