Emergent Properties of Human-Environment Systems
Or
What determines the vulnerability and resilience of human-environment systems?

[Notes to co-authors: Steward: Turner; Correspondents: Matson, Ostrom
1) Reformatted version of Turner version 1.0 dated 080401, then labeled as Ch 9]

Note to NCEAS Seminar Participants from Bill Clark:
This draft was originally formulated to address the set of emergent properties of human-environment systems that we felt had been most thoroughly researched, ie. vulnerability and resilience of coupled HES. It has since the original version become clear that there is more needed here, including at least the burgeoning work on tipping points and thresholds and probably including something from the emerging work on seeing HES as complex adaptive systems (sensu Levin). So we will be expanding this version substantially. The question is how, with what mix of theory and empirical evidence. Suggestions most welcome, and much needed.

9.1 Why Vulnerability

Determining the robustness of human-environment systems in the face of various types of hazards acting on them is a major goal of sustainability science. A disturbance [a] (perturbation, hazard, or stressor) is an event or process that challenges some part of the coupled system, with implications for the well being of people and those environmental functions that provide the ecosystem services for that well being. Disturbances s are both societal (e.g. very large and rapid changes in the price structure for resources generated by the coupled system that threaten the local economy) and environmental (e.g., climate change). Disturbances may operate as persistent or chronic forcings over long time scales (e.g., malnutrition or soil degradation) or as irregular, short-term, “big bang” events (e.g., warfare or tsunamis).[1] Major disturbances or hazards may originate beyond the immediate human-environment system in question, as in the case El Niño-induced local droughts. Others may be generated within a system, such as floods that under normal rainfall conditions would not occur but are triggered by land use changesthat enhance the occupation of the land but have not led to investments in flood control works.[2] Interaction effects may occur where multiple stressors collectively degrade the adaptive capacity of a system or increase the level of exposure.

Serious concerns exist about the increasing frequency and magnitude of different kinds of disturbances now and in the future, under the processes of globalization and global environmental change.[3] Joining known hazards (those a particular society has already

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[a] A note from Lin: I would suggest that we use a term such as “disturbance” rather than “hazard” – hazard is an important kind of disturbance but it is related mainly to the disaster literature – which is a very important foundation for our work, but moving forward to the Sustainability Science approach of this book I recommend against a focus primarily on disaster. So I have changed it but I wanted Pam and Billie to know why.

experienced) are surprise ones—new or unknown hazards. Surprise hazards stem from the complexity of interactions within and among coupled human-environment systems, the increasingly rapid pace of change in these systems, and the uncertainties in the outcomes of the changes underway. The thinning of the ozone layer and its human health consequences constitutes one such surprise disturbance of recent year.[4] Expected increases in known and surprise hazards obviously challenge the robustness—or vulnerability—of the coupled system.

9.2 Vulnerability and Resilience

Variously defined,[5] vulnerability may be seen as "… the degree to which a system, subsystem, or system component is likely to experience harm due to the exposure to a hazard."[6] The concept is the outgrowth of research and practice in the interdisciplinary subfields interested in the potential negative impacts of natural and technological hazards (i.e., tornadoes to medical procedures) on human well being, both individuals and society.[7] Resilience resides in the coping capacity of the system. For the most part, research on risk and hazards as well as early vulnerability research did not consider the environmental subsystem in its own right.[8] Much attention, however, was given to questions of sustainable development, especially in developing contexts where immediate uses of natural resources are typically essential to the use-system in question.[9] Exploitation of these resources, in turn, is commonly accelerated by the export demands globalization processes.

The original concept of resilience emerged from research in ecology attempting to understand the different capacities of ecosystems and landscapes to withstand perturbations or shocks.[10] This resilience refers to the ability of an environmental system "to absorb change and disturbance and still maintain" its base structure and function, including reorganization of the system.[11] Recognition of systems with non- and multi-equilibrium states, owing to regular disturbance by natural processes, makes the resilience concept complex.[12] The loss of resilience makes an ecosystem vulnerable to change. As ecological research began to include a human component—people as part of ecosystems—resilience concepts developed almost wholly from ecosystems were applied to the human subsystem.[13]

Concerns about global environment change, especially climate change, has helped to foster fusions and further interactions among the risk-hazards and ecological research communities concerned with the impacts of shocks or perturbations on coupled human-environment or social-ecological systems.[14] The interaction is a welcome development, and has contributed to the wide recognition that human and environmental subsystems are so intimately linked that failure to include and consider both render seriously deficient any contemporary analyses of sustainability. These developments have not yet yielded a genuine fusion of concepts from the two communities or even agreement on the basic vocabulary to apply when analyzing linked human and social systems. It is widely recognized, however, that the human and environmental subsystems are intimately linked that assessments lacking either are deficient for questions of contemporary sustainability.[15]

9.3 Unpacking Vulnerability

Given that sustainability science emphasizes the environment in relation to its consequences on human well being, we employ the vulnerability orientation to coupled systems assessment. In this scheme, vulnerability (defined above) is a function of three broad factors: exposure to disturbances, the sensitivity of the exposed system, and the resilience or coping capacity of that system (Fig. 9.1).

[Fig. one here]

Exposure refers to the frequency, intensity, and timing of the different kinds of perturbations or stressors operating on a coupled system (Fig. 9.2). These hazards are both societal and environmental in kind, as in the case of economic globalization and climate change, or what has been called "double exposure."[16] As noted, hazards may operate as perturbations or stressors of the system with different forcing characteristics (e.g., short-term but large magnitude events and persistent, low magnitude processes). Considerable attention has been given to categorizing natural hazards in this way.[17] Less attention has been given to the timing of multiple hazards on a system as opposed to single events. Imagine the consequences in southern California of a major landscape fire, followed by intensive rainfall and an earthquake.

Exposure to a hazard does not generate the same immediate forcing on all coupled systems or the same components within a system. This forcing is determined by the sensitivity of the coupled system to the hazard, and this sensitivity resides in the systems conditions generated by the synergy between its human and environmental subsystems (Fig. 9.2). Indeed, the forcing process could even proceed sequentially, affecting primarily environmental subsystems and then on human ones or vice versa. Hurricane Katrina illuminates these complex inter-relationships. By reshaping the hydrology of the of Mississippi delta for riverine flood control, shipping, and access to wellheads in marsh-swamps, the aggradation of the delta below New Orleans was substantially halted, reducing the delta's capacity to withstand storm damage and to serve as barrier to storm surges into the city, surges that were amplified by the canals.[18] [b] Thus the synergy between the human and environmental subsystems increased the vulnerability of the entire system to high-level hurricanes.

[Fig. 2 here]

Given exposure and sensitivity, the response capacity of the coupled systems determines its vulnerability. Environmental subsystems are differentially resilient to a hazard, predicated on their biophysical characteristics (which may have been affected by human actions). At the landscape level, for example, ecosystems with low levels of biomass, high levels of diversity, low levels of connectivity are thought to be the least sensitive

[b] Need better reference than Travis

and the most resilient (low levels of vulnerability) to perturbations.[19] [c] General characteristics of this kind for human subsystems are less commonly proposed, although the role of entitlements, broadly interpreted, has received considerable attention.[20] Entitlements are "the set of alternative commodity bundles that [an individual, household, or community] can command in a society using the totality of rights and opportunities [confronted]."[21] [d] Originally developed in regard to food, the concept may be applied to various kinds of resources. Following work on famines, societal conditions that expand entitlements are presumed to be less sensitive and vulnerable to a perturbation. In addition, human subsystems maintain coping mechanisms, some which anticipate hazard impacts and attempt to mitigate them in advance by policy (e.g., land use zoning and rules relating to access, use, management, and alienation)[22] or altering the coupled system (e.g., dykes and levees to control flooding)(Fig. 9.2).

Human societies may also have developed substantial social capital which increases their resilience to external shocks.[23] Local communities that have developed strong horizontal links to other communities (or vertical links to higher level agencies) can call upon one another at times of emergencies and survive floods, landslides, and other environmental hazards due to their well-developed mutual trust and reciprocity.[24] As well, human subsystems may possess disaster relief and other mechanisms to assist societal recovery from the impacts incurred. In some case, attempts to mitigate one type of hazard, affects the vulnerability of other parts of the system, illustrated in the Mississippi flood control and loss of delta aggradation noted above. Finally, vulnerability is affected by adjustments and adaptations in the coupled system triggered by experiences with different types of hazards. Again in the Mississippi case, repeated riverine flooding of New Orleans led to the hydraulic works intended to spare the city from this source of flooding.

Coupled systems are connected to others operating at the same and other spatio-temporal scales (Fig. 3.x).[25] These connections mean that the vulnerability of a local system, for example, is affected by changes in regional and global systems. [26]Again focusing on New Orleans, its vulnerability to riverine floods (as opposed to storm-surge floods) is affected by changes in runoff triggered by land changes throughout the Mississippi watershed, and the frequency and intensity of precipitation in that watershed generated by climate change. Likewise, attempts to mitigate this flooding have regional consequences that have, as noted, helped to reduce sediment build up in the delta and directed so much nutrients into Gulf of Mexico as to render a New Jersey-size hypoxic zone killing the once a highly productive fishing grounds.[27] These scalar dimensions of vulnerability, embedded as they are in cross-border, multiple-level governance systems, raise serious issues regarding management and response.[28]

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[c] I hope I have this correct. Billie – this is how it is expressed by Holling but I think the concept of connectivity is not well developed. I think for now, lets leave the sentence – Pam may be able to replace this sentence with a more general statement of characteristic of ecosystems that make them more resilient.
[d] I have taken liberties to expand Sen's individual to household and community because this is what the literature beyond Sen does. However, I may break economic convention by doing this. If so, we can reword by retaining Sen's original quote and then adding a sentence.

9.4 Characterizing Vulnerability[e]

To be vulnerable "human-environment systems not only must be exposed and sensitive to the effects [of a hazard (perturbation or stessor)], but also must have limited ability to adapt (low resilience). Conversely, systems are less vulnerable—perhaps sustainable, i.e., able to persist in the long-term in the face of [hazards]—if they are less exposed, less sensitive, or possess strong adaptive capacity."[29]

Sustainability science in its full dimensions treats the vulnerability of coupled human-environment systems. This means that the sensitivity and resilience of either subsystem cannot be treated alone because subsystem interactions affect both of these dimensions for each subsystem.[30] This coupling makes vulnerability analysis complex and difficult to reduce to simple measures and metrics.[31] The various parts (i.e., ecosystems, landscapes, infrastructure, people) of the coupled system are differentially vulnerable to different hazards, and vulnerability itself changes as the coupled system changes.[32] Coupled system assessment must treat multiple hazards acting on the system, and should incorporate some indicator of thresholds beyond which a forcing factor moves the system (or its parts) into endangered conditions.[33] This complexity is enlarged by the need to consider dimensions of human well being beyond economic indicators alone, the temporal dynamics of risk, the distribution of vulnerability within the system, and the recognition that vulnerability is relational, the outcome strongly affected by the specifics of the coupled system.[34]

Meta-frameworks appear to be coalescing in regard to the base structure and proposed linkages in this coupling (Figs. 9.1-9.3).[35] They serve to guide the analytical frameworks and nomenclatures used for case study comparisons and the search for general principles crossing these cases. For example, Downing and colleagues provide a mathematical nomenclature for a relational, social vulnerability.[36] It incorporates the hazard or threat (*T*, e.g., tornadoes, floods), social sector (*s*, e.g., food system, health), group affected (g, *e.g*., ethnic, class) and the impact or consequence (*c*, e.g., famine, death):

$$(T)\ V^{c}_{s\,,\,g}$$

This nomenclature can be adjusted to account for environmental subsystem vulnerability by substituting *e* (ecosystem services) and *f* (functioning of environmental unit) for *s* and *g*, respectively, and permitting *c* to refer to impacts on the unit's capacity to function and deliver services.

Polsky and associates offer a Vulnerability Scoping Diagram (VSD) as a framework to facilitate comparisons of vulnerability assessments (Fig. 9.4).[37] Following Figure 9.6, vulnerability (inner circle) refers to specific hazards or hazard sets. The inner ring captures the base dimensions of vulnerability as captured in the meta-template above

[e] This title is poor – HOW ABOUT: Vulnerability and Sustainability Science???? eo

(Fig. 9.1): exposure, sensitivity, adaptive capacity (or resilience). The intermediate ring is the components of these three dimensions and the outer ring is the actual measurement of the components. In their example, the hazard is drought and the exposure unit is a community user group. The components and measures are taken from four case studies to demonstrate how comparisons evolve. Collecting a sufficient number of completed VSDs for different types of hazards, accompanied by the narratives for each case, provides a means by which to address the general characteristics of that hazard or hazard set for different types of coupled systems.

Finally, comparative studies are generating important clues about general principles to be tested..Resilience researchers propose that landscape resilience is dependent on three factors: biomass, diversity, and connectedness (above).[38] Systems with low biomass and high diversity and connectedness are less vulnerable to perturbations and stressors (hazards), while the reverse conditions are more vulnerable (Fig. 9.5). Fraser embeds historical case studies of famine into this framework to derive clues about societal vulnerability (Fig. 9.6).[39] He suggests that food system resilience (or vulnerability) is a product of the robustness of the agro-ecosystem, the diversity of livelihood options, and institutional capacities. Resilience increases and vulnerability decreases in conditions of robust agro-ecosystems, abundant livelihood options, and high levels of institutional response; low resilience and high vulnerability reside in the opposite sphere of these conditions. In this vision, similar "system" attributes help explain the vulnerability and resilience of an agro-ecological system.[f] The larger applicability of such conceptual coupling of human-environment systems as well as the fit of themes and concepts developed in one subsystem for understanding the other remains an open question, however.

[Figs. 9.3-9.5 here]

[f] Elaborate from ecological economics or resilience alliance.

Figures

Fig. 9.1 Vulnerability: Coupled System in Context

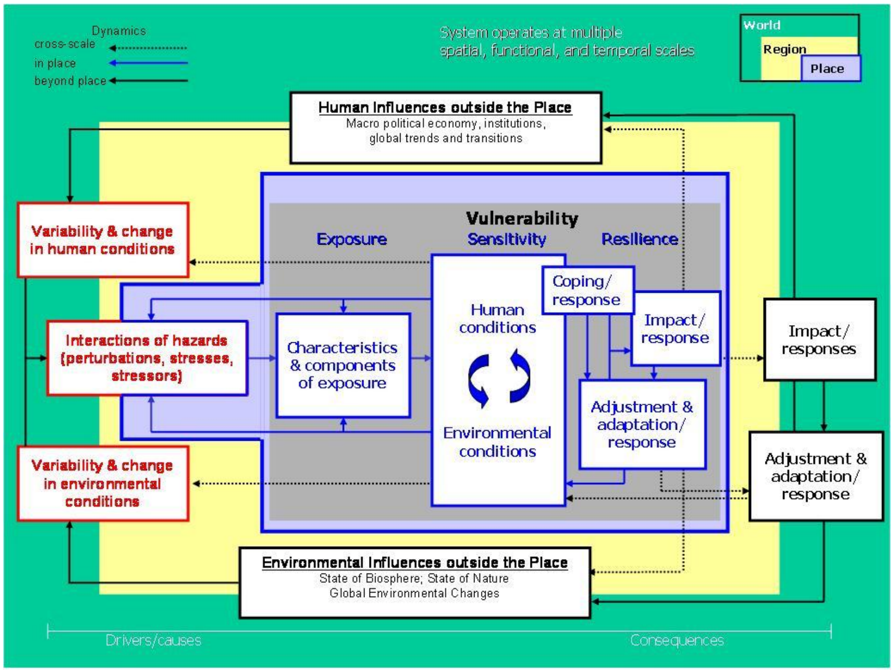


Fig. 9.2 Vulnerability: Details of Coupled System

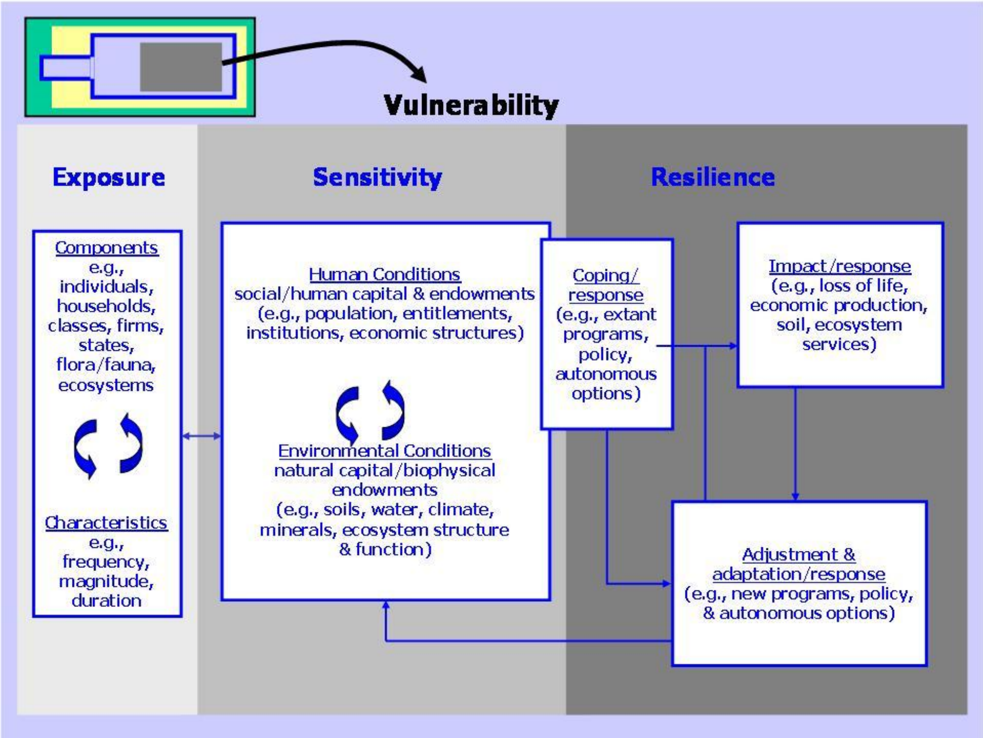


Fig. 9.3 Climate Change Adaptation Model Consistent with SUST Framework

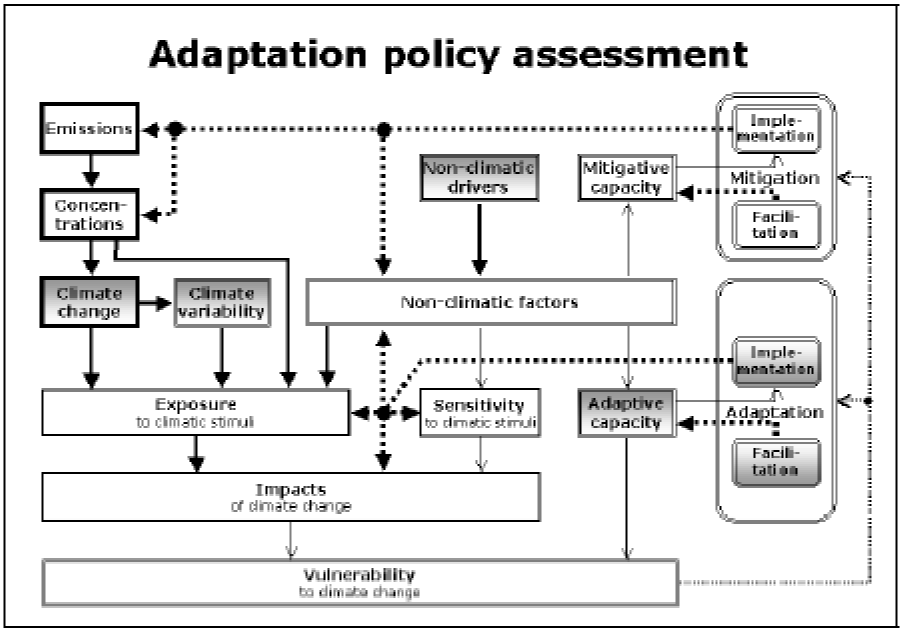


Figure 6. Conceptual framework for an adaptation policy assessment.

Fig. 9.4 Vulnerability Scoping Diagram (Polsky et al. 2007)

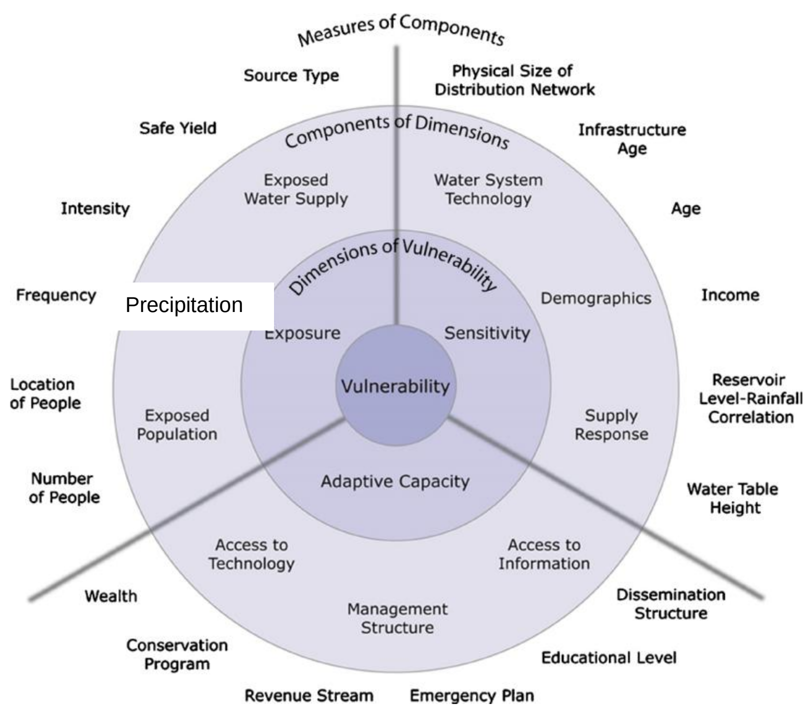


Fig. 9.5 Resilience of Ecosystems and Landscapes (following Fraser 2005)

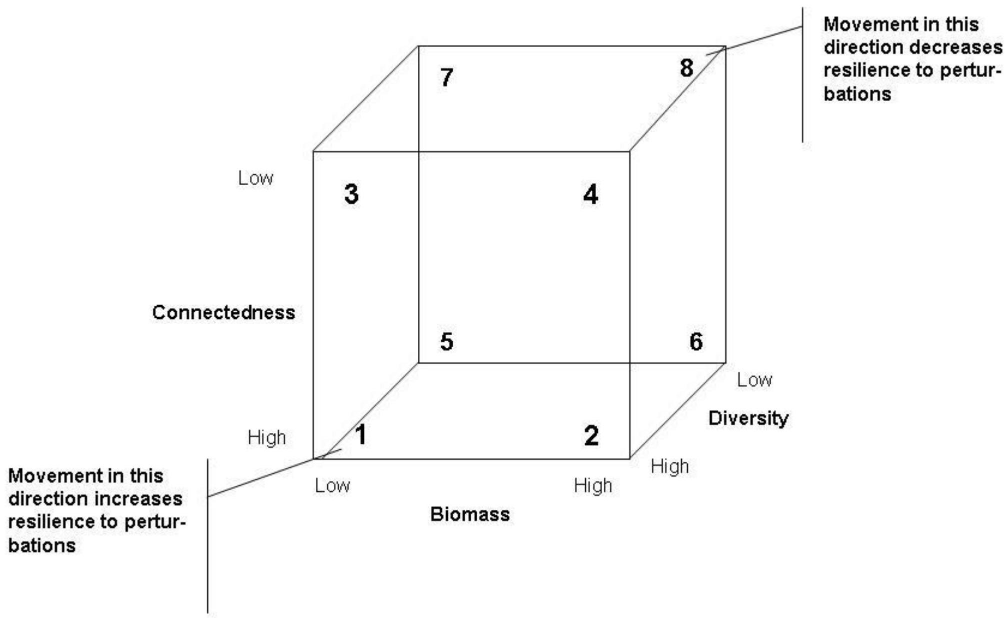
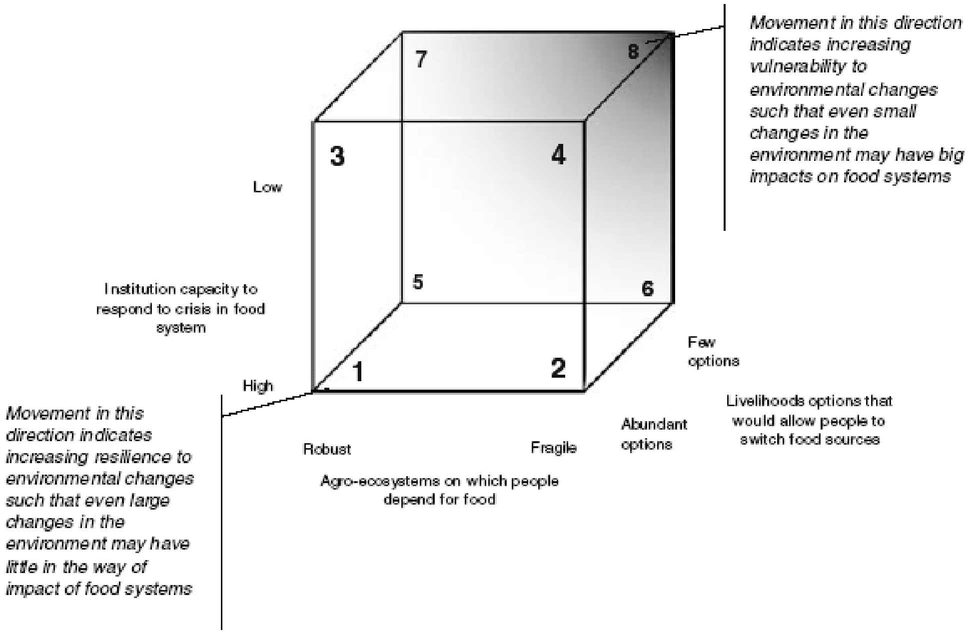


Fig. 9.6. Food System Resilience-Vulnerability (Fraser 2005)



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Endnotes

[1] Burton, Kates, white (1978)
[2] Turner et al. 2004
[3] Schneider et al (1988), Kates and Clark (1996)
[4] Schneider et al (1988)
[5] Cutter (1966), Fussel and Klein (2006), Adger (2006)
[6] Turner et al (2003a: 874)
[7] Kasperson et al. (2005)
[8] Hewitt (1983), Blaikie et al. (1994), Cutter (2003)
[9] André et al. (2004)
[10] Holling (1973), Gunderson and Holling (2002)
[11] Holling (1973): 14, Peterson et al. (1998), Walker et al. (2004)
[12] Peterson et al. (1998), Ludwig et al (1997); Anderies, et al., (2004)
[13] Berkes and Folke (1998), Levin et al. (1998) Peterson (2000), Folke et al. (2002), Anderies et al. (2004), Daily (2004), MEA (2005), Eakin and Luers (2006)
[14] Adger (2006), Turner et al. (2003a), Fussel and Klein (2006); McGinnis and Ostrom (1992)
[15] Schröter et al. (2005), Schröter, Polcky and Patt (2005)
[16] O'Biren and Leichenko (2000)
[17] Xx??
[18] Travis (2005)
[19] Gunderson and Holling (2002), Peterson (2002)
[20] Blaikie et al. (1994), Adger (2006)
[21] Sen (1984): 497
[22] Blomquist et al., (2004); Schlager and Ostrom (1992)
[23] Ostrom and Ahn (2003)
[24] Baker, (2005); Barabasi, 2000; Watts, 2003.
[25] Wilbanks and Kates (1999)
[26] Janssen, et al. (2007)
[27] Day et al. (2000), Malakoff (1988)
[28] Cash and Moser (2000)
[29] Polsky et al. (2007): 473
[30] Liverman (1990), Luers (2003), Turner et al. (2003b)
[31] A number of vulnerability indexes exist: for small islands (Briguglio 1995), small states (Atkins et al. 1966), place (Cutter et al. 2000), and the human subsystem (Cutter et al. 2003; Cutter and Finch 2008; Kamanou and Murdoch 2004), especially to climate change (Moss et al. 2001). These indexes invariably treat one or some small set of social dimension, such as famine, hunger, or poverty. Various efforts have used a number of these dimensions to map the distribution of social vulnerability (Downing et al. 2001; Brooks et al. 2005; O'Brien et al. 2004; Schröter et al. 2005)
[32] Adger (2006).
[33] Luers (2005)
[34] Adger (2006); Dowing et al. (2005), Eakin and Luers (2006)
[35] Eakin and Luers (2006); Turner et al. (2003a); Fussel and Klein (2002):199x
[36] Dowing et al. (2005), Eakin and Luers (2006)
[37] Polsky et al. (2007)
[38] Gunderson and Holling (2002); Peterson (2002)
[39] Fraser (2005)l Fraser et al. (2003; 2005)