Metrics for Evaluating and Improving Community Resilience

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Abstract: The growing risk of natural and artificial or manufactured hazards combined with a lack of community preparedness have revealed the necessity for comprehensive and effective metrics for evaluating and improving a community's resilience, i.e., the ability of communities to prepare for, withstand, and recover from disasters. In this paper, the authors review existing community resilience metrics and tools, classifying them into one of three main categories: community-level, sector-specific, or sociological. The paper provides short descriptions of each metric and comparisons across metrics within the three main categories and across classes. The authors assess the strengths and limitations of these metrics, discuss challenges in improving community resilience, and provide recommendations for the development of new measures of resilience. The paper concludes with an outlook on the future of community resilience, particularly the need for metrics that apply across hazards, geographic areas, and factors affecting resilience. The authors propose that effective metrics are characterized by: breadth, measures that address community resilience comprehensively; utility, measures that are able to be utilized by the relevant entities to undertake actions to improve resilience; and scientific merit, measures that are scientifically validated through statistical methods, case studies, and fieldwork. **DOI: 10.1061/(ASCE)IS.1943-555X.0000329.**

Introduction

Community resilience is defined as *the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change* (Adger 2000). It links the adaptive capacities of a community to its responses and changes after disruptions (Cutter et al. 2010). Rather than waiting for the next disaster to occur, a resilient community anticipates future disasters and is able to prepare for and recover from adverse events more effectively and efficiently by investing in resilience (NRC 2012). Enhanced resilience is essential to an increasing number of individuals and communities as they face the challenge of living more safely and sustainably in areas vulnerable not only to natural disasters, but also the effects of climate change (NRC 2014; NOAA 2014; Association of Public and Land-Grant Universities 2014).

Historically, most cities have been designed without resilience in mind, and therefore have inadequate performance objectives. Design and construction requirements are focused on preventing loss of life and ignore the possible range of building damage states after a disaster and measures of postdisaster usability. In addition, for existing structures, little action is being taken to rehabilitate older structures that were built without disaster-resistant design and that are often the most vulnerable to damage. Currently, no consistent approach exists that is aimed at providing, maintaining, and restoring necessary systems for recovery after disasters (SPUR 2009). Additionally, many infrastructure components are not currently operating as designed. The American Society of Civil Engineers gave America's infrastructure a $D+$ on the 2013 Report Card for America's Infrastructure (2013 Report Card for America's Infrastructure Advisory Council of ASCE 2013). Impacts of disasters on communities span economic, environmental, health, and well-being effects. Disaster-related events caused $380 billion of financial loss in 2011 (Munich 2012), and these costs are increasing (Kunreuther and Michel-Kerjan 2009). Disasters led to the loss of 30,733 lives and affected 244.7 million people in 2011 (Guha-Sapir et al. 2012). In the coming years, because of climate change, the intensity of natural disasters is expected to grow (Boin and McConnell 2007), further increasing the potential negative impacts of disasters on communities.

To date, much of the research on the impacts of disasters has consisted of case studies of single disasters in one geographic location (Peacock et al. 2011) and most studies in disaster research focus on only one attribute of the complex systems that contribute to resilience (NRC 2006). Metrics are necessary to assess the ability of a community to withstand and recover from all types of disasters, to compare across communities, to assess potential outcomes across different strategies for improving resilience, and to quantify any improvements in a community's resilience. Resilience metrics have been created to decrease the vulnerability of communities, speed up recovery, and protect citizens from life-threatening physical harm (OSSPAC 2013). They are necessary to educate communities on the spectrum of threats they face, disseminate knowledge from previous events to communities who want to take action, address increasingly constrained resources, and diversify the stakeholders involved in a community's resilience (CRSI 2011). Metrics enable cities to determine their community's baseline and to monitor their improvements over time (UNISDR 2012). Many resilience metrics identify specific areas in which a community can improve to increase adaptability and resilience to disasters (Sempier et al. 2010). To achieve a successful community resilience

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plan, stakeholders in the community must be involved and knowledgeable about the potential consequences the community could face and the measures that they can take to decrease them. Therefore, many resilience metrics involve a component of communicating with the community. This can range from educating students to alerting entire communities of an impending hazard. The overall goal is to create resilient communities where critical networks can regain operation shortly after a disaster, people are protected and can stay in their homes, and the community can return to a *new* normal within several years (SPUR 2009).

In accordance with this goal, many measures of resilience have been proposed and developed in recent years. These include both generalized metrics and resilience tools. The tools have their own methods of rating resilience of a community, so are included in the assessment of metrics in this paper. The authors classify these metrics into one of three main categories: community-level, sector-specific, and sociological metrics. In this paper, the authors provide a detailed summary review of the current state of the methods used to measure and improve community resilience. The metrics were selected by a comprehensive search of measures that are used or have been developed and proposed for assessing community resilience. Many of the metrics referred to were validated based on case studies and implementation in the communities that they concern. This paper serves as an overview of existing methods and provides descriptions of specific metrics that a community may choose to use based on its particular characteristics. The authors provide evaluations and comparisons across metrics and describe the components of effective resilience metrics such that the paper can also be used as a basis for the development of new, potentially standardized, metrics. The rest of the paper is organized as follows: First, community-level, sector-specific, and sociological measures of resilience are discussed. Next, the authors provide a summary of resilience metrics across categories, including limitations of existing metrics and challenges in improving community resilience. The authors then discuss recommendations for the development of new metrics before concluding with an outlook on the future of community resilience.

Community-Level Resilience Metrics

Although the importance of resilience may be readily recognized after a disaster, the benefits of improved resilience are rarely acknowledged or prioritized before a disaster takes place, making the benefits of predisaster resilience actions challenging for communities to demonstrate. Community-level metrics are one way to document these actions as well as potential returns on investment. The *Whole Community* approach of the Federal Emergency Management Agency (FEMA) enables communities to have agency involvement in their disaster response, and be able to rely on their own assets to fund recovery, rather than depending on resources from the federal government, which may be insufficient or delayed in arriving (FEMA 2011). When disasters occur, communities often turn to nongovernmental agencies and private companies to acquire needed resources (Eisenman et al. 2014). Community-level plans can serve as the blueprint for the assets that are needed from these organizations and recommend how these resources should be distributed. By understanding potential impacts of disasters and ways to improve resilience, communities can specify their needs to other organizations, align their incentives, and create successful partnerships (Chen et al. 2013). Community-level resilience plans enable individual communities to assess, measure, and improve their resilience to threats and disruptions (CARRI 2015).

Metrics

Table 1 provides a summary of community-level resilience metrics. This includes: a framework by the Community and Regional Resilience Institute (CARRI) (CARRI 2015); Characteristics of a Safe and Resilient Community developed by the International Federation of the Red Cross along with Arup's International Development team (Arup International Development 2011); Arup and the Rockefeller Foundation's City Resilience Index (Arup 2014); the Coastal Resilience Index, a community self-assessment tool to understand a community's preparation for disaster (Sempier et al. 2010); the Environmental Vulnerability Index, a report card for each country assessed, which classifies vulnerability based on 50 indicators (SOPAC et al. 2005); the Flood Resilience Checklist developed by the U.S. Environmental Protection Agency (EPA) (EPA 2014); Getting to Resilience, an online tool that allows a community to visualize exposure to current and future hazards (NRCCI 2015); Hazus-MH, a tool created by FEMA to estimate potential losses from disasters (FEMA 2008); a monitoring and evaluation framework created by the Recovery Sub-Committee of the Australia and New Zealand Emergency Management to take recovery support and intervention by all levels of the government into account (Council of Australian Governments 2014); the National Resilience Scorecard, a community resilience metric that is in development by the National Institute of Standards and Technology (NIST) (NIST 2015); the New Orleans Index used to track the recovery of the city using economic growth, inclusion, quality of life, and sustainability indicators (Plyer et al. 2013); the Oregon Resilience Plan developed by the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) with the goal of reducing risk and improving recovery from future Cascadia seismic events (OSSPAC 2013); the San Francisco Planning Urban Research Association metric for the community (SPUR 2009); the United Nations (U.N.) Disaster Resilience Scorecard based on the United International Strategy for Disaster Risk Reduction's (UNISDR's) *Ten Essentials* of disaster management (UNISDR 2012); and the Vulnerability-Resilience Indicators Model developed for the U.S. Department of Energy to assess the significance of potential future changes in climate for natural resources and socioeconomic systems (Moss et al. 2001).

Evaluation and Comparison of Community-Level Resilience Metrics

These community-level resilience metrics provide various means for a community to assess its preparedness for various disasters. Several of the metrics—CARRI Community Resilience System, Getting to Resilience, Hazus-MH, and the Vulnerability-Resilience Indicators Model—are computer-based tools that allow community decision makers to determine their preparedness for disasters and ways to improve their resilience. Similarly, the Coastal Resilience Index is a community self-assessment tool, although it is paper based. Three of the metrics—Coastal Resilience Index, Flood Resilience Checklist, and Getting to Resilience—are assessed through yes/no questions. Hazus-MH provides an online tool that evaluates multiple hazards including hurricanes, earthquakes, and floods. The metric calculates risk across scales, from a local up to a national scale. All of these tools provide a simple method for planners to identify gaps and set priorities that can improve their community's resilience. Based on the pilot tests performed in eight communities, CARRI realized the necessity of simple, robust tools that comply with a whole community approach to preparedness and resilience (CARRI 2013).

It is noted that Hazus-MH is not strictly a tool to assess and improve resilience. Instead, it assesses risk, though the results from

Table 1. Summary of Community-Level Resilience Metrics

Metric	Description
CARRI Community Resilience System	Computer program that assesses community resilience for various disruptions Based on quantifying community's functional capacity
Characteristics of a Safe and Resilient Community	Six characteristics that exemplify a resilient community Characteristics determined from the Red Cross's Community Based Disaster Risk Reduction Programs
City Resilience Index	Framework of 12 indicators that define a resilient city Indicators segmented into people, place, organization, and knowledge
Coastal Resilience Index	Community self-assessment for a *bad storm* based on historical record Results in resilience indices—low, medium, or high—for each evaluated sector
Environmental Vulnerability Indicator	Aimed at Small Island Developing States 50 indicators arranged into hazards, resistance, and damage
Flood Resilience Checklist	Checklist of yes/no questions on flood resilience policies Addresses overall strategies, land use, protection of people and infrastructure, planning, and storm water management
Getting to Resilience	Online tool consisting of surveys on risk and vulnerability, public engagement, planning, integrating, disaster preparedness and recovery, and hazard mitigation implementation Specific to New Jersey
Hazus-MH	FEMA's software that estimates potential loss from disaster Applies to county officials, code officials, engineers, risk managers, and political leaders
Monitoring and Evaluation Project Steering Group	In development by Australia and New Zealand Emergency Management Committee Monitoring and evaluation framework to measure effectiveness and value for money of relief and recovery arrangements in the natural disaster context
National Resilience Scorecard	75% Draft released by NIST Intends to address comprehensiveness, utility, impacts assessed, techniques used, and overall merit with respect to maturity, innovativeness, objectivity, and scientific merit of the methodology
The New Orleans Index	Tracks recovery of New Orleans neighborhoods since Hurricane Katrina in 2007 Uses economic growth, inclusion, quality of life, and sustainability indicators
Oregon Resilience Plan	Metric for Cascadia subduction zone Goals are to protect Oregon citizens from physical harm, decrease time to recovery, and reduce vulnerability Eight task groups were assigned to determine suggestions for different sectors
San Francisco Planning and Urban Research Association	Specific measure for San Francisco Performance levels are based on expected magnitude 7.2 earthquake Eight task groups were assigned to determine suggestions for different sectors
U.N. Disaster Resilience Scorecard	Rates variables based on ten essentials for resilience Considers organization, budget, preparation, infrastructure, safety of essential facilities, building regulations, training for disaster, ecosystem protection, warning systems, and restoration needs
Vulnerability-Resilience Indicators Model	Determines a community's vulnerability to climate change in the future Computer-based program with climate-sensitivity and coping-capacity indicators

the risk assessment can be used to improve community resilience by strengthening the areas of greatest estimated negative impacts due to hazards. In general, resilience and risk reduction are related in that implementing measures to improve resilience leads to risk reduction in a community. However, resilience measures account for the full life cycle of an infrastructure system or community, whereas traditional risk reduction focuses on predisaster states. Risk reduction is a form of disaster management that decreases the potential consequences of a disaster before the event occurs. Reducing risk before a disaster requires knowledge about the community, including vulnerable groups, vulnerable areas, and what effects the disruptive event could have (Birkmann 2007). Looking over the full life cycle for resilience can inform risk reduction strategies. For example, if many resources are allotted to a certain risk area but the risk is then transferred to a new area, there may be no overall risk reduction (Cox et al. 2011). In addition to disaster preparedness, resilience accounts for the event response and recovery, and future adaptation and mitigation stages as well.

In evaluating community-level resilience metrics, some of the measures—Characteristics of a Safe and Resilience Community, the City Resilience Index, the Flood Resilience Checklist, and the DROP model—provide no quantifiable or comparable metric of a community's resilience. Instead, they provide general suggestions or a framework for metric development. In addition, many of the metrics are not generalizable, including the Coastal Resilience Index, the Environmental Vulnerability Index, the Flood Resilience Index, Getting to Resilience, the Oregon Resilience Plan, SPUR, and the Vulnerability-Resilience Indicators Model. These are designed for coastal communities, Small Island Developing States, floodplains, New Jersey, Oregon, San Francisco, and to measure particular vulnerability to climate change, respectively. The specificity of these metrics to a geographical location, certain disaster, or other classification limits their applicability across communities.

The U.N. Disaster Resilience Scorecard was created to integrate all aspects of disaster resilience, as well as identify shortfalls in communities' resilience plans. The metric is among the most comprehensive and detailed, with 85 different criteria addressing the ten essentials of disaster management. The UNISDR would also like to create a web-based tool to facilitate the responses (UNISDR 2012). The National Resilience Scorecard is still in development, but aims to address gaps in many of the other metrics presented, including comprehensiveness, utility, range of impacts assessed, range of techniques implemented, and critical rigor. It also is proposed to be adaptable and scalable to any community. It is anticipated to be completed in the next few years and a review of its utility and capabilities will be required once completed.

Sector-Specific Resilience Metrics

Compared to community-level metrics that look at communities as a whole, sector-specific resilience metrics define measures for the recovery of specific sectors comprising a community, including critical infrastructure systems, buildings, and other critical assets. A review of existing sector-specific metrics follows.

Metrics

Metrics that assess the resilience of specific sectors of a community are summarized in Table 2. These include: resilience metrics for electricity, oil, and natural gas systems in development by the Office of Energy Policy and Systems Analysis at the Quadrennial Energy Review Technical Workshop in April 2014; the resilience measurement index (RMI), an all-hazards methodology that emphasizes protection, preparedness, mitigation, response, and recovery of 16 critical infrastructure sectors as defined by the Presidential Policy Directive 21 (2013) (Petit et al. 2013); Resilience STAR, which is under development by the Department of Homeland Security to build and retrofit more disaster-resistant homes (IBHS 2013); Risk Analysis and Management for Critical Asset Protection (RAMCAP) developed by the U.S. Department of Homeland Security (Moteff 2005); The Cabinet of the United Kingdom's 11 sector-specific resilience plans (Cabinet Office 2014); and the U.S. Resiliency Council (USRC) Building Rating System, intended to communicate risk of natural and artificial or manufactured hazards to building owners, tenants, buyers and sellers, and lenders and insurers (USRC 2014).

Evaluation and Comparison of Sector-Specific Resilience Metrics

The preceding metrics provide measures of resilience for various sectors that support the health, security, and functioning of an overall community. These include critical infrastructures, critical assets, and buildings. While two of the metrics are still in development (measuring the resilience of energy distribution systems and Resilience STAR), they intend to incorporate multiple stakeholders and provide a quantitative assessment of the resilience of their specific systems.

Several of the metrics are specific to one infrastructure sector. Measuring the Resilience of Energy Distribution Systems is intended for electricity, oil, and natural gas distributing systems. The resilience measurement index and risk analysis and management for critical asset protection provide resilience metrics for critical infrastructure systems. Resilience STAR and the USRC Building Rating System both focus on the building sector.

The Sector Resilience Plans developed by the United Kingdom Cabinet Office provide recommendations for improving resilience for 11 different infrastructure sectors. Due to the sensitive nature of each sector, the individual infrastructure plans are classified, so the sector-specific information is generalized and provides suggestions for planning rather than providing a specific output. In general, sector-specific measures provide detailed information on particular sectors, but on their own, they are not sufficient to evaluate the resilience of a community overall.

Sociological Resilience Metrics

Sociological resilience uses societal measures to quantify the resilience of a community. Within this context, resilience is defined as a process linking the myriad of adaptive capacities of a community to responses and changes due to adverse events (Norris et al. 2008). For example, some places highly vulnerable to natural hazards may be more resilient than others due to extensive supportive and well-informed social networks, strong planning, and financial stability, whereas a less vulnerable location may in fact be less resilient due to a lack of these characteristics (Lyles et al. 2012). A strong adaptive capacity of a community, quantified through sociological measures, enables it to cope with and mitigate vulnerabilities.

Sociological factors impact resilience by providing more widespread disaster insurance, improving social networks, increasing community participation, and increasing local understanding of risk (Cutter et al. 2010). Societal metrics are one approach that can be used to understand hazard vulnerability; identify areas that would benefit from building supportive coalitions of communities; and motivate planning, policy decisions, and actions aimed at anticipating and preparing for the future (Berkes 2007; Chapin et al. 2010; Folke 2006; Norris et al. 2008). The following provides a description, evaluation, and comparison of these sociological resilience metrics.

Table 2. Summary of Sector-Specific Resilience Metrics

Metric	Description
Measuring the Resilience of Energy Distribution Systems	In development by the Office of Energy Policy and Systems Analysis Proposals for resilience metrics for electricity, oil, and natural gas
Resilience Measurement Index	Focuses on critical infrastructure necessary to the nation's security All-hazards methodology
Resilience STAR	Metric under development by the Department of Homeland Security to build and retrofit more disaster resilient homes Intended to expand to the 16 critical infrastructure sectors defined by the Presidential Policy Directive 21
Risk Analysis and Management for Critical Asset Protection	Assessment of critical assets' resilience against terrorist attacks List of seven assessments to analyze critical assets
Sector Resilience Plans	Summary of resilience metrics for 11 infrastructure sectors in the United Kingdom
U.S. Resiliency Council Building Rating System	Building rating system to estimate impacts of natural and manufactured disasters Factors include safety, repair cost, and time to regain basic functions

Table 3. Summary of Sociological Resilience Metrics

Metric	Description
Baseline Resilience Indicators	Baseline conditions that allow monitoring of community resilience indicators over time Variables include social, economic, institutional, infrastructure, and community factors
Canterbury Wellbeing Index	Index that tracks progress of social recovery Based on seven range indicators that provide information on sociological well-being and emerging social trends Specific to Christchurch, New Zealand
Disaster Recovery Tracking Tool	Uses 79 metrics organized into financial, process, social, and public sector categories Online tool allows community to recognize trends in resilience measures
Resilience Capacity Index	Single statistic representing 12 sociological indicators Comparative metric between metropolitan areas
Rural Disaster Resilience Planning Tool	Specifies a resilience metric for rural communities Includes planning, assessing resilience, building a resilience plan, and implementing the plan
Social Vulnerability Index	Comparative measure of social, economic, demographic, and housing characteristics between counties Identifies capacities for reduction of disaster impacts Helps determine differential recovery from disasters

Metrics

Sociological resilience metrics are summarized in Table 3. These include: the Disaster Resilience Indicators for Benchmarking Baseline Conditions, which provides a set of baseline conditions for communities that allow for monitoring of changes in resilience over time in a particular location (Cutter et al. 2010); The Canterbury Wellbeing Index developed in Christchurch, New Zealand, after the Christchurch earthquakes in 2010 and 2011 (CERA 2014); the Disaster Recovery Tracking Tool developed to facilitate a community's evaluation of recovery outcomes (Horney 2014; Dwyer and Horney 2014; Horney et al. 2016; Coastal Hazards Center 2008); the Resilience Capacity Index (RCI), a single statistic that summarizes 12 equally weighted indicators, grouped into regional economic, socio-demographic, and community connectivity capacities (Building Resilience Regions Network 2011); the Rural Disaster Resilience Planning Tool developed by the Justice Institute of British Columbia (JIBC 2013); and the social vulnerability index (SoVI) developed to measure the social vulnerability of counties in the United States to environmental hazards (HVRI 2010, 2014).

Evaluation and Comparison of Sociological Resilience Metrics

The metrics presented in this section measure a community's resilience based on sociological factors determined using data from community planners or the U.S. Census. Some of these sociological metrics are specific to a certain type of community or area. The Canterbury Wellbeing Index is specific to Christchurch, New Zealand; the Resilience Capacity Index is geared toward metropolitan areas; the Rural Disaster Planning Tool is for rural communities that depend on resource-based jobs and may lack access to other risk mitigation methods. In addition, SoVI has implementations for specific disasters. It has, however, been widely used in studies in the United States for assessments of the social vulnerability of communities (Cutter and Emrich 2013; NOAA 2015; Oxfam America 2009; Chang 2005). Finally, many of these metrics are comparative in nature, both over time and across communities, including baseline resilience indicators, the Canterbury Wellbeing Index, the resilience capacity index, and the social vulnerability index.

Two limitations of several of these sociological metrics are that they require high involvement from the developers or rely on outdated data sources. For example, the Canterbury Wellbeing Index has no generalized tool and the developers are required for completion. Both baseline resilience indicators for communities and SoVI need data from sources that are out of date or inadequate (Cutter et al. 2010). Other metrics have tools that make use more manageable by community leaders. These include the disaster recovery tracking tool and the rural disaster resilience planning tool.

Summary of Resilience Metrics

In recent years, there has been increasing recognition of the need to be able to measure and quantify improvements in the resilience of communities to natural and artificial or manufactured hazards. Accordingly, many resilience metrics have been developed. These metrics have been categorized into one of three main categories: community-level, sector-specific, and sociological measures of resilience. Community-level resilience metrics are intended to be comprehensive, covering all aspects of a community's recovery from disaster. They often recommend actions and serve as a blueprint for the resources needed for a community to improve resilience. Sector-specific metrics are more detailed plans for the specific sector they address, rather than providing an overall view of the resilience of a community. Sociological resilience metrics focus on economic, social, and demographic factors that affect the ability of a community to recover from disaster. However, they serve primarily as resilience assessment tools rather than providing more tangible resilience plans.

Community-level metrics tend to be specific to particular geographical locations, but can be used as a basis for developing resilience plans in other communities. Both domestic and international metrics are described in this paper. These differ mainly in their applications to different geographical locations. Implications for these metrics, however, may be different based on varying community cultures around the world, e.g., for more individual-based compared to community-based societies, as well as varying governance structures, e.g., for more centralized compared to decentralized governments. For sector-specific metrics, though they focus on individual sectors, they can generally be applied to those particular sectors across communities. Several of the existing sociological metrics apply to a certain geographic area or type of community, but can be used as models for assessing resilience in other communities or at other geographic levels. A comparison of all resilience metrics described in this paper is provided in Table 4.

Table 4. Comparison of All Resilience Metrics

Metric	Tool	Location	Result	Hazards	Purpose	Pilot Study
Community-level metrics						
CARRI Community Resilience System	Online framework with templates and checklists	Global	Identification of threats and development of action plan	All	Assess resilience	Eight communities
Characteristics of a Safe and Resilient Community	None	Global	None	All	Planning tool	Over 700 communities
City Resilience Index	None	Metropolitan areas	Framework describing characteristics possessed by 12 indicators	All	Assess resilience	14 city case studies and six with fieldwork
Coastal Resilience Index	Paper-based tool with yes-or-no questions	Coastal communities	Low, medium, or high index for categories	Storms, flooding, and tsunamis	Assess resilience	17 communities in southern U.S.
Environmental Vulnerability Index	None	Small Island Developing States	Report card relating to extreme vulnerability, high vulnerability, vulnerability, risk, and resilience	All	Assess resilience	Rankings for a selection of countries
Flood Resilience Checklist	Checklist	Coastal communities	Suggestions to improve resilience	Flooding	Planning tool	None
Getting to Resilience	Online tool with yes-or-no questions	New Jersey	Suggestions to improve resilience and incentives for resilience activities	Storms and flooding	Assess resilience and planning tool	Two communities in New Jersey
Hazus-MH	Online program	Global	Estimate of loss of life and property and customized maps	All	Assess resilience	Many tests by individual communities
Monitoring and Evaluation Project Steering Group	In development by Council of Australian governments, framework taking all levels of government into account					
National Resilience Scorecard	In development, aims to assess multiple hazards and be scalable to any location					
The New Orleans Index	None	New Orleans	Overview of New Orleans's path to resilience	Storms and flooding	Assess resilience	Implemented regularly in New Orleans
Oregon Resilience Plan	None	Cascadia Subduction Zone	Suggestions to improve resilience	Earthquakes and tsunamis	Assess resilience	Proposed in four communities
San Francisco Planning and Urban Research Association	None	Peninsula of San Andreas Fault	Assessment of performance of structures and utilities	Earthquakes	Assess resilience and planning tool	None
U.N. Disaster Resilience Scorecard	None	Global	Score for ten essentials to guide communities toward optimal resilience	All	Assess resilience	Seven example scorecards
Vulnerability-Resilience Indicators Model	Web-based tool	Global	Means of sector indices used to calculate overall index	Climate change	Assess resilience	Historic data case studies
Sector-specific metrics						
Energy Distribution Systems	In development, proposed metrics for electricity, oil, and natural gas distribution					
Resilience Measurement Index	None	Critical infrastructure	Resilience Measurement Index from 0 to 100	All	Assess resilience	None
Resilience STAR	In development, building and retrofitting homes in hurricane-prone communities					
RAMCAP	None	Critical infrastructure	Suggestions to improve resilience	Terrorist attacks	Planning tool	None

Table 4. (*Continued.*)

Metric	Tool	Location	Result	Hazards	Purpose	Pilot Study
Sector Resilience Plans	None	United Kingdom	Unspecified	All	Planning tool	Unspecified
U.S. Resiliency Council Building Rating System	None	Buildings globally	One- to five-star rating for safety, repair cost, and time to regain basic function	All	Assess resilience	None
			Sociological resilience metrics			
Baseline Resilience Indicators	None	Nationwide	Comparative visualization of changes in resilience over time	Natural Hazards	Assess resilience	Applied to southeastern U.S.
Canterbury Wellbeing Index	None	New Zealand	Comparative index of changes over time	Earthquakes	Assess resilience	Applied to Christchurch, New Zealand
Disaster Recovery Tracking Tool	Online tool	Global	Progress in disaster recovery with suggestions to increase resilience	All	Assess resilience	Two communities recovering from disasters
Resilience Capacity Index	None	Metropolitan areas	Single metric summarizing resilience through socio-demographics, economics, and community connectivity	All	Assess resilience	Applied to 361 cities
Rural Disaster Resilience Planning Tool	Online templates and activities	Rural communities	Suggestions to improve resilience	All	Planning tool	None
Social Vulnerability Index	None	United States	Comparative index between counties	Environmental hazards	Assess resilience and planning tool	3,143 U.S. counties

Limitations of Existing Metrics

There are several limitations of existing resilience metrics, which prevent their generalized application across communities. The first is the specificity of a metric for a certain geographic area or a particular hazard. The National Resilience Scorecard aims to overcome this limitation, but this will require either a set of very generalized indices or the inclusion of detailed, comprehensive measures that cover the different demands that are imposed alongside varying geographic areas, hazard types, and community classifications, e.g., urban, suburban, or rural communities. The growing number of people living in metropolitan areas, for example, creates risks that suburban and rural communities do not face. Urban planning becomes a focus to increase the resilience of cities, while rural communities face the challenge of decreased access to many of the resources of a large city. Similarly, larger communities will often have access to more resources than smaller communities. Geographic diversity poses another challenge in assessing resilience. For example, coastal communities are at risk to hazards that inland communities do not face, including hurricane storm surge and tsunamis, while only communities in seismic hazard zones need improve resilience to earthquakes. When looking across hazard types, preparing for a flood or hurricane requires a different approach than that for an earthquake or tsunami. This reveals a limitation in the scalability of resilience metrics across hazards as well as across communities of varying sizes, locations, and characteristics.

Another shortcoming of several of the resilience metrics is the lack of an explicit or quantitative outcome. Many of the metrics (e.g., CARRI, the City Resilience Index, the U.N. Disaster Resilience Scorecard, and the U.S. Resiliency Council Building Rating System) only provide a framework to assess the current status of the community with some generalized goals toward achieving resilience. While these may be beneficial starting points, it is often necessary to examine the specifics of a community to give more customized suggestions and recommendations for actions. The Oregon Resilience Plan results in an effective and individualized plan for the community. SPUR also provides definitive assessments of structures and utilities with tangible recommendations to improve community resilience. However, both of these metrics are focused on particular geographic areas exposed to specific threats and are difficult to generalize because of the in-depth knowledge of the communities required to evaluate them.

Challenges in Improving Community Resilience

One way to motivate communities to increase resilience is to provide incentives for resilience-improving or disincentives for resilience-decreasing activities. The Disaster Resilience Framework proposes a tax incentive to underwrite activities that are necessary to increase resilience (NIST 2015). Getting to Resilience provides discounted insurance rates and certifications to communities who undertake resilience-enforcing activities that lead to long-term sustainability (NRCCI 2015). Sadiq and Noonan (2015) analyzed the responsiveness of communities to the incentives of the Community Rating System. The Community Rating System has a tiered scheme where communities can choose to *upgrade* to the next tier of resilience by implementing resilience activities and increasing subsidies for these activities, or *downgrade* tiers if achieving only minimum standards. The study found that communities that upgrade often adopt passive resilience activities to achieve the standards. Yet, these passive activities may not increase resilience as well as active actions. Communities with more resources were found to be more responsive to incentives, while also facing fewer risks compared to communities with fewer resources.

Kohiyama et al. (2008) performed a study that compared incentives for seismic risk management for homeowners in the United States and Japan. The United States and Japan both have policies outlining seismic retrofitting techniques for existing buildings and standards for new construction. However, several differences exist in those policies that affect outcomes. Japan's local governments provide subsidies for seismic diagnosis and support for retrofitting houses built before 1981. Some cities in the United States provide grants to low- to moderate-income homeowners and support programs that provide rebates on property taxes. The authors found that in Japan, these incentives did not always convince homeowners to retrofit their houses due to a lack of disaster awareness and distrust in contractors. This demonstrates the importance of education in the community on the ways that increasing resilience can be beneficial to support successful implementation of incentives to improve resilience. In Japan, despite incentives, approximately 40% of detached homes were found to have insufficient seismic performance. In California, 20% or fewer of the homes built before 1960 had been retrofitted by 1999. The study found that while incentives can provide some impetus to improve resilience, the impact is often small. This can be attributed to a variety of factors, including cumbersome mechanisms for implementing the incentives, insufficient support levels, or an incorrect choice of type of incentive for the community.

Governance challenges also exist as barriers to achieving community resilience. In order to create an effective community resilience plan, a system must be in place that provides leadership and accountability in preparation for and in response to a disaster. Mamula-Seadon and McLean (2015) performed a study on the changes in governance in the Canterbury Region of New Zealand following two earthquakes in 2010 and 2011. Prior to these earthquakes, a Civil Defence Emergency Management Act was in effect that declared the central government responsible for implementation and coordination of a tiered emergency governance system. Local governments were tasked with increasing resilience but had to heed complex legislation at the national level to integrate policy, planning, and service delivery while accounting for the needs of all community stakeholders. As resources were not immediately available to respond after both earthquakes, as well as to increase resilience, local governments faced difficulties in coordinating emergency management activities. After the 2010 earthquake occurred, a Canterbury Earthquake Recovery Commission was established that was part of the central government, but ended up having little influence on local governments' recovery efforts. Ad-hoc, local community recovery groups had more influence than the central government. In response to the 2011 earthquake, the central government formed a planning group and an operations group. The effectiveness of these groups has not yet been tested. The Canterbury experience demonstrates the need for both horizontal and vertical integration in governance involving policy, disaster planning, and stakeholder engagement to improve resilience.

Development of New Metrics

To have measures that assess community resilience comprehensively and accurately, it is likely necessary to combine the advantages from several metrics. Community-level metrics inform overall resilience assessments, while sector-specific metrics provide the detail required to improve the performance of particular systems under different hazard scenarios. Sociological-level metrics address important societal and institutional factors that may be missing from the other measures.

In thinking about the development of new metrics, Harrald (2012) proposed a framework for developing and assessing

Table 5. Resilience Capacities and Activities to Improve Resilience

Capacity	Activities to account for in a resilience metric
Resistant	Develop chain of custody for resilience measures from government-level to citizens
	Increase the strength of infrastructure systems
	Determine safety thresholds for systems that can be impacted and regularly monitor them
	Install sensors and implement community-wide actions that decrease the vulnerability of the community to potential disasters
Absorptive	Execute administrative actions that accelerate decision making in the event of an emergency (Ouyang 2014)
	Create redundancy in infrastructure systems to reduce impacts of hazards and equipment failures
	Prepare the community on actions to take in the case of a disaster
Restorative	Develop a plan involving the community as well as community leaders to respond to a disaster
	Create emergency notification and information-sharing systems
	Optimize sequences and resource allocation for restoring systems in the community (Ouyang 2014)

resilience metrics that evaluates how communities resist, absorb, and recover from extreme events. The framework looks at rural, wealthy, and urban coastal communities to measure vulnerability and resilience; discuss the role of culture, complexity, and social networks; and assess the role of intergovernmental relations. The framework includes measurable criteria, perceived threats, and community vulnerability. The measures and activities output from the framework are used to gauge the efficiency of the metric-development process. Effectiveness of the process is determined based on the ability of the framework outputs to measure linkages to desired resilience outcomes. Ouyang (2014) defines resilience as the *joint ability of a system to resist (prevent and withstand) any possible damage, absorb the initial damage, and recover to normal operation*. Each of these capacities—resistant, absorptive, and restorative—can be increased through various activities as shown in Table 5. Resilience metrics should address these capacities and the existence of measures accounting for each of the activities can be used as a framework under which to evaluate a given metric.

The authors propose that effective community resilience metrics are characterized by: *breadth*, *utility*, and *scientific merit*. Resilience metrics with *breadth* comprehensively address all aspects of a community. The Characteristics of a Safe and Resilient Community metric, for example, defines six overarching characteristics of a resilient community. Other metrics similarly attempt to describe the factors affecting resilience. An effective metric will quantify each of these factors. A metric should measure the knowledge and health of a community. It is important to gauge how aware the community is of potential hazards and the social preparedness of its citizens. A comprehensive metric also addresses the organization of the community. A community should have effective and well-distributed evacuation plans, and be able to prioritize both resilience preparations prior to a disaster and recovery efforts after a disaster occurs to provide and maintain a community's basic needs. An effective metric should measure the connectedness of the community both internally and with external entities. A resilient community has relationships with governmental and private agencies that can respond in emergencies and ensure response capacity and the provision of resources when they are needed. The resilience of critical infrastructure systems and services should also be included in the index, to measure the ability of infrastructure to recover quickly after a hazard and the presence of emergency shelters that will withstand a disaster. Effective metrics should take economic opportunities into account, measuring flexibility when change is made necessary by a disruption and quantifying the ability to maintain businesses and recover economically after a disaster. A community's management of its natural assets is important to measure to assess its ability to mitigate against further damage from disasters. Additionally, it is beneficial for communities to account for interdependencies between society and the built environment. Citizens' awareness of potential impending hazards can provide an impetus to be proactive and a desire to reinforce buildings and infrastructure, gain connectivity, and organize in an effort to improve the resilience of their communities.

Effective resilience metrics must also possess *utility*. The National Resilience Scorecard draft describes utility as maintenance of user friendliness, utility without hired assistance, and a high value of outputs for resilience planning (NIST 2015). Beneficial metrics have intuitive web-based tools that guide decision makers, and provide recommendations and the necessary information for relevant entities to undertake actions to improve resilience. Effective metrics can be evaluated and utilized directly by communities without the need to rely on outside experts or organizations to perform the assessment. CARRI has a detailed and integrated tool, for example, that walks decision makers step-by-step through engaging community leadership, performing a resilience assessment, developing a shared community vision, action planning and establishing a mechanism to implement and sustain the plan, and evaluating and updating the plan over time (CARRI 2011). These are all necessary steps to establish and implement an effective resilience plan and address the need to update the plan as the community evolves.

Finally, *scientific merit* is necessary to validate an effective resilience metric. This can be achieved through statistical methods, case studies, and/or fieldwork. For example, Hazus-MH uses geographic information system (GIS) technology and probabilistic events to substantiate their resilience measures. Many of the discussed metrics performed pilot tests in communities to verify their merit. The Coastal Resilience Index was implemented in 17 communities and strengths and weaknesses of the metric were documented. Pilot studies reveal how user-friendly and comprehensive a metric is and can suggest additional aspects of a community to include that may not have been considered previously. Fieldwork was performed when developing the City Resilience Index to determine the aspects of resilience that are well understood and to establish the characteristics of cities that contribute to resilience. This fieldwork can also reveal strengths and weaknesses of proposed community resilience systems and provide suggestions for further development.

Whether through the use of a new metric or the application of an appropriate existing metric given the specific characteristics of a community, quantitative resilience measures enable community decision makers to determine baseline levels of performance, monitor improvements to resilience across varying strategies, and compare their performance relative to other communities to motivate new actions. Decisions for investment in the community to improve resilience must be met with some tangible benefit to the community. A comprehensive, user-friendly, scientifically-based metric to measure these costs and benefits will be a way to inform these decisions to improve community resilience.

Conclusions

The growing risk of natural and artificial or manufactured hazards around the world confirms the need for comprehensive community resilience metrics that aim to address multiple hazards, multiple geographic areas, and a variety of resilience factors. Currently, there exist many metrics within each of the three categories of community-level, sector-specific, and sociological measures of resilience. These have been described and compared based on the metric, type of tool, applicable location, framework outputs, hazards addressed, and communities studied. Many of these are limited based on the specific geographic area, hazard, or type of community considered. In addition, the metrics are all stand-alone indices, while integrating them, or developing a measure that combines the strengths of multiple metrics, would be beneficial. For example, integrating a technological metric (e.g., Hazus-MH, which has an online tool and uses science, engineering, mathematical modeling, and GIS technology) with a metric that defines clear goals for resilience (e.g., baseline resilience indicators for communities or Characteristics of a Safe and Resilient Community) would provide a more thorough assessment of the assets and vulnerabilities of a community for resilience. In addition, combining community-level metrics with sector-specific and sociological measures would enable an assessment with the breadth and detail required to comprehensively address resilience. Looking ahead, the National Resilience Scorecard in development by NIST aims to provide a single community resilience metric that accomplishes this and is scalable across communities. Resilience metrics are important for education, establishing a baseline, and for the planning, implementation, and evaluation of strategies and actions to improve the resilience of communities to disasters. There has been significant movement toward establishing metrics to achieve this, and there is the opportunity to create metrics that have the breadth, utility, and scientific grounding to be effective in evaluating and improving the resilience of our communities.

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