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From Knowledge to Action

From Social Vulnerability to Resilience: Measuring Progress toward Disaster Risk Reduction

by Melanie Gall

InterSecTions
'**Inter**disciplinary **Sec**urity Connec**Tions**'
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United Nations University
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UN Campus
Hermann-Ehlers-Str. 10
53113 Bonn, Germany
Tel.: + 49-228-815-0200
Fax: + 49-228-815-0299
e-mail: info@ehs.unu.edu

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About the author

Dr. Melanie Gall is a hazards geographer and certified floodplain manager (CFM) with expertise in the quantification of disaster losses, social vulnerability, flood insurance, hazard mitigation planning, geospatial analysis, and impact assessments. She combines geospatial technologies with social science methods to answer pertinent questions in hazards geography and emergency management.

Her publications can be found in *Natural Hazards Review, Disasters, Bulletin of the American Meteorological Society,* and other journals. Her experience includes post-disaster research in Haiti, Mozambique and the United States Gulf Coast. She serves on the Hazard Mitigation and Adaptation Committee of the Natural Hazard Mitigation Association and is currently a visiting assistant professor at Claflin University, South Carolina, where she teaches classes on environmental justice, natural disasters and social statistics. She holds a PhD in Geography from the University of South Carolina (USA).

Dr. Melanie Gall

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Measuring Progress toward Disaster Risk Reduction

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We would like to thank Katharina Brach and Andrea Wendeler for their support in editing and publishing this article.

We are grateful to the Munich Re Foundation for its support and friendship. Our thanks go to Thomas Loster and Christian Barthelt who made the Munich Re Foundation Chair on Social Vulnerability such a successful seven-year long project!

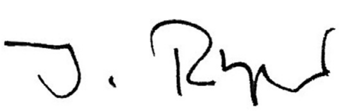
Foreword

Vulnerability and resilience are complex concepts, used extensively and in many variations. Vulnerability most often includes elements of exposure (people, places and infrastructure at risk from a hazard), susceptibility (the degree to which the people, places or infrastructure are harmed), coping capacity (the skills, resources and opportunities of people and places to survive, absorb the impacts and manage the adverse outcomes) and adaptation capacity (the ability of people to implement necessary measures to reduce risks) (Cutter and Corendea, 2013; Beck et al., 2012). Resilience, on the other hand, is simply the obverse of vulnerability; while for others, vulnerability and resilience are interrelated but separate concepts (Cutter et al., 2008; Turner, 2010).

There are many debates in the literature on the concepts of social vulnerability and resilience, but these simplified approaches capture their essence. Social vulnerability and different types of resilience broadly provide sufficient opportunities for (non-) governmental organizations to frame policies and practices for their specific mandates and, in this way, support the shift from theory to practice in order to support communities in becoming more sustainable and resilient.

The Summer Academy 2012 successfully attempted to add practicality to concepts and helped its participants to realize the roles of social vulnerability and resilience in the realities we face today. Professor Susan Cutter, as Chair of the Munich Re Foundation Chair on Social Vulnerability, shifted the perspective of interpreting climate change events into a broader, more functional outlook which, I am sure, in the future will open a new path in climate change research and, later, in policy-making. Putting knowledge into action – paraphrasing our partners at Munich Re Foundation – the participants of the Summer Academy 2012 had an opportunity to develop and sharpen their own understanding of social vulnerability and resilience, according to their own experiences, creating a large spectrum of perceptions and future applications.

As this is the last foreword for a Munich Re Foundation Chair on Social Vulnerability publication, which concludes a series of 18 publications during the last seven years, I would like to thank Munich Re Foundation, in particular Mr. Thomas Loster and Mr. Christian Barthelt for their enduring support in this project and their wonderful friendship. Here at the United Nations University Institute for Environment and Human Security (UNU-EHS), we treasure every moment of one of our longest and most successful projects. To our Chairs and facilitators over the years, thank you so much for your dedication and support: over 150 students from around the world can vouch for their appreciation of your guidance! And to our UNU-EHS team, who worked so hard to bring these publications alive together with providing major policy contributions – the famous paragraph 14f or the Loss and Damage Programme – I express my deepest gratitude and appreciation.



Prof. Dr. Jakob Rhyner
Director, UNU-EHS

Foreword

Since 2005, the Munich Re Foundation has supported a Foundation Chair at the Institute for Environment and Human Security of the UN University in Bonn. The Chair on Social Vulnerability project and the related Summer Academies investigated how social vulnerability can be measured and how vulnerability influences various areas of human life.

We have conducted research on where the decisive factors of vulnerability lie in cities and in the countryside, how vulnerability varies according to gender and what role it plays in the context of natural hazards and catastrophes. Environmental and climate changes and migration (which is often linked to them) take place in physical space, so geography has been a constant companion in research into these areas.

Analytical methods that take space into consideration, such as Geographic Information Systems (GISs), play a special role in the context of vulnerability. They are far more than a mere cartographer's tool. GISs support the investigation of people – place relationships and are a valuable planning tool. Because GISs are so powerful, we made them a focus of the final year of the Foundation Chair project and of the Summer Academy at Hohenkammer near Munich. Through case studies and hands-on activities, students explored the value of GISs in the context of social vulnerability and in increasing resiliency.

This edition of *InterSecTions* discusses the challenges associated with assessments of resilience. Although GISs support the analytical process and visualization of results, they cannot replace decisions at the front-end: which resilience framework to choose and how to implement it? Many modelling decisions and assumptions are required along the way when creating a resilience assessment. Data availability and accuracy might prohibit the implementation of certain approaches, whereas other frameworks might be nearly impossible to operationalize as a result of their complexity. There are many knowledge gaps and limitations associated with measuring resilience, which are outlined here. Choose your framework wisely, implement the model carefully and GISs will generate reliable and justifiable results.

We wish you a stimulating and informative read!

Thomas Loster
Chairman of the Munich Re Foundation

Table of contents

User guide

The margins of the InterSecTions series – A service for the cursory reader

The InterSections Series means to provide direct, knowledge-based recommendations as basis for well-founded decisions.

Our InterSecTions Series provides authoritative research and information for policy-makers and decision makers; additionally we provide a service for the cursory reader.

To receive the full message of the respective page one has to read the quotations provided in the margins. In those margins the reader will find thought-provoking, but well researched policy recommendations and the quintessence of the page.

Additionally, the quotations are placed directly beside the respective paragraph, so if the reader wishes to find out more, the quotations can easily be found in the text and the reading can be taken from there.

The editorial team of UNU-EHS hopes this format will be well received. However, any comments and/or recommendations of improvements are very welcome.

Introduction

What does it mean to be resilient? The answer depends on whom you ask. A psychologist would say it is a person's capacity to overcome stress, loss, trauma and other forms of adversity (Kirmayer et al., 2009). For a materials science engineer, elasticity represents resilience and the term is often used in conjunction with toughness, describing a material's ability to deform under pressure and regain its shape without fracturing (Ohring, 1995). And an ecologist considers a natural system resilient when it is capable of absorbing external shocks while maintaining its functionality (Holling, 1973). In the context of disaster risk reduction, resilience is 'the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions' (UNISDR, 2009).

Disasters consistently pose a challenge to society's resilience. In 2011, disasters triggered record costs of more than $380 billion, with the Tohoku earthquake in Japan accounting for more $200 billion alone (Government of Mexico and World Bank, 2012). Since 1992 natural disasters have caused more than 1.3 million deaths and more than $2 trillion in losses (UNISDR, 2012). The concentration of people and assets in high-risk areas combined with insufficient preparedness, response and mitigation approaches are contributors to this escalation of losses (Changnon et al., 2000; Sarewitz et al., 2003; Patt et al., 2010). Limiting exposure, reducing vulnerability and improving resilience are mechanisms for and avenues to stabilizing and perhaps even reducing losses.

The need for strengthening resilience is of particular importance given the looming challenges associated with climate change. Climate forecasts predict more frequent and more extreme events (IPCC, 2012), meaning accelerated disaster losses under business as usual conditions. This trend, if unmitigated, threatens the financial stability and sustainable development of many economies – including those of developed countries (Government of Mexico and World Bank, 2012; Michel-Kerjan et al., 2012).

The need for strengthening resilience is of particular importance given the looming challenges associated with climate change.

Creating disaster-resilient communities by enhancing and building adaptive capacities through investments in disaster prevention and preparedness avoids future losses. Making the case for investments in resilience requires facts and empirical evidence, especially during times of economic difficulties: disaster losses are inadequately documented (Bouwer et al., 2007; Gall et al., 2009; Kron et al., 2012), while benefits from resilience investments are difficult to estimate due to their complex, multi-faceted, often indirect and long-term nature. This leads to an underestimation of costs and resilience benefits, which undermines the full value of disaster risk reduction.

However, if measured comprehensively, the pay-off and return on investments from resilience-building efforts should far exceed the costs. As recommended in a report by the Global Facility for Disaster Reduction and Recovery (Government of Mexico and World Bank, 2012, p. 8), '(r)esilience to natural hazards should be a core element in the design of development programs'. In order to promote resilience as a loss-curbing strategy, advancements in the assessment and quantification of resilience are needed. If progress in resilience cannot be detected, monitored and evaluated, it will be difficult to justify the allocation of scarce monetary resources.

It is not only important to be or become resilient but also to assess and quantify resilience baselines and progress.

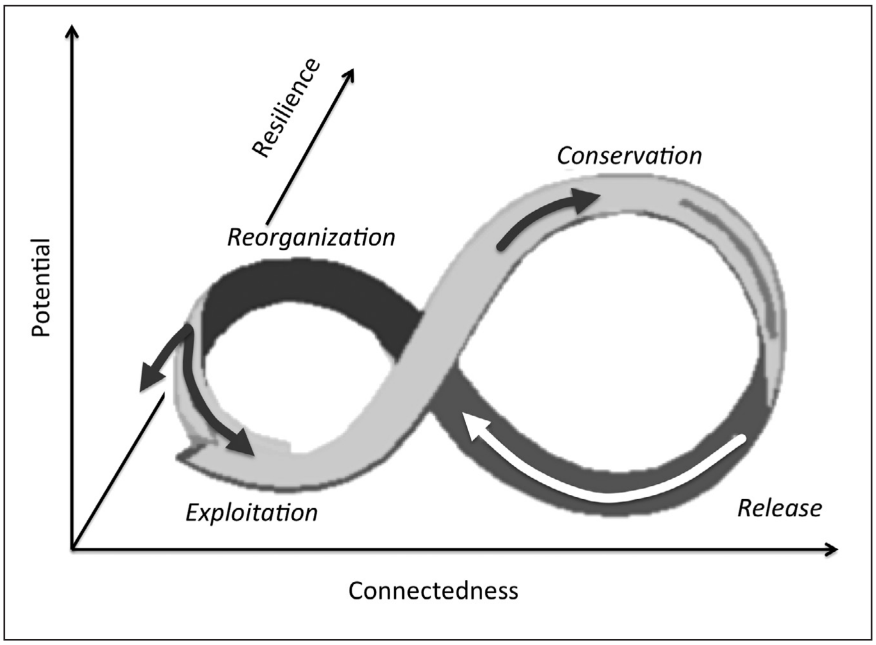
Thus, it is not only important to be or become resilient but also to assess and quantify resilience baselines and progress. Who is resilient and to what? Whose resilience is it? When is someone or something resilient? How does someone or something acquire resilience?

Many of these questions were raised during the 2012 Summer Academy 'From Social Vulnerability to Resilience: Measuring Progress toward Disaster Risk Reduction' organized by UNU-EHS and Munich Re Foundation in Hohenkammer, Germany. This publication draws on discussions and presentations given at the 2012 Summer Academy (http://www.ehs.unu.edu/article/read/summer-academy) and reviews existing research outlining the current state of resilience assessments. It concludes with several suggestions for and steps towards answering the above questions and moving resilience research forward.

From vulnerability to disaster resilience

Many different meanings of resilience exist (Brand and Jax, 2007). In its essence, resilience is a concept that captures the relationship between the environment and society, particularly how the social-ecological system responds to stresses and shocks in order to maintain functionality (Folke, 2006). The concept originated in the field of ecology (Holling, 1973). Its etymology is Latin, derived from the word *resilire,* which means to leap back, rebound, contract or shrink. In ecology, resilience represents a dimension of the adaptive cycle (see Figure 1), which consists of enterpreneurial exploitation, organizational consolidation, creative destruction and re- or destructuring (Gunderson and Holling, 2002).

Figure 1: Resilience influences the cycle of exploitation, conservation, release and re-organization that operates at multiple levels.



Source: adapted from Gunderson and Holling (2002).

Vulnerabilities are systemic conditions that adversely affect, destabilize or erode ecological resilience (Gunderson, 2010). In fact, high degrees of vulnerability create favourable conditions for shifts in the adaptive cycle (Holling, 2004). Embracing change and adaptation led many researchers in the field of adaptive systems to replacing the term 'recovery' with 'renewal', 're-organization' or 'regeneration' (Folke, 2006).

Vulnerabilities are systemic conditions that adversely affect, destabilize or erode ecological resilience.

In its current form, the concept of disaster resilience is less influenced by ecological resilience than by research in the social sciences and engineering resilience. Over the past two decades, vulnerability evolved from sustainability, quality of life and environmental justice research (Cutter, 1996). Similar to resilience, there are many definitions of vulnerability, which vary by context (e.g. hazard mitigation planning, livelihood studies, food security, climate change, etc.) and academic discipline (Cutter et al., 2003; Adger, 2006; Eakin and Luers, 2006; Gallopín, 2006). Broadly defined, vulnerability considers the 'characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard' (UNISDR, 2009). According to this interpretation, vulnerability is a product of exposure, sensitivity and coping mechanism, which reflects pre-existing conditions (Adger, 2006; Oliver-Smith et al., 2012). It is therefore a fairly static concept, unlike ecological resilience (see Table 1).

Table 1: Comparison of analytical concepts in ecological resilience and vulnerability.

Analytical concept	**Ecological resilience**	**Vulnerability**
Integrated social-ecological analyses	Move from ecological toward social dimensions within coupled social-ecological system; social often considered secondary	From social to coupled social-ecological system or human-environment systems; still rare to truly integrate ecological processes
Approach to system	System thinking	Unit of analysis
Slow versus fast variables of change	Core	Core (understood as shocks and stresses)
Multiple stressors	Multiple variables	Core
Scale	Core (physical units from local to global)	Core (usually social units from local to global or geophysical units such as watersheds, etc.)
Alternate stable states	Core	Weak (except in terms of livelihood or governance strategies)
Social-ecological feedback	Core	Weak
Thresholds	Core (understood primarily as physical)	Rare
Adaptation	Core	Core
Transformation	Core	Weak (except in terms of livelihoods; rarely is attention given to the processes enabling or underlying transformation)
Adaptive management	Core	Core
Perturbations	Core	Core
Agency	Weak	Core

Source: adapted from Miller et al. (2010).

As a result, vulnerability assessments tend to create inventories of one or more societal systems (e.g. social, economic, built-environment, cultural, etc.). The objective is to pinpoint underlying conditions that place society at risk from the impacts of natural disasters.

The definition of disaster resilience (see Introduction) contains the word ‘resist’, which originates in engineering – not in ecological – resilience. It assumes that there is one equilibrium, the pre-disaster state, to which society returns after the event through recovery (Holling, 1996; Folke, 2006). Research on recovery times exemplifies this line of thinking (Cimellaro et al., 2010). According to this line of thinking, a community is resilient if it swiftly recovers after a disaster. Is a resilient community therefore not vulnerable?

Engineering resilience (Holling, 1996), also a term from ecology, is about resisting change and maintaining the constancy of the system. Flood control structures – or any other form of structural hazard mitigation – are an example of engineering resilience. Instead of changing and allowing the system to adapt, efforts are exerted to control flood waters by building more flood wall and storm surge gates, higher levees, more diversions and so forth.

Thus far, disaster resilience has not (yet) made the leap to incorporate system/regime changes. Some argue that system or regime changes are perhaps less applicable to human systems. Unlike ecological systems, human systems can plan, anticipate and mitigate future events (Gunderson, 2010). This has the potential for avoiding catastrophic impacts, enabling quick recovery and possibly sidestepping the issue of system thresholds. Adaptive actions ultimately advance – rather than transform – the human system. Discussion surrounding the impacts from climate-intensified extreme events (IPCC, 2012), however, could possibly require a broadening of the disaster resilience concept. According to Holling (2004), resisting change and avoiding adaptation allows a system to remain ‘locked in’ thereby increasing its vulnerability and chance of catastrophic collapse.

To reiterate, at present, natural hazards and disasters are not perceived as external shocks that trigger regime shifts. Oliver-Smith et al. (2012) see natural hazards and climate risks as routine disturbances and therefore only as stressors – not as shocks – which shape human societies. Post-disaster recovery provides ‘windows of opportunity for alternative system configurations’ (Gunderson, 2010) and fosters ongoing system evolvement while maintaining functionality.

At present, natural hazards and disasters are not perceived as external shocks that trigger regime shifts.

It is at this intersection of disaster resilience and disaster risk reduction, i.e. the shaping of systems to better cope with disasters, where the importance of assessing resilience is of greatest value. Without sound assessments, it is difficult to determine a disaster resilience baseline, monitor changes and evaluate the effectiveness of risk reduction efforts.

Elements of resilience

All frameworks aim at capturing an array of systems and factors representing exposure, vulnerability and coping capacity.

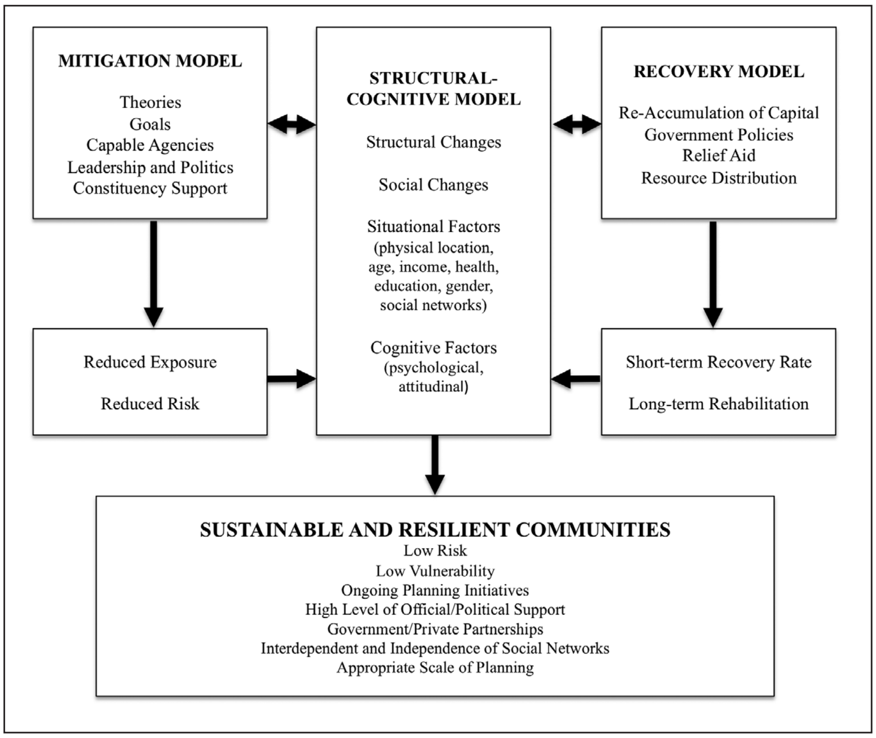
The tension between definitions of ecological and engineering resilience re-emerges in the construction of resilience frameworks. Systems-orientated approaches tend to draw heavily on the concept of ecological resilience and strive to incorporate change and dynamic aspects of resilience, whereas vulnerability- and adaptation-driven frameworks are more static with an actor- and/or place-centred perspective (Nelson et al., 2007). Although conceptual variations lead to slightly different representations of systems and system interactions, sources and underlying drivers of resilience remain fairly consistent across frameworks. In general, all frameworks aim at capturing an array of systems and factors representing exposure, vulnerability and coping capacity. Dependent on the purpose and scope of the framework, this includes one or more of the following systems:

- Physical system (e.g. critical infrastructure, communication systems, etc.)
- Human system (e.g. skills, knowledge, health, education, etc.)
- Social system (e.g. community networks, trust, civic engagement, norms, etc.)
- Institutional system (e.g. first responders, response systems, etc.)
- Technical system (e.g. warning systems, emergency plans, etc.)
- Economic system (e.g. income, productivity, etc.)
- Environmental system (e.g. fresh water, arable land, etc.)
- Ecological system (e.g. pollination, carbon sinks, etc.)

For more information, see Sherrieb et al. (2010), Cutter et al. (2010) and Constanza (2012).

Resilience is largely interpreted as system response, including time of recovery and degree of risk reduction. For example, the community resilience framework by Tobin (1999) considers resilience as a function of mitigation/adaptation and recovery, dependent on exposure and pre-existing conditions (see Figure 2). This model fits squarely into the traditional disaster resilience definition. It considers long-term, sustainable development rather than external shocks and emergent consequences.

Figure 2: Analytical framework for sustainable and resilient communities.

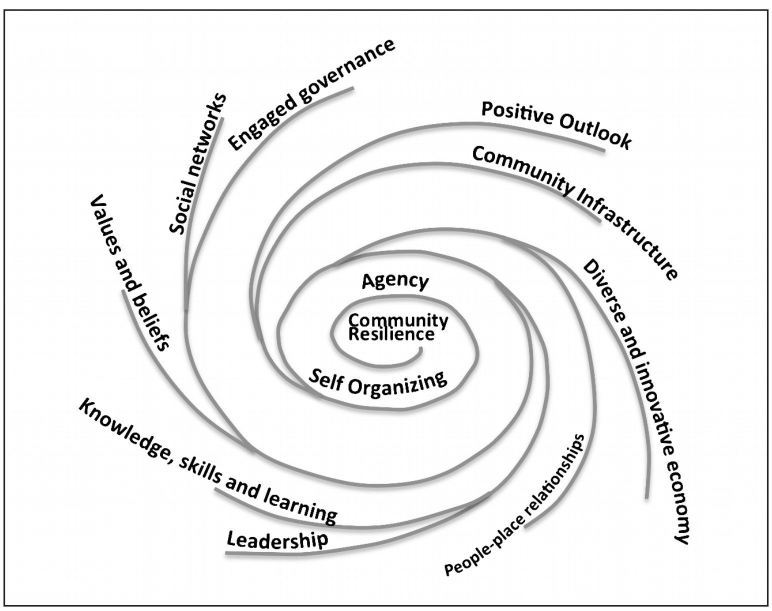


Source: Tobin (1999).

Interestingly enough, Berkes – who represents the ecological resilience school of thought – recently released a 'hurricane-shaped' community resilience framework (see Figure 3). The framework combines ecological resilience with psychological and developmental resilience. It also includes people–place connections, such as social and economic assets, while maintaining aspects of non-linearity, renewal cycles, scale and more. This appears to be a first step towards integrating ecological and disaster resilience.

The framework combines ecological resilience with psychological and developmental resilience.

Figure 3: Community resilience framework.



Source: Berkes and Ross (2013).

Resilience can therefore be interpreted as a system of systems and complex adaptive system.

Resilience as a system of systems

Aside from definitional differences, there are also implementation differences between resilience assessments. Among these is the issue of how to incorporate the scale-transcending or cross-scalar character of resilience. The various systems that create resilience share synergies, linkages and interactions across spatial as well as temporal scales. Resilience can therefore be interpreted as a system of systems (Bristow et al., 2012) and complex adaptive system (Allen et al., 2005). See Table 2.

Table 2: Components and system behaviours of complicated and complex systems.

	System of subsystems (complicated systems)	**System of systems (complex systems)**
Necessary system architecture	*Operational dependence of components:* Components cannot function as intended if they are disconnected from the system. *Centralized control of components:* Components do not make decisions for themselves.	*Operational independence of components:* Components can perform tasks without any connection to other components. *Managerial independence of components:* Components are self-governed to a degree; directed (hierarchy, leader sets goals), collaborative (teams, group decides goals) and virtual ('flat world', individuals negotiate goals).
Generally follows from system architecture, but not necessarily	*Localized distribution:* Components are physically 'close' to each other. *(Predictable) emergent behaviour:* As per requirements, the system achieves intended goals that components cannot accomplish separately. *End-product development:* Fixed arrangement – The system maintains the same structure, processes and purposes. Optimized – The system functions best within a specified range of operating conditions.	*Geographic distribution:* Components are physically 'far' from each other. *(Unexpected) emergent behaviour:* The system performs functions that components cannot do alone and carries out purposes that were not necessarily its original goals. *Evolutionary development:* Self-organization – Components and interfaces can be added, removed and modified, thereby altering the system's structure, processes and purposes. Adaptation – The system can adjust to changing operating conditions.

Source: Bristow et al. (2012).

Much of the system complexity arises from the interactions between system participants and the resulting responses. Participants interact within as well as between systems – and across scales. They range from individuals, households, groups (e.g. children) and organizations (e.g. for-profit, non-profit, governmental, etc.) to communities and nations. Gunderson and Holling (2002) coined the term 'panarchy' to describe the interaction and interlinkages between coupled human–natural systems and their continual cycles of adaptation, growth and restructuring (see Figure 1).

To illustrate this systems approach, imagine an individual infected by a highly contagious flu virus: the virus will incapacitate this person and likely the entire household. Without swift quarantine of the individual and/or household, the virus will spread quickly within the community and perhaps into neighbouring countries. As more and more people succumb to the virus, social, economic and institutional systems will reduce or lose functionality. Workers stay at home. Schools close down. Factories lose productivity and perhaps even close down. Health workers abandon their jobs. Tax revenue declines. Air travel comes to a halt. System participants can respond in many more ways to the pandemic – but the question is, who and what was resilient? If the individual had been quarantined, the effects would have been largely contained hereby making the system of systems more resilient. However, would the affected family have been resilient enough to cope with the quarantine and consequences of the flu?

As shown, the ability of the system of systems to respond and cope with the event depends not only on its participants but, more importantly, on how these participants influence each other. Based on vulnerability and risk research, knowledge regarding system participants – the resilience of whom or what – has significantly improved in recent years (Pelling, 2003; Forbes et al., 2004; Rose, 2004; Adger et al., 2005; Janssen et al., 2006); however, understanding the complex interactions within and between them remains rudimentary. This represents a major challenge in measuring resilience. System participants behave in a predictable way but also produce emergent behaviour with unpredictable and unintended impacts and consequences (Bristow et al., 2012). This complexity makes it nearly impossible to study interaction effects in linear systems. Even non-linear models are difficult to determine given the sheer number of variables that interact with each other (Pich et al., 2000). In addition, much of this interaction and the degree of interactions are unknown (McFadden, 2010).

The ability of the system of systems to respond and cope with the event depends not only on its participants but, more importantly, on how these participants influence each other.

A further complicating fact is that objectives and preferences of system participants are not necessarily congruent – perhaps even conflicting. For example, during a pandemic, healthy households might seek to travel to reduce their chance of infection. Imposing a travel ban to contain the outbreak would be in direct opposition to the interests of the household. As Cox states: 'The healthy functioning of the community over a range of stresses, including responses to and recovery from occasional rare catastrophes, depends largely on how well its members can adapt together to changing circumstances' (2012, p. 1929).

There is also considerable disagreement on the type and timing of when and how resilience can be detected. Haimes argues that, 'resilience of a system can be measured only in terms of the specific threat (input) and the system's recovery time and the associated composite costs and risks' (2009, p. 498). This contrasts the holistic approach promoted by all-hazards frameworks, which do not specify a specific stressor (Cutter et al., 2010; Ebi, 2011). In regard to the timing of resilience, Allen

Emergent complex systems such as resilience require the development of new and innovative analytics to overcome the limitations outlined above.

et al. (2005) question whether resilience can be assessed before a stress or shock is exercised since there is no system response without an event. Others claim that, '[a]t any given time, the actual or potential performance of any system can be measured as a point in a multidimensional space of performance measures' (Bruneau et al., 2003, p. 736).

Now which is it? Is there resilience to a specific hazard or is there general resilience? Is resilience only revealed after pressure is exercised or is it measurable at all times? Can resilience only be assessed when the entire system of systems is determined? It appears that emergent complex systems such as resilience require the development of new and innovative analytics to overcome the limitations outlined above.

Measuring disaster resilience

Given the novelty of resilience frameworks and the challenges associated with their implementation, researchers tend to rely on approaches and methodologies developed elsewhere – such as in the vulnerability community (e.g. self-assessments, rankings, etc.). Resilience research seems to parallel the trajectory of vulnerability studies, which would explain the development of general resilience frameworks (Cutter et al., 2008; Tobin, 1999), as well as specialized frameworks in regard to a select threat or for a specific sector/participant (Bruneau et al., 2003). As the body of research increases it will be necessary to consolidate, validate and connect the ever-increasing number of frameworks through implementation, meta-analysis, longitudinal research, follow-up studies, comparative analyses and other methods.

However, this is easier said than done. Putting a framework into action requires the selection of indicators, identification of feedback loops and so forth. Frameworks are a great starting point but many decisions on how to implement the model and measure resilience are left unresolved. Ideally, practitioners and researchers would mirror a framework's approach as much as possible, though this is rarely feasible given limited data availability, uncertain feedback loops and interaction effects, constrained computational resources to model cross-scale interactions and more. In fact, researchers found that there are frequent gaps and incoherences between the asserted definitional and contextual meanings of resilience/vulnerability and their implementation – particularly the absence of explicit frameworks (Hinkel, 2009; Ionescu et al., 2009). For example, in 128 instances of vulnerability assessments, Zou and Thomalla (2008) found only 14 per cent referencing a vulnerability framework.

Putting a framework into action requires the selection of indicators, identification of feedback loops and so forth.

Considering the seemingly insurmountable conceptual as well as methodological challenges, how can one assess resilience? What are existing measures of resilience and how are resilience frameworks operationalized? Is there one model that does the 'best' in assessing resilience? Unfortunately, a sound assessment tool capable of operationalizing resilience in its entire complexity has yet to emerge. It would appear that resilience assessments are undergoing growing pains similar to those experienced by vulnerability assessments in their early years. Many resilience case studies propose their own frameworks and metrics, limiting their generalizability and applicability in different contexts. Existing resilience assessments tend to compartmentalize the issue at hand by focusing on the resilience of specific localities, groups/organizations, infrastructure sectors and subsystems or on resilience against a specific threat. At present, there are four categories of resilience assessments, which can contain quantitative, qualitative (e.g. self-assessments) and mixed-method methodologies:

1. *Outcome-driven approaches* – focusing on estimating and/or modelling losses, recovery times and similar (e.g. Miles and Chang, 2006; Cimellaro et al., 2010; Beck et al., 2012).

2. *Input-driven approaches* – identifying underlying factors that influence resilience, including vulnerability (e.g. IADB, 2005; Fisher et al., 2009).

3. *Scenario-driven approaches* – documenting past or future system responses to a specific risk (e.g. Sempier, 2010).

4. *Complex system approaches* – inventorying independent elements of resilience with unknown feedback loops (e.g. Cutter et al., 2010).

A systems approach – or a system of systems – has yet to materialize.

A systems approach, meaning an approach capable of capturing the adaptive complex systems of resilience – or a system of systems – has yet to materialize. This is likely attributable to the lack of new and innovative methodologies suitable for representing dynamic, non-linear features and feedback loops. In their absence, the above listed approaches draw heavily on three different techniques gleaned from vulnerability assessments:

1. Probability theory, including fragility curves and stochastics.

2. Indexing by means of a single metric that scores units of analysis comparatively.

3. Qualitative ratings (self-assessments).

Indexing and qualitative rating are static snapshot assessments. While these are valid and feasible techniques for measuring vulnerability, they tend to contort the concept of resilience by removing some of its essential characteristics. For example, indices and rankings do not account for the interactions between system participants. All components are generally treated as independent entities, thereby eliminating the capacity for emergent behaviour. Probability theory, on the other hand, is a promising approach since it allows for dynamic developments, evaluation of system performance and the incorporation of surprise. It is capable of capturing the degree of change a system can accommodate while remaining within specified boundaries and system configurations. Thus far, though, the methodology has been exclusively applied to infrastructure resilience (Cimellaro et al., 2010) and outcome-driven approaches utilizing an engineering resilience framework that is characterized by system robustness, redundancy, resourcefulness and rapidity (Bruneau et al., 2003). Somewhat problematic, though, is the fact that probability-based approaches tend to rely on performance metrics such as recovery times or disaster losses, which might be flawed in their own way (Rose, 2004; Gall et al., 2009).

So, how can we overcome these weaknesses? Joint efforts and knowledge provide a largely untapped source. Evolving beyond vulnerability science, learning from ecological resilience as well as more collaboration between sustainable development, engineering, computer sciences, ecosystem management, disaster management and climate change adaptation, among others, may provide a path forward (Miller et al., 2010).

Research needs

Ecologists are now beginning to embrace and include societal systems and place-based aspects in their conceptualization of resilience (Gunderson, 2010; Berkes and Ross, 2013). They concede that human and ecological systems differ in terms of planning and anticipation. The ability to predict extreme events and impacts allows communities to make adjustments before the stress occurs and/or to mitigate its full impact (Westley et al., 2001). Social systems are capable of modifying thresholds and thus, delaying system transformation. But for how long?

This idea of system transformation and re-organization is rarely part of resilience discussion within the disaster risk community. While human systems might be able to postpone or influence how a system changes, it seems shortsighted to ignore this characteristic of resilience. Perhaps it is not the thresholds within human systems that force re-organization but rather thresholds and abrupt changes in the natural systems that impose change upon the human system. It is therefore prudent to further investigate the relationship between human and natural systems.

Folke et al. (2003) identified four additional areas, which have been largely ignored in the context of disaster resilience: learning to live with change and uncertainty; nurturing diversity; melding different types of knowledge to advance learning; and embracing opportunities for self-organization and cross-scale linkages. Applied to the advancement of resilience metrics, this could be translated into the following research agenda:

1. *Reveal uncertainties:* Resilience metrics are rarely accompanied by information regarding their uncertainties. Managing uncertainties is a central component of post-normal science (Funtowicz and Ravetz, 1993; Rotmans et al., 2001). Resilience measures and models should identify and reveal uncertainties to improve the comparative evaluation of approaches.

Resilience measures and models should identify and reveal uncertainties to improve the comparative evaluation of approaches.

2. *Look beyond your discipline:* As called for by Bristow et al. (2012), the diversity in interdisciplinary resilience research as well as methodologies must be improved. Intellectual 'cross-pollination' should be encouraged rather than resisted to tackle methodological weakness in measuring resilience.

3. *Collect new data:* Data on system responses and system changes are not as widely available as census data. This poses particular challenges for global assessments of resilience and the improvement of resilience models. Generating new and more resilience-specific data would foster better alignment of conceptual frameworks and their implementation.

4. *Develop innovative methods:* Resilience assessments rely heavily on indexing and qualitative assessments. Stochastic methods are left to engineers, physical scientists and mathematicians. The lack of collaboration between social and non-social scientists impedes the development of hybrid methods that combine qualitative approaches and probability theory. For example, modelling resilience as a system of systems is resource intensive but could be overcome by adopting ensemble modelling, which is standard in climate research.

It is time to explore the meaning of transformation and self-organization.

5. *Consider thresholds and multi-equilibria:* The terms ‘self-organization’ and ‘transformation’ are still largely absent from disaster resilience definitions. It is time to explore the meaning of transformation and self-organization – within social systems as well as in regard to the social meaning of transformations within the ecological system. Research on thresholds and equilibria should not be restricted to ecological systems (Allen et al., 2005; Folke, 2006).

It is time to invest in post-vulnerability science. Disasters and therefore resilience are ‘wicked problems’ (Rittel and Webber, 1973, p. 162); something for which there is no absolute problem formulation and for which it is difficult to identify a singular root cause or prescribe unambiguous solutions.

Conclusion

In sum, disaster risk management has made great strides in incorporating concepts of resilience. Existing resilience assessments and metrics are an excellent starting point from which to further advance methodologies and conceptual frameworks. Shortcomings in implementation and validation, though, are impeding the use of resilience metrics as decision-making tools and curbing their contribution to science-based policies (UNFCCC, 2012; NRC, 2012). The absence of effective assessment tools hampers the evaluation of adaptation actions and their effect on resilience, particularly in the context of climate change. Limited work on thresholds (and subsequently climate change resilience) may place the disaster risk reduction community and its focus on hazard mitigation/adaptation at odds with the climate change community, which favours climate mitigation and the reduction of greenhouse gas emissions. Constructing resilience as a system's ability to cope and persist does not bode well for transforming and developing a fundamentally new system largely independent from burning fossil fuels. Advocating disaster resilience and only 'tweaking' rather than transforming social, economic and technical systems (among others) could result in adverse long-term effects (Miller et al., 2010).

The absence of effective assessment tools hampers the evaluation of adaptation actions and their effect on resilience, particularly in the context of climate change.

In 2011, the Cancun Adaptation Framework, part of the Cancun Agreements at the 2010 Climate Change Conference in Cancun, Mexico, called for more adaptation actions to reduce vulnerability and build resilience, especially in developing countries (UNFCCC, 2011); however, the quality and capabilities of existing resilience assessment tools lag behind this pragmatic request. More work needs to be done to reduce uncertainties, comply with the Hyogo Framework for Action and 'use knowledge, innovation and education to build a culture of safety and resilience at all levels' (UN-ISDR, 2005, p. 11).

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UNITED NATIONS UNIVERSITY
Institute for Environment and Human Security (UNU-EHS)
UN Campus
Hermann-Ehlers-Str. 10
53113 Bonn, Germany

Tel: +49 228 815-0200
Fax: +49 228 815-0299
E-mail: info@ehs.unu.edu
Website: www.ehs.unu.edu