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Mountain hazards and the resilience of social–ecological systems: lessons learned in India and Canada

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Abstract Mountain regions are subject to a variety of hazardous processes. Earthquakes, landslides, snow avalanches, floods, debris flows, epidemics and fires, among other processes, have caused injury, death, damage and destruction. They also face challenges from increased populations, and expansion and intensification of activities, land uses and infrastructure. The combination of a dynamic bio-geophysical environment and intensified human use has increased the vulnerability of mountain social–ecological systems to risk from hazards. The ability of social–ecological systems to build resilience in the context of hazards is an important factor in their long-term sustainability. The role of resilience building in understanding the impact of hazards in mountain areas is examined and illustrated, in part, through examples from Canada and India. Resilient social–ecological systems have the ability to learn and adjust, use all forms of knowledge, to self-organize and to develop positive institutional linkages with other social–ecological systems in the face of hazards. The analysis suggests that traditional social–ecological systems built resilience through avoidance, which was effective for localized hazards. The more recent development and implementation of cross-scale institutional linkages is shown to be a particularly effective means of resilience building in mountain social–ecological systems in the face of all hazards.

Keywords Mountains · Hazards · Vulnerability · Resilience · Social–ecological systems · Institutional linkages

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1 Introduction

Until recently, perceptions of mountains were embedded with connotations of danger (Nicholson 1963). Nevertheless, people have inhabited the mountains for generations, living with the dangers posed by earthquakes, landslides, avalanches, flash floods, fires, cold temperatures, storms, wild animals, etc. (Hewitt 1997a). Any process or condition that constitutes a threat to human safety and property may be considered a hazard. Today, perceptions of danger have ameliorated but record numbers of people travel through, visit and inhabit mountain regions and levels of risk and vulnerability are high, if not increasing (Hewitt 1997a). Even if the frequencies and magnitudes of hazards are not increasing in mountain areas, the level of risk and vulnerability are, due to changes in economic and social conditions (Gardner 2002).

Three factors are important in understanding hazards in mountain regions. First, mountain regions are relatively active geophysically and hydrologically and they are biologically diverse by virtue of an altitude- and aspect-driven variability in energy and moisture. Second, mountain regions are diverse in the make-up of their social systems, which range from relatively small, isolated settlements based on subsistence agriculture, animal husbandry and/or gathering and hunting, to complex, diversified and linked population centers made up of permanent residents, economic migrants, amenity migrants, tourists and other transients. Third, the linkages between mountains and other areas are defined by flows of air, water, materials, animals, people, goods, services, information, money and influence or authority and, in every respect, these highland-lowland linkages have increased in number and importance in the 20th Century.

The understanding of hazards and the consequent disasters rests as much on knowledge of the human dimensions as the bio-geophysical dimensions (Blaikie et al. 1994; Steinberg 2000; Klinenberg 2002). The work of Barrows (1923) and the early natural hazards research, exemplified in Burton et al. (1978) and Hewitt and Burton (1971), recognized the importance of both natural and human factors. Yet, much subsequent hazards research and mitigation has focussed on forecasting, controlling and/or preventing the bio-geophysical conditions and processes, neglecting the human factors and with little effect in terms of reductions in loss of life, injury, property damage and disruption of economic or other activity (Hewitt 1983). Mountain areas have become increasingly disaster-prone in the 20th Century and a disproportionately high number of disasters occur there, as compared with other environments (Hewitt 1997b).

The goal of this paper is to contribute to understanding hazards in mountain social–ecological systems through the use of the concept of resilience (Folke et al. 2003; Resilience Alliance 2003). Social–ecological systems are integrated systems of people, including their resource-use practices and technological and institutional arrangements, set within their natural environments. We hypothesize that resilience-building and enhancement in social–ecological systems can ameliorate and mitigate the impacts of hazardous processes significantly. Resilience-building and enhancement in mountain social–ecological systems refers to increasing the ability to learn and adjust, to use all forms of knowledge, to self-organize and to develop constructive institutional linkages with other and higher order social–ecological systems. The objective of the paper is to articulate the conditions that contribute to resilience building and enhancement in mountain social–ecological systems in the face of hazards and in the aftermath of a damaging and destructive event (i.e., a disaster).

The methodological approach taken in the paper is expository and historical. That is, examples are used to illustrate a concept, resilience, and the elements that support it or not in a mountain environment. The examples are not meant to be a representative sample of all cases. The data and information presented through the examples are from previously published, (i.e. secondary sources), and from archival records (i.e. unpublished reports, diaries, letters, newspapers, maps and photographs). The examples were chosen to illustrate similarities and differences between situations in contrasting societies. Most importantly, the examples were chosen to provide an historical dimension. Indeed, in the best of all worlds, value is added through the learning provided by events in the past. History also provides examples in which learning does not take place and/or where the conditions leading to and accompanying disaster are immutable through time. In either case, examples from the past are presented to emphasize the importance of learning from disaster, particularly if the goal is to enhance resilience and sustainability of social–ecological systems. Finally, the examples were chosen to illustrate similarities and differences between hazards of differing types.

2 Resilience as a concept

Resilience has emerged in literature on psychology, ecology, food aid and famine, resources management, health, and climate change (e.g., Holling 1986; Folke et al. 2003; Berkes et al. 2003; Bingeman et al. 2004; Chapin et al. 2004). Some limited applications are found in recent treatments of hazards in mountain regions (Weichselgartner and Sendzimir 2004; Robledo et al. 2004). Resilience is sometimes seen as a corollary of vulnerability (Buckle et al. 2000) and both terms have been used with a variety of meanings and without consensus. Kasperson and Kasperson (2001) define resilience as a component of vulnerability and Buckle et al. (2000) point out that qualities of a community that reduce vulnerability are indicative of resilience. However, the relationships between vulnerability, as the degree of exposure of a social–ecological system to hazards and risks (Blaikie et al. 1994), and resilience may be more complex. Vulnerability and resilience may have positive and negative correlates depending on the situation. A social–ecological system that is highly resilient at a certain location or time, also may be highly vulnerable, and vice versa. Much of the hazards literature focuses on vulnerability. The focus on resilience building is a positive approach with a focus on the strengths of a system as opposed to its weaknesses.

Berkes et al. (2003) identify resilient social–ecological systems as those that enable livelihood sustainability in the face of change through self-organization, re-organization and learning. Characteristics that enhance resilience include: vibrant leadership, shared goals and values, established institutions and organizations, positive socio-economic trends (stable and healthy population and diversified economic base), constructive external partnerships and linkages and the availability and use of resources and skills (Buckle et al. 2000) (Fig. 1). As such, they will be sensitive to locational and temporal aspects of hazardous processes and will seek to incorporate diversity, redundancies, skills, resources, technologies, partnerships and institutions intended to mitigate the impacts of hazards. Among these characteristics, those related to human and social capital are key to building and enhancing resilience. Social capital includes the capacity of individuals and groups to build relations of trust and reciprocity, to adhere to commonly agreed rules, norms and sanctions, and to be able to work together and with other institutions (e.g., Ostrom

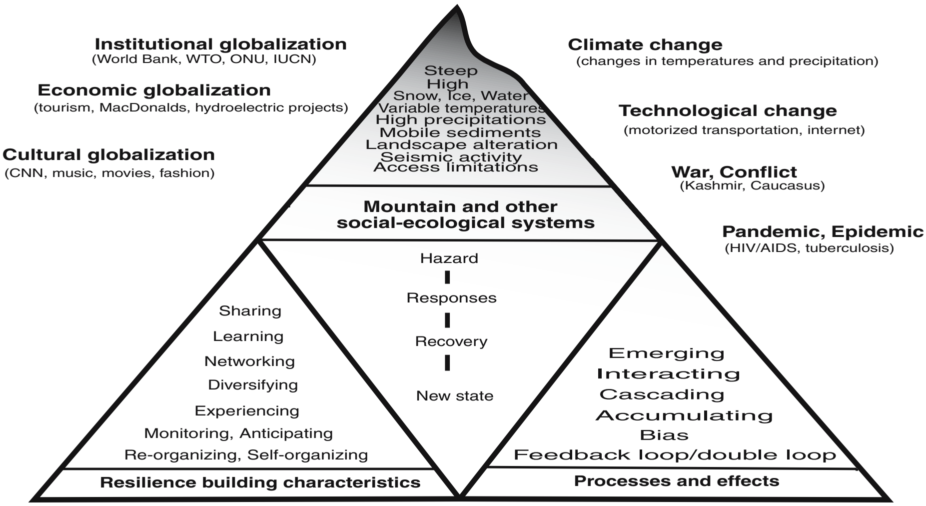

Fig. 1 Building resilience of mountain social–ecological systems. *Note*: The impacts of any particular hazard process (i.e., hazard, responses, recovery, new state) are a product of the magnitude of a biogeophysical process and the levels of vulnerability and resilience of the social–ecological system. These are influenced by global factors, different types of processes and effects, and the resilience-building characteristics of the social–ecological system

1992; Pretty and Ward 2004). Social capital in the form of associations and entrepreneurial behavior can influence the degree of cooperation locally and beyond and thus influence peoples' ability to adjust in the face of change.

Caution must be taken as some of the same characteristics that enhance resilience can lead to rigidity and conservatism in the face of stresses, strains and crises. For instance, shared goals and values and established institutions and organizations may produce resistance to change so that the system becomes less resilient in the face of future hazards. The corollary of each of these characteristics almost certainly produces a condition of high vulnerability and an inability to cope and adapt in the context of disaster (Dekens 2005).

The key qualities in building resilience are the ability to learn, i.e., to acquire knowledge, and the ability to apply it to a situation or anticipated situations, i.e., to adapt. Knowledge is acquired through experience and observation and that of others past and present, and through the ability to apply general principles to particular situations. Adaptation requires that the knowledge is then used to purposefully adjust the characteristics of the social–ecological system and/or alter the characteristics of the physical environment, in this case to reduce the impact of future hazardous events, including those that may be unanticipated. Thus, adaptation or adaptability is central to resilience. Much of the research on human adaptation in a social–ecological context is described in the literature of Geography and Anthropology (e.g. Firth 1969) and the focus has been on local realities and the static measures in place rather than on the dynamics of change (Goodman and Leatherman 2001). Batterbury and Forsyth (1999) pointed out that there are many more components to sustaining livelihoods than simple adaptation to environmental change. Limited attention to cross-scale effects and influences and its static nature (Brooke 2001) have led to criticism of the human adaptation approach and have stimulated attempts to move beyond it to the concept of resilience.

3 Resilience and scale

Most hazards and disasters have local and external components at different scales. Interacting and cascading effects operate within and across scales and make the understanding and mitigation of hazards complicated. A particular landslide or flood may test the resilience of a social–ecological system but factors far removed from the time and location of the event also may influence resilience. Global factors including, climate change, technological change, economic, cultural and institutional globalization, war and conflict and pandemic and epidemics (Table 1, Fig. 1) are examples. Their influences are eventually felt even in the most remote mountain communities and the pace of such articulation and impact has increased over time.

Each global factor may have particular outcomes at the regional/national level that, in turn, influence resilience and the impact of hazard events at the local level. For example, global climate change may produce magnified regional shifts in temperatures and precipitation. The archeological and historical records bear witness to movements of human populations into and out of mountain areas coincident with climate variations over the past 40,000 years. Continuing climate change and variation in mountain areas could lead to changes in the frequency and magnitude of floods, fires, landslides, snow avalanches, droughts, etc., thus influencing hazards at the local scale. Various global economic changes, such as the 1930s economic depression, and pandemics, such as the 1918 influenza, had impacts in local mountain communities increasing their vulnerability and decreasing resilience in the face of further shocks, stresses or crises.

Interacting and cascading effects operate across scales, though not exclusively. For example, a mountain social–ecological system may become less resilient as a result of an aging population that itself may result from out-migration or diminution of a younger, productive segment of the population. In turn, this may be due to external attraction of cash-paying jobs, disturbances such as war, and diseases such as HIV/AIDS. In another example, a mountain social–ecological system may become less resilient to hazards associated with unusual, high magnitude rainfall events that produce catastrophic soil erosion and loss of agricultural productivity. This may result from deforestation in the surrounding area. The deforestation may have been stimulated by regional or global increases in demand and, therefore prices, for wood products and facilitated by the incursion of a sophisticated commercial system of contract buying, as occurred in parts of the Himalaya under British administration in the 19th Century (Tucker 1982).

Cascading effects in hazard events, often operating across scales, have tested and eroded the resilience of mountain social–ecological systems. For example, in high mountain regions such as the Himalaya and Andes, earthquakes are usually regional in their impacts, causing the collapse of structures and damage to infrastructure of all sorts over wide areas (Hewitt 1976). At the same time, they may produce secondary landslides and snow avalanches that have their own more localized impacts, including damage to structures and roads and death and injury (Barnard et al. 2001). Hewitt (1984, 1997b) suggests that the impacts of slope failures arising from earthquakes have been underestimated. One of the inherent vulnerabilities in mountain terrain is that access is especially susceptible to blockage by landslides and snow avalanches. The linearity of power transmission lines, pipelines and land-based telephone lines also makes them especially vulnerable. The disruption and

Table 1 Global factors affecting hazards and resilience in mountain regions

Factor/trend	Mechanisms (examples)	Local impacts (examples)
Climate change	Reduction/increase in precipitation and/or temperature	Increased/decrease prevalence of floods, droughts, landslides, storms, avalanches, fires
	Reduction/increase in precipitation type and intensity	Change in seasonality or timing of weather thresholds such as onset of frosts, onset of monsoon/rainy season
	Reduction/increase in extreme temperatures	Change in growing season, degree-days, etc.
Globalization	Dispersal and diffusion of information, ideas, preferences, materials, technologies, etc.	Increased demand for new goods and services (mountain tourism)
	Changes in market conditions	Raised expectations vis-à-vis living standards
	Changes in number and type of employment opportunities	New markets for local products (medicinal plants)
		Increased cash income and demand for cash income (out-migration)
		Greater competition for markets (local products no longer competitive)
War/conflict	Restrictions and limitations on movement and travel	Population decline
	Changes in political and social relations and alliances	Death and injury in civilian population (loss of productive capacity)
	Changes in population and its structure	Erosion of trade networks and economic base (tourism)
	Forced migrations	Destruction of property and infrastructure
		Damage to environment and resource base (soil and water contamination)
		Depopulation of specific areas/regions
Organizational shifts	Changes in international/national protocols, standards and alliances	Conservation protocols leading to land use restrictions and limitations (protected areas)
	Changes in political and governmental structures	New livelihood opportunities (eco-tourism)
		New governmental priorities (focus on environmental protection, basic education, health care)
Pandemics epidemics	Population reductions	Loss of productive capacity
	Changes in population age structure and sex ratios	Isolation and disruption of economic and social linkages (tourism and trade)
	Chronic illness and reduction in productive capacity	Resources diverted from livelihood support (economic decline)
	Reductions in life expectancy and longevity	
Improved health care, nutrition, etc.	Increase in population	Agricultural expansion, deforestation, erosion, etc.
	Increase in demand for food and services	Increased waste production, pollution and contamination
	Increased longevity and life expectancy	Productive capacity to population ratio may decrease or increase

interruption of access, communications and energy and water supplies significantly hampers rescue and recovery operations and delays medical and other services, which may engender the spread of infectious diseases, in this case a tertiary hazard. Thus an earthquake produces a number of disruptions across scales through a cascade of subsidiary hazardous processes and effects, thus testing the resilience of social–ecological systems in several ways.

Finally, hazards and disasters offer more than only creating negative consequences. Resilient social–ecological systems may benefit from new opportunities presented in the aftermath. First, this may occur as a result of learning from the crisis and making adjustments to deal with future events. Second, a disaster may produce an infusion of large sums of money and other resources through institutional cross-scale linkages. Such relief is usually targeted for rebuilding infrastructure and housing which generates significant numbers of new jobs and other economic opportunities through spin-off effects, in addition to replacing aging and inadequate infrastructure that could have otherwise been a drain on the social–ecological system. Third, the infusion of emergency medical and social services may produce a legacy through a continuation of a higher level of such service on a permanent basis. Fourth, some hazardous processes result in the revitalization of resources such as soil and plant life as in the case of floods, hurricanes and volcanic eruptions (e.g., Colding et al. 2003). Finally, disasters make the news and the affected social–ecological systems may be able to turn this notoriety and attention to their future benefit through the development of ‘‘attractions’’ for visitors and aid from international donors. Thus, resilience may be measured as well by the ability of a social–ecological system to take advantage of opportunities presented by hazards and disasters. At the same time, cross-scale dependencies may be created that discourage local-level initiatives to build resilience.

4 Building resilience

Building resilience is necessary for effective mitigation of hazards. Folke et al. (2002) identify learning from crises, nurturing diversity, utilizing all forms of knowledge and creating opportunities for self-organization as resilience building and enhancement attributes. Later analysis will show that developing external links and partnerships may be important as well. Building resilience is a challenge in the rapidly changing conditions in many mountain regions. Changes include shifts in biogeophysical conditions, expansion of infrastructure such as buildings, facilities and roads, erosion of traditional knowledge and practices, natural population growth through a reduction in mortality due to improved nutrition and health care, in-migration of permanent and transient residents, natural resource extraction, development of commercial agriculture and horticulture, protection of strategic interests and national security, war, and tourism development (e.g. Gardner et al. 2002).

4.1 Learning

Learning from previous crises, including those affecting others, is important in building resilience and mitigating the impacts of hazards. Mountain regions provide examples of such learning as well as of situations where people have not learned from experience (de Scally and Gardner 1994). Experience is useful in identifying locational and temporal aspects and conditions associated with event occurrence. Many mountain communities know through generations the areas subject to floods, landslides, snow avalanches, etc. and the conditions under which they occur. They know how to avoid dangerous areas and restrict their use at dangerous times. Today, sophisticated knowledge and technologies exist for hazard assessment and mapping that can assist in this process (Gardner and Saczuk 2004). Apparent absence of learning may be related to limited alternatives, lacking, ignored or lost knowledge, inadequate transfer of knowledge between places, communities and organizations and inadequate tradeoffs between the perceived benefits of the status quo and the costs of changing.

4.2 Diversity

Social–ecological diversity builds resilience by creating and maintaining options and choices. This is especially important in maintaining sustainable livelihoods. Knowing how and what diversity is required to enhance resilience comes about by learning through experience. Various levels and types of ecological diversity are present in mountain regions as demonstrated by topographic, geological, climatic, hydrological and biological diversity within relatively small areas. The range in altitude and slope aspect produces variable moisture and energy balances that, in turn, produce a diversity of micro-climates and ecosystems. The resulting diversity of natural products and conditions can support a variety of livelihood activities. Typically, mountain social–ecological systems rely on a range of activities that includes hunting, gathering, shifting and sedentary agriculture, animal husbandry, horticulture, etc. Within the individual activities, diversity and redundancy may be built in to protect against hazards. Diverse crops provide dietary variety as well as protection against damage by species-specific diseases. Household fields may be dispersed rather than contiguous to provide protection in the event of floods, water shortages, landslides and diseases that are place specific. Climatic and ecological seasonality is a form of temporal diversity. Although hazards and limitations accompany seasonality, it does also increase the variety of livelihood options. Examples are found in the lower elevation Himalaya, where winter and summer cropping is practiced with wheat, barley and maize alternating with paddy rice, and in temperate mountains where winter ski tourism replaces other forms of summer tourism and agriculture.

Social–ecological diversity may be enhanced further by manifestations of modernity. Economic activities that accompany incursions of people, facilities and infrastructure into the mountains provide livelihood options in the form of cash employment that can supplement or supercede traditional practices. Tourism development is an example. These opportunities increase income and diversify livelihood options that in combination enhance resilience. However, over-reliance on new opportunities, such as tourism, without attention to diversity may lead to increased vulnerability to hazards. The collapse of the tourist industry and livelihoods in Kashmir with the rise of armed conflict in 1989 (Gardner et al. 2002) is an example, as is the decline of tourism throughout the mountains of South Asia following the attacks of September 11, 2001. Further, the process of economic diversification does not mean that everyone in a social–ecological system can benefit from it. Lack of equality and equity within such systems may prevent or erode resilience and increase vulnerability among the disadvantaged populations.

4.3 Local knowledge

Folke et al. (2002) and Davidson-Hunt and Berkes (2003) demonstrate that combining different types and systems of knowledge can enhance resilience. Lack of attention and sensitivity to local knowledge can lead to increased vulnerability of life and property. Social–ecological systems, present in hazardous environments over many generations, usually have resilience in many forms not always apparent. In addition, they may have customary land use practices, which are designed to ensure livelihoods. The associated knowledge, often referred to as indigenous, traditional or local knowledge, is contained and transmitted in forms different from those associated with western scientific knowledge (Ramakrishnan et al. 2005). As a result, outside interests may discount, discredit or simply ignore the indigenous knowledge. In the context of resilience, the resulting dangers are threefold: introduced facilities, people and activities are improperly located and/or timed, new technologies are introduced that may increase vulnerability, and new institutions, rules and procedures are introduced which erode the local livelihood sustainability making the people and communities less resilient.

For the most part, indigenous social–ecological systems in the mountains have an acute understanding of the ecological resources and hazards (Duffield et al. 1998). The results are seen in the location, materials and building styles of homes and other structures, the layout of settlements, organization and types of agricultural practices and products and the annular patterns of life. Lack of attention to the knowledge and understanding, which lies behind these arrangements by newcomers, can result in unnecessary risk and, sometimes, disaster (de Scally and Gardner 1994).

Interventions may change or disrupt local practices and make people less resilient. A common example comes about as a result of new land use or land tenure rules. The establishment of Reserved Forests in the mountainous parts of British India in the 19th Century altered indigenous livelihood systems and made some people and communities less resilient by denying access to forest-based livelihoods. The establishment of parks, wildlife reserves, and other protected areas in mountain regions following international standards and guidelines has eroded traditional livelihoods at the local level in Kunjerab Park in northern Pakistan (Ali and Butz 2003), Great Himalayan National Park in Himachal Pradesh (Saberwal and Chattre 2001) and Nanda Devi Biosphere Reserve in Garhwal, for example. An extreme case is found in the story of the Ik (mountain) people of northwest Kenya whose social–ecological system was destroyed as result of the creation of a national park in combination with the onset of drought (Turnbull 1972). Building resilience in mountain social–ecological systems demands recognition of, and attention to, local knowledge and practices to avoid these situations.

4.4 Self-organization

Self-organization refers to the ability of a social–ecological system to establish agencies, arrangements and institutions to mitigate the effects of hazards. Self-organization is useful in forecasting and publicizing hazard events, reacting in an organized and effective way in the face of an emergency and having in place organizations and institutions to oversee longer-term rehabilitation and reconstruction. In traditional mountain settings, examples of self-organization arise as a result of learning through experience in dealing with hazards and risks. The learning produces local knowledge, retained and passed on by a variety of means. The knowledge is translated into practical measures that may help mitigate and ameliorate hazards and risks and deal with the aftermath of disasters. The process of shared learning and the creation of a shared body of knowledge that is intergenerational requires self-organization. Community sanctions and prohibitions against building in dangerous areas are products of self-organization. Commonly used methods of avoidance such as the migration of whole communities out of danger zones at certain times of the year as happens in snow and avalanche-prone areas of the western Himalaya during winter (de Scally and Gardner 1994) is another example of self-organization that builds resilience.

Assisted by the introduction of new technologies and knowledge, communities through various means of self-organization may develop warning systems that ameliorate hazard and risk. Flood, landslide and avalanche warning systems, including the technologies and administrative structures, are examples. More often, local knowledge and existing institutions are either ignored or over-ridden and new laws and practices are put in place. In mountain areas subject to external influences, including the in-migration of new people and activities, the traditional prohibitions may become codified in law, or they may not and new practices and laws are codified to suit the newcomers. The establishment, in the affected place, of organizations, technologies and institutions may or may not improve resilience in the face of hazards.

4.5 Linkages and partnerships

The establishment of institutional linkages and partnerships is an essential component in mitigation, amelioration and recovery from disasters and, therefore, resilience building. The role of external influences and linkages has been twofold. On the one hand, external influences have contributed to the erosion of resilience in mountain regions through influences on bio-geophysical conditions and, more so, through alterations in the extent, intensity and type of human activities thus exposing more people and property to danger and, through social change, by altering the ability of communities to adjust to disaster. On the other hand, external linkages and partnerships do provide a medium through which resources and assistance flow to the affected area and populations in the event of disaster. Without this flow, sustainability of some communities would be doubtful. We would argue that this is of critical importance in mountain regions where the physical reality of isolation from main centers of population and authority, has exacerbated disaster in the past. Where the balance lies is difficult to tell and varies from one situation to the next (Dekens 2005).

5 Resilience in mountain social–ecological systems: examples

Mountain regions provide many examples by which to examine the role of resilience in social–ecological systems in the face of hazards. As noted in our discussion of methodology, the examples are meant to be expository and are not representative samples. They are used to illustrate some key points as outlined earlier. By using an historical approach, lessons learned may be demonstrated, as may be lessons not learned. Some factors leading to disaster may be immutable and unchangeable through time. Not only have the levels of risk and the impacts of hazards in mountain regions increased over the past Century largely as a result of human activities, but the possibilities and means through which to ensure resilience of mountain social–ecological systems have increased as well. Clearly, this has happened in some instances but not in all.

5.1 Epidemics in the Kootenays, British Columbia, Canada

Epidemics of new contagious diseases (smallpox, measles, influenzas) swept through the southern interior mountain region of British Columbia in the 19th Century (Harris 1997; Gordon 2004). In the Kootenays (50N/118W), the impact was sufficient to decimate the existing populations of indigenous peoples such that newly arrived migrants entered into essentially ''uninhabited'' lands. The legacy today is a confusion of traditional rights and codified ownership. This is a story repeated in many mountain areas of the world (Hewitt 1997b), and elsewhere, as outsiders introduced new diseases. In the 19th Century and before, no effective means of treatment or immunization were available and, of course, natural immunities were rare if they existed at all. In the face of such hazards, human vulnerability was extremely high and social–ecological systems collapsed quickly as their productive and reproductive capacities eroded. The situation in the 19th Century in the Kootenays is an extreme example in the sense that there was no prior learning, local knowledge provided no effective responses, helpful external linkages were non-existent and effective interventions did not exist anywhere. It is an historical example but could it be repeated?

Infectious diseases continue to impose a toll on mountain social–ecological systems (Hewitt 1997b) despite a build-up of resilience through interventions for prevention, treatment and care. Gastro-intestinal infections, cancers, tuberculosis, and influenzas, some drug-resistant, continue to take a toll in loss of life and livelihood sustainability. The emergence in the 1980s of HIV/AIDS as a pandemic that has reached into the mountain regions, worsened the situation (Seddon 1995a; Cox 2000). Bio-medically, HIV is easily prevented and is becoming treatable. Its growth to pandemic proportions has been driven by social, economic and political factors that are less easily controlled. Few aspects of this hazard are distinctive to mountain regions apart from the fact that men and women in mountain communities have become increasingly mobile in search of cash-paying jobs and mobility is one of important factors in spread of HIV infection (Seddon 1995b; Mann 1992). Its transformation to AIDS lays humans open to opportunistic infections, such as some of the above, which do the killing. Its impact is felt most among the productive age groups and the young in any social–ecological system, thereby attacking the very basis of its resilience. Young women are increasingly subject to infection through heterosexual transmission. The pandemic is a disaster in progress and it could well be the defining human disaster of the 21st Century, as were smallpox and measles for the indigenous mountain people of the Kootenays in the 19th Century and the ''Spanish'' flu for the newcomers in the Kootenays, and others the world over in 1918.

The lessons in this example are: (1) the vulnerability of human populations to new infectious diseases is extremely high and this has not changed through time, (2) geographical and social isolation of some populations makes interventions, and especially those enacted through external linkages, very difficult, and (3) the geographical, social and economic characteristics of social–ecological systems strongly influence the impact of this hazard and the impact is felt through generations.

5.2 Floods and debris torrents in Kullu, Himachal Pradesh, India

Floods and debris torrents are a commonly occurring hazard in the Kullu District (32 N/77 E) of Himachal Pradesh, in the heart of the Pir Panjal Himalaya. They include monsoon rainfall and snowmelt floods on the main stem of the Beas River and rainfall-generated floods in its steep, low-order tributaries. Some speculation in the media and scientific literature suggests that the frequency and impact of these events has increased in the 20th Century due to deforestation and over-grazing in this part of the Himalaya. The speculation arises in the aftermath of deadly and damaging events such as those in 1993, 1996, 2002 and 2003. However, subsequent research (Gardner 2002) has demonstrated that deforestation has been limited in the relevant areas and any increase in the impact of the events can be attributable mainly to the extension and intensification of human activities in the area.

The geography of settlements in Kullu attracted the attention of early colonial administrators in the 1850's (Harcourt 1871). Each settlement consisted of a tight assemblage of wood and stone structures, situated on valley-side terraces well away from the Beas River and, for the most part, away from valley-side streams, gullies and active landslide areas and avalanche slopes. Settlements were located at approximately regular intervals. Each was surrounded by a layout of cultivated and, usually, terraced fields owned by members of the community. This pattern was conditioned, in part, by local knowledge of the most dangerous places with respect to flooding and related hazards. In other words, the permanent residents had developed some measure of resilience through locational choices. This was buttressed and supplemented by institutions (i.e., rules) about the building of residences outside the confines of existing settlements.

A review of documentary records of the area from 1850 to the present provides little evidence of flood damage until 1894 when a major flood/debris torrent swept down the Phojal Nalla (stream) killing over 200 people and hundreds of sheep, goats and cattle and destroying crops near its confluence with the Beas River (Civil and Military Gazette 1894). This event was caused by a landslide that dammed the stream and created a small lake, followed by a dam burst and torrent that swept through a temporary encampment of traders and herders on the active floodplain at the Beas/Phojal confluence. This is a demonstration of the relatively higher vulnerability of temporary residents by virtue of location, in contrast to permanent settlements. The loss of many members of the trading fraternity affected the long-standing Kullu to Lahul, Spiti and Tibet trade link for years afterwards, giving advantage to the trans-Himalayan trade links through Kashmir and Garhwal (Civil and Military Gazette 1894; Rizvi 1999).

The 1993 event also affected the Phojal Nalla, destroying and damaging newly built homes and shops outside the traditional settlement areas. The 1996, 2002 and 2003 events disproportionately impacted camps of migrant construction workers and their families, in this case from the plains and neighboring Nepal. These losses did not have long-term impacts as in 1894 because surplus and mobile labor exists in South Asia today and losses are quickly and easily replaced.

The lessons in this example are: (1) the rapid onset of damaging events in the mountains affords little warning, (2) prior learning about hazardous terrain by long-established residents provides the basis for placing settlements and valuable property in safe locations, (3) newcomers, temporary residents and migratory workers may occupy land that is highly vulnerable to hazards, and (4) hazardous processes reoccur in the same locations and reoccurring and increasing impacts at those locations are related as much to the human factors as to the physical factors.

5.3 The 1905 Kangra earthquake, Himachal Pradesh, India

The Kangra (32 N/76 E) earthquake occurred on April 4, 1905 and measured at least 8 on the magnitude scale. It had impacts throughout the northwest Himalaya, including the Kullu District, and was felt throughout India (Civil and Military Gazette, April 1905). Kullu was among the mountain areas most affected and the impacts are described here to illustrate cascading and interactive effects in such a hazard. Also, in the context of the current situation, the example illustrates the importance of external linkages as an element of resilience. The main shock struck Kullu at about 6am on April 4, 1905, a time at which many people were still indoors and during a season when most livestock were still housed in the lower floors and surroundings of the houses. In Kullu alone 827 people died, over 10,000 livestock perished, 17,058 houses were destroyed and 16,208 houses were damaged (Punjab District Gazeteer 1918). No fatalities occurred among the European settlers in the area.

The relative inaccessibility of the Kullu area is illustrated by two points: news of the devastation in Kullu did not reach the "outside world" until April 12, and the colonial administrator of the area, Mr. Calvert, was outside the area when the earthquake struck and, despite an attempt at a speedy return, was not able to reach Sultanpur, the capital and site of major damage, until April 21 because of the blockage of trails and tracks by landslides and snow avalanches. This was before the time of motorized transport. Damaging aftershocks continued well into July and landslides continued to obstruct access and pose a hazard until the end of the monsoon season in September, 1905, as a result of the weakened state of sediments on hillslopes (Civil and Military Gazette 1905). Throughout the aftermath, outbreaks of cholera and other infections were reported in settlements in the area.

The example illustrates cascading effects initiated by the earthquake and its aftershocks, largely through landslides and other secondary and tertiary hazards, and the consequences of limited access becoming even more limited as a result. The emergency response phase was left entirely to the local community, as was the initial part of the recovery and reconstruction phase. Reconstruction of destroyed houses was not completed for several years in some cases and it was left to the devices of the local community and district administration. One administrative action that assisted in this was the lifting of timber-cutting restrictions so that local people could replace destroyed and damaged structures. Evidence of built-in resiliency is found in the fewer fatalities among people and livestock in the traditional wood and stone structures which withstood the initial shock as opposed to the more recently built masonry structures in Sultanpur which collapsed (Punjab Gazetteer 1918). The impacts on life and livelihoods in Kullu were enormous and felt for years following but the communities did "bounce back" and recover, largely through their own devices.

Many of the same qualities characterize earthquake disasters in the mountains in more recent times (Hewitt 1976), including secondary and tertiary hazards, differential structural damage and death, disruptions to access and retarded emergency response and, perhaps, limited external support in long-term recovery for at least some sectors of the affected population. Significant advances in emergency response and recovery, and therefore resilience, have been made as a result of rapid dissemination of information, improved overland access, access by air, improved health care and public health measures, increased strategic importance of many mountain areas and new international organizations and agencies focused on disaster relief. For the most part, elements of new resiliency in mountain social–ecological systems in the face of earthquake hazard result from external linkages and influences.

The October 8, 2005 earthquake in northern Pakistan reiterates that some of the vulnerabilities present in 1905 remain and may be inherent to mountain regions. Emergency relief and recovery were slowed and hampered by the mountain weather and terrain, by continuing aftershocks and fear, by landslides, by the broader institutional unpreparedness, by the lack of financial and other resources and by the political sensitivities in the region. Large numbers of people remain without shelter long after the event, food stores were destroyed and the onset of cold winter weather had secondary impacts on the health and safety of the populace. Increased populations, incessant conflict and the widespread building of unsafe structures, in contrast to the traditional construction, in the area have exacerbated the impact beyond that experienced in 1905.

The lessons learned in this example are: (1) mountain terrain and weather make relief and rescue efforts extremely difficult, even in the present circumstances, causing mountain communities to be especially vulnerable and lacking in resilience in the short term, (2) traditional and indigenous construction technologies provide some measure of protection in the face of earthquake hazard, (3) the impacts of earthquakes are felt regionally so that assistance from near-by is often not available, and (4) earthquakes cause a number of secondary and tertiary hazards at the local level in the mountains that exacerbate and magnify impacts and impede relief and recovery.

5.4 Snow in Carpenter Creek, British Columbia, Canada

Snow is both a hazard and a resource in high mountain regions. Snow and snow avalanches have long disrupted movements of people and transportation of goods and services, caused death and injury to people and animals and damaged property and infrastructure. Also, the lack of snow in the mountains contributes to water shortages, localized droughts, failed winter tourism and increased forest fire hazard in following seasons. In other words, mountain social–ecological systems must adjust to the effects of too much as well as too little snow. The effects are not only localized. Transportation delays caused by avalanches can affect a regional and national economy as in Canada where the main rail and highway transport routes traverse avalanche hazard areas in British Columbia (Woods and Marsh 1983). Perhaps more importantly, too much snow or too little snow in mountain watersheds during the winter may lead to water surpluses (floods) and water shortages (hydrological droughts) in rivers affecting regions well outside the mountains. At present, snow avalanches continue to pose a hazard to transportation in British Columbia, as they do in snowy mountain terrain elsewhere. In addition, the growth of skiing in its several forms and back country snowmobiling have exposed large numbers of recreationists to the hazard and this sector is most affected through fatalities and injury today in British Columbia.

This bittersweet story of snow in the mountains could be illustrated with many examples. The role of snow in the early history of commercial mining in British Columbia illustrates some of the key points (Gardner 1986). Carpenter Creek (50 N/118), also in the Kootenays, opened to silver mining in 1892 with a ''rush'' of several thousand miners appearing within a few months. The town of Sandon, with a maximum population of about 5000, came into being within 2 years and it was linked by cart roads and a railroad to mainline transport routes to facilitate the transport of people, goods and ore. This rapidly emerged social–ecological system had no reason for being other than the mining of galena, the ore of silver, lead and zinc. Many of the new arrivals had little experience of living and working in snowy, mountain country. The steep, forested slopes of Carpenter Creek valley provided a ready supply of town and mine construction materials as well as fuel for heating, processing and transport. Uncut forest areas were burned to more clearly see exposures of ore-bearing rocks (Gardner 1986).

The Columbian (Selkirk) Mountains of British Columbia are known for their avalanche hazard. An elevated snow avalanche hazard at town sites and mine sites and along the transport routes between confronted the miners in Carpenter Creek valley. In heavy snow years, such as 1904, lives were lost and injuries were sustained; buildings, mine portals and water flumes were destroyed or damaged; and transportation of ore within and out of the area was delayed, causing significant economic losses. In light snow years, such as 1910, mining and ore concentration were curtailed because of water shortages and the subsequent summer's operations were curtailed further by extensive forest fires because of the drought.

The social–ecological system was in a situation of extreme vulnerability, much of it centered directly or indirectly on snow. At the same time, it exhibited remarkable resilience in managing snow as a water and power resource, using it to transport ore from difficult to access mine sites during winter through a practice called ''rawhiding'' along snow and ice-lined trails and chutes and adjusting the timing of transport of ore and goods, movements of people and mining activities to mitigate hazards (Gardner 1986). The Carpenter Creek mining community had its ups and downs through the years but it persisted until 1929–1930. Its collapse came about not because of difficulties with too much or too little snow but because of the collapse of silver prices on the world market, a global factor external to the particular social–ecological system.

The lessons in this example are: (1) social–ecological systems may exacerbate an existing hazard through uninformed environmental alteration, in this case by clearing the forest on steep slopes, (2) pursuit of a particular livelihood activity, in this case mining, can put social–ecological systems at extreme risk, (3) at the same time, remarkable resilience can be demonstrated in mitigating the hazard and taking advantage of the beneficial aspects of the material or process, and (4) resilience in dealing with hazards at the local level may be entirely negated by a lack of livelihood resilience in the face of pervasive global factors, such as falling commodity prices and economic downturns.

5.5 Wildfires of 2003 in British Columbia, Canada

June though September, 2003, was one of the worst forest fire seasons ever in British Columbia. Over 2500 fires, spread over a vast area of the mountainous interior, were recorded (Filmon 2004). In 2003, the fires destroyed over 400 homes and businesses in various locations, 45,000 people were evacuated, the total cost of fires (2003) was estimated at over $700 million and approximately 260,000 ha of forest were burned. Forest fires are not a new phenomenon in the mountains of British Columbia but the fires of 2003 caused more damage and disruption than any up to this time. Fires occurred prior to European settlement and they have certainly been a factor throughout the 200 years of settlement in the interior of the Province. For example, in the previous case from the Carpenter Creek area, it is known that the summer of 1910 experienced widespread, destructive fires throughout the southern interior and some of these impinged on mining operations in the Carpenter Creek valley and surrounding areas. Other years of widespread forest fires subsequently occurred. Usually, these outbreaks followed on several years of below normal precipitation that produces progressive drying of living and dead flammable material. The year 2003 was no exception as it was the fourth year of successive drought (Filmon 2004).

Other causal factors, in both the bio-geophysical conditions and the social–ecological systems, are now shaping the wildfire hazard in British Columbia. For at least 70 years, forest management practices in British Columbia have emphasized fire prevention, suppression and control, as has been the case throughout much of mountainous North America. In the 1970s, this approach began to change as it was realized that periodic fire performs useful functions in forest ecosystem health and maintenance. Fire prevention and suppression interfered with these processes and allowed the build-up of flammable material in forested areas, heightening the risk of fire and large, rapidly expanding wildfire outbreaks. In some areas, such as National Parks, controlled burns and removal of flammable material have entered into forest management practices, in part to prevent the outbreak of high magnitude wildfires. Over the same period as fuel built up, people, settlements and other infrastructure expanded into the forested areas, raising levels of risk and vulnerability. In the two decades prior to 2003, increasing numbers of problematic fires were ‘‘interface fires’’ (Buchan 2004; Filmon 2004) or fires that impinged on human settlements. This increasing hazard and increasing vulnerability has been recognized for some time but until 2003, few communities and governments took it into consideration in their land regulation and management practices.

The 2003 fire season and the Okanagan Mountain Park Fire in particular that burned into the southern suburbs of the City of Kelowna in August 2003 may have changed that. Pictures of high-priced homes burning quickly found their way into the national and international media, drawing attention to what was really a localized disaster with minor impacts in terms of loss of life and property and erosion of livelihoods when compared with many disasters in mountain regions around the world. The visual aspects of the fire were spectacular and added to the attention. Within days, regional, provincial, national and even international linkages and partnerships came into play to assist in the emergency response. A year later, most of the destroyed and damaged buildings had been replaced and repaired through federal and provincial disaster subsidies and private insurance claims. The construction trades and materials suppliers thrived. It has been a remarkable demonstration of resilience in the face of disaster, coming about through external linkages. At the same time, flammable material has been removed, therefore reducing risk levels for the near future. However, many similar interface situations are present throughout mountainous North America. While one would hope that learning from the 2003 events will inform practices in the future and elsewhere, new realities such as the widespread expansion of pine bark beetle, which kills trees and adds to the dry fuel load, and a trend to warmer and drier weather, increases the hazard in general.

Lessons learned in this example include: (1) wildfire hazard has been exacerbated by forest management practices of the recent past and vulnerability of human settlements has increased as a result of expansion of urban-fringe residences into forested areas, (2) spectacular visual effects of wildfire impinging on up-scale urban-fringe areas quickly gets attention through the media, especially television, and this brings into play rapid response throughout the local to international spectrum, (3) visibility, cross-scale institutional linkages, effective management and access to a variety of financial resources can ameliorate the effects of disaster in a remarkably short period of time, demonstrating high levels of resilience despite very high levels of vulnerability.

6 Conclusions

Mountain regions are subject to a variety of hazards and provide examples of many disasters. In part, this is a consequence of the bio-geophysical characteristics of the environment (Fig. 1). Also, population increases and changes in the type and intensity of land uses have changed the nature of mountain social–ecological systems and the exposure of people and property to risks from natural hazards. Vulnerability has increased as a result. These changes at the sub-regional and local levels often arise from large-scale global factors and trends such as climate change, economic, institutional and cultural globalization, technological change, war/conflict/terrorism and pandemics and epidemics.

The purpose of this paper was to examine the resilience of mountain social–ecological systems in the context of hazards. Some literature suggests that resilience is the corollary of vulnerability or, in other words, as resilience increases, vulnerability decreases. This review suggests a variant in the sense that vulnerability describes a condition of exposure while resilience refers to processes that come into play during and following an event that allow a social–ecological system to carry on, perhaps in an altered state. This, in turn, may produce a change in vulnerability, or it may not. Resilient systems have the ability to learn from experience and make adjustments, along with a number of other characteristics that have been articulated (Fig. 1).

In conclusion, five general points emerge. They are:

1. In "traditional" mountain social–ecological systems, higher levels of resilience were achieved primarily through avoidance by management of location and time, diversification of agricultural products and utilization of the variable and diverse micro-ecosystems that characterize mountain environments.
2. This worked well for localized hazards (e.g., landslides, floods, debris torrents) but did not do so in the case of regional hazards such as earthquakes, droughts, epidemics and fire that produce widespread and lagged interactive and cascading effects.
3. Global and regional factors (e.g., climate change, institutional change, war, epidemics) may act to increase or decrease vulnerability and resilience of mountain social–ecological systems.
4. While vulnerabilities may have increased in mountain social–ecological systems in the 20th Century, resilience of those systems has increased as well through the

emergence and effectiveness of cross-scale and other linkages and partnerships with other regions and organizations operating at national and international scales and has been facilitated by an ability to move information, materials, services and resources over great distances quickly.

5. Having said this, disasters still occur in mountain regions and they bear similar characteristics to those that have occurred in the past. Despite evidence of increased resilience, rugged and complex terrain, variable and extreme weather, distance and isolation, social, political and economic inequities, and poverty, marginality and powerlessness magnify the impacts of and prolong recovery from disaster.

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