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A place-based model for understanding community resilience to natural disasters

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ABSTRACT

There is considerable research interest on the meaning and measurement of resilience from a variety of research perspectives including those from the hazards/disasters and global change communities. The identification of standards and metrics for measuring disaster resilience is one of the challenges faced by local, state, and federal agencies, especially in the United States. This paper provides a new framework, the disaster resilience of place (DROP) model, designed to improve comparative assessments of disaster resilience at the local or community level. A candidate set of variables for implementing the model are also presented as a first step towards its implementation.

1. Introduction

Despite nearly a half century of concerted research and public policy practice, the US government remains uncommitted to reducing society's vulnerability to natural hazards. The escalation of disaster losses and the increasing movement of Americans into highly hazardous areas support this assertion (Cutter and Emrich, 2005; Cutter et al., 2007). Although there may be recognition of the hazards in many communities, risk reduction and vulnerability often are not salient concerns until after the disaster occurs. Residents have other issues that assume priority, and local elected officials do not want to dwell on the hazard vulnerability of their communities as it might hurt economic investment and growth.

Among US federal agencies, there has been a noticeable shift in the rhetoric about hazards, moving from disaster vulnerability to disaster resilience, the latter viewed as a more proactive and positive expression of community engagement with natural hazard reduction. The identification of standards and metrics for assessing disaster resilience is one of the grand challenges requiring federal investment according to US federal agencies (Subcommittee on Disaster Reduction, 2005). As the report states,

> …with consistent factors and regularly updated metrics, communities will be able to maintain report cards that accurately assess the community's level of disaster resilience. This, in turn, will support comparability among communities and provide a context for action to further reduce vulnerability (Subcommittee on Disaster Reduction, 2005, p. 10).

While numerous research efforts have assessed various dimensions of community resilience, challenges remain in the development of consistent factors or standard metrics that can be used to evaluate the disaster resilience of communities. This paper takes the first step in this process by (1) providing a conceptual framework for natural disaster resilience drawn from the global change, hazards, political ecology, ecosystems, and planning literatures, and (2) describing a candidate set of variables for measuring resilience based on the same literature.

2. The research policy nexus

In the aftermath of the devastating 1964 Alaskan earthquake, the US federal government sought an assessment on what was known about the human occupance of hazard zones, the range of societal adjustments to natural hazards, social acceptance or tolerance of risk, and the dissemination of research to state and local officials (White and Haas, 1975). This *first assessment* concluded that losses and potential losses from natural hazards were rising and the nation's vulnerability to them was increasing due to: (1) suburbanization with more people living in unprotected floodplains, seismic zones, and coastal locations; (2)

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residential mobility with more people moving into areas where they were unfamiliar with the local hazards and ways of coping with them; (3) the increased size of corporations permitting more risk-taking behavior in terms of plant locations in highly hazardous areas because they had the capacity to absorb the loss; and (4) the increased proportion of the affordable housing stock in mobile homes (White and Haas, 1975).

Twenty-five years later, the *second assessment* (Mileti, 1999) sought a new philosophical approach to reducing losses from natural hazards and disasters, one that involved the development of disaster-resistant communities. This shift emphasized the interactive nature of natural and human systems, the built environment, and the role of human agency in producing hazards and disasters (acts of people, not acts of God). The importance of unsustainable environmental practices in increasing societal vulnerability is recognized, especially as it reduces the opportunity for achieving disaster-resistant communities.

The notion of building disaster-resistant communities received federal governmental support in 1994, when the US Federal Emergency Management Agency (FEMA) announced its National Mitigation Strategy—an effort to reduce the escalating disaster losses by fostering public–private partnerships and incentives for mitigation. Formalized in 1997 under Project Impact, communities were designated disaster resistant if they built partnerships with all community stakeholders; identified their hazards and vulnerabilities; prioritized them and implemented hazard risk reduction actions; and then communicated their success to others (National Research Council, 2006). With the 2000 US Presidential election and a change in administrations the Project Impact initiative was terminated before any evaluation of its success was made (Rubin, 2007).

Internationally, there has been a parallel effort to build frameworks for disaster risk reduction, starting in 1990 with the International Decade for Natural Disaster Reduction (IDNDR). In 1994 the World Conference on Natural Disaster Reduction was held in Yokohama, Japan and was the first UN World Conference that specifically addressed disaster risk reduction and the importance of the social aspects of vulnerability (United Nations, 1994). By the end of the IDNDR, the human dimensions of risk reduction had come to the forefront of the international focus supplanting the engineered-based thinking that had dominated earlier.

Another development in the international arena was the Millennium Declaration of 2000 and the accompanying Millennium Development Goals. These goals, consisting of 18 targets measured by 48 specific indicators, have now become the benchmarks by which all signatory countries assess their own progress in the global effort to reduce poverty. As a result, there is increasing awareness of the integral link between the reduction of both poverty and natural disasters. Natural disaster risk reduction is also finding its place in the increasingly popular goals of sustainable development (Wisner et al., 2004).

The most recent international efforts are those embodied in the Hyogo World Conference on Disaster Reduction held in 2005 in Kobe, Japan. The Hyogo Framework for Action identified both the need for and ways to build resilient communities by (1) integrating disaster prevention, mitigation, preparedness, and vulnerability reduction perspectives into sustainable development policies; (2) increasing local capacity (institutions and mechanisms) for building hazard resilience; and (3) incorporating risk reduction into the design and implementation of emergency preparedness, response, recovery, and reconstruction programs in affected communities (International Strategy for Disaster Reduction, 2005).

3. Why resilience and not vulnerability?

Because there are semantic differences in the definitions of key hazard terms, we begin with the definitions we have adopted for this paper. Vulnerability is the pre-event, inherent characteristics or qualities of social systems that create the potential for harm. Vulnerability is a function of the exposure (who or what is at risk) and sensitivity of system (the degree to which people and places can be harmed) (Adger, 2006; Cutter, 1996). Resilience is the ability of a social system to respond and recover from disasters and includes those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change, and learn in response to a threat. Vulnerability and resilience are dynamic processes, but for measurement purposes are often viewed as static phenomena.

We view communities as the totality of social system interactions within a defined geographic space such as a neighborhood, census tract, city, or county. We recognize that there are many different communities within such geographically defined spaces and sub-populations may indeed have different levels of vulnerability and resilience that could result in recovery disparities. This model is designed to capture such disparities by focusing on the place and the spatial interactions among the social system, built environment, and natural processes.

3.1. Assessing vulnerability

Numerous frameworks, conceptual models, and vulnerability assessment techniques have been developed to advance both the theoretical underpinnings and practical applications of vulnerability (Adger, 2006; Eakin and Luers, 2006; Fussel, 2007; Green and Penning-Rowsell, 2007; Manuel-Navarrette et al., 2007; McLaughlin and Dietz, 2008; Polsky et al., 2007; Gallopin, 2006). Despite their differences, a number of common elements are found: (1) the examination of vulnerability from a social-ecological perspective; (2) the importance of place-based studies; (3) the conceptualization of vulnerability as an equity or human rights issue (Sarewitz et al., 2003) and (4) the use of vulnerability assessments to identify hazard zones, thereby forming the basis for pre-impact and hazard mitigation planning (Brooks et al., 2005; Clark et al., 2000; Cutter et al., 2000; O'Brien et al., 2004). Challenges in moving from single stressors (hazards) to multiple stressors (global change), understanding how cross-scalar dynamics influence the vulnerability of a place, incorporating the dynamic nature of vulnerability (spatially and temporally), including perceptions of vulnerable populations, and providing a theoretically sound conceptualization that can be applied to local problems hamper our understanding of disaster vulnerability and its link to resilience.

3.2. Defining resilience to hazards

Holling (1973) first used the term resilience to describe a "measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables (Holling, 1973, p. 14)." Like vulnerability, multiple definitions of resilience exist within the literature, with no broadly accepted single definition (Klein et al., 2003; Manyena, 2006). The global environmental change community has been very active in further conceptualizing resilience in human-environment interactions (or socio-ecological systems) (Janssen et al., 2006). In this research domain, resilience is defined as a system's capacity to absorb disturbance and re-organize into a fully functioning system. It includes not only a system's capacity

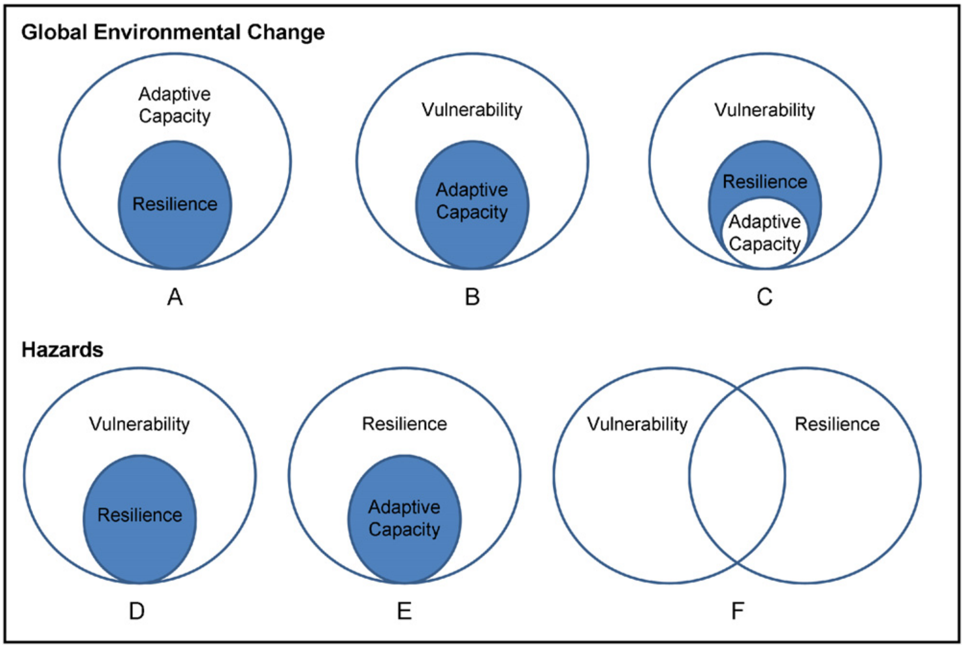

Fig. 1. Conceptual linkages between vulnerability, resilience, and adaptive capacity.

to return to the state (or multiple states) that existed before the disturbance, but also to advance the state through learning and adaptation (Adger et al., 2005; Klein et al., 2003; Folke, 2006). Political ecology and global environmental change research also incorporate the idea of adaptive capacity with resilience. Adaptive capacity is defined in this literature as the ability of a system to adjust to change, moderate the effects, and cope with a disturbance (Burton et al., 2002; Brooks et al., 2005).

While adaptive capacity is a prominent theme in the global environmental change view of resilience; it is less prevalent in the hazards perspective. Instead, mitigation is a key construct that bears a similar connotation as adaptation. Hazard mitigation is any action taken to reduce or avoid risk or damage from hazard events (Godschalk, 2002; Mileti, 1999). Similar to adaptive capacity, the use of mitigation techniques and planning can increase a system's or society's resilience to hazards (Bruneau et al., 2003; Burby et al., 2000).

The relationship between vulnerability, resilience, and adaptive capacity is still not well articulated as shown in Fig. 1. According to some researchers, resilience is an integral part of adaptive capacity (Fig. 1a) (Adger, 2006; Birkmann, 2006a; Folke, 2006) while others view adaptive capacity as a main component of vulnerability (Fig. 1b) (Burton et al., 2002; O'Brien et al., 2004; Smit et al., 1999). A third perspective sees them as nested concepts within an overall vulnerability structure (Fig. 1c) (Gallopin, 2006; Turner et al., 2003).

In hazards research, the definition of resilience is refined to mean the ability to survive and cope with a disaster with minimum impact and damage (Berke and Campanella, 2006; National Research Council, 2006). It incorporates the capacity to reduce or avoid losses, contain the effects of disasters, and recover with minimal social disruptions (Buckle et al., 2000; Manyena, 2006; Tierney and Bruneau, 2007). Resilience within hazards research is generally focused on engineered and social systems, and includes pre-event measures to prevent hazard-related damage and losses (preparedness) and post-event strategies to help cope with and minimize disaster impacts (Bruneau et al., 2003; Tierney and Bruneau, 2007).

The use of resilience as an outcome or a process also distinguished the research communities. For example, resilience is considered an outcome when defined as the ability to bounce back or cope with a hazard event and is imbedded within vulnerability (Fig. 1d) (Manyena, 2006). Process-related resilience is defined more in terms of continual learning and taking responsibility for making better decisions to improve the capacity to handle hazards. Determining whether resilience is an outcome or a process is an important step toward its application to disaster reduction. When compared to the global change perspective, hazards researchers often embed adaptive capacity or mitigation within resilience (1e) (Paton and Johnston, 2001; Paton and Johnston, 2006; Bruneau et al., 2003; Tierney and Bruneau, 2007). This paper views resilience and vulnerability as separate but often linked concepts (Fig. 1f).

4. Modeling hazard vulnerability and resilience

4.1. Vulnerability frameworks

The literature is divided when it comes to explaining the causal structure of vulnerability. Some research argues that vulnerability arises from underlying social conditions that are often remote from the initiating event. Here, exposure is treated as given, and research under this perspective searches for patterns of differential access to resources or differential susceptibility to loss. A second perspective within vulnerability research explains causality by modeling potential exposure to hazard events. This view assumes vulnerability is simply a function of proximity to the source of risk or hazard (Alexander, 1993; Heyman et al., 1991). A third theme in vulnerability research integrates both the biophysical and social perspectives. In this view, vulnerability is a function of biophysical risk and social response and how this manifests itself locally, or the hazardousness of place (Hewitt and Burton, 1971).

Considering such multifaceted approaches to vulnerability research, it is not surprising that vulnerability models diverge in terms of explaining the root causes of vulnerability. Few researchers have attempted to combine all the factors that contribute to vulnerability, let alone measure them empirically (Cutter et al., 2003). The most often cited conceptual models for hazard vulnerability include: (1) Blaikie and Wisner et al.'s pressure and release model (Wisner et al., 2004); (2) Turner et al.'s (2003) vulnerability/sustainability framework; and (3) Cutter's hazards-of-place model of vulnerability (Cutter, 1996; Cutter et al., 2000). The pressure and release model tracks the progression of vulnerability from root causes to dynamic pressures to unsafe conditions, yet it fails to adequately address the coupled human–environment system associated with the proximity to a hazard. Turner et al.'s vulnerability/sustainability framework uses a place-based approach locating local vulnerability within the larger contexts that influence it; however, the model fails to clearly differentiate between exposure and sensitivity and also does not include a temporal dimension that shows where vulnerability begins and ends. Cutter's hazards-of-place model integrates systems exposure and social vulnerability, but fails to account for the root causes of the antecedent social vulnerability, larger contexts, and post-disaster impact and recovery.

4.2. Resilience frameworks

Resilient communities are far less vulnerable to hazards and disasters than less resilient places. For this assumption to be validated and useful, knowledge of how resilience is determined, measured, enhanced, maintained, and reduced is vital (Klein et al., 2003). It is not obvious what leads to resilience within coupled human–environment systems or what variables should be utilized to measure it. Because of the multidimensional nature of resilience and its different component parts, a broad model of resilience has yet to be empirically tested at the community level (Cumming et al., 2005). Several works, however, have attempted to highlight the fundamental aspects of resilience (Berkes et al., 2003; Plummer and Armitage, 2007).

Perhaps the most ambitious conceptual structure is panarchy (Gunderson and Holling, 2001). The panarchy framework is a hierarchical structure where natural systems and human systems are linked in non-stop adaptive cycles of growth, accumulation, restructuring, and renewal. These cycles occur in nested sets of ecological, temporal, and spatial resolutions and most occupy discrete niches in space or time. Within the model, structures and processes are also linked across scales. It is argued that the dynamics of a system at one particular scale of interest cannot be fully understood in lieu of accounting for the dynamics of other cross-scalar and hierarchical influences within the system. To foster resilience and sustainability within a system, an understanding of adaptive cycles within the coupled human–environmental system, and the scale at which they occur, is necessary.

In the hazards arena, most of the resilience models involve engineered systems. In these frameworks, the properties of resilient infrastructure—robustness, redundancy, resourcefulness, and rapidity—reduce the probability of failures (Bruneau et al., 2003; Tierney and Bruneau, 2007), yet these frameworks often fail to capture antecedent social factors that occur at the most local levels or to account for the vulnerability or resilience of the natural environment. Resilience has two qualities: inherent (functions well during non-crisis periods); and adaptive (flexibility in response during disasters) and can be applied to infrastructure, institutions, organizations, social systems, or economic systems.

To ameliorate the shortcomings in existing vulnerability and resilience models and to provide a conceptual basis for establishing baselines for measuring resilience, we have developed a disaster resilience of place (DROP) model. The disaster of place model is designed to present the relationship between vulnerability and resilience, one that is theoretically grounded, amenable to empirical testing, and one that can be applied to address real-world problems in local communities.

5. Confounding issues

5.1. Resilience within the broader context of sustainability

The resilience of a community is inextricably linked to the condition of the environment and the treatment of its resources; therefore the concept of sustainability is central to studies of resilience. Within the context of natural disasters, sustainability is defined as the ability to "tolerate—and overcome—damage, diminished productivity, and reduced quality of life from an extreme event without significant outside assistance" (Mileti, 1999, p. 4). An environment stressed by unsustainable practices may experience more severe environmental hazards. For example, large-scale deforestation was a factor in increasing the flooding hazard, in the 1998 floods in China (Wisner et al., 2004), and loss of coastal wetlands is a contributing factor to the severity of impacts of tropical storms and hurricanes on coastal Louisiana (Austin, 2006). There has been a call for a shift from *ad hoc*, disaster-driven, and reactive systems and policies to a proactive, threat-driven, and mitigative focus (Godschalk, 1999) These efforts not only make sense for reducing the impacts of environmental hazards, but they are also much more in line with the generational equity concerns inherent in sustainability science.

5.2. Scale and unit of analysis

There is a bifurcation in the research literature on scale. The global change domain analyzes large-scale global processes and changes and what these mean to humans and the environment that sustains us. While the scale of these processes is global, the unit of analysis varies from the individual to the continental. With differences in scale and unit of analysis comes a unique nomenclature. For example, at the individual or household level, issues of livelihood and entitlements come into play, yet at the national and regional scale the Gross Domestic Product (GDP) is often used as an indicator of resilience (International Strategy for Disaster Reduction, 2004; Pelling, 2003). From the hazards research perspective, natural processes and impacts are localized and event-specific. Cross-national and global comparisons are possible normally resulting in the aggregation of local information to broader spatial units, in contrast to the global change literature, where global processes are downscaled to assess their impacts on the local level.

Regardless of whether one is downscaling or aggregating, there is considerable consensus about those attributes, characteristics, and practices that influence the potential impact of the hazard or stress. For example, an abundance of monetary resources reduces the potential impact of a given hazard. However, the interpretation of wealth as a characteristic that increases adaptive capacity, increases resilience, decreases vulnerability, or all of the above is highly variable among knowledge domains. Furthermore, the specific variables used to measure wealth vary with both scale and the unit of analysis. For example, wealth could be measured as mean income, personal savings, collective communal wealth, Gross Regional Product, or Gross National Product.

5.3. Temporal variability

In addition to scale, the rates of onset of the initiating event measured in minutes to years if not decades, is another confounding issue in resilience. Rapid onset events such as hurricanes or earthquakes require an immediate response and the time for change or modification in behaviors and practices in the preparedness (pre-event) or post-event (mitigation) phases. In this context, some indicators of resilience could be community evacuation plans, the level of seismic retrofit on structures, or mandated mitigation such as storm shutters. Slow onset hazards include global temperature variations, sea level rise, drought, disease, and famine. This relatively slow rate of onset paired with less definitive spatial extents may contribute to a preference in the human dimensions of global change literature to conceptualize these hazards as "pressures". It may also contribute to the prevalence of adaptive capacity concepts because slow onset events allow an individual or community the opportunity to change or modify existing behaviors and practices to reduce the impact of a hazard while the event is unfolding. In this context, indicators of resilience might include conversion to drought-resistant crop species, water conservation, or the development of more sustainable land use practices.

6. The disaster resilience of place (DROP) model

With recognition of both the contributions from existing models and their limitations in the context of resilience and vulnerability, we propose the DROP as a new conceptualization of natural disaster resilience. This model is designed to present the relationship between vulnerability and resilience; one that is theoretically grounded, amenable to quantification; and one that can be readily applied to address real problems in real places. In the remaining sections of this paper we outline the assumptions of the DROP model and then explain each component.

6.1. *Critical assumptions*

Because models are a simplification of reality, several assumptions are implicit in our conceptualization of the DROP. First, the model was created specifically to address natural hazards, but could be adapted to other rapid onset events such as terrorism or technological hazards, or slow onset natural hazards like drought. Second, the DROP focuses on resilience at the community level, thus distinguishing it from models created to assess resilience at the meso- or macro-level or models based on sectors. Third, the main focus of this model is on the social resilience of places; however, we acknowledge that other forms of resilience exist and cannot be separated from social processes. Natural systems, social systems, and the built environment are interconnected and therefore their separation is arbitrary. Human actions impact the state of the environment and, in turn, a degraded environment provides less protection against hazards. Thus, the DROP presents resilience as both an inherent or antecedent condition and a process. The antecedent conditions can be viewed as a snapshot in time or as a static state, yet the post-event processes embedded within the model allow the conceptualization to also be dynamic. Finally, while the DROP is a place-based model, we recognize that exogenous factors such as federal policies and state regulations do exert powerful influences on resilience at the community level.

6.2. *Explanation of DROP*

The starting point of this model begins with the antecedent conditions, which are a product of place-specific multiscalar processes that occur within and between social, natural, and built environment systems. Antecedent conditions include both inherent vulnerability and inherent resilience. This concept is represented as nested triangles (Fig. 2) illustrating how this inherent process occurs at the local scale, resulting in community-level endogenous factors, as well as at the broader scales (larger triangles) which embody exogenous factors. The exogenous factors influence the endogenous factors, although their impact may not be directly measurable. Contrary to some conceptualizations where resilience and vulnerability are oppositional, we propose that there is overlap within these concepts so that they are not totally mutually exclusive, nor totally mutually inclusive. There are many characteristics that influence only the vulnerability or only the resilience of a community. On the other hand, there are social characteristics that influence both vulnerability and resilience (socio-economic status, education, and insurance, for example).

Antecedent conditions interact with the hazard event characteristics to produce immediate effects. The event characteristics include frequency, duration, intensity, magnitude, and rate of onset, which vary depending on the type of hazard and the location of the study area. The immediate effects are attenuated or amplified by the presence or absence of mitigating actions and coping responses in the community, which themselves are a function of antecedent conditions. This is represented in the model with a plus (amplified) or minus (attenuated). Coping

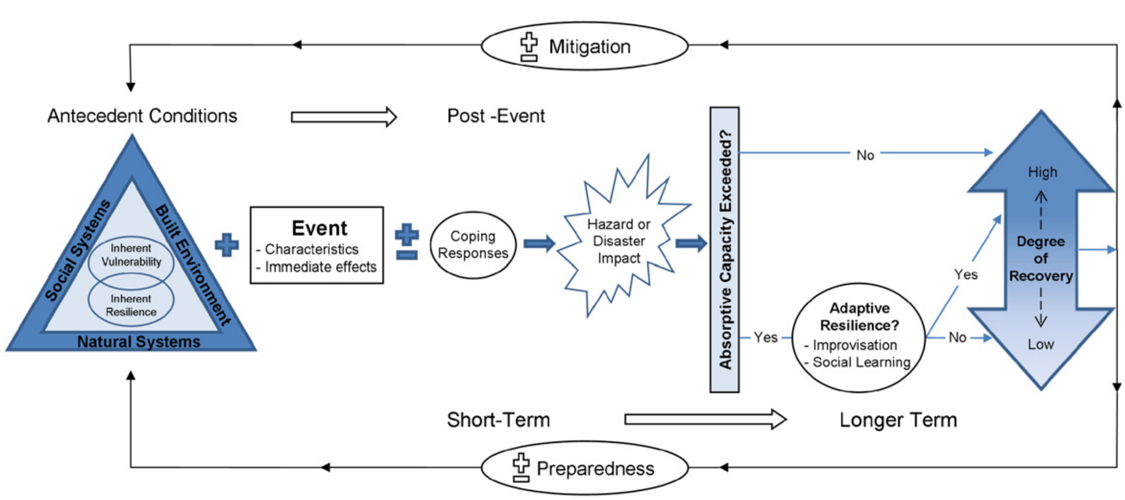

Fig. 2. Schematic representation of the disaster resilience of place (DROP) model.

responses are actions that allow a community to respond in a certain way to the immediate event impacts and include predetermined evacuation plans, creation of shelters, information dissemination, and emergency response plans. After these coping responses are implemented, the hazard or disaster impact is realized.

The total hazard or disaster impact is a cumulative effect (or sum) of the antecedent conditions, event characteristics, and coping responses. The overall local impact can be moderated by the absorptive capacity of the community. Absorptive capacity (or threshold) is the ability of the community to absorb event impacts using predetermined coping responses. If a community implements sufficient coping responses, the impact of the hazard event will be attenuated and the absorptive capacity of the community will not be exceeded, leading to a high degree of recovery. A community's absorptive capacity or threshold can be exceeded in two ways. First, if the hazard event is so large it overwhelms local capacity; and second if the event is less catastrophic, but existing coping responses are insufficient to handle the impact, the community's absorptive capacity will be exceeded pushing it closer to disaster. If either occurs the community may exercise its adaptive resilience through improvisation and learning. Improvisation includes impromptu actions which may aid in the recovery process. Social learning is defined as "the diversity of adaptations, and the promotion of strong local social cohesion and mechanisms for collective action" (Adger et al., 2005, p. 1038). Social learning occurs when beneficial impromptu actions are formalized into institutional policy for handling future events and is particularly important because individual memory is subject to decay over time. Manifestations of social learning include policy making and pre-event preparedness improvements. When improvisation and social learning take place, they directly alter the inherent resilience for the next event as illustrated by the feedback loops in Fig. 2.

It is important to distinguish between learning in the context of the adaptive resilience process and "lessons learned" in the coping process. Lessons learned are debriefings after the event is over and are used to identify what went right and what went wrong in the response. In reality, lessons learned are merely lessons identified. They are commonly formulated as recommendations that may or may not be implemented in time for the next hazard event or at all, providing a differentiation between this and social learning.

The degree of recovery can be thought of as a continuum ranging from high to low. If a community's absorptive capacity is not exceeded, higher rates of the recovery are reached quickly. If the absorptive capacity is exceeded and the adaptive resilience process does not occur, a lower degree of recovery may result. This is illustrated in the diagram with the "No" arrow following adaptive resilience. However, if the absorptive capacity is exceeded and the adaptive resilience process does occur the community may be more likely to achieve a higher degree of recovery. Regardless, overall recovery is an ongoing process and can continue until the next event.

Both the degree of recovery and the potential knowledge gained from the adaptive resilience process influence the state of the social, natural, and built environment systems and the resultant antecedent conditions for the next event. For example, if wetlands are not restored after a hurricane, there will be less natural protection available to serve as a buffer for the next storm. In addition, the new knowledge gained through the adaptive resilience process can both influence the antecedent conditions and enhance the inherent resilience through the implementation of new coping strategies. The feedback process includes the potential to modify both preparedness and mitigation. It is not assumed that preparedness and mitigation will be enhanced; however, if social learning occurs, there is a greater likelihood that mitigation and preparedness will be improved.

7. The first step: measuring inherent resilience

Since the primary impetus for understanding the drivers and processes of disaster resilience is to develop management plans to enhance it, assessments are needed to evaluate not only the baselines conditions, but also adverse impacts, and factors that inhibit effective response (Clark et al., 2000). The transition from conceptual frameworks to assessment is challenging due to the multifaceted nature of resilience including the physical, social, institutional, economic, and ecological dimensions.

The majority of assessment techniques are quantitative and use selected indicators or variables as proxies since it is often difficult to quantify resilience in absolute terms without any external reference with which to validate the calculations (Schneiderbauer and Ehrlich, 2006). As a result, indicators are typically used to assess relative levels of resilience, either to compare between places, or to analyze resilience trends over time. Important criteria for indicator selection include validity, sensitivity, robustness, reproducibility, scope, availability, affordability, simplicity, and relevance (Birkmann, 2006b; de León and Carlos, 2006). The most important of these is validity, which speaks to the question of whether the indicator is representative of the resilience dimension of interest. Another important criterion is robustness, a characteristic that many of the existing vulnerability indices, for example, exhibit significant shortcomings (Gall, 2007). Several criticisms of the quantitative indicator approach have been noted by researchers, including subjectivity regarding variable selection and weighting, lack of availability of certain variables, problems with aggregation to different scales, and difficulties validating the results (Luers et al., 2003; de León and Carlos, 2006). However, the usefulness of quantitative indicators for reducing complexity, measuring progress, mapping, and setting priorities makes them an important tool for decision makers.

The challenges in constructing techniques of measurement for resilience lay in its multifaceted nature, and beg the question of resilience *of* what and *to* what (Carpenter et al., 2001). As noted earlier, the conditions defining resilience are dynamic and ultimately change with differences in spatial, social, and temporal scales. A society may be deemed as resilient to environmental hazards at one time scale (e.g. short-term phenomena such as severe weather) due to mitigation measures that have been adopted but not another (e.g. long-term such as climate change). The temporal scale at which resilience is measured is another important consideration, for it will affect the variables and parameters chosen to develop general indicators as well as their availability.

There are several types of resilience that are distinguished in the literature, and these require different forms of measurement (Table 1). The resilience of ecological systems is influenced by factors like biodiversity, redundancies, response diversity, spatiality, and governance and management plans (Adger, 2006; Adger et al., 2005; Folke, 2006; Brenkert and Malone, 2005; Heinz, 2002). Social resilience can be increased through improvements in communications, risk awareness, and preparedness (Paton and Johnston, 2006; Paton et al., 2000). Social resilience can be enhanced through the development and implementation of disaster plans, the purchase of insurance, and the sharing of information to aid in the recovery process. Some of these are a function of the demographic characteristics of the community and its access to resources.

Table 1
Community resilience indicators

Dimension	Candidate variables
Ecological	Wetlands acreage and loss Erosion rates % impervious surface Biodiversity # coastal defense structures
Social	Demographics (age, race, class, gender, occupation) Social networks and social embeddedness Community values-cohesion Faith-based organizations
Economic	Employment Value of property Wealth generation Municipal finance/revenues
Institutional	Participation in hazard reduction programs (NFIP, Storm Ready) Hazard mitigation plans Emergency services Zoning and building standards Emergency response plans Interoperable communications Continuity of operations plans
Infrastructure	Lifelines and critical infrastructure Transportation network Residential housing stock and age Commercial and manufacturing establishments
Community competence	Local understanding of risk Counseling services Absence of psychopathologies (alcohol, drug, spousal abuse) Health and wellness (low rates mental illness, stress-related outcomes) Quality of life (high satisfaction)

Metrics for assessing economic resilience to hazard events have typically employed the use of loss estimation models to measure the property loss and the effects of business disruption post-event (Chang and Shinozuka, 2004; Rose, 2004). Business disruption refers strictly to the human role in the operation of businesses, organizational, and institutional entities. Property loss measures are typically incurred during the short-term phases of the disaster whereas the business interruptions occur during the longer period of recovery. The role of economic resilience in reducing monetary losses in disasters is achieved through the adoption of mitigation strategies that aim to lessen the probability of failure (Rose, 2006). Researchers in this arena frequently identify the difficulties encountered in gathering data on resilience for input into these models.

Organizational resilience includes institutions and organizations and requires assessments of the physical properties of the organizations such as number of members, communications technology, number of emergency assets such as vehicles, hospital beds, etc. Organizational resilience also includes elements that measure how organizations manage or respond to disasters such as organizational structure, capacity, leadership, training, and experience (Tierney and Bruneau, 2007). For example, an organization that is hierarchical with a command and control structure is less flexible in the face of a disaster (and therefore less resilient) than one that has a more vertical and integrated management structure that encourages flexibility and adaptation to changing conditions.

Infrastructure resilience also includes both the physical systems themselves such as the number of pipelines, road miles, etc., as well as their dependence and interdependence on other infrastructure. The more tightly coupled and interconnected the infrastructure system (Perrow, 1999), the less resilience it exhibits. A high degree of interdependence reduces resilience since a disruption (either upstream or downstream) in one sector cascades into impacts on other sectors (Chang et al., 2007; McDaniels et al., 2007).

Community competence is another form of resilience and highlights those attributes of places that promote population wellness, quality of life, and emotional health (Norris et al., 2008). Community competence measures how well the community functions pre-and post-disaster including a sense of community and ideals as well as attachment to place and the desire to preserve pre-disaster cultural norms and icons (Vale and Campanella, 2005). Despite these varied conceptualizations for describing and assessing resilience, none of these metaphorical and theoretical models have progressed to the operational stages where they effectively measure or monitor resilience at the local level.

8. Next steps

There is an exciting, but fragmented body of literature focused on resilience. This paper provided an integration of the literatures and provided the theoretical justification for a new conceptualization for understanding and measuring community-level resilience to natural hazards, called the DROP model. This model presents resilience as a dynamic process dependent on antecedent conditions, the disaster's severity, time between hazard events, and influences from exogenous factors. Although conceptually dynamic, immediately preceding the disaster, the degree of recovery leads to the static depiction of the antecedent conditions. For example, if a community experiences a 10 year flood, it is unlikely that its absorptive capacity will be exceeded. However, if this same community experiences a 10 year flood every year for several years, each event has reduced the monetary resources available to cope with the next event, making it that much harder to recover. Conversely, if the community learns from the hazard event and the opportunity to improve mitigation and preparedness are utilized, the community is likely to have increased its inherent resilience before the next event occurs.

The next step is to operationalize the model, develop a set of common indicators, and then test it in a real-world application. This necessitates additional research on resilience metrics. Such an application should provide sound measurements for assessing what makes some places more resilient in the face of natural disasters than others and would permit the comparison of community resilience over time and across space using the same set of measures. It should provide the guidance for implementing more sustainable practices that empower local communities to take their risks seriously, and at the same time provide guidance on the structural, economic, social, and environmental policy changes needed to enhance their own resilience.

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