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ORIGINAL PAPER

Understanding uncertainty and reducing vulnerability: lessons from resilience thinking

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Abstract Vulnerability is registered not by exposure to hazards alone; it also resides in the resilience of the system experiencing the hazard. Resilience (the capacity of a system to absorb recurrent disturbances, such as natural disasters, so as to retain essential structures, processes and feedbacks) is important for the discussion of vulnerability for three reasons: (1) it helps evaluate hazards holistically in coupled human–environment systems, (2) it puts the emphasis on the ability of a system to deal with a hazard, absorbing the disturbance or adapting to it, and (3) it is forward-looking and helps explore policy options for dealing with uncertainty and future change. Building resilience into human–environment systems is an effective way to cope with change characterized by surprises and unknowable risks. There seem to be four clusters of factors relevant to building resilience: (1) learning to live with change and uncertainty, (2) nurturing various types of ecological, social and political diversity for increasing options and reducing risks, (3) increasing the range of knowledge for learning and problem-solving, and (4) creating opportunities for self-organization, including strengthening of local institutions and building cross-scale linkages and problem-solving networks.

Keywords Resilience · Vulnerability · Ecosystems · Complex adaptive systems · Communities · Adaptation · Learning · Institutions · Cross-scale linkages

1 Introduction

Many natural hazards studies have focused on floods, hurricanes, earthquakes, wildfires, ice storms and other extreme weather events, examining why people move into disaster-prone areas and how they understand risk. Most research has taken either a physical or a human emphasis. I discuss an approach that integrates the two,

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and helps to understand uncertainty and to reduce vulnerability—the resilience approach. Throughout the paper, two arguments are pursued. The first concerns the irreducible nature of uncertainty in complex systems, and the necessity of living with change and uncertainty. The second concerns the question of reducing vulnerability by building resilience.

A key concept of natural hazards studies is vulnerability, the propensity to suffer some degree of loss from a hazardous event (Etkin et al. 2004). Turner et al. (2003) define vulnerability as the degree to which a system is likely to experience harm due to exposure to a hazard, either a perturbation (disturbance or shock) or a stress. However, vulnerability is registered not by exposure to hazards alone; it also resides in the resilience of the system experiencing the hazard (Turner et al. 2003). Resilience is defined as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al. 2004). Resilience is important for the discussion of vulnerability for three reasons.

First, resilience thinking helps provide an all-hazards approach, consistent with trends in hazards research to evaluate hazards holistically (Hewitt 2004). Resilience deals with coupled human–environment systems and contributes to a comprehensive vulnerability analysis by avoiding the artificial divide between a physical and a social emphasis.

Second, resilience puts the emphasis on the ability of a system to deal with a hazard. It allows for the multiple ways in which a response may occur, including the ability of the system to absorb the disturbance, or to learn from it and to adapt to it, or to reorganize following the impact. These processes are often occurring simultaneously, across scale, in subsystems nested in larger subsystems, referred to as panarchy (Holling 2001, 2004).

Third, because it deals with the dynamics of response to hazards, resilience is forward-looking and helps explore policy options for dealing with uncertainty and change. As Tompkins and Adger (2004) put it, building resilience into human–environment systems is an effective way to cope with change characterized by future surprises or unknowable risks. It provides a way for thinking about policies for future environmental change, an important consideration in a world characterized by unprecedented hazards and transformations (Folke et al. 2002).

The objectives of the paper are (1) to explore how resilience thinking deals with uncertainty and change in general, and (2) to discuss the ways in which vulnerability may be reduced by building resilience. Examples related to partnerships and the role of local-level and community-based approaches are provided throughout. The first part of the paper deals with the background theory regarding uncertainty, complex systems and resilience. The second part deals with four clusters of factors relevant to resilience building: living with uncertainty; nurturing diversity; using different kinds of knowledge for learning; and creating opportunities for self-organization.

2 Uncertainty and resilience: the background

> Social and ecological systems are sufficiently complex that our knowledge of them, and our ability to predict their future dynamics, will never be complete. We must work to reduce uncertainties when possible, improve assessments of the likelihood of various important future events, and learn (Kinzig et al. 2000).

Practitioners know that uncertainty looms high in the area of natural hazards. Earthquakes along a major fault line are inevitable, but we cannot forecast when the next one will occur. We know that a number of hurricanes will be spawned in the tropical North Atlantic. But we cannot tell beforehand if there will be a Hurricane Mitch or Katrina among them or where exactly they will hit. We can reduce the vulnerability of Manitoba communities by creating disincentives to build on the floodplain but cannot forecast the next Red River Flood of the magnitude of the 1997 one.

The importance of uncertainties is generally well known, but the irreducible nature of uncertainties in complex systems is generally not appreciated. Social and environmental systems are complex systems. Our knowledge of them and our ability to predict their future changes will never be complete, even after a great deal of research. Therefore, we need a two-pronged approach. We need to discover ways to reduce the degree of uncertainty about the dynamics of these complex systems. At the same time, we need to develop new approaches to cope with change that cannot be predicted.

Until recently, scientists in the area of natural hazards and in many other areas have usually examined biophysical factors in isolation from social factors. Yet the ways in which human social systems change will depend on biophysical variables. In turn, changes in the biophysical variables will depend on the extent, intensity, and type of human activity. For example, the intensity and extent of forest fires in British Columbia will depend not only on ignition factors, wind and so on, but also on the history of fire control in the area and the fuel load on the forest floor. The resilience of linked social and environmental systems will depend on the ways in which these systems have co-evolved in a two-way feedback relationship.

We need to know when and under what circumstances a hazard or perturbation might lead to a non-linear response, a response that is out of proportion to the size of the perturbation, that might have serious and unanticipated consequences (Kinzig et al. 2000). Some insights could be gained through long-term studies of gradual change. But more importantly, we need insights from non-linear changes, that is, when the rate of transformation is suddenly altered, or change occurs in a discontinuous way. Thus, we need an analysis of integrated social environmental systems to improve our ability to forecast and respond to change (Berkes et al. 2003).

We also need to know when and under what circumstances a hazard might trigger a threshold effect (a breakpoint that occurs in systems with multiple stable states). Discontinuous change is often linked to crossing a threshold, although not all non-linear change is discontinuous. The shift from one stable state to another is a regime shift or a flip. Such a regime shift occurs when the threshold level of a controlling variable is exceeded, such that the nature of feedbacks changes, resulting in a change of direction (trajectory) of the system itself (Walker and Meyers 2004). Threshold effects may not be widely discussed in an explicit way in the hazards literature, but they are implicit for example in models of mudslides and avalanches. The possibility of runaway feedbacks (for example, due to permafrost thawing and methane release) is one kind of threshold effect that has been discussed for some time in the area of climate change (Holling 1986). Threshold effects are in fact pervasive in both biophysical systems (e.g., the breaching of a dam due to earthquake) and social systems (e.g., a society dissolving into chaos after a war or natural disaster).

The recognition of the pervasiveness of non-linear responses and threshold effects are part of the revolution in the current science of ecology. The traditional notions of stability (‘‘balance of nature’’), linear progression and succession that have guided ecosystem management for almost a century have given way to the idea of non-equilibrium systems, multiple steady states and surprises (Scheffer and Carpenter 2003; Holling 2001, 2004). Much of ecosystem research (as well findings in other disciplines) contradicts the assumptions of predictability and controllability. Rather, ecosystems are increasingly seen as inherently unpredictable, and not stable or equilibrium-centered.

Quantitative predictions of the system as a whole (as opposed to specific processes in the system) are thought to be difficult; as well, there is the recognition of an irreducable unpredictability. These considerations have resulted in many ecosystem-oriented ecologists moving away from the idea of ‘‘control of nature’’ and ‘‘managing’’ ecosystems as such for stable yields of products (e.g., maximum sustained yields of timber and fish). It precipitated a new emphasis on the study of non-equilibrium systems and managing ecosystem processes (rather than products) for resilience (Holling 2004).

For these ecologists, ecosystems research has moved closer to hazards research. There is a great deal of ecological work in progress dealing with shocks and stresses in ecosystems. The emphasis is on hazards that can precipitate regime shifts (flips), such as those from productive fishery systems to murky waters dominated by jellyfish, or from rich tropical forests to sun-baked tropical soils covered by scrub vegetation.

Resilience thinking, as originally developed by Holling (1973, 1986), is closely related to the theory of complex adaptive systems. Recognizing that ecosystems often exhibit multiple stable states, Holling’s resilience is used to characterize the capacity of a system to maintain itself despite disturbance. Resilience theory envisions ecosystems as constantly changing and focuses on renewal and reorganization processes rather than on stable states. It focuses on scale (for example, subsystems nested in one another in a panarchy) as well as on non-linear effects and thresholds. All these characteristics of resilience thinking place the concept squarely in the theory of complex adaptive systems (Holling 2001, 2004).

The Holling definition of resilience is one of many. There are other definitions of resilience, including one in psychology that focuses on the ability of an individual to bounce back from adversity. Practitioners in the hazards area tend to use the resilience concept rather loosely (e.g., Centre for Community Enterprise 2004). A second definition of resilience in the field of ecology focuses on bouncing back to a reference state after a disturbance. This definition is probably less useful for the discussion of vulnerability since there often is no such fixed reference state in coupled social and ecological systems to bounce back to.

Originally developed as an ecological concept, resilience is being applied to coupled human–environment systems (or social–ecological systems). The idea is to focus not merely on ecosystems per se or societies it per se, but on the integrated social–ecological system (Berkes and Folke 1998; Berkes et al. 2003). Many of the current uses of resilience acknowledge reciprocal interactions between human and natural systems, underscoring the necessity to learn from past events. This development in resilience theory has led to the consideration of the key ideas of adaptive capacity and the ability of social systems (such as institutions) to learn and adapt in response to perturbations (Folke et al. 2005).

Adaptive capacity refers to the ability of the actors in a system to influence or manage resilience (Walker and Meyers 2004). Since human actions dominate social–ecological systems, adaptability is mainly a function of the social component of the integrated system. However, adaptation is not a mechanistic or predetermined outcome. Human agency, including the role of individuals, leaders and institutions, is important and influences outcomes. This collective capacity to manage resilience determines whether thresholds can be successfully avoided.

In the case of climate change, for example, the production of a critical level of greenhouse gases could cause the system to exceed a threshold beyond which there may be a runaway feedback effect resulting in rapid (as opposed to gradual) global temperature change. Adaptive capacity in this example refers to the ability of society to move toward the kind of institutions, resource extraction practices, and economic organization that take advantage of new opportunities, mitigate the worst impacts, and allow for the necessary learning and innovation to cope with a new climate regime.

Organizations and institutions can ‘‘learn’’ as individuals do; hence, learning in the resilience sense refers to social and institutional learning, as in learning-by-doing, also known as adaptive management (Lee 1993). For purposes of the vulnerability discussion, it is essential to recognize the importance of institutional learning that emerges out of society's response to previous crises and the institutions that serve as social memory (Adger et al. 2005).

Institutional learning can be stored in the memory of individuals and communities. In many indigenous societies, the elders of the community are the holders of social memory; in the industrial society, it is not clear who (if anyone) carries social memory, although much of this function may reside in various media (books, films) or storage (libraries and archives). The creation of platforms for dialogue and innovation, following a crisis, is key to the stimulation of learning to deal with uncertainties. It helps reorganize conceptual models and paradigms, based on a revised understanding of the conditions generating the crisis. In many cases, institutions emerge as a response to crisis and are reshaped by crisis (Folke et al. 2005).

Resilience thinking challenges the widely held notions about stability and resistance to change implicit in risk and hazard management policies around the world (Adger et al. 2005). For example, resilience thinking would hold that fire prevention policies can increase vulnerability to large and disastrous fires, such as the Yellowstone National Park fire of 1988 or the Kelowna, British Columbia, fires of 2003. The policy prescription of resilience would be in favor of generating disturbances (small fires) that mimic the natural fire regime in the fire-driven landscape mosaic, and remove and recycle the accumulated fuel load on the forest floor. Allowing small forest fires and the use of prescribed fires as a way of reducing vulnerability and preventing large fires, as done in recent years, is a significantly different policy prescription than that from stability and resistance thinking.

3 Building resilience

Folke et al. (2003), identified four critical factors, or clusters of factors, that interact across temporal and spatial scales and that seem to be important in building resilience in social–ecological systems. These factors are (1) learning to live with change and uncertainty, (2) nurturing diversity in its various forms, (3) combining different types of knowledge for learning, and (4) creating opportunity for self-organization and cross-scale linkages. I deal with each in turn, followed by a brief discussion of the obstacles that stand in the way of resilience-building strategies.

3.1 Living with change and uncertainty

Living with uncertainty starts with the observation that many long-enduring societies have developed adaptations to deal with disturbances. For example, rural societies in Bangladesh are adapted to periodic floods, as much of Bangladesh is a floodplain and agricultural and fish production depends on harnessing the flood cycle (Haque and Zaman 1993; Haque 1998). Normal flood is good flood (*borsha* in Bangla language); it is the abnormal flood that is the ''bad'' flood (*bonna*) (Haque 1994). Bangladesh is not unique in having a flood-adapted population. In the area of Tonle Sap, Cambodia's Great Lake, water level seasonally fluctuates from monsoon rains and the backflow of the Mekong through the Tonle Sap River. In this huge floodplain area, the ''fish basket'' of Cambodia, rural communities have three alternative strategies to deal with water level changes. Some communities seasonally migrate to the higher ground. Some communities build their houses on stilts, typically 5–6 m above the ground level. And, some communities have floating villages that may be seen bobbing on the lake in the high water season (Melissa Marschke, pers. comm.).

How do traditional communities deal with uncertainties? Some Pacific island societies have a protocol of responses to damage from major hurricanes. For example, when the anthropologist Raymond Firth returned to Tikopia, he found an island devastated by a hurricane; hurricanes of such intensity only occurred on the average of once every 20 years. Firth described a variety of responses to the disaster: chiefs directed repair works in the village, took measures to reduce theft, directed labor to planting rather than fishing, and sent workers abroad for wage work. Household level responses included reduced hospitality, restricted kinship obligations, reduced ceremonies and the use of unripe crops. People used shorter fallows in the agricultural fields, restricted planting and collecting rights, and demarcated land boundaries more strictly than they did in normal times (Lees and Bates 1990).

Such responses as documented from Tikopia are embedded in local institutions and kept alive in the social memory of elders. The example shows that social memory extends at least 20 years. From a hazard management point of view, it is of particular interest to find out the limits of social memory. Following the December 2004 tsunami, several reports indicated that specialized groups of fishing peoples in Andaman Islands and Sumatra seemed to have a social memory of tsunamis and used it to avoid casualties (Adger et al. 2005). However, subsequent research on the coast of Bangladesh (A. Deb, pers. comm.) and Orissa, India (M. Gadgil, pers. comm.) failed to show widespread local knowledge of tsunamis. Given that the previous two tsunamis in the Indian Ocean were in the 1940s and the 1880s (T. Murty, pers. comm.), this indicates that the social memory of hazards with a 60-year frequency is not common or reliable, unlike those with a 20-year cycle (Lees and Bates 1990).

Learning to live with uncertainty requires building a memory of past events, abandoning the notion of stability, expecting the unexpected, and increasing the capability to learn from crisis. ''Expecting the unexpected'' is an oxymoron, but it means having the tools and the codes of conduct to fall back on when an unexpected event happens (Hewitt 2004). Major change, as in natural disasters, can of course be very damaging, but some degree of change and renewal is necessary for the system. Thus, a resilient system retains the necessary elements for organization and renewal (Folke et al. 2005). Social memory (as in rules of conduct in the event of a hurricane) and ecological memory (as in seeds that survive a forest fire) are part of the elements of system renewal. Each new renewal cycle brings with it windows of opportunity for change.

3.2 Nurturing diversity

The main idea behind diversity is that it provides the seeds for new opportunities in the renewal cycle. It increases the options for coping with shocks and stresses, making the system less vulnerable. Diversification is the universal strategy aimed at reducing risks (by spreading them out, as in an investment portfolio), and increasing options in the face of hazards (Turner et al. 2003). Several kinds of diversity are relevant to the hazards discussion.

Diversity in the ecological sense refers to the genetic, species, and landscape levels of biodiversity, the availability of which is often important for resource-based rural communities of the world. Livelihood options are in turn based on access to these resources in space and time. Many traditional societies have specialized resource management practices and knowledge. Compared to the simplified ecosystems created by agro-industrial monocultures, many traditional management systems use (and maintain) a diversity of resources that provide livelihood portfolios (Berkes and Folke 1998).

The range of economic opportunities available is another aspect of diversity. As documented extensively by the Millennium Ecosystem Assessment project, rural livelihoods and well-being are strongly dependent on the diversity and health of ecosystems and the services they provide, such as food, fuel, water purification, and disease regulation (MEA 2003). In parts of the world, such as northern countries where local level economies are heavily impacted by large-scale resource developments for the global economy, local economic diversification has been identified as an important policy objective for building resilience (Ullsten et al. 2004).

Mitchell (2004) emphasizes the diversity of partnerships, and the significance of bringing additional constituencies into the policy arena. The implications of hazards, and the impacts, mitigation and adaptation issues they raise are addressed differently by different actors. For example, establishing tsunami warning systems is one key response at the national and international levels. At the local level, however, the main issue may be the availability of access to high points of land. A diversity of constituencies in the policy arena brings a diversity of views and considerations into the discussion, a key tenet of sustainability science (Kates et al. 2001; Turner et al. 2003). Increasing the diversity of players has the potential of bringing new thinking, and expanding the role of information, education, and dialogue.

3.3 Combining different kinds of knowledge for learning

There are several potential areas or ways in which science and traditional knowledge can develop collaboration and communication. Climate change can be used as an example to illustrate the potential contributions of local and traditional knowledge. The combined observations from several Canadian and Alaskan Arctic indigenous communities indicate that there are three interrelated phenomena that characterize climate change as observed at the local level: weather is *more variable*, weather is *less predictable*, and there is an increased frequency of *extreme weather events* (Berkes 2002).

These findings indicate that, from the point of view of Inuit communities in the western Arctic, the averaged-out temperature projections are not very meaningful because the major impact of climate change is not the average increase in the annual temperatures. Rather, climate change manifests itself in terms of the three observations above. Of these, extreme weather events are well known to hazard researchers involved in floods, ice-storms and hurricanes. In the western Arctic, they include extremes of warm and cold periods, extremes in snowfall, and extremes in ice freeze-up and break-up dates. Something as (apparently) simple as warm spells in mid-winter can disrupt local and regional economies by interrupting transportation on ice-roads, as happened in Canada's Northwest Territories in 2000/01 and in Northern Manitoba in 1998, 2000 and 2002 (Berkes 2002).

The significance of these local observations and knowledge is that they complement global science. Climate change research has resulted in numerous global circulation models. These models provide a powerful tool for climate change research but are limited in their explanatory power, especially at the local level. Environmental change, as a complex systems problem, cannot be analyzed at one level alone. Complex adaptive systems thinking (Holling 2004) informs us that complex systems phenomena, such as climate change, occur at multiple scales, with feedbacks across scale. Thus, no single level is the "correct" one for analysis. Climate change cannot be understood at the global level alone, just as it cannot be understood at the local level alone. Community-based monitoring and indigenous observations are significant in this regard because they fill in the gaps of global science and provide insights regarding local impacts and adaptations (Berkes 2002).

Bringing different kinds of knowledge together and focusing on the complementarity of these knowledge systems helps increase the capacity to learn. In the case of the Canadian Arctic, interactive meetings for the sharing of knowledge between local experts and scientists have been helpful for creating learning environments (Berkes 2002). Such partnerships bring together parties with different relative strengths in terms of knowledge and backgrounds. For example, co-management boards associated with northern land claims agreements function as boundary organizations in dealing with persistent organic pollutants and more recently climate change (Berkes 2002). The creation of platforms for cross-scale dialogue, allowing each partner to bring their expertize to the table, is a particularly effective strategy for bridging scales to stimulate learning and innovation (Cash and Moser 2000).

3.4 Creating opportunities for self-organization

The resilience of a system is closely related to its capacity for self-organization because nature's cycles involve renewal and reorganization (Holling 2001). From the point of view of reducing vulnerability to hazards, several aspects of self-organization merit discussion: (a) strengthening community-based management (Berkes and Folke 1998), (b) building cross-scale management capabilities (Folke et al. 2005), (c) strengthening institutional memory (Folke et al. 2005), and (d) and nurturing learning organizations and adaptive co-management (Olsson et al. 2004).

The first involves maintaining the local capacity for social and political organization in the face of disasters. Response by the community itself, through its own institutions, is key to effective response and adaptation (Tompkins and Adger 2004). Elmqvist (pers. comm.) observed in his work in the Pacific that when a recent hurricane hit Samoa, the people were prepared and capable in responding to the crisis (see the earlier descriptions of the traditional Tikopia response). But in the adjacent American Samoa, much more affluent and used to outside aid for disasters, the institutions for local response were weaker and local response capability largely lacking. In the Arctic, Huntington et al. (2005) pointed out that colonial-style administration policies have eroded the resilience, adaptability and self-reliance of the traditional Inuit society, and called for policies to strengthen the ability of communities to respond to change through their own institutions.

Second, community-based management is a necessary but insufficient condition to deal with hazards in a complex world. Problems such as climate change in the Arctic show that community institutions such as Inuit hunter-trapper committees need to work with regional organizations, national organizations and international organizations such as the Arctic Council. These institutional linkages may be horizontal (across the same level) and/or vertical (across levels of organization). Such governance systems have the potential to provide for a tighter coupling of monitoring and response so that decisions are not made far from the scene where hazards are being experienced (Adger et al. 2005). The creation of governance systems with multi-level partnerships is a fundamental shift from the usual top–down approach to management. It responds to the need for building resilience by using cross-scale thinking and partnerships (Cash and Moser 2000; Huntington et al. 2005).

Third, institutional memory is important for self-organization and the emergence of new structures to deal with a disaster. In systems theory, these are known as dissipative structures, i.e., they last only as long as the gradient is in place to maintain them. The equivalent in dealing with hazards might be an emergency response that allows for new communication networks, on-the-ground aid and emergency management. This probably is the most important aspect of an effective response and must somehow emerge out of community and regional management systems. Adger et al. (2005) note that networks originally established to deal with coral reef management in Trinidad and Tobago have also played a key role in disaster preparedness.

Fourth, a dynamic learning component is crucial for providing a rapid ability to innovate in terms of the capacity to create new responses or arrangements. Such learning can be improved by adaptive co-management, defined as a process by which institutional arrangements and environmental knowledge are tested and revised in a dynamic, ongoing, self-organized process of learning-by-doing (Folke et al. 2002). Learning organizations allow for errors and risk-taking behavior as part of the learning process. Adaptive co-management combines the *dynamic learning* characteristic of adaptive management (Lee 1993) with the *linkage* and *partnership* characteristics of cooperative management. Adaptive co-management is typically carried out by networks of actors sharing management power and responsibility and can be seen as iterative, collaborative, feedback-based problem-solving (Olsson et al. 2004).

3.5 Obstacles for strategies for building resilience

There are a number of obstacles that stand in the way of resilience-building strategies. Regarding uncertainty, a large literature exists on planning under uncertainty, including environmental systems optimization under uncertainty. In the area of water management, for example, scholars have developed fuzzy multiobjective optimization tools to incorporate uncertainty into decision models (e.g., Huang and Loucks 2000). The problem is often with decision-makers who find it difficult to deal with the variety of considerations needed to cope with uncertainty; this issue is well known in the classical literature of operations research (Beer 1975).

Regarding nurturing diversity in its various forms, the ecological aspects of diversity (biodiversity at various scales) are well recognized in the international environmental policy agenda. But this is not so in the area social, institutional and economic diversity. It is not so well recognized, for example, that governance and management frameworks can help spread risk by diversifying resource use by encouraging alternate activities and livelihoods (Turner et al. 2003; Adger et al. 2005).

Combining different types of knowledge for learning raises important questions about how science and traditional knowledge are both necessary elements of building resilience. However, integrating these two kinds of knowledge into decision-making is a difficult proposition that has come under discussion only relatively recently. The experience under the Millennium Ecosystem Assessment indicates a mixed record, largely related to the effectiveness with which the problem of power imbalance between the two knowledge systems can be resolved (Reid et al. 2006).

Creating opportunity for self-organization and cross-scale linkages may appear to be a self-evident goal, but there are many complications. Self-organization is often hampered by policies of centralization of decision-making, depriving the various levels of political organization from learning from their own mistakes (Huntington et al. 2005). Building cross-scale linkages has been facilitated by various kinds of multistakeholder processes and co-management arrangements that have proliferated internationally, resulting in the nurturing of learning organizations (Olsson et al. 2004). Translating or communicating findings from one level to another, through what Cash and Moser (2000) have called boundary organizations, appears to be a key aspect of this.

A large part of the obstacle for resilience strategies appears to be related to the creation of institutions at various levels that can learn from the experience of natural hazards in an iterative way. This involves combining different kinds of knowledge, including scientific and local, building institutions for knowledge sharing (such as boundary organizations), and generally fostering partnerships that provide complementary knowledge and skills, leading to creative problem-solving in the face of crisis and uncertainty.

4 Conclusions

Vulnerability is registered by exposure to hazards, but it also resides in the resilience of the system experiencing the hazard. In a way, resilience is the flip side of vulnerability, placing the emphasis on the ability of the linked social–ecological system to deal with the hazard and providing insights on what makes a system less vulnerable. Resilience provides a conceptual tool to deal with uncertainty and future change. Hence, a number of policy-oriented, forward-looking international environmental assessments have incorporated resilience thinking. Examples include sustainability science (Kates et al. 2001; Turner et al. 2003), Millennium Ecosystem

Table 1 Strategies that have a high probability of enhancing resilience to future change

Strategies	Description
Foster ecological, economic and cultural diversity	Diversity provides the seeds for new opportunities and maximizes the options for coping with change. By supporting and protecting ecological, economic and social diversity, countries or regions make themselves less vulnerable to adverse effects of future change.
Plan for changes that are likely to occur	By recognizing the directional nature of current changes, and by identifying external drivers of change, countries have the opportunity to design the institutional flexibility necessary to anticipate and adjust to change.
Foster learning	Countries, communities, NGOs, and government agencies can learn from one another. By collaborating closely to examine patterns of response to hazards, it is possible to learn which policy options show promise. Particularly effective are learning networks of public, private and civil society actors.
Communicate the societal consequences of recent changes	Societal consequences of hazards are felt at multiple levels. The communication of the consequences of perturbations is important in understanding actual local impacts and adaptations. Such communication helps make a convincing case that the global nature of causes warrants global action.

Adapted from Ullsten et al. (2004)

Assessment (MEA 2003), and Arctic Climate Impact Assessment (Huntington et al. 2005).

Table 1 is based on the findings of a symposium dealing with sustainability in high latitudes. It is adapted from a document prepared for policy-makers regarding strategies that have a high probability of enhancing resilience to future change (Ullsten et al. 2004). With its emphasis on the diversity of options to deal with uncertainty, the importance of tracking trends and maintaining flexibility, the key role of learning from experience, and the communication of change, Table 1 can be applied to many cases dealing with hazards. The importance of partnerships is underscored by the role of various players to perceive and assess hazards and, as the case may be, to respond and adapt to them.

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