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Assessing Vulnerabilities to the Effects of Global Change: An Eight-Step Approach

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This paper was written as part of the Research and Assessment Systems for Sustainability Program. The Program seeks to foster the design and evaluation of strategies with which the next generation of national and international global environmental change programs might more effectively integrate and support its research, assessment and decision support activities. In particular, we intend to catalyze and contribute to four interrelated lines of work: 1) broadening the science-defined agenda for studying global environmental change to engage more explicitly the socially defined agenda for sustainable development; 2) exploring the long-term trends in nature and society that serve as currents which can be used to navigate towards a sustainability transition; 3) deepening a place-based, integrated understanding of social and ecological vulnerability to global change; and 4) exploring the design and management of systems that can better integrate research, assessment and decision support activities on problems of global change and sustainability. The Program seeks to contribute to the evolution of strategies for pursuing these goals through collaboration among a small, international group of scholars and program managers involved in the production, assessment, and application of knowledge relating to global environmental change and development.

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Preface

This paper summarizes the main findings of a workshop held at Harvard University where participants discussed methodological guidelines for researching vulnerability to the effects of social and environmental changes. The idea to hold this workshop flowed from discussions held under the auspices of two research projects, Research and Assessment Systems for Sustainability (Sustainability Systems) based at Harvard University (http://sust.harvard.edu), and the Environmental Vulnerability Assessment (EVA) project at the Potsdam Institute for Climate Impact Research (PIK; http://www.pik-potsdam.de). During a summer 2001 visit to PIK by a Sustainability Systems Principal Investigator (William C. Clark), it became clear that the two research projects were converging on the issue of vulnerability. Sustainability Systems researchers were finishing a paper outlining the conceptual and theoretical foundations of vulnerability, and EVA researchers were attempting a set of place-based vulnerability assessments, as well as refining the theoretical foundations. Both teams expressed an interest in collectively exploring the issue of methods and models for vulnerability research.

William Clark, Sustainability Systems collaborator Robert W. Corell, and PIK Director Hans Joachim (John) Schellnhuber suggested that the two teams jointly organize a workshop to assess the status of methods and models for vulnerability research. Three researchers (Colin Polsky at Harvard, Dagmar Schröter at PIK, and Tony Patt, who is affiliated with PIK and Boston University) organized a workshop on this topic for October 17-19, 2002, at the Harvard University Center for the Environment. The group of invitees constituted an interdisciplinary group of scholars interested in the intersection of methods and models with vulnerability analysis (see the Authors' Acknowledgements for those workshop participants not included in the author list). The organizers made an effort to keep the group size small, to facilitate discussion, even though the small size meant that some experienced voices would not be heard.

Our objective was to be able to make a statement after the workshop about vulnerability assessment that could be used to lay a framework for advancing the science. By making that statement public in this paper, we now hope to hear reactions from the rest of the community of interested researchers and practitioners. Our hope is that the framework outlined in this paper will encourage large-scale collaborations on the topic, as this area of inquiry is far too complex to be tackled by small numbers of researchers alone.

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Abstract

There is a growing call among researchers interested in studying global change and associated effects on society and ecosystems to examine vulnerabilities as well as impacts. Such a move would require a renewed emphasis on the factors that constrain and enable coupled human-environment systems to adapt to stress. Although a picture is emerging of what general factors global change vulnerability assessments should address, it is less clear what methods are needed for this endeavor. This paper presents results from a workshop held in October 2002 to explore the issue of methods and models for vulnerability assessments. The results include an objective for global change vulnerability assessments, a set of five information criteria that vulnerability assessments should satisfy for achieving this objective, and a set of eight steps designed to satisfy those criteria. The proposed objective for global change vulnerability assessments is to inform the decision-making of specific stakeholders about options for adapting to the effects of global change. The five criteria for achieving the objective are that vulnerability assessments should: engage a flexible knowledge base, be place-based, consider multiple and interacting stresses, examine differential adaptive capacity between and within populations, and be prospective as well as historical. The eight steps for satisfying the criteria are: define the study area in tandem with stakeholders, get to know places over time, hypothesize who is vulnerable to what, develop a causal model of vulnerability, find indicators for the components of vulnerability, weight and combine the indicators, project future vulnerability, and communicate vulnerability creatively. 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. Thus taken together the eight steps presented here constitute a novel methodological framework.

Authors' Acknowledgements

The authors wish to extend special thanks to Robert W. Corell, William C. Clark, and Hans Joachim (John) Schellnhuber for their sage support and assistance throughout this process, and to the other workshop attendees, Jonathan Borck, Shari Fox, Paul Raskin, and Jesse Ribot, for their motivating comments and encouragement.

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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., associated with 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. A common (if implicit) theme in the growing scholarly discussion is 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).

The point of departure for this paper is a workshop held in October 2002 on the topic of methods and models for vulnerability assessments. Workshop participants share a common experience in – and frustration with – the lack of critical discussion on methods and best practices in the global change literature in general and the (emerging) vulnerability literature in particular. To be sure, there have been several notable efforts to codify appropriate practices in the impacts/adaptation/resilience research domain (e.g., Carter et al., 1994; Klein et al., 1999; Smit et al., 1999; Walker et al., 2002). However, we believe a fresh discussion on this topic is deserved because of the recent high-profile focus on vulnerability (e.g., Kasperson, 2001; McCarthy et al., 2001). The premise for the workshop (and by extension, this paper) was, if the *vulnerability* perspective is such a promising and innovative research direction, then how does one do it?

The two specific purposes of this paper are to specify what is novel about global change vulnerability assessments, and to propose a common methodology for conducting such assessments, for a broad multi-disciplinary audience. In Section 2, we assert a common definition and objective for global change vulnerability assessments, and relate these concepts to the literatures from which they derive. We claim that vulnerability assessments should exhibit five criteria that can be satisfied by following a set of eight steps. Most readers should 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 presented here constitute a novel methodological framework. In Section 3, we evaluate the proposed steps against examples of recent research. In Section 4, we provide an initial assessment of the utility of the proposed methodological guidelines. We also point to several emerging vulnerability assessments that may soon provide the basis for a full testing of the utility of the proposed steps. In Section 5, we provide a brief conclusion on implications of this new research direction for linking vulnerability assessments to pathways for achieving more sustainable societies.

2 Describing Vulnerability

2.1 Definitions and Objective

Some important terms used in the discussion of vulnerability research are discussed here. Vulnerability is typically described to be a function of three overlapping characteristics: *exposure*, *sensitivity*, and *adaptive capacity* (Turner et al., 2003a). For example, agricultural vulnerability to the effects of climate change could be described in terms of exposure to elevated temperatures; crop yield sensitivity to the elevated temperatures; and the ability of farmers to adapt to the effects of that sensitivity, such as 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 may experience harm from exposure to stresses associated with alterations of societies and the biosphere, 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 it is clear that global change vulnerability assessments link directly with the broader aim of sustainable development and sustainability science, where successful research is measured by not only pure scientific merit but also by the utility 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 possible impacts associated with a stress, or enact anticipatory adaptations designed to reduce the importance of the possible 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).

The emerging field of global change vulnerability assessment draws heavily from these three research streams. *Thus the novelty of global change vulnerability assessment 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 adaptation constraints associated with multiple and interacting stresses (cf. food security assessments), and for multiple and unintended consequences associated with the social amplification of risk (cf. risk/hazards assessments). Inspection of the milestones 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 particularly 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 by a similarly critical review of methods for examining 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, we propose the following set of five minimal criteria that global change vulnerability assessments should satisfy, to achieve the objective outlined above.

- *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. To the extent that scientists are unaware of local concerns in depth, it is also imperative to engage indigenous, or local, knowledge – despite difficulties in testing such information within a scientific framework.
- *Vulnerability research and assessments should be "place-based"*: 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). However, the most important feature of a place is that, whatever the boundaries chosen for a vulnerability assessment, the analysis should not exclude processes operating at other spatial scales. The definition of a place should encompass the relationships manifest within a study area plus important relationships involving other scales (e.g., NRC, 1999, 2001; Easterling and Polsky, forthcoming).
- *The stresses examined should be recognized as multiple and interacting instead of unique or multiple and independent*: Communities rarely face only one challenge at a time. In some instances, the perceived importance or immediacy of a single threat, such as climate change, may be dominated by other factors, such as falling employment associated with large-scale economic restructuring. In other cases the interaction of the multiple trends may give rise, through a "double exposure," to an amplification of risk (Kasperson et al., 1988; NRC, 1999; O'Brien and Leichenko, 2000).

- *The research 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 much 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: 8 Steps

Following from the above discussion, we propose a set of 8 steps for conducting vulnerability assessments that should lead to achieving the objective by satisfying the 5 criteria (Figure 1). 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 presented here constitute a novel methodological framework.

In general, the tasks in each of the boxes in Figure 1 should be performed sequentially, reading left to right. 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 above the steps suggests the fluid and unpredictable nature of the research and assessment process. We break down the eight 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). Finally, these eight steps constitute a method 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.

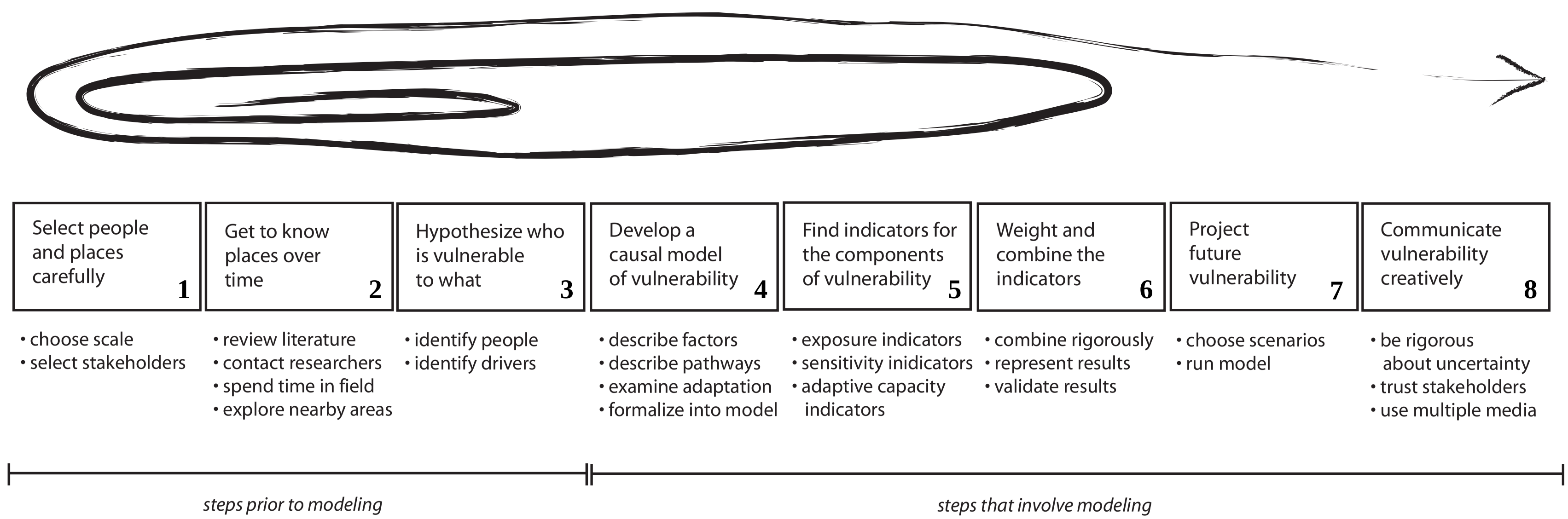

Figure 1: Eight-Step Methodology for Vulnerability Research

2.4.1 Steps Prior to Modeling

Step 1: Define study area in tandem with stakeholders

A proper vulnerability assessment is more than a report or a product, it is also an evolving social process by which scientists and stakeholders enter into a dialogue (Farrell et al., 2001). Such dialogues are necessary to produce 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.

Step 2: Get to know places over time

Once the study area has been selected in tandem with stakeholders, it is essential to develop in-depth knowledge of the stakeholders, the ecosystem services they value and why, the important vulnerability drivers over which they may have control (e.g., use of their own land) or not (e.g., use of other people's land), and the management options available. 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 certain types of verbal communication. Important 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 important for the vulnerability assessment but unimportant for (and hence 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 people in different settings, from formal meetings to discussion over food to playing on their football teams or attending their poetry readings.

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 the greatest risk of harm to 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 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. As a result, unless researchers keep this imperative to focus in mind, they may soon be sacrificing meaningful depth for excessive breadth. An example of a compromise between breadth and depth in a global change vulnerability assessment is the ongoing research on Saami reindeer herders in northern Norway (McCarthy et al., in preparation). In this case, the working hypothesis that this livelihood system is threatened by the combination of climate change, pasture loss, and government policies, is broad enough to allow for comprehensive analysis but focused enough to permit significant insights.

2.4.2 Steps that Involve Modeling

Step 4: Develop a causal model of vulnerability

A causal model of vulnerability is needed to explain which factors – both those coming from outside the system such as the local effects of global climate change, and those coming from within the system such as local power relationships – lead to vulnerability and the form and strength of the pathways linking these factors. Such models are important because they 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 again, the example of the Saami reindeer herding vulnerability assessment is instructive: the causal model of vulnerability developed through stakeholder interactions asserts that pasture loss is a function of changes in snow quality and specific government policies on ruminant production and species protection. 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 components 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.[1] 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 U.S. than for a study in Senegal. Consequently, the methods for evaluating and then projecting the indicators (Steps 6 and 7) may vary between the two studies (e.g., a computable general equilibrium model may provide good projections of GDP per capita for the U.S., but a more qualitative 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, the methods 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

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

the indicator, and how this could bias model results.

Step 6: Weight and combine the indicators

The indicators of exposure, sensitivity and adaptive capacity should be combined to produce overall measures of vulnerability. This combination can be achieved through straightforward map overlaying, 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). When constructing these indicators, researchers should strive for credibility and transparency, if stakeholders are to make decisions based on model results. For the credibility of these indicators (and by extension, of the associated projections; see Step 7), researchers should validate the indicators by comparing results 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 indicators but also of the constituent parts (exposure, sensitivity, adaptive capacity), where relevant (Downing et al., 2001). In this way loci of high vulnerability can be interactively explored to identify the factors contributing to that vulnerability.

Step 7: Project future vulnerability

The projection of vulnerability should include a range of scenarios of the values for the relevant driving variables, be they climatic, socio-economic, biogeochemical, etc. Projections should be based on a set of scenarios that demonstrate the full range of likely trends in important driving variables, as determined by expert panels. An excellent example of this approach is the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC-SRES) (Nakicenovic and Swart, 2000). However, projecting the future is a difficult and contentious task; the SRES products have been criticized for the assumptions about environment, economy, and environment-economy interactions underlying those projections. Nevertheless the SRES scenarios have to be acknowledged as a crucial step toward standardisation and comparability in global change research, providing a starting point for future improvements. With the recent emergence of competing visions of "future worlds" (e.g., Raskin et al., 2002; Warwick et al., 2003), it is fair to expect an increasing array of projections of important global change variables in the near future. In general, the assumptions underlying any projection should be examined closely and outlined explicitly. How far the scenarios project into the future should be decided with stakeholders to correspond to the time horizons of their management decisions. 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.

Step 8: Communicate vulnerability creatively

The communication of the modeled vulnerabilities should encourage a two-way flow of information between researchers and stakeholders. The large literature from the field of risk communication should be leveraged to facilitate this process. For example, communicators should anticipate that people may have difficulties interpreting probabilistic information (Patt, 2001), comparing possible gains and losses (Kahneman and Tversky, 1979), and reacting to anticipated events (Loewenstein and Elster, 1992). Quantitative and qualitative descriptions should be provided, using a variety of media. For example, in a multimedia CD-ROM, Fox (2002) relates selected perspectives on recent environmental changes by stakeholders in two Inuit communities in Arctic Canada (Baker Lake and Clyde River, Nunavut). This interactive medium integrates interview video and audio clips, maps, drawings, text and photos. 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 relevant, insofar as the underlying assumptions are derived in part from their observations (Cash et al., 2003). Moreover, this type of research product also provides immediate educational benefits for the younger generations in the communities being studied.

Finally, we recognize that by putting this step on communication at the "end" of our proposed set of steps, we risk making the impression that communication is a part of vulnerability assessment that can be left for last. In fact, creative, sustained communication between stakeholders and analysts is crucial for (and implicit in) all steps listed here. In Step 8, we simply stress the importance of establishing robust, bi-directional communications once a picture of vulnerability begins to emerge from the research process.

3 Evaluating the Utility 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 demonstrate the utility 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. As helpful as studies from those antecedent research traditions may be for other purposes, they are less helpful for enlightening stakeholders about options for adapting to the effects of global change.

3.1 Adaptation in Econometric Terms: the U.S. 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 U.S. 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, $n\approx7$ 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. 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.

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 with 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 climate variability and change.

The ZFA project has included several of the eight steps, but omitted others. 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) are weak. (This weakness is at least in part by design, as researchers do not want bureaucratic concerns to compromise the independence of the researchers in the field.) ZFA researchers have also achieved Steps 3-5 and 8 by building a model of sensitivity and adaptation to climate variability and change, but they have not integrated across these components with an eye for emergent vulnerability. As a result, the ZFA satisfies the criterion of examining differential adaptive capacities, but not of examining multiple stresses. Finally, the failure to weight and combine the indicators into a holistic measure of vulnerability means that Steps 6 and 7 are not addressed, so the criterion of future-looking analyses is not satisfied.

4 Discussion

Based on the foregoing, we suggest that many global change studies that address vulnerability may fail to achieve the goal stated in Section 2.1 because they omit one or more of the eight steps outlined in Section 2.4. (Of course not achieving this goal does not mean those studies are not useful for other purposes.) We believe that the eight steps for achieving the objective of global change vulnerability assessments should produce results that enable stakeholders to prepare for the effects of global change. However, we cannot prove this, as there are few self-proclaimed global change vulnerability studies against which to evaluate this proposition. A thorough test of the utility of the methodological guidelines presented here should be possible in coming years, as several nascent global change vulnerability assessments are completed. We are aware of several global change vulnerability studies that will be well positioned to test the effectiveness of these methodological guidelines in coming years. 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 U.S. Southwest; and Finan and Nelson (2001) describe research on Northeast Brazil. Surely there are other projects that deserve mention here; we restrict the remaining discussion to three other 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 14 different ecosystem models is designed. Some 20 different scenarios of global change are input to the models, to translate the global changes into changes in ecosystem services. Results will be mapped onto a 16 x 16 km grid for 4 time slices over the next 100 years.

The AVS project (Arctic Vulnerability Study; http://sust.harvard.edu/avs) is designed to assess the vulnerability of selected Arctic coupled 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 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, in tandem 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 to stakeholders, based on stakeholder descriptions of the climate variables that are most relevant for their activities. This common, broad organizing framework is designed to permit cross-site comparisons for distinguishing generalizable lessons from particular circumstances. Within this common framework, each study site will pursue additional modeling and assessment activities the local researcher-stakeholder teams deem important.

This issue of cross-site comparability is fundamental to the HERO project (Human-Environment Regional Observatory; http://hero.geog.psu.edu/), which is designed to create the infrastructure for supporting and coordinating vulnerability assessments across study sites. The HERO team is developing and applying the same vulnerability research protocol in central Massachusetts, central Pennsylvania, southwest Kansas, and the southern Arizona/northern Mexico border region. As such HERO represents an in-depth attempt to operationalize (at least) Steps 5-8 in a way that allows for cross-site comparability. Such efforts are crucial for the field to advance beyond individualized case studies to common lessons that can inform stakeholder decision-making. The benefits of protocol development go beyond the insights generated for the four HERO study sites. Assessing vulnerability in this way creates a "public good." Insights from one assessment can be applied by other vulnerability researchers with little additional effort.

The common use of data and other resources should not be restricted to assessments of historical exposure, sensitivities, and adaptive capacities. Given the axiomatic need to project vulnerability into the future, comparisons across vulnerability assessments would be facilitated if researchers also used common future scenarios of the variables driving global change. This does not mean all scenarios should be common across studies, but simply that a common core of scenarios of the future should be used. Any number of additional scenarios can then be appended to this core set. To achieve this goal, it may be helpful to reference the Intergovernmental Panel on Climate Change, which has sponsored at least two efforts to produce suites of standardized future scenarios, as 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. These products are evolving and should not be interpreted as providing the definitive word on projecting the future state of the world. Indeed, if future scenario development efforts applied the eight-step approach outlined in this paper, then some of the controversy surrounding the IPCC-SRES scenarios might be avoided.

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 for conducting such analyses 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 analysts 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" objective of developing a set of research projects designed according to common principles for the purpose of facilitating additional insights through cross-study comparisons. 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, multi-year research efforts, researchers cannot possibly provide – on a timely basis – site-specific projections of imminent vulnerabilities and associated solutions for even a small proportion of all communities that need these products. Generalizable insights can be gained by testing the hypothesis put forward in this paper.

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