3RG REPORT

SKI Focus Report 8
Measuring Resilience: Benefits and Limitations of Resilience Indices

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TABLE OF CONTENTS

1 INTRODUCTION

This Focus Report provides a background to the measurement of resilience. Its first section introduces the topic and explores the reasons why resilience should be measured. Looking at the utilities of a resilience index, this report differentiates between the most central awareness and policy-guidance functions of such an instrument. The report's second section presents three different approaches to measure resilience. In each case study, the report explores the development and application, benefits and limitations of the index at hand. The third section discusses the pitfalls and potentials of resilience index-making at a more general level. The concluding section highlights the likely implications arising from this discussion for the development of a resilience index in Switzerland.

2 DEFINING RESILIENCE AND VULNERABILITY

Resilience and vulnerability have become key terms in the language of risk and security in recent times.[1] Both are used widely to denote general states of an entity – this community is 'resilient'; infrastructure is 'vulnerable' to attack; the organisation's 'resilience' has fallen *etc*. However, while these terms have become part of the risk vernacular, their actual meanings can vary as much as the uses to which they are put. Importantly, these meanings are rarely made explicit, whether in the context of academic or policy settings.

The Oxford dictionary gives two fundamental meanings for resilience, for example:

a) the ability of a substance or object to spring back into shape -> elasticity
b) the capacity to recover quickly from difficulties -> toughness

These meanings become considerably more nuanced, when applied in a risk context, breeding variability between disciplines.[2] A large part of the obscurity of resilience and vulnerability, when used in the contexts of risk and security, likely owes to their inherent complexity as concepts, and the uncertain linkages between them.[3] Indeed, this complexity and interconnectedness often mirrors the social, economic or environmental systems (and the entities that comprise these systems) we are attempting to characterise as resilient or vulnerable.

Adding to the stock of definitions is not the objective of this report, but adequately and consistently defining resilience and vulnerability has an impact on the ability to measure them. A recent publication from the CSS[4] provides working definitions for vulnerability: the tendency of a system to be damaged, when exposed to a hazard (or threat); and resilience: the degree of impairment a system can accomodate without becoming unstable. While these definitions are operational and representative of much of the relevant literature, they lack important nuance relevant to the study of resilience and vulnerability in complex systems. A somewhat different take on resilience has been advanced by Norris and other scholars[5], who examine community resilience in the context of disasters. They considered resilience a process linking resources like adaptive capacity, to outcomes like adaptation, readiness and response. These authors draw on a broad variety of literatures in taking this definition, and while more complicated, provides a better picture of how resilience manifests in systems. Perhaps neither definition is perfect for all contexts, but these are drawn on in this Focus Report. The nature of resilience, and its application in the literature and in practice is explored further in the Center for Security Studies factsheet No. 8.[6]

1 Bara and Brönnimann (2011).

2 Which could either be useful, or a barrier to operationalising these terms. See Strunz (2012) for an exploration of the dangers and possibilities that conceptual vagueness can bring to resilience development.

3 See for example (Adger, 2006; Folke, 2006; Gallopín, 2006; Haimes, 2009; Walker and Cooper, 2011) for a range of views on the origins, definitions and uses of, and linkages between 'resilience' and 'vulnerability' in the contexts of several disciplines.

4 Hagmann (2012).

5 Norris *et al.* (2008).

6 Giroux and Prior (2013).

3 MEASURING COMPLEX PHENOMENA LIKE RESILIENCE AND VULNERABILITY

Vulnerability and resilience are undoubtedly important system states in a security or risk context, and measuring these states has become a priority for academics, companies and governments. Many indices of resilience and vulnerability have been developed in disciplines like the humanities, environmental science, ecology, and information technology. In general, these measures employ different definitions of resilience and vulnerability, they are constructed using dissimilar constituents (indicators or variables), they are utilised for different purposes – and as a result they ultimately measure different things.

Even a basic exploration of what might constitute a measure (or index) of resilience, for example, reveals the difficulty in establishing a measure that is both accurate and "fit for purpose".[7] The application of a resilience index for use in an environmental (e.g. macroalgae resilience to marine pollution) or a psychological (e.g. children's resilience to post-traumatic stress) context might be difficult, but indices for such phenomena exist suggesting these endeavours are manageable and applicable. However, establishing an index to measure resilience in a linked socio-environmental (e.g. resilience to flooding) or socio-technical (e.g. water infrastructure) system requires an altogether deeper understanding of the relationships present within and between the systems.[8]

Even so, using indices or indicators (as proxies or relative measures) has become a key mechanism by which scientific information can be translated into policy outcomes. To political institutions, indices aim to provide authoritative guidance for resource allocation and programmatic decision-making, i.e., a much warranted decision support tool. However, any measurement requires a phenomenon to be observable and permit systematic attribution of value (like heat or height) – concepts like resilience and vulnerability are as yet highly conceptual and therefore hard to measure directly.

An example is useful to highlight why an index might be inadequate when applied to the purpose for which it is developed. Human development can be 'measured' using the Human Development Index,[9] which is calculated from three indicators: life expectancy at birth, knowledge and education, and standard of living. It can be used to indicate the vulnerability of a country, but while multidimensional (as opposed to other measures of development like GDP), it nevertheless paints only a simplistic picture of a country's progress or lack thereof because life expectancy, education and standard of living are only subjetive indicators of national development.[10] Ultimately, scientists are yet to agree on clear-cut conventions for measuring resilience or vulnerability, and there is consequently a significant literature discussing both how and whether these phenomena can and should be measured.[11]

3.1 Why measure resilience?

While resilience can be considered an inherent attribute of most entities, its expression is only evident in a post-threat (or disruption, or disturbance, or pertur-

7 Hinkel (2011: 203–205).

8 An interesting discussion of system complexity, resilience and vulnerability is provided by Holling (2001).

9 Anand and Sen (1994).

10 Sagar and Najam (1998).

11 See Hinkel (2011) for a systematic discussion of the application and appropriateness of vulnerability indicators.

bation) environment.[12] It is at this time when the level of an entity's resilience materialises in adaptation, recovery, resistance, rapidity or robustness, or in all of these.[13] In a security context, understanding how resilient societies, infrastructure or economies are to terror attack for instance, and how this resilience manifests, has significant implications for security policy and its development, and for the development of preparedness or mitigation strategies. Ultimately, building resilience is believed to minimise threat impacts and speed up recovery following an incident, so knowing *how* resilient an entity is becomes important.

Yet equally important is an appreciation of the difficulties of measuring concepts or processes like resilience, and whether it should (can) be done at all. Some of these issues are raised in relation to the particular reasons, why one might measure resilience described in this section. Section 5 provides greater detail on the main criticisms of measuring complex phenomena in order to couch the information presented in this report in the ongoing discussion about the use (and limits) of indices.

There are several generic reasons why resilience might be measured: a) to identify ways to build resilience; b) to raise awareness about the need for reslience; c) to allocate resources for the purposes of building resilience; d) to monitor the performance of policy designed to build resilience; e) characterising an entity's resilience.

12 Cutter *et al.* (2008).

13 Various authors from the fields of social science, psychology, ecology, economics, global change science and others have discussed and debated how resilience manifests. In reality, the manifestation of resilience varies hugely (and predictably) between different targets of the research in these disciplines, between the forms of disaster/disturbance/perturbation they assess, and with respect to the way they define resilience. Pertinent reviews and insights are provided by Holling (2001), Folke (2006), Norris *et al.* (2008), Walker and Cooper (2011), and Haimes (2009).

a) <u>Building resilience</u>: If resilience is an important process that contributes to an entity's response and recovery after disruption, then identifying entities with low resilience is important for managing that disruption and its consequences. Knowing the extent of resilience can help risk management agencies to best direct their assistance measures.

   A measure might allow a resilience 'threshold' to be developed for instance, that allows planners to make resilience-related policy decisions. For example, communities with resilience levels below a certain threshold might receive special assistance from government or social organisations, or guidance on how to build up their own resilience. Additionally, without measuring resilience it is difficult to gauge how resilience changes as a result of disruption or following the implementation of resilience-building practices or processes.

b) <u>Raising awareness</u>: For governments, methods of communicating the need to be resilient to entities can be assisted with an observable measure of resilience. While the most useful forms of information provided to entities in a risk communication process (for example that encourages resilient behaviour or actions) is still the subject of much discussion,[14] observations of resilience could at least help managers to direct resilience-related information to entities whose resilience is lower than some predetermined threshold. This activity is better encapsulated in the practice of risk communication than in the development and application of resilience measures *per se*.[15]

   The process of risk communication is intended to address some of the recognised (and perceived)

14 Several perspectives are provided by Grothmann (2006), Peters (2012) and Eriksen and Prior (2011).

15 Cf. Giroux, Hagmann, Dunn Cavelty (2009).

deficiencies in the mitigation of, or adaptation to disaster.

c) Allocating resources for resilience: Measurement allows the quantitative comparison of resilience between entities, and this becomes useful when risk management resources are limited. More funds, personnel or other resources might be directed towards building resilience in those entities whose resilience is considered to be low relative to a particular threat or disturbance, and to other entities (cf. the different, politically hierarchised, resilience profiles displayed in figure 1). A resilience index could be used (in the same way as risk matrices[16]) to argue that allocation of funds is made in an objective manner.
However, one of the key issues in allocating resources for resilience building (indeed in any proactive approach to mitigating the impacts of disaster) is not the establishment of the resilience index, but the creation and legitimisation of a suitable institution to manage the allocation.[17]

d) Monitoring policy performance: Once implemented, the effectiveness of resilience-building policy can theoretically be assessed by longitudinal comparisons of resilience in those entities targeted by the policy. Care must be taken, however, to ensure that before an index is developed, the purpose of the policy is explicit. An index to measure resilience is not a policy performance analysis tool, but a way of assessing the policy's efficacy in building resilience. To this end, the development of resilience-building policy should integrate the identification of policy goals and targets against which efficacy, or 'on-the-ground' outcomes might be assessed.

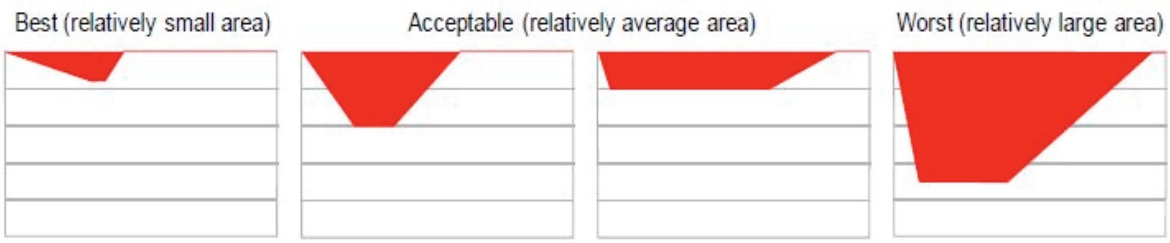

Figure 1: Different resilience profiles and their political hierarchisation (x-axes denote time, y-axes severity of impact). Image sourced from United States Homeland Security Studies & Analysis Institute (2010: 20).

17 Hinkel (2011) notes that allocating resilience resources based merely on an 'algorithm' is both practically and politically difficult. It is practically difficult because of the complexity of the concept/process, and the disagreement this might incite between those who receive resources and those who do not. It is politically challenging because the allocation of resources is always a politicised process where negotiation among parties is likely to outweigh the results of the application of any index.

16 Habegger (2010).

e) Characterising resilience: Given its multidimensionality, developing a measure for resilience can be a step towards characterising resilience in a particular context (such as flooding, or political turmoil). Establishing an adequate and usable measure of resilience first requires an articulation of the constituents, i.e., determining the indicators and variables of such case-specific resilience. This is especially so in an academic context, where both adequacy and reliability of those constituents as indicators of resilience should be validated and tested both theoretically and empirically.

9. Testing and validation aside, characterisation also results in a somewhat objective description of resilience as a fundamentally theoretical concept or process. Developing detailed characterisations of resilience can also allow reflection on the context in which such characterisation takes place, and deeper thinking about what the components of resilience mean relative to each other, and for resilience itself. Of course, this requires identification and articulation of the appropriate indicators.

4 EVALUATING EXISTING RESILIENCE INDICES

How is resilience measured in practice? What lessons can be learned from resilience and related indices? This section looks at attempts to systematically assess resilience. In choosing case study indices, no attempt is made to restrict the discussion to a narrow conception of security. Instead the view is taken that not only traditional threats influence security, but also non-conventional threats like resource scarcity, infectious disease, rapid population growth *etc*. In any case, there is a vast literature examining resilience indices and their development, which exists in a range of disciplines (ecology, disaster studies, psychology and others). These diverse indices provide a useful suite of examples to illustrate the objectives of this report, and to offer insights that can inform security resilience index-making.

In this section, we describe three approaches to measuring resilience that have different applications and implications. The first two are examples of quantitive measures of resilience – the Enhanced Critical Infrastructure Protection program and the disaster resilience of place (DROP) model. The last example illustrates a mixed-methods approach to measurement that incorporates both qualitative and quantitative assessment techniques. In each case, the development, benefits and limitations of the discussed approach are discussed (and summarised in table 1 at the end of section 4).

The examples discussed in this section are intended to provide the reader with a background on a variety of approaches to measuring resilience, ranging from quantitative to qualitative, from conceptual to empirical. These examples merely highlight that measuring resilience has been accomplished in very different ways, and the technique, or techniques used will depend on the measurer's requirements and the characteristics of the system they are interested in. Indeed, there seems to be no 'right' way to measure resilience, as long as the methodology used is robust and replicable.

4.1 Case 1: The Enhanced Critical Infrastructure Protection program[18]

Recent research sponsored by the US Department of Homeland Security (DHS) has focused on the development of several quantitative indices designed to assist in the risk management of critical infrastructures. The Protective Measures Index (PMI), Resilience Index (RI) and Criticality Index (CI) are intended to be used in an integrated fashion as part of the DHS's Enhanced Critical Infrastructure Protection Program. The initiative draws on this triumvirate of indices to conduct assessments that identify infrastructure vulnerabilities and build resilience through partnerships with federal, state, local and private sector stakeholders.

4.1.1 Application

Data is collected during critical infrastructure site visits, where an extensive network of Protective Security Advisers (PSAs – DHS employees) uses a survey tool comprising more than 1500 data points (variables). This information is used to characterise a facility in six key areas[19]: physical security (*e.g.* fences, lighting), security management (*e.g.* emergency action plan, staff background checks), the security force (*e.g.* training, patrols), level of information sharing (*e.g.*

18 Fisher and Norman (2010); Petit *et al.* (2011).

19 For a full list of the components within this survey refer to Petit *et al.* (2011).

threat sources), protective measures assessment (*e.g.* random security measures), dependencies (e.g. electricity, telecommunications). Data collection by the PSA takes between four and eight hours and data is analysed to calculate the PMI.[20]

The Resilience and Criticality Indices are formulated in the same hierarchical way. For resilience, the overarching components of robustness, recovery and resourcefulness are broken into specific subcomponents. Aggregating weighted values for each set of subcomponents yields the particular index, and the protective measures, resilience and criticality indices can be combined in a risk matrix to give an overall view of a facility's security.

4.1.2 Benefits

By integrating the aspects of vulnerability (the PMI is a proxy for vulnerability), resilience and criticality, the ECIP initiative aims to characterise the elements of harm and consequence before and after a threat, thereby assessing the entire spectrum of a given risk to some form of critical infrastructure or key resource. In addition, the regular execution of the three-component assessment[21] allows security planners to capture and analyse longitudinal changes in security for single infrastructures, and between similar infrastructures grouped in the same infrastructure sectors (for example, critical infrastructure used to deliver electricity or petroleum is classed in the energy infrastructure sector). Both features are designed to gain a better understanding of the relationship between the critical infrastructure and the environment.

The ECIP program is designed around a public-private partnership. A key feature of the program is the need to strengthen relationships and improve information sharing between government departments and the organisations that own and manage critical infrastructure. This program gives owners of critical infrastructure the ability to compare the security of their assets with other similar assets that might be managed in a different way. ECIP provides the DHS with a mechanism and guidelines to prioritise national protection efforts (allocation of resources to increase resilience and decrease vulnerability). To facilitate communication of results, information collated by the Program's analysts is shared with facility owners with an easy to use 'dashboard' or software interface that can represent data in a readable and understandable way (Figure 2).

4.1.3 Limitations

The extraordinary comprehensiveness of this set of measures generates its most significant limitations. The key limitations are summarised below:

a) The methodology established is very comprehensive, but requires a huge network of data collectors (PSAs) and analysts. Of course, this merely reflects the diversity and number of critical infrastructures supporting today's society. In 2010, the DHS employed 93 PSAs at an annual cost of USD 12 million, which was forecast to increase by an extra 15 officers in 2012.
b) Because the infrastructure survey collects information on over 1500 variables, the analysis and interpretation process is very demanding.
c) The methodology is used across a broad range of critical infrastructure and key resource sectors. As such, the indicators are necessarily generic (not

20 The PMI is an aggregation of these 'key areas', and the subcomponents within these areas. Each subcomponent (fence, threat source, emergency action plan *etc*) has been assigned a relative importance (weight) by an expert panel based on its contribution to protection. The PMI is a weighted sum of the values measured in the six key areas.

21 In 2010, 674 ECIP surveys were conducted, with a larger number planned for 2012. See DHS National Protection and Programs Directorate (March, 2011).

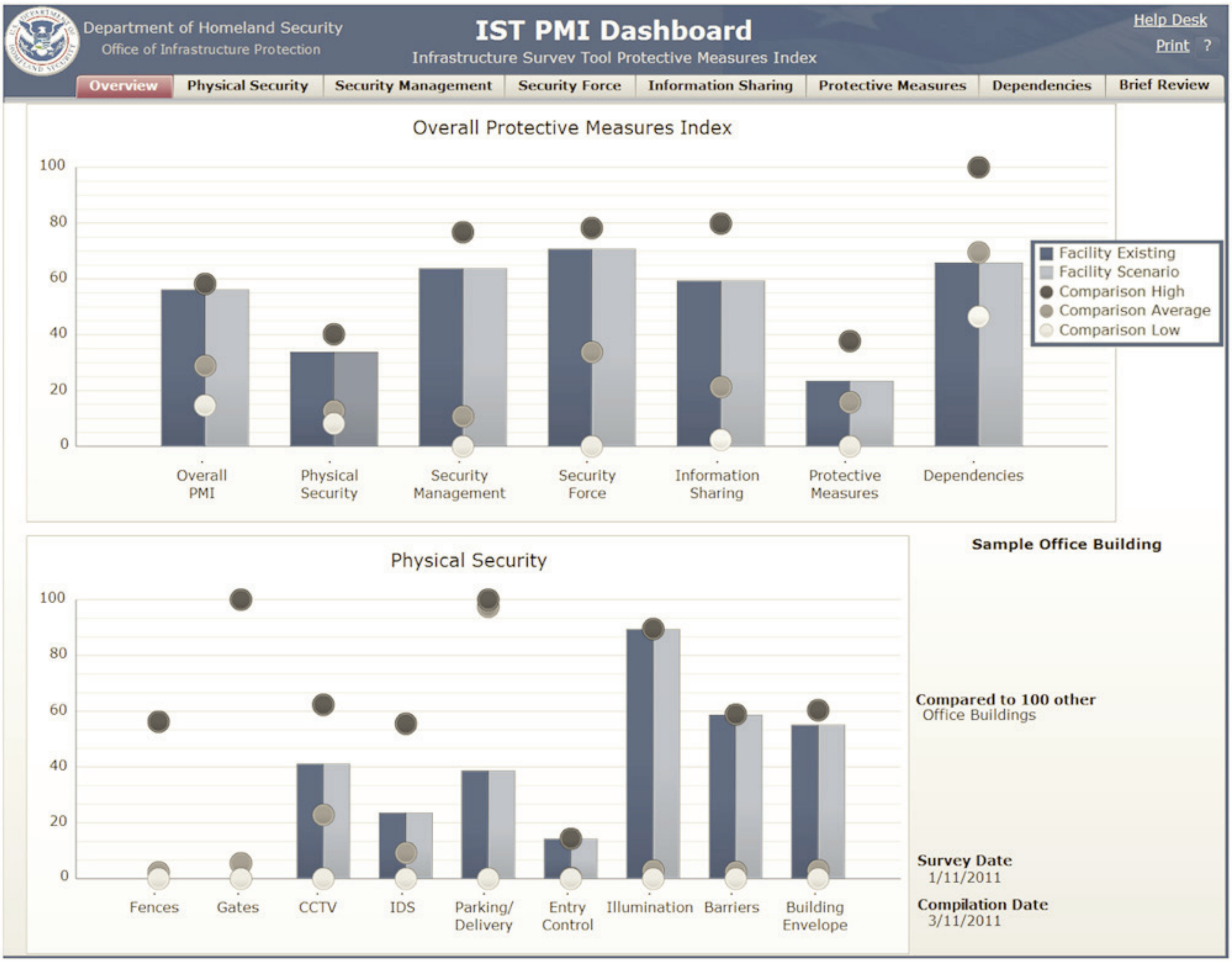

Figure 2: A sample screenshot of the PMI dashboard used to communicate resilience results to infrastructure facility managers. The top image gives an overall view of the resilience of the particular facility, with different coloured dots indicating the facility's relative resilience when compared to other similar facilities. The lower image breaks down physical security into its components, indicating again how the facility (in this case an office building) compares to 100 other similar buildings. Image sourced from http://www.dis.anl.gov/projects/ri.html.

specific for each sector) meaning the index yields a generic picture of CI security, resilience and vulnerability.

d) The analysis is fully systems-internal (looking only at the infrastructure) and does not explore external factors that might influence national security (like the infrastructure's geographic location near a large population, or position on a fault line, for example).

e) Overall, the Enhanced Critical Infrastructure Protection program is very expensive. In 2012 the DHS National Protection and Programs Directorate (under which the ECIP Program falls) requested USD 27.5 million to run the program.

f) Finally, like most indices the methodology yields only a *relative measure* of resilience, i.e., a high measure of resilience in reality may not (by definition) translate to a facility that is impregnable and unwavering. Nor does a measure of low resilience mean that a similar facility's operation will be completely shut down by the same event.

4.2 Case 2: The Disaster Resilience of Place model[22]

The disaster resilience of place (DROP) model is a conceptual framework for community disaster resilience that is yet to be *fully* operationalised. The model draws on and integrates resilience measurement processes and practices from a range of literatures to establish a complex resilience schema (Figure 3). It also identifies key variables that might be used to measure community disaster resilience.

4.2.1 Development

The authors contest that the DROP model fills a gap in the resilience measurement literature, which they (rightly) point out is littered with inconsistent indicators and non-standard metrics. This is particularly the case in the disaster literature, where resilience models are often focussed on engineered systems (like the ECIP model described above – robustness, recovery and resourcefulness), but largely fail to capture social factors, inherent resilience, and the antecedent processes that promote or degrade resilience. Five dimensions (with underlying candidate variables) are proposed as prospective resilience indicators, including: social resilience[23] (*e.g.* average age, health coverage), economic resilience (*e.g.* employment, income equality), institutional resilience (*e.g.* community mitigation actions, insurance), infrastructure resilience (*e.g.* housing type, shelters), and community capital (*e.g.* social networks, place attachment).

The model is articulated in a longitudinal process: Inherent levels of vulnerability and resilience are affected by the immediate effects of an event. These antecedent conditions, the event itself and the initial coping responses define the magnitude of the disas-

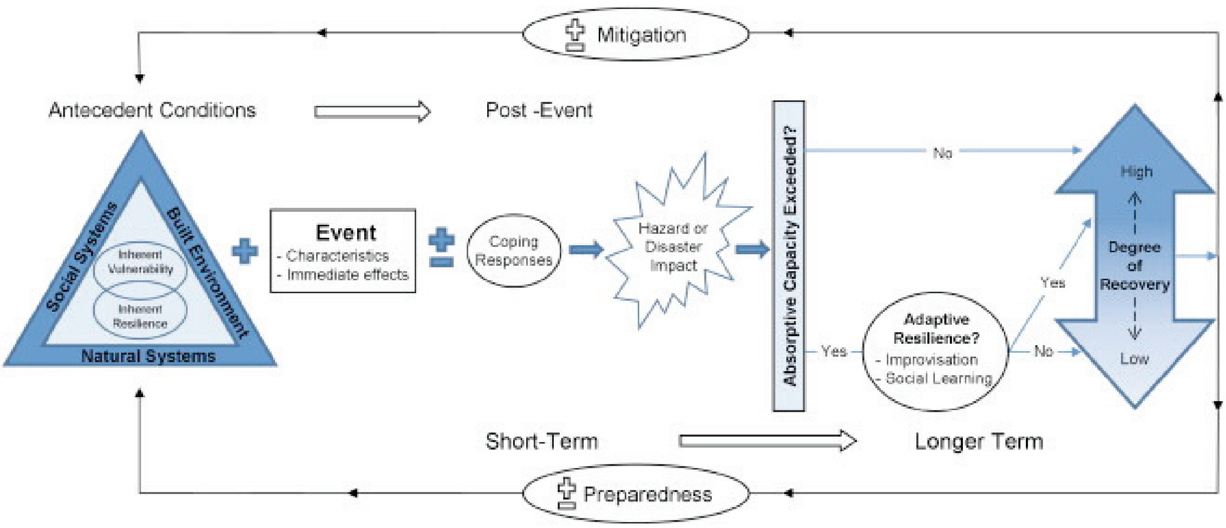

Figure 3: The Disaster Resilience of Place (DROP) model. Image source from Cutter et al. (2008).

22 Cutter *et al.* (2008); Cutter *et al.* (2010).

23 There is a large literature discussing the difference between and community resilience, and the type of resilience under examination must be made explicit in the development of a measurement index. See for example Boon *et al.* (2012).

ter impact (Figure 3). The consequences of the event are moderated by the community's coping responses (which are also inherent), and event magnitude and duration determine whether coping responses (collectively termed the absorptive capacity) are sufficient. In chronic or severe events, or if several events occur in rapid succession, absorptive capacities may be reduced to a point, where recovery following the event becomes more difficult.[24] Whether recovery is fast or slow (based on the maintenance or diminishment of the absorptive capacity), the community is expected to develop some adaptive resilience through social learning. If it does not, then resilience remains low also following an event.

4.2.2 Benefits

The model aims to explicitly connect vulnerability and resilience in a longitudinal manner in order to capture the dynamic nature of these processes/concepts. This then allows the model to better account for some of the challenges or frustrations that have plagued resilience and vulnerability measurement: multiple or gradual onset events, place specificity and context/circumstance, spatial and temporal dynamics of vulnerability and resilience, and the perceptions or attitudes of those people affected.

The model's longitudinal nature and the fact it incorporates antecedent measures of vulnerability and resilience also allows it to account for the influence of exogenous factors like policy regulation. Well executed preparedness or mitigation policy could have a significant influence on antecedent vulnerability or resilience, coping responses and processes that support adaptive resilience post-event, and capturing this change is of great importance from a policy dimension.

4.2.3 Limitations

No attempt (that could be found) has been made to operationalise this model as a whole. A first step has been made to create composite indicators of community resilience to assess baseline (inherent or antecedent) community resilience,[25] however, this provides a useful tool to assess and compare underlying community resilience between geographic locations (in this case the south eastern states of the United States).

The DROP model's theoretical application is powerful and meaningful, but practically very difficult to apply. Some general limitations of the model include:

a) At present, the model does not articulate how the suggeted community resilience indicators might be utilised in the conceptual model, which has to date not been tested in an empirical case study.[26]
b) The model is designed for application at the community scale, yet most disasters occur at the meso- and macro-scales. Upscaling this model would likely result in as resource intensive process as decribed for the Enhanced Critical Infrastructure Protection program above.[27]
c) An important feature in mitigation (institutional resilience) is government policy and proactivness towards mitigation, yet this aspect is not included in the resilience indicator set.
d) Likewise, there is no inclusion of ecological/environmental resilience either as a resilience cat-

24 Smit and Wandel (2006: 286–288) explore systemic 'coping ability' in some detail, reflecting on the relationship between recovery and adaptive capacity (somewhat analogous to 'absorptive capacity' used by Cutter and colleagues in the DROP model).

25 Cutter *et al.* (2010).

26 But see Cutter *et al.* (2010).

27 C.S. Holling (widely considered the progenitor of modern resilience thinking) postulated that systemic resilience was an interaction between and within multiple spatial and temporal scales. Without this interaction, the change in resilience could not adequately be described. See Holling (2001).

egory or variable, despite clear documentation that social or community resilience is closely connected to the environment and resources derived from ecological processes.[28]

4.3 Case 3: Assessing resilience with mixed qualitative and quantitative techniques

A mixed methodology approach is one where both qualitative and quantitative techniques are used to analyse a situation or process. It allows a triangulation of two forms of information as a means of improving analytical rigour and deepening understanding. The mixed methodology is particularly applicable to assessments of community resilience, and the social interaction between communities and their environments, and the structural aspects they rely on. Many authors argue that the complexity of phenomena like resilience and vulnerability can best be captured in a qualitative manner. The two models described subsequently are representative of such an approach to measuring resilience.

4.3.1 Development

The mixed methodology resilience measure, or conceptual model is designed to capture both the structural and experiential response of a community to a disaster, disturbance or perturbation. One such model is *'Bronfenbrenner's bio-ecological theory of development and resilience'*,[29] which is designed to relate individual and community resilience within a hierarchy of systems.[30] This model is used to illustrate how individual resilience factors like adaptive coping and self-efficacy are influenced by external processes like health provision or government financial support, and is somewhat analogous to Holling's panarchy theory of resilience (i.e. the understanding that there are multiple possible equilibriums in a given system, and that there can be moves between those caused by phase-shifts in the system), but with a strong social focus. Boon and colleagues provide an example of how the proposed theory might be applied to measure community resilience.[31]

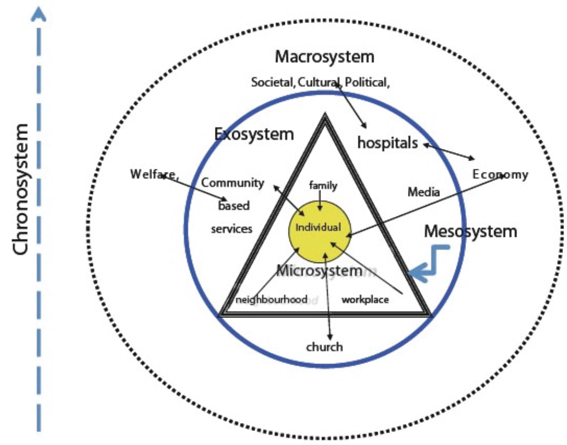

Figure 4: This model of Bronfrenbrenner's bio-ecological theory is adapted by Boon and colleagues to illustrate how different actors, structures and institutions, operating at different scales, influence individual and community resilience. Image sourced from Boon et al. (2012).

A second mixed methods resilience model proposed by Flint and Luloff aims to bridge the divide between theoretical debate and community experience with a *'Mid-range model of community response to disaster'*.[32] This model aims to describe the interac-

28 There is a huge literature discussing ecosystem services and the well-being people derive from these resources, which connects closely with the resilience literature. See for example Haines-Young & Potschin (2010: 72) and Norris *et al.* (2008).

29 Bronfenbrenner, Urie, and Stephen J. Ceci. «Nature-nurture reconceptualized in developmental perspective: A bioecological model.» *Psychological review* 101.4 (1994): 568–586.

30 Boon *et al.* (2012)

31 Boon *et al.* (2012: 397–402).

32 Flint and Luloff (2005).

tional characteristics of a community, and their ability to act collectively to respond to problems facing the community. The model is premised on the assumption that closely interacting communities are more capable of mobilising resources for response and recovery.

4.3.2 Benefits

Resilience is both contextual and heterogeneous, and the mixed methods approach to measurement aims to capture more of the complexity and richness of this concept/process. By focussing on individuals, communities and places in analyses of resilience, this approach is designed to explore the human elements of exposure to hazards, and the way these elements interact with the structural features of social systems. A purely quantitative approach to measuring community resilience (that uses income, age, education, access to information for example, as the measures of resilience) will be unable to explore and describe the social determinants of, and influence on, community and individual resilience features like experience, well-being, adaptive capacity, sense of community, collective efficacy – all of which are highlighted as important resilience features.

4.3.3 Limitations

While mixed methodologies seem to lend themselves particularly well to measuring the interaction between social and structural features in a community or social system, their application in practice is limited. To some extent, this stems from the general limitations of qualitative work, but is also due to the current state of development in mixed methods resilience and vulnerability index-making.

a) Qualitative approaches to analysis are commonly criticised for their subjectivity (whereas quantitative are challenged for an exaggerated pretence at objectivism). However, this issue might be overcome if qualitative descriptions can be coupled with quantitative measures of resilience for validation.
b) Applying mixed methodologies in data collection and analyses is time consuming, though not as resource intensive as quantitative approaches like the ECIP.
c) Ultimately, authorities prefer assessments that provide 'clear-cut' guidance for policy-making. A qualitative approach to measuring resilience, even if potentially more contextualised and detailed than other approaches, might not yield a sufficiently objective ranking of resilience profiles.

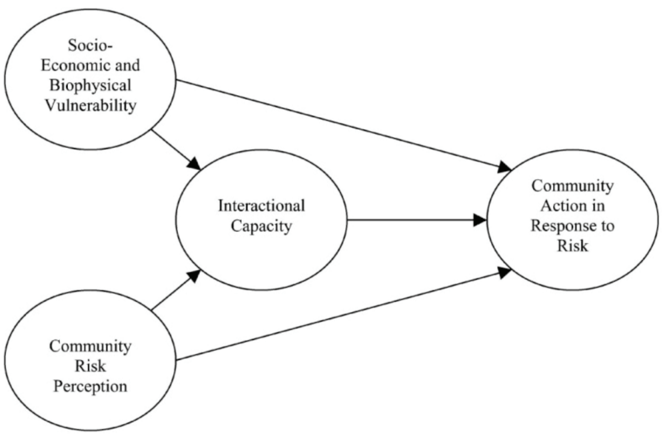

Figure 5: The mid-range model of community action in response to risk. Image sourced from Flint and Luloff (2005).

Measure	Type	Operational?	Benefits	Limitations
ECIP Program	Quantitative	Yes	Characterises elements of harm and consequence before and after incident. Assesses entire risk spectrum for a critical infrastructure. Allows security planners to capture and analyse longitudinal changes in vulnerability/resilience. Designed around a public-private partnership, with easy information sharing.	Time, money and labour intensive. Analysis and interpretation is highly demanding. Only yields a very generic picture of CI security. Does not explore external influences on security. Provides a relative measure.
DROP Model	Quantitative	No, conceptual	Connects vulnerability and resilience in a longitudinal manner to show their dynamic nature. Can account for new hazard characteristics: multiple & gradual onset events, place specificity, spatial/temporal dynamics, peoples' perceptions/attitudes. Incorporates antecedent measures of vulnerability and resilience to account for exogenous factors like policy.	Not tested empirically. Community resilience indicators not articulated. Up-scaling model would be difficult. No inclusion of ecological/environmental resilience.
Mixed Methods	Quant./Qual.	No, conceptual	Mixed methods can capture richness and complexity of resilience. Lends itself well to examining the contextual and heterogeneous nature of resilience of systems. Explores the way human elements interact with structural features of social systems.	Qualitative analyses can be subjective. Mixed methodologies are time consuming. More difficult to provide 'clear-cut' directions to policy makers that can be ranked in decision-making.

Table 1: Summary of resilience measures.

5 GENERAL LESSONS FOR RESILIENCE INDEX-MAKING

The intention to measure resilience or vulnerability is not new. As discussed in this Focus Report, there are many reasons to do so. Yet the diverse, and often contradictory literature, highlights both the difficulty and dilemmas associated with measuring these phenomena, concepts or processes. For this reason, it is very important to think critically about measurement in order to identify and understand what problems measurement might raise or encounter, and where caution should be taken in the development of a resilience index. Several of the main criticisms are outlined below (in no order of importance).

a) Simplifying complexity: Einstein once noted that theory should be "as simple as possible, but not simpler." This pointer is highly valuable for the resilience measurer, but also illustrates a conundrum – how can you simplify a complex process or concept so that it is understandable and measureable without losing the very complexity and deepness of meaning you are trying to capture? Resilience and vulnerability are inherently complex, but with increasing complexity comes greater difficulties in establishing measures, and in the interpretation of the results. Developing a methodology that satisfies the necessity of interpretation and that captures the complexity of resilience as a policy-relevant phenomena will be time consuming and expensive. The issue of simplification leads to the following point.

b) Absolute vs. relative evaluation[33]: An index is a way of simplifying the complexity as duely noted. Indeed many variables used to indicate phenomena are proximal representations of the actual subject of measurement, and only assumed to be representative.[34] For this reason, most indices only yield a relative measure, rather than an absolute measure. A relative measure is not exact, and depending on the rigour of the development process, may not tell you a lot about the resilience of the entity you are interested in. As long as the measure is calculated consistently between entities, all a relative measure allows is a comparison between places, between entities, or over time. This is good enough if you only want a relational understanding of resilience (for example, to allocate resilience development funding), but it will not tell you if the river-side community you are concerned about has the capacity to cope with a major flooding event. Developing resilience/vulnerability benchmarks for at-risk entities is a step towards avoiding this problem.[35]

c) Indicator arbitrariness and weightings: The fact that there is considerable discussion about the exact meanings of resilience and vulnerability in the risk-related literature results in arbitrary or subjective application of indicators. Based on the example of the Human Development Index (HDI), it could be validly argued that indicators like education, life expectancy and income are arbitrary indicators of national development, even though they give some multidimensionality to development unlike Gross Domestic Product.

It is almost impossible to identify and choose indicators for resilience or vulnerability that can

33 Mori and Christodoulou (2012).

34 Though in psychological resilience measurement a central necessity is the estimation of 'reliability' (Chronbach's α), which is a statistical test that assesses how well the proxies used for resilience are actually measuring what they are intended to measure. See Windle (2011) for an overview of psychological resilience measurement.

35 Cutter *et al.* (2010); Mori and Christodoulou (2012).

be measured on the same scales. In order to integrate these indicators into an index, a transformation of these measures to the same scale is necessary. Secondly, different indicators are assumed to contribute differently to resilience or vulnerability, and are assigned weightings to differentiate these contributions. Assigning weightings is a time consuming and subjective process, especially without an in-depth knowledge of the way particular behaviours, structures, policies etc. contribute to the resilience of the entity under examination.[36]

d) Data quality, availability and suitability: A valid measure of resilience could be limited by data quality, availability or suitability. In most cases, the indicators (and therefore the data) used to measure resilience will not have been established to explicitly do so – as noted at point b) above, indicators are often proxies. As such, data collected for these indicators may be easily available, but not specifically applicable to the situation or measure they are intended to be used in.

   Easy data availability may also be a problem in itself. Where data is easily available, there lies the temptation to use it, whether or not it is suitable for measuring the phenomenon under question. Using proxies highlights the possibility that these, and the data that represent them, may ultimately define resilience, rather than the needs of the measurer.

e) Context, place and hazard specificity: Almost all authors recognise that resilience and vulnerability vary dramatically between places, and with respect to the events they are examined in relation to. This means that it is very difficult (if not impossible) to construct a generic and direct measure of resilience. This difficulty is evidenced by the huge variety of proposed measures and theoretical conceptions of resilience presented in the academic literature. While difficult to sift through, this literature does provide the mechanics for the development of a resilience measure if approached with care and a clear frame of what resilience means in the context and circumstance in which it will be applied.

f) Fit for purpose (non-explicit policy, research questions or system definition): Given its vagueness, clear framing of resilience is likely the most important step in developing a measure of resilience. From a policy perspective three considerations can yield clarity:

   i. a sound definition;
   ii. explicit policy linked to the definition;
   iii. explicit articulation of scale and context.

   Creating a useable and meaningful measure of resilience requires a sound articulation of the definition with respect to the reason the measurement is required (e.g. disaster mitigation policy). Connecting the definition to the policy will assist the development of a measure of resilience that is fit for the purpose it is intended. A measure can only be as good as the articulation of the problem (or policy question) to be explored, and relies on the early and explicit determination of policy goals and targets.

36 In assigning weightings for the Protective Measures Index described at section 3.1, the DHS and Argonne National Laboratories engaged an expert panel to determine the weightings for each indicator used.

6 MEASURING RESILIENCE FOR SWISS CRITICAL INFRASTRUCTURE PROTECTION

The vision detailed in the draft of the national CIP strategy of Switzerland (*Nationale Strategie zum Schutz Kritischer Infrastrukturen*) is two-pronged. It notes that Switzerland should become "resilient in relation to critical infrastructure to prevent large scale and catastrophic failure, and to ensure the extent of damage is limited." In this context, resilience is taken to mean "the ability of systems, organisations and society to withstand disturbance, and maintain or regain function quickly." A resilience index would be a useful tool to support this vision, allowing the assessment of resilience in critical infrastructures over time, and particularly as a way to observe the impact of local, cantonal and federal policies aimed at increasing critical infrastructure resilience.

That the vision identifies that "*Switzerland* [becomes resilient] *in relation to critical infrastructure...*" has implications for the way resilience should be measured. The authors of this focus report interpret this notion of critical infrastructure resilience as a national priorty, requiring a systemic approach that assesses resilience in an holistic manner. In this case, a systemic approach to measuring resilience would require three actions: a) articulating the system components; b) methodology development; c) aggregation of measured data. These three actions are discussed in relation to energy infrastructure in Switzerland.

Taking a systemic approach to resilience measurement first requires an articulation of the components within a system. This process could be well-informed using a stakeholder mapping process, where, in the case of the energy infrastructure of Switzerland, those stakeholders (Cantons, private organisations, government departments, maintenance contractors *etc*) of the energy system would be engaged in a discussion about the composition of the energy system. This discussion should be detailed and exhaustive, so that all components of the system are identified and their roles in the system elucidated.

A second step would be the establishment of measures (or proxy indicators) that appropriately assess and characterise the resilience of the system's components. Quantitative resilience indicators like those discussed in section 4.1 (the DHS's ECIP Program) might be most appropriate for energy infrastructure like power stations, hydro-electric dams, or power lines, while more qualitative measures (like those discussed in sections 4.2 and 4.3) that can better determine the quality of people's interactions with infrasctructure could be used to assess the resilience of the organisations that operate and maintain Switzerland's energy infrastructure.

Lastly, measuring systemic resilience would require an exploration of the way the component measures of resilience could be aggregated to define the system's resilience. While it is not clear how this might be done without clear knowledge of the indicators that would be used to measure component resilience (nor whether this aggregation would actually be meaningful), assessing systemic resilience is nevertheless important to inform a strategy of national critical infrastructure protection. What could be more meaningful, and qualitatively useful in regard to systemic resilience would be a determination of the way in which the system components (and their resilience) interact – what is the nature of the relationships between the components? Do these relationships build or erode resilience? What do these relationships mean for the system's resilience?

7 CONCLUSION

Developing measurement methodologies for systemic critical infrastructure resilience will be difficult, but is of significant relevance and interest to Switzerland – particularly in relation to the country's National Strategy for Critical Infrastructure Protection. However, the development of resilience measurement methodologies raises a number of concerns, from conceptual definition and political program to resources, questions of monitoring, and international cooperation, all of which must necessarily be addressed. This last section gives an overview of the most pressing questions to answer in the event that a critical infrastructure resilience index were to be designed, developed and applied in Switzerland.

a) The resilience of who or what is measured? The first question should encourage critical thought about the context in which the prospective measurement will be applied. This would include consideration of whether the index will be applied at a micro- (individual), meso- (community) or macro-level (state, nation, or international), and a corresponding designation of authorities and actors responsible for such measurement.

b) What kind of resilience is assessed? Whether an index will be used as a relational measure (*e.g. community* 'A' is more resilient to an critical infrastructure failure than *community* 'B'), or as an absolute quanficiation is an important question to consider. Also relevant is a consideration of what kinds of hazards, disturbances or perturbations will be the subject of assessment, and questions of how a resilience index would be linked to other risk registers and maps.

c) How will this measurement help Swiss authorities? Answering this third question should help reflect the resilience issue that requires measurement. It should encourage the development of clearly defined policy-specific goals that the resilience index should help to meet. Answering this question eventually helps to identify how the index should be developed, what style of measurement might be required (qualitative, quantitative or mixed-methods), what indicators should be used, and the kinds of data that must be obtained (either from existing sources, or newly collected). Lastly, it is important to consider how the results of the measurement might influence policy (and even society) once first results are in – what might the measurement show, and what will be the implications?

d) How will development and application be resourced? The last question is one of reality and practicality. Undoubtedly measuring resilience properly and accurately is difficult, expensive and resource intensive. Central considerations in the early discussion about an index for resilience must include how much it will cost to develop? What partnerships will support the development? For example, in Switzerland, where much of the infrastructure is (semi-)privately owned and operated, measuring resilience is likely to require strong private-public partnerships to ensure reciprocity in data sharing, policy development and decision making.[37] At the same time, different political authorities will also have to agree on a compatible scheme for resourcing a national resilience index.

Taken together, these are some central questions to be addressed by Swiss authorities if a national resil-

37 See Dunn Cavelty and Suter (2009) for a broader discussion of public-private partnerships in the context of critical infrastructure protection.

ience index were to be developed. As these questions and the preceeding discussion suggest, the production of resilience indices is (its political appeal and utility notwithstanding) a demanding, though not impossible endeavour. In the end, however, the value of developing such an index does not necessarily lie so much in the quantification and objective capture of resilience as such, but in the advancement of an analytical and political process regarding the characteristics of, and dynamic relationships between, disasters, disturbances or perturbations on the one hand, and adaptive capacities of people, places and structures on the other. Developing these analytical and political processes requires additional research effort.

8 REFERENCES

Adger, W.N. (2006) Vulnerability. *Global Environmental Change-Human and Policy Dimensions* 16, 268–281.

Anand, S., & Sen, A. (1994). Human Development Index: Methodology and Measurement. *Human Development Report Office Occasional Papers* (1992–2007).

Bara, C., & Brönnimann, G. (2011). Resilience – Trends in Policy and Research. Zürich: Center for Security Studies (CSS), ETH Zürich.

Boon, H. J., Cottrell, A., King, D., Stevenson, R. B., & Millar, J. (2012). Bronfenbrenner's Bioecological Theory for Modelling Community Resilience to Natural Disasters. *Natural Hazards, 60*(2), 381–408.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A Place-Based Model for Understanding Community Resilience to Natural Disasters. *Global Environmental Change, 18*(4), 598–606.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. *Journal of Homeland Security and Emergency Management, 7*(1). doi: DOI: 10.2202/1547-7355.1732

DHS National Protection and Programs Directorate (2011). NPPD Fiscal Year 2012 Budget Request – Cyber Security and Infrastructure Protection Programs. URL [*http://www.dhs.gov/ynews/testimony/testimony_1301595025263.shtm*](http://www.dhs.gov/ynews/testimony/testimony_1301595025263.shtm).

Dunn-Cavelty, M., & Suter, M. (2009). Public-Private Partnerships are no Silver Bullet: An Expanded Governance Model for Critical Infrastructure Protection. *International Journal of Critical Infrastructure Protection, 2*(4), 179–187.

Eriksen, C., & Prior, T. (2011). The Art of Learning: Wildfire, Amenity Migration and Local Environmental Knowledge. *International Journal of Wildland Fire, 20,* 612–624.

Fisher, R. E., & Norman, M. (2010). Developing Measurement Indices to Enhance Protection and Resilience of Critical Infrastructure and Key Resources. *Journal of business continuity & emergency planning, 4*(3), 191–206.

Flint, C. G., & Luloff, A. E. (2005). Natural Resource-Based Communities, Risk, and Disaster: An Intersection of Theories. *Society and Natural Resources, 18*(5), 399–412.

Folke, C. (2006). Resilience: The Emergence of a Perspective for Social-Ecological Systems Analyses. *Global Environmental Change, 16*(3), 253–267.

Gallopín, G.C. (2006) Linkages Between Vulnerability, Resilience, and Adaptive Capacity. *Global Environmental Change 16,* 293–303.

Giroux, J., Hagmann, J., Dunn Cavelty, M. (2009). Risk Communication in the Public Sector. Center for Security Studies (CSS), ETH Zurich.

Giroux and Prior (forthcoming). Expressions of Resilience: From 'Bounce Back' to Adaptation. SKI Factsheet No. 8, Center for Security Studies (CSS), ETH Zurich.

Grothmann, T., & Patt, A. (2005). Adaptive Capacity and Human Cognition: The Process of Individual Adaptation to Climate Change. *Global Environmental Change, 15*(3), 199–213.

Habegger, Beat (2010). Bewertung von Risiken. Factsheet, Center for Security Studies (CSS), ETH Zurich.

Hagmann (2012). Risiko, Verwundbarkeit, Resilienz: Neue Gefahrenkonzept in der Internationalen Sicherheitsanalyse. Factsheet No. 7, Center for Security Studies (CSS), ETH Zurich.

Haimes, Y. Y. (2009). On the Definition of Resilience in Systems. *Risk Analysis, 29*(4), 498–501.

Haines-Young, R., & Potschin, M. (2010). The Links Between Biodiversity, Ecosystem Services and Human Well-Being. In C. Frid & D. Raffaell (Eds.), *Ecosystem Ecology: A New Synthesis.* Cambridge: Cambridge University Press.

Hinkel, J. (2011). Indicators of Vulnerability and Adaptive Capacity: Towards a Clarification of the Science-Policy Interface. *Global Environmental Change, 21*(1), 198-208.

Holling, C.S. (2001) Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* 4, 390–405.

Mori, K., & Christodoulou, A. (2012). Review of Sustainability Indices and Indicators: Towards a New City Sustainability Index (CSI). *Environmental Impact Assessment Review, 32*(1), 94–106.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. *American Journal of Community Psychology, 41*(1–2), 127–150.

Peters, E. (2012). Beyond Comprehension: The Role of Numeracy in Judgments and Decisions. *Current Directions in Psychological Science, 21*(1), 31–35.

Petit, F., Buehring, W., Whitfield, R., Fisher, R., & Collins, M. (2011). Protective Measures and Vulnerability Indices for the Enhanced Critical Infrastructure Protection Programme. *International Journal of Critical Infrastructures, 7*(3), 200–219.

Sagar, A. D., & Najam, A. (1998). The Human Development Index: A Critical Review. *Ecological Economics, 25*(3), 249–264.

Smit, B., & Wandel, J. (2006). Adaptation, Adaptive Capacity and Vulnerability. *Global Environmental Change, 16*(3), 282–292.

United States Homeland Security Studies & Analysis Institute (2010). Risk and Resilience: Exploring the Relationship. Washington: National Infrastructure Advisory Council. Arlington.

Walker, J., & Cooper, M. (2011). Genealogies of Resilience: From Systems Ecology to the Political Economy of Crisis Adaptation. *Security Dialogue, 42*(2), 143–160.

Windle, G., Bennett, K. M., & Noyes, J. (2011). A Methodological Review of Resilience Measurement Scales. *Health and Quality of Life Outcomes, 9*.

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