

chological and physiological discomfort, and health aspects of residents. The relation between physical characteristics of the source and the aversive reactions can be described as a stress situation, because the reactions covary with the degree of emission, and residents usually cannot stop the emissions of the source directly. In addition, situational, personal, and social variables moderate the dose-response relationship.

See also: Crowding and Other Environmental Stressors; Environmental Challenges in Organizations; Environmental Risk and Hazards; Job Stress, Coping with; Post-traumatic Stress Disorder; Stress and Coping Theories; Stress and Health Research; Stress at Work

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R. Guski

Environmental Surprise

Decision makers at all scales (individuals, firms, and local, national, and international governmental organizations) are concerned about reducing their vulnerability to (or the likelihood of) unexpected events or 'surprises.' After briefly and selectively reviewing the literature on uncertainty and surprise, a definition of 'surprise' is introduced that does not include the strict requirement that it apply to a wholly unexpected outcome, but rather recognizes that many events are often anticipated by some, even if not most observers. Thus, an 'imaginable surprise' is defined as an event or process that departs from the expectations of some definable community, yet is a concept related to, but distinct from risk and uncertainty. Therefore, what gets labeled as 'surprise' depends on the extent to which what happens departs from community expectations and on the salience of the problem (for elaboration see Schneider et al. 1998). Impediments to overcoming ignorance range from the need for more 'normal science' to phenomenological impediments (e.g., inherent unpredictability in some chaotic systems) to epistemological ignorance (e.g., ideological blocks to reducing ignorance). The substantive focus will concentrate on the theme of global change. Examples of 'imaginable surprises' in the global change context are presented. Improving the anticipation of surprises is an interdisciplinary enterprise

that should offer a skeptical welcoming of outlier ideas and methods, tempered by broad-based assessments that attempt to estimate the subjective probabilities of all imaginable outcomes (e.g., Schneider 2001).

Strictly speaking, a surprise cannot be anticipated; by definition it is an unexpected event. Potential climate change, and more broadly global environmental change, is replete with the truly unexpected because of the enormous complexities of processes and interrelationships involved and our insufficient understanding of them (such as coupling ocean, atmosphere, and terrestrial systems). However risk, hazard, and related research demonstrate repeatedly that the event, process, or outcome registered as a surprise by the community in question was frequently known or forecast by others or the same event was knowable within the competing frameworks of understanding (Darmstadter and Toman 1993).

Much of the current work on surprise has grown out of an extensive body of research on uncertainty. Yet, although widely acknowledged and studied, uncertainty remains a difficult concept to define or codify. Different conceptualizations and approaches to uncertainty abound in the literature, cross numerous fields of study and touch a wide range of problem types. Two basic options are invariably followed in the face of uncertainty. The first is to reduce the uncertainties through data collection, research, modeling, simulation techniques, and so forth. Following this option, the objective is to overcome uncertainty, to make the unknown known. But the daunting nature of uncertainties surrounding global environmental change (what some have labeled 'deep uncertainty'), as well as the need to make decisions before the 'normal' science option can provide resolution, force a second option—that of managing or integrating uncertainty directly into the decision-making or policy-making process. Before uncertainty can be so integrated, however, the nature and extent of the uncertainty must be clarified.

The fields of mathematics, statistics, and more recently physics, provide the 'science of uncertainty' with many powerful means and techniques to conceptualize, quantify, and manage uncertainty, ranging from the frequency distributions of probability theory, to the possibility and belief statements of Bayesian statistics. Addressing other aspects of uncertainty, fuzzy set logic offers an alternative to classical set theory for situations where the definitions of set membership are vague, ambiguous, or non-exclusive. More recently, researchers have proposed chaos theory and complexification theory to focus on expecting the unexpected in models and theory (e.g., Casti 1994).

The practical application of many of these techniques was originally pioneered by researchers in decision analysis (see Raiffa 1968). In the fields of economics and decision theory, researchers continue to study rational decision making under uncertainty and how to assess the value of collecting additional

information (e.g., Clemen 1991). Methods for modeling risk attitudes, leading to the terms risk-prone and risk-averse, attempt to capture how different people faced with making a decision react to the uncertainty surrounding the expected outcomes. Uncertainty and its related context, surprise, are treated largely as the realization that events, currently unknown, will occur affecting the final outcome of a process or decision.

This acknowledgment of uncertainty has found a prominent place in many other fields of study, each one speaking its own language of uncertainty. Research on uncertainty cross-cuts a number of different disciplines. For example, researchers making risk assessments and setting safety standards find it most useful to distinguish between risk (the probability of a certain negative effect resulting from a hazard occurrence, given the specified level of exposure), variability (inter-individual differences in vulnerability and susceptibility), and uncertainty (model parameter variability and any unexplained residual). In work related to hazards and risk, sociologists, anthropologists, psychologists, and geographers have made important contributions to the discussions on risk perception, risk communication, and the social amplification of risk (Kahneman et al. 1982, Kasperson et al. 1988, see Gigerenzer 1996 for a criticism). Similarly, work on visualizing or graphically conveying uncertainty also crosses a diverse set of disciplines including psychology, computer science, and Geographic Information Systems (e.g., MacEachren 1992).

Wynne (1992) emphasizes that the modeling of environmental risk systems requires examination of not only the scientific evidence and competing interpretations, but also investigation of the nature, assumptions, and inherent limitations of the scientific knowledge behind the data and the model. He specifies four types of uncertainty—risk, uncertainty, ignorance, and indeterminacy—each overlaying dimensions of uncertainty. *Risk* refers to a situation when the system behavior is well known and the chances of different outcomes can be quantified by probability distributions. If, however, the important system parameters are known but not the associated probabilities, then in Wynne's definitions, *uncertainty* exists. *Ignorance* is that which is not known (or even that we are aware that we do not know it) and, for Wynne, is endemic because scientific knowledge must set the bounds of uncertainty in order to function. *Indeterminacy* captures the unbounded complexity of causal chains and open networks. *Uncertainty*, in part, stems not only from an incomplete understanding of determinate relationships, but also from the interaction of these relationships with contingent and unpredictable actors and processes. However, the extent to which situations are truly 'indeterminate', as opposed to simply containing a very broad distribution of subjective probability estimates, is not a straightforward classification, for often very ill understood phenomena can still be bounded to some extent by

existing knowledge, and thus not truly indeterminate. In the areas of environmental policy and resource management, policy makers struggle with the need to make decisions utilizing vague and ambiguous concepts (such as sustainability), with sparse and imprecise information, in decisions that have far-reaching, and often irreversible, impacts on both environment and society. Not surprisingly, efforts to incorporate uncertainty into the decision-making process quickly move to the forefront with the advent of decision-making paradigms, such as the precautionary principle, adaptive environmental management, the preventative paradigm or stewardship. Ravetz (1986) takes the concept of 'usable knowledge in the context of incomplete science' one step further by introducing the idea of usable ignorance. To Ravetz, acknowledging the 'ignorance factor' means becoming aware of the limits of our knowledge. Ravetz argues that ignorance cannot be overcome with any amount of sophisticated calculations. Rather, coping with ignorance demands a better articulation of the policy process and a greater awareness of how that process operates. He recognizes that one can only replace ignorance by gaining more knowledge, but stresses that by 'being aware of our ignorance we do not encounter disastrous pitfalls in our supposedly secure knowledge or supposedly effective technique' (p. 429).

The emphasis on managing uncertainty rather than mastering it can be traced to work on resilience in ecology (e.g., Holling 1986). Whereas resistance implies an ability to withstand change or impact within some measure of performance, resilience captures the ability to give with the forcing function, without disrupting the overall health of the system. In this framework, adaptation is an ecological mechanism whose aim is not to overcome or control environmental uncertainty, but to live with, and in some case, thrive upon, it.

To recap, risk typically is defined as the condition in which the event, process, or outcome, and the probability that each will occur, is known. In reality, of course, complete or perfect knowledge of complex systems, which would permit the credible calculation of objective or frequentist probabilities rarely exists. Likewise, the full range of potential outcomes is usually not known. Thus, risk almost always is accompanied by varying degrees of uncertainty. Uncertainty is usually defined as the condition in which the event, process or outcome is known (factually or hypothetically), but the probabilities that it will occur are not known, or are highly subjective estimates (see, e.g., Moss and Schneider 2000).

Strictly speaking, surprise is the condition in which the event, process or outcome is not known or expected. In this 'strict' meaning, the attribution of surprise shifts toward the event, process or outcome itself. We may expect surprises to occur, but we are surprised by the specific event, process, or outcome involved. This meaning, as noted, begs the issue of

anticipation, because the very act of anticipation implies some level of knowledge or foresight. However, it may be possible to identify 'imaginable conditions for surprise' where the conditions that might induce surprises are known even though the actual surprise events are not, for example, rapid forcing of non-linear systems (e.g., Moss and Schneider 2000).

Because of the impracticality of the strict definition of surprise for policy making, various studies advocate the use of another meaning for surprise, one in which the attribution of 'surprise' shifts more toward the expectations of the observer. Holling (1986, p. 294) recognized this meaning of surprise as a condition in which perceived reality departs qualitatively from expectations. It is this more interpretive or relational meaning of surprise—which has been labeled 'imaginable surprise'—that portends to be most useful for global change studies (Schneider et al. 1998).

Almost every event may constitute an imaginable surprise to someone. But since global change phenomena and their environmental and societal impacts are a community-scale set of issues, little can be gained for our purposes by focusing on whether someone, somewhere, may or may not have once predicted or hinted at some surprise event. More fruitful is the recognition that groups, communities, and cultures may share expectations such that a particular event is likely to qualify as a surprise for most within them. In these cases, what gets labeled as a surprise depends upon the extent to which reality departs from community expectations, and on the salience of the problems imposed.

Imaginable surprise applies to communities of experts, policy makers, managers, and educators who share common ranges of expectation that are generated by group dynamics, leaders, and signal processors, including the dominant educational and research paradigms (Kasperson et al. 1988). For these communities, shared expectations follow from dominant interpretations among the expert community (e.g., global warming is likely), from their fit with broader policy agendas (e.g., environmentally benign economic development is possible), and from vested interest, conscious or unconscious, of an agency or group to maintain a particular view (e.g., global population growth is environmentally damaging, or, alternatively, good for the economy). Since policy making often reflects a blend of public and interest group perceptions of reality, the imaginable surprise formulation is much more relevant to global change policy issues than a strict definition of surprise as an unimaginable outcome.

Since natural and social global change science remains in a range of developmental stages, the unknowns are sufficiently large to warrant attention to divergent themes about similar processes and outcomes. To facilitate this range of research, (a) measures should be taken to ensure a more open

discourse and evaluation of alternatives, such as by a more open airing and professional evaluation as opposed to uncritical, 'equal time' and equal credibility often afforded to polarized viewpoints in the popular media of less dominant or unconventional views, including those by advocacy science and scientist; and (b) by reducing the redundancy of research focused on the dominant views and theses while still preserving a diversity of approaches within dominant paradigms, that is, create research 'overlap-without-cloning.'

The assumptions associated with the standard paradigm of global climate change impact assessment, for example, although recognizing the wide range of uncertainty, are essentially surprise free. One approach is to postulate low, or uncertain, probability cases in which little climate change, on the one hand, or catastrophic surprises, on the other hand, might occur and multiply the lower probability times the much larger potential costs or benefits. Analysts, however, customarily use a few standard general circulation model CO₂-doubling scenarios to 'bracket the uncertainty' rather than to postulate extremely serious or relatively negligible climatic change outcomes. A strategic approach, that is, one that considers a wide range of probabilities and outcomes, may be more appropriate for global climate change impact assessments given the high plausibility of surprises, even if we have but limited capacity to anticipate specific details right now (Moss and Schneider 2000).

An assumption in cost-benefit calculations within the standard assessment paradigm is that 'nature' is either constant or irrelevant. For example, ecological services such as pest control or waste recycling are assumed as constants, or of no economic value in most assessment calculations. Yet should climatic change occur in the middle to upper range of that typically projected, it is highly likely that communities of species will be disassembled, and the probability of significant alterations to existing patterns of pests and weeds seem virtually certain. Some argue that pests, should their patterns be altered, can simply be controlled by pesticides and herbicides. The side effects of many such controls are well-known. What is not considered in the standard paradigm is the consideration of a 'surprise' scenario such as a change in public consciousness regarding the value of nature that would reject pesticide or herbicide application as a 'tech-fix' response to global changes.

Finally, global change portends alterations to the basic processes that govern the state of the biosphere. Global change research, therefore, might do well to anticipate these alterations, an effort that will require more than the study of extant processes and conditions alone. Various modes of analysis and approaches appropriate for such explorations, but typically underutilized in the research community, should be encouraged. Among these are: (a) backcasting scenarios from posited future states and/or reconstructing past

scenarios in alternative ways to identify events or processes that might happen (recognizing, of course, that diffusion processes usually are not reversible and diffusion-dominated systems cannot be meaningfully backcast); (b) increasing attention to and support for the study of 'outlier' outcomes, searching for the reasons they appear deviant and the lessons that might be drawn from them (e.g., Hassol et al. 1997); and (c) exploring the 'resilience' paradigm (e.g., precautionary principle) alongside the 'optimization' paradigm (e.g., aggregated cost-benefit analyses) to inform policy making and diagnose alternative outcomes and risk management strategies. Other means of improving the anticipation of surprise in global change science would emerge from convening additional expert groups and asking them for more exhaustive assessments of the issues. Balanced assessments will likely lead to recommendations that 'research as usual' be tempered with more alternative or even unusual research.

In summary, global change science and policy making will have to deal with uncertainty and surprise for the foreseeable future. Thus, more systematic analysis of surprise issues and more formal and consistent methods of incorporation of uncertainty into global change assessments will become increasingly necessary. Improvements in dealing with scientific surprise in climate change in particular and global change in general, therefore, require the research and funding communities to seek a better balance among traditional and experimental research alternatives (also Kates and Clark 1996, p. 31). This aim, in turn, requires strategies that will facilitate this balance, including the difficult problem of assessing 'quality' in an interdisciplinary context.

See also: Environmental Adaptation and Adjustments; Environmental Challenges in Organizations; Environmental Risk and Hazards; Environmental Vulnerability; Risk, Sociology and Politics of

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S. H. Schneider

Environmental Vulnerability

Global changes are accelerating at an ever increasing pace with varying impacts. While some societies are becoming more globalized and equipped with modern technology, others live in poverty, they struggle to survive amidst the challenges of fluctuating daily provisions, inadequate shelter, and poor provision of essential services including health and water. Both societal groups may confront environmentally vulnerable situations. People living in industrialized cities may, for example, have to encounter technological hazards (e.g., toxic chemical accidents) and those living in less-developed locations may be at risk of poorly constructed homes and inadequate basic services provision such as water (White 1974, Kates et al. 1985).

A host of practitioners (nongovernment organizations, relief workers, disaster managers), scientists, academics, and policy makers are endeavoring to understand the processes that shape the welfare and daily conditions of people and how their lives are influenced by environmental change. One way of

trying to understand what enables some to better manage changing events is through a careful probing and examination of 'environmental vulnerability.' In this article environmental vulnerability will be examined particularly from the perspective of human vulnerability. Environmental vulnerability will be defined followed by examples of how the concept has changed and been used over time.

1. Defining Environmental Vulnerability

There have been several attempts to define and capture what is meant by environmental vulnerability ranging from geophysical, engineering, and technological aspects of environmental vulnerability through to the social, political, economic, and political dimensions. In the 1970s and 1980s, the importance of integrating these dimensions as a means to understand how such factors shape people's lives and their exposure and vulnerability to changing environments was recognized. This thinking influenced the generation of theories and concepts that were subsequently adopted in the lexicons of development, disaster management, and in global change science. One key concept which reflects this holistic view is environmental vulnerability.

Environmental vulnerability is the product of a combination of circumstances related to a host of issues which include living with risks and hazards (sudden events such as floods, earthquakes, and slow-onset events such as droughts, e.g., see *Environmental Risk and Hazards*). Other factors such as health, poverty, and gender also exacerbate existing risks/hazards, thereby heightening vulnerability and weakening positive responses to such phenomena. Environmental vulnerability is thus described with reference to the physical and social environment or the milieu in which a group may find themselves (Fig. 1).

Having briefly described what is meant by environmental vulnerability, the focus now shifts to examine how it is used in a variety of contexts. In some fields, environmental vulnerability is associated with geophysical aspects of risk and 'hazard science.' In many cases, however, particularly those characterized by poverty, certain risks, hazards, and potential disasters are not only linked to natural events but also related to slow, continuous processes that are advanced by environmental and socioeconomic vulnerability. In these regions, 'traditional' hazard/risk analyses are often compounded by other mitigating factors such as lack of access to resources, lack of accessible information, reduced response to shocks because of poverty or other factors. Recognizing this complexity, a strong emphasis on the human dimensions of vulnerability has emerged which describes both *internal dimensions* (inability or ability to cope and respond) and *external dimensions* (such as ex-

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