Exploring diverse perspectives of coastal resilience: The state of resilience model

By

Laura Szczyrba,[1*] Justin Shawler,[2] Ali Mohammad Rezaie,[3] and Vanessa Constant[4]

1) Department of Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, ON K7R 3K7, Canada
2) U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS 39180, USA
3) Department of Civil Engineering, University of Asia Pacific, Dhaka 1205, Bangladesh
4) National Academies of Sciences, Engineering, and Medicine, Washington, DC 20001, USA
[*]Corresponding author: 20LDS@queensu.ca

ABSTRACT

In the context of climate change, the term resilience was popularized by the field of ecology to describe how ecological systems respond to stress and has since been adopted and significantly adapted by various fields, including psychology, policy, urban planning, and engineering. The exact meaning of resilience has blurred over time. In the context of coastal hazards, "resilience" is a holistic idea that relates long and short-term physical hazards with societal and biological impacts and mitigation measures. However, applying this idea to community-based mitigation planning remains challenging due to: (1) the diverse meanings, perspectives, and applications of the term, (2) the tendency of the term to defer to the status quo, thereby neglecting the voices of historically marginalized populations, and (3) the non-participatory and quantitative nature of resilience studies, often depending on cost-benefit analyses. In this paper, an interdisciplinary team of researchers and practitioners develops and proposes a new conceptual model for coastal resilience that offers to help address these aforementioned challenges by focusing on meaningful community engagement. The goal of this paper is to introduce the pitfalls of existing interpretations of coastal resilience, describe the team-based approach applied to develop this framework, and provide a theoretical path forward that addresses the current challenges in describing coastal resilience. This new framework (a) integrates relevant factors of coastal resilience including hazards, exposure, vulnerability, adaptation, mitigation and preparedness to qualitatively explore a community's perception and state of resilience which (b) transcends existing models and (c) can be interpreted through a variety of perspectives. This model can be applied to document and assess locally differential understandings of coastal resilience and to engage communities in reflections of their individual and collective sense of resilience.

KEYWORDS: Resilience, vulnerability, equity, community engagement.

Manuscript submitted 14 May 2022, revised & accepted 16 August 2022.

As intensifying hazards continue to threaten coastal systems, it is becoming increasingly important to explore the concept of coastal resilience and question its current interpretations. In the United States (U.S.), coastlines are heavily populated economic hubs with over 118 million people residing in shoreline counties, concentrating 37% of the U.S. population into 18% of its land area (Kildow *et al.* 2016). Coastal systems also provide diverse habitats that support a range of vital ecosystem services, such as coastal storm protection, nutrient cycling, and water and air purification (Kirwan and Megonigal 2013).

However, these coupled human-natural systems are subject to various hazards that may be worsening as a result of climate change, including storm frequency and intensity (Walsh *et al.* 2016), sunny-day flooding (Jacobs *et al.* 2018), erosion (List *et al.* 1997; Mentaschi *et al.* 2018), saltwater intrusion (Barlow and Reichard 2010; White and Kaplan 2017), intensified wave impacts (BaMasoud and Byrne 2012; Bertin *et al.* 2013), and extreme precipitation (Kunkel *et al.* 2010). With over $1 trillion of U.S. wealth held in coastal real estate, the ability to live and recreate safely on the coast is at risk (AIR Worldwide 2016).

While coastal population centers continue to expand, many policymakers and researchers are turning towards "resilience" as the solution to coastal risk (Coaffee and Clarke 2015; Leichenko 2011). The colloquial use of the term is on the rise, often attributed to an increasing awareness of climate change and the worsening impacts of natural hazards. With an aspirational focus on "bouncing back" from shocks and persistence, resilience is a broadly appealing solution to various community challenges (Béné *et al.* 2018). At the same time, resilience is a multidimensional idea that is open to sometimes conflicting definitions.

Since the concept's emergence in the field of ecology (Holling 1985; Holling 1973), resilience has been adopted by many different disciplines, including psychology (Hill *et al.* 2018), geomorphology (Kombiadou *et al.* 2019), finance (Markman and Venzin 2014), international development (Barrett and Constas 2014), among many others. Each field crafted a unique definition to suit their needs and resilience transitioned into a malleable paradigm. As of 2016, 25 unique definitions of resilience have been identified (Meerow *et al.* 2016) and the titles of almost a dozen books published between 2005 and 2013 included the term "resilient city" (Vale 2014). According to Bonds (2018), "resilience has become something of a silver bullet: a crucial tool in the so-called 'war on terrorism,'

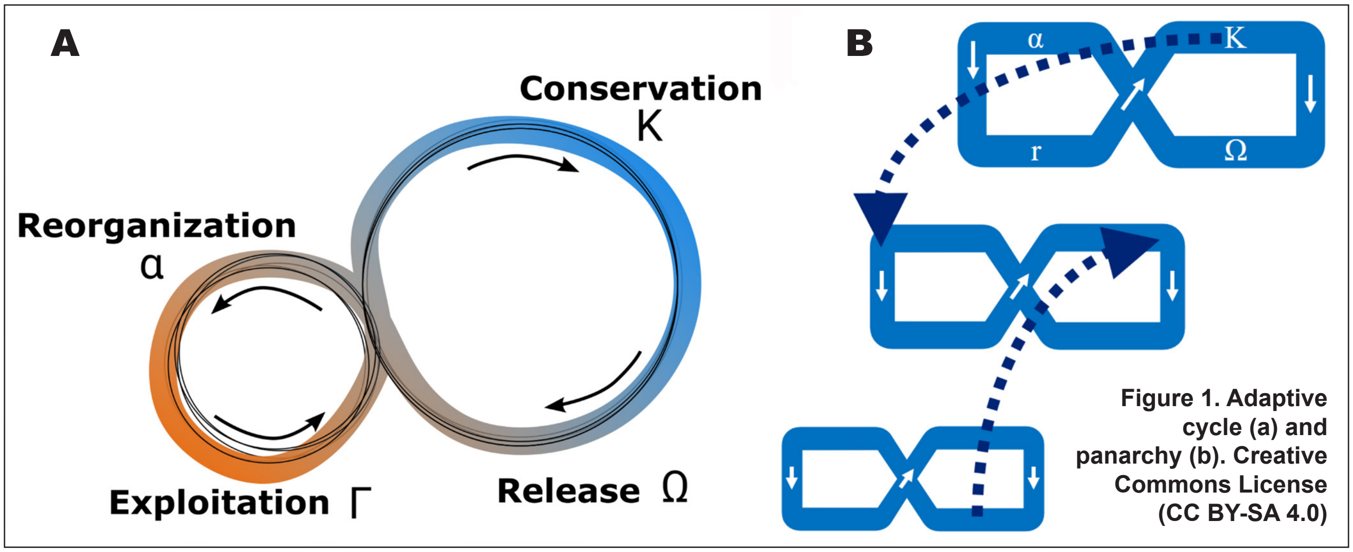

Figure 1. Adaptive cycle (a) and panarchy (b). Creative Commons License (CC BY-SA 4.0)

the solution to poverty and inequality, a central response to climate change and environmental disaster, and, not the least, the key to individual happiness."

An engineering approach to resilience is often applied to human-coastal systems, with a focus on minimizing the threat of coastal hazards. Many assessments of coastal resilience are quantitative studies that include statistical return periods (e.g. 1% annual chance aka "100-year" flood events), sea level projections, and infrastructure data (FEMA 2021). These assessments are traditionally implemented by governing bodies in order to promote general public safety and well-being (Donaldson *et al.* 2013). However, by abstracting individuals from coastal risk assessments and resulting mitigation measures, coastal resilience efforts are becoming increasingly technocratic projects (Mehring *et al.* 2018) that are prone to the influence of inherent economic, political, and social biases (Adeola and Picou 2017; Gotham 2014). For example, many studies have concluded that investments in beach nourishment can result in variable wealth concentrations along shoreline segments which, in turn, justifies further resource investment and establishes an economic feedback loop resulting in diverging property values (Keeler *et al.* 2018; McNamara *et al.* 2015). Consequently, this becomes one of many contributions to the unequal, highly politicized distribution of flood risk across the U.S. and is a major critique of coastal resilience efforts (Chakraborty *et al.* 2014; Cutter and Emrich 2006; Donner and Rodríguez 2008).

In response to the drawbacks of current definitions, Masselink and Lazarus (2019) offered a revised definition of coastal resilience that is more holistic and highlights the importance of socioeconomic factors:

"Coastal resilience is the capacity of the socioeconomic and natural systems in the coastal environment to cope with disturbances, induced by factors such as sea level rise, extreme events and human impacts, by adapting whilst maintaining their essential functions."

The inclusion of socioeconomic factors is a critical step towards improving coastal resilience because efforts in the name of resilience are inevitably mapped onto geographies of highly variable social conditions. Community landscapes are shaped by politics, economics, and, consequently, detrimental social processes including racial discrimination and financial exclusion (Bonds 2018). Social inequities must be addressed to improve the uneven distribution of coastal resilience across the U.S. (Meerow *et al.* 2019). However, resilience is often discussed in depoliticized terms and, as explicated later in this paper, this is a major critique of existing interpretations of resilience theory.

Incorporating participatory approaches may produce more equitable outcomes when planning for coastal resilience (Fainstein 2015). Because the coastline is a tightly coupled human-environmental system, it is especially vital to include social inputs in democratic resilience assessments via inclusive and participatory methods. It is insufficient to rely exclusively on common socioeconomic proxies in coastal resilience models since resilience is contextually dependent. Rather, this paper argues it is important to directly engage a diverse, representative set of stakeholders in these assessments to co-develop an accurate, holistic representation of coastal resilience. The remainder of this paper further reflects upon the challenges to current definitions of coastal resilience, contextualizes the role of social inequalities in coastal risk, and reviews the importance of coupling traditional resilience assessments with intentional community engagement. This paper ends by offering a new conceptual framework that encourages researchers, practitioners, and stakeholders to move beyond disciplinary perspectives and co-develop more inclusive, equitable understandings of coastal resilience.

CHALLENGES TO COASTAL RESILIENCE

Among the most well-known conceptual models for socio-environmental resilience includes the adaptive cycle (Figure 1, a) and panarchy (Figure 1, b), which evolved from the ecological foundations of resilience theory and took root in systems thinking (Holling and Gunderson 2002). The adaptive cycle includes phases of growth or exploitation (Γ), conservation (κ), release via disruptive events (Ω), and reorganization (α). Panarchy nests the adaptive cycle within a non-hierarchical system of various levels. In this expanded model, linked processes occurring at different scales can influence the system of interest by providing "a form of memory that encourages reorganization around the same structures and processes rather than a different set" and includes both bottom-up and top-down controls (Allen *et al.* 2014). These frameworks are well-tested and valid for characterizing ecosystems. If applied to social systems, they can accurately reflect socio-political hysteresis and other external influences.

However, popular frameworks of resilience do not directly incorporate diverse perspectives of qualitative resilience and therefore fail to capture the nuances of local social conditions. When applied to coastal communities, resilience frameworks may paint technical pictures that cover up the underlying politically sensitive drivers of risk. Without explicitly incorporating social factors and, most importantly, community input, resilience efforts can fall victim to top-down, expert-determined strategies that fail to respect the highly differentiated community landscape. For example, after Hurricane Katrina, New Orleans released the "green dot" map that identified city zones that were to be converted into green areas for flood management. Unfortunately, these zones coincided with the most impoverished portions of the city (Lamb 2020; Olshansky and Johnson 2017). The plan failed to proactively acknowledge that the most environmentally risky land (with challenges including: air pollution, water contamination, flood prone, etc.) often becomes the only affordable areas for low-income individuals to reside (Tierney 2014). Relevant conceptual frameworks that do focus on social realities include vulnerability frameworks (Cutter 1996) where vulnerability is one component of assessing overall risk and resilience. Socioeconomic variables and procedural equity are, thus, increasingly demanded in human-environmental resilience frameworks.

While at its core, coastal resilience describes a community's ability to cope with and recover from a variety of hazards threatening the shoreline (Masselink and Lazarus 2019), in practical applications resilience plans often neglect social equity. In a review of cities participating in the Rockefeller Foundation's 100 Resilient Cities program, Meerow *et al.* (2019) found most cities did not consider the influence of variable power, politics, and social justice sufficiently in their resilience plans, while those that did solely focused on the distribution of economic assets and opportunities. With a few exceptions, the cities' resilience plans failed to address procedural equity, i.e. inclusive and fair decision-making processes (Domingue and Emrich 2019).

Planning for procedural equity in coastal resilience efforts is vital because one of the dominant critiques of resilience theory argues it neglects uneven power distributions that contribute to vulnerability (Meerow *et al.* 2016). Care needs to be taken that decision makers are not defining a community's vision for resilience without substantial, collaborative community engagement and questions of "resilience for whom, what, when, where, and why" need to be collectively addressed to ensure a nondiscriminatory path (Vale 2014). Traditional avenues towards resilience involve tough decisions regarding how to invest limited resources to reduce vulnerability, however the most socioeconomically vulnerable groups tend to be excluded from decision making processes and, consequently, their needs are not prioritized (Vale 2014). In many cases, decision makers can easily identify physical vulnerabilities but struggle to recognize underlying factors related to social and financial capital that ultimately drive community resilience (Aldrich and Meyer 2015). This misconception can lead to unsuccessful efforts in the name of resilience, such as the failed relocation of communities following the 2004 Indian Ocean tsunami (Arlikatti and Andrew 2012; Ingram *et al.* 2006).

One other critique of resilience theory is the tendency for definitions to defer to the status quo, thereby neglecting opportunities for substantial reorganization that can address systemic issues. For example, the definition of resilience according to the United Nations Office for Disaster Risk Reduction (UNDRR) emphasizes "…the preservation and restoration of its essential basic structures and functions through risk management"[1] (UNDRR 2022), which leaves little room to reimagine progressive social alternatives and may indirectly encourage the continuation of pre-existing power balances and structures present in society. The concept of "bouncing back" is often used in resilience conceptualizations, which inherently conserves conventional norms (Davoudi *et al.* 2012). In response, "bouncing back better" is often the favored goal, but still begs the following questions: (a) better for whom (Vale 2014) and (b) who decides what is best for a community? As a result, studies have suggested that many resilience efforts tend to reinforce preexisting patterns of privilege and largely benefit those who are already in positions of economic and political power (Fainstein 2015).

Without intentional effort, coastal resilience planning may fail to address underlying systemic social equity issues that perpetuate the uneven distribution of coastal risk. To address this, coastal resilience assessments should integrate a diverse set of interests by ensuring that a representative set of stakeholders, particularly from marginalized groups, meaningfully contribute to a community's vision of coastal resilience.

SOCIAL FACTORS AND COASTAL HAZARDS

Consequently, it is important to reflect upon the potential shortcomings of current approaches to understanding coastal resilience since many of the voices often excluded from resilience assessments belong to groups that are disproportionately burdened by coastal disasters. Across a variety of hazards, socioeconomic status is consistently found to be a contributor to disaster-related damage (Fothergill and Peek 2004). In many cases, correlations between income and housing quality help to explain these observations. Studies analyzing hurricane damage find that older and more affordable homes, often occupied by low income individuals, are more susceptible to wind and flood forcings (Van Zandt and Rohe 2011) and sustain more relative damage compared to more expensive homes (Highfield *et al.* 2014).

Furthermore, property value is often used as a metric in the distribution of the Federal Emergency Management Agency's (FEMA's) flood hazard mitigation grants because their approach relies upon cost-benefit analyses (Rose *et al.* 2007). However, property values play an important role in how we understand the disproportionate impacts of flooding on specific coastal communities (Rezaie *et al.* 2021). For example, a study of flood impacts in Vermont by Gourevitch *et al.* (2022) found that risk exposure was higher among low-income groups when measuring the absolute number of properties. However, when assessing the economic valuation of assets exposed, higher-value properties were found to be

1) The full definition from UNDRR is as follows: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."

at higher risk. These studies emphasize the importance of social context when quantifying and mitigating flood risk. If equity issues are not accounted for, "…these methodologies create perverse incentives in prioritizing flood mitigation interventions, whereby wealthier property owners often receive greatest protection" (Gourevitch *et al.* 2022).

However, income and property values are not the sole factors contributing to the uneven distribution of disaster impacts. Preexisting structures of marginalization are highlighted and exacerbated in the aftermath of extreme events (Bolin and Kurtz 2018). Race (Hartman *et al.* 2006), class (Dash *et al.* 2007), gender (Morrow and Enarson 1996), age (Ngo 2001), and sexual orientation (Goldsmith *et al.* 2021) have all been linked to higher coastal-disaster-related vulnerability due to legacies of structural and environmental discrimination. Vulnerability, in this context, refers to the likelihood that groups or individuals will be harmed by natural hazards and is shaped by both physical and social positioning (Cutter 1996; Dow 1992). In another study of Hurricane Katrina, Fussell *et al.* (2010) explained how a history of residential segregation siphoned black communities into low-lying, vulnerable areas of New Orleans and resulted in higher damage rates among communities of color.

Studies that incorporate holistic measures of vulnerability (e.g. Cutter's Social Vulnerability Index or SoVI; Cutter *et al.* 2003), into coastal disaster assessments have found that hazard data alone do not explain damage patterns. A study investigating the building damage caused by Hurricane María in Puerto Rico found that traditional indicators, such as flood extent and wind speed, contributed to damage patterns, but census-derived vulnerability indicators were the leading predictors of housing damage (Szczyrba *et al.* 2021).

Not only is socioeconomic vulnerability a factor in determining disaster impacts, it also affects recovery trajectories. Low-income individuals often struggle to fund needed repairs after unexpected damage (Van Zandt and Rohe 2011). After Hurricanes Ike and Andrew, home values in wealthier neighborhoods recuperated faster post-event than lower-income neighborhoods (Peacock *et al.* 2014). Among those who were displaced by Hurricane Katrina, black individuals returned to New Orleans at slower rates than non-black individuals (Fussell *et al.* 2010). Communities of color that sustained intense building damage also experienced rapid gentrification in the decade after Katrina (Van Holm and Wyczalkowski 2019). Furthermore, an empirical study assessing the distribution of federal aid following Hurricane Sandy found that the (1) percentage of foreign-born individuals and (2) local level of educational attainment were significantly correlated with the amount of federal assistance disbursed (Grube *et al.* 2018). They hypothesized that those factors added barriers that precluded many from accessing aid and recovery programs.

As a result, inequality and climate-related hazards are locked in a vicious cycle whereby vulnerable groups are increasingly susceptible to and unable to recover from harm (Islam and Winkel 2017). Because the impacts of coastal disasters are influenced by socioeconomic vulnerability, visions of coastal resilience should not only account for physical measures, but should also consider the social position of all who may be affected. Community participation in decision making is one strategy to overcome these legacies of inequity.

NEED FOR STAKEHOLDER ENGAGEMENT

While the call to measure resilience continues to grow (Quinlan *et al.* 2016), such emphasis on quantifying resilience overshadows the need for, and benefit from, qualitative input from direct stakeholder engagement. In many cases, community self-assessments of resilience produce more qualitative data than numerical, and this information often fails to be incorporated into resilience models (Anguelovski *et al.* 2016). Stories and lived experiences capture information that numerical models often miss and should be incorporated into assessments of community coastal resilience (Borie *et al.* 2019) and studies confirm the merit of inclusive and participatory processes (Meerow *et al.* 2019).

"Negotiated resilience" emphasizes equitable procedural processes in resilience decision making (Harris *et al.* 2018). In their approach, Harris *et al.* (2018) argue for early and frequent engagement of diverse perspectives and interests across various scales. Inclusive participatory processes denote a shift away from financially motivated cost-benefit risk calculations and towards a regime of more equitable outcomes. To achieve this, a focus on the processes that support these goals is also needed (Ziervogel *et al.* 2017). As a baseline assumption, negotiated resilience recognizes a multiplicity of competing interests and creates a procedural framework to manage trade-offs and decision priorities. Furthermore, negotiated resilience acknowledges the differing abilities of diverse power holders to advocate for their own interests and commits to addressing existing gaps in capacity (Harris *et al.* 2018).

TOWARD A NEW FRAMEWORK TO EXPLORE COASTAL RESILIENCE

In recognition of the (1) importance of co-creating inclusive visions of coastal resilience and (2) limitations of current frameworks, we propose the state of resilience model (STORM) as a new conceptualization of coastal resilience that incorporates both technical and social factors (Figure 2). STORM, as a proof of concept, is designed as a discipline-neutral framework to allow diverse stakeholder groups to discover, acknowledge, and explore various perspectives of coastal resilience. It draws from the definition of coastal resilience from Masselink and Lazarus (2019) to incorporate the physical and social dimensions that may increase or decrease community resilience. Critically, STORM acknowledges that resilience can be promoted with social strategies that address underlying causes of social vulnerability, rather than focusing on solely technical mitigation solutions, and it can be applied to facilitate community conversations. In the remainder of this paper, we share how STORM was co-produced, explain each component of the conceptual model, and offer potential applications.

Approach

Virginia Sea Grant gathered an interdisciplinary team of engineers, geologists, lawyers, ecologists, and landscape architects at a Team Science Training to reflect on the meaning of the term "resilience" (Hartley *et al.* 2018). Each team member shared current paradigms within their individual expertise by creating a framework of coastal resilience stemming from their unique perspective. Members of the group applied brain-sketching

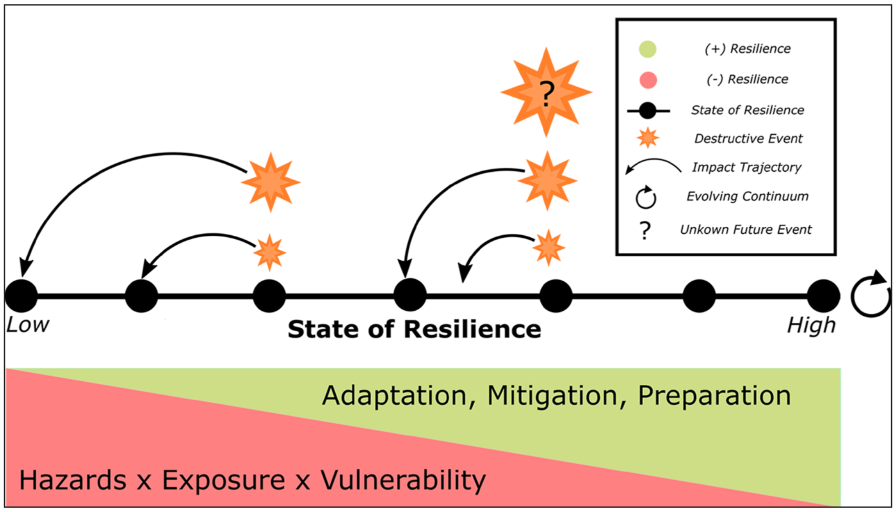

Figure 2. The state of resilience model (STORM). In STORM, a community's state of resilience (black line with nodes) can be explored via factors that enhance resilience (adaptation, mitigation, preparation) and factors that contribute to risk and diminish resilience (hazards x exposure x vulnerability). External events of varying magnitudes (stars) also affect a community's current state of resilience and may temporarily lower resilience.

techniques (i.e. a visual form of brainstorming; Van der Lugt 2002), to generate ideas and externalize group cognition. Through guided formal and informal discussions, the team evaluated the collection of sketches and converged on the shared underlying themes (Bennett and Gadlin 2012; Fiore 2008) that described the relevant processes that contribute to community coastal resilience.

Our team grounded the identified themes with variables that are well-established in current literature (Table 1). This required discussion and negotiation, given that some disciplinary distinctions led to definitional differences (Pennington 2011). For example, ecologists and geologists may focus on hazards that cause environmental degradation while lawyers and planners may focus on hazards that disrupt economic and social processes, and each perspective is valuable to incorporate. Through these discussions, we developed the final conceptual framework and drew from visualization techniques used in systems thinking, disaster science, scenario planning, team science training, and ecosystem service assessments (Ash *et al.* 2010; Pohl *et al.* 2021; Potschin-Young *et al.* 2018). As a result of this unique approach, STORM is a readily interpretable and visually engaging representation of coastal resilience.

Assumptions and theoretical foundation

All models are simplifications of reality, and STORM is no exception. Several assumptions were incorporated into the development of this conceptual model. Firstly, STORM was designed to assess holistic coastal resilience at the community level with a particular focus on the coupled human-environmental system in the U.S. It is assumed that social processes are inextricably linked to coastal resilience and therefore, (a) the model draws from hazards-of-place theory (Cutter 1996) and (b) the definitions of variables used in the model stem largely from disaster science (Table 1). However, the model may be adapted to specifically explore natural systems, such as the resilience of coastal sand dunes, coral reefs, or wetlands, although some factors may be less relevant (e.g. preparedness). Finally, resilience is assumed to be a dynamic process continuously evolving in time, rather than a permanent state that can be attained, since external factors such as disastrous or extreme events, climate change, and policy decisions at the state or federal level can constantly rework the system.

Explanation

STORM visualizes a community's state of resilience along a continuum and relates it with factors that either diminish or enhance resilience (Figure 2). The state of resilience is illustrated by a path with nodes indicating equilibria conditions. A community's current state of resilience takes into account antecedent conditions, which includes processes from the social, natural, and built environment.

Resilience increases from left to right as adaptation, mitigation, and preparation (Figure 2) dominate over hazards, exposure, and vulnerability (Figure 2). In disaster science, community risk is defined by the likelihood of the occurrence of physical hazards multiplied by the assets (both infrastructure and people) exposed to potential harm multiplied by the sensitivity of those assets to damage (Schneiderbauer and Ehrlich 2004). The concept of vulnerability, including social and structural vulnerability, offers a critical opportunity to explore the dynamic social drivers of risk. In other words, risk relates physical hazards with the potential for disparate negative societal consequences and high risk reduces overall community resilience.

Factors that combat preexisting and future risk include adaptation, mitigation, and preparation (Figure 2). These concepts are related, but distinct (Table 1). Adaptation refers to long-term adjustments in response to evolving processes and changing conditions (Barnett *et al.* 2014). An emerging strategy, termed adaptation pathways, allows for coastal communities to implement policy changes in response to scientifically defined thresholds (Anderson *et al.* 2022). Adaptation also includes social adaptation, whereby long-term social improvements can correct for social and racial inequities embedded in antecedent understandings of resilience (Bonds 2018). Mitigation measures reduce the impacts of crises on people and places, such as incorporating green or grey infrastructure to reinforce shorelines, and also includes efforts to reduce socioeconomic vulnerability by integrating economic development and social justice efforts. Finally, preparedness is a state of readiness, meaning that members of a community understand their behavioral role in anticipation of and response to challenging circumstances (UNDRR 2022). Preparedness is conceptually linked to social capital in disaster research, which has been shown to increase community resilience (Morsut *et al.* 2021).

Disastrous coastal hazards include destructive hurricanes, tsunamis, oil spills, and harmful algal blooms, among many other natural and anthropogenic phenomena. Longer-term threats, such as coastal erosion, sea level change, and pollution, can also be included in this definition. The magnitude and frequency of these events affect coastal community resilience and are represented by eight-pointed stars of various sizes (Figure 2, stars). Disasters can decrease community resilience, illustrated with impact trajectory arrows, requiring communities to recover back to their initial state of resilience. Communities with higher levels of resilience are likely to be less affected by disastrous events and have narrower impact trajectories whereas events of similar magnitude that affect communities with lower levels of resilience have much more severe impacts. When multiple disasters occur in close succession without allowing for full community recovery, resilience is continuously reduced and impacts are compounded.

In an ideal and predictable world, the path towards resilience would be linear; however unexpected exogenous factors can force slow or rapid nonlinear changes. For example, slow-onset events or processes such as sea level rise or increases in salinity can cause both economic and non-economic damage (van der Geest and van den Berg 2021) that can lead to relocation away from ancestral lands and loss of cultural heritage (McNamara *et al.* 2021). Alternatively, rapid events including political changes (Fiack 2022) or global catastrophes (e.g. the COVID-19 pandemic) could disrupt the status quo (Collins *et al.* 2021) and would necessitate the reassessment of the current state of resilience under a new reality. In this sense, STORM draws from the concept of panarchy from Holling and Gunderson (2002), specifically the non-hierarchical and nonlinear nature of community evolution. A semicircle with an arrow at the end of the path is a simple representation of the potential for a system to evolve nonlinearly (Figure 2). It offers an opportunity to consider radical system transformations beyond the status quo.

The necessary qualities for interdisciplinary resilience frameworks that permit co-created understandings of resilience include flexibility, integration, and trust (Kench *et al.* 2018). STORM maintains conceptual flexibility by incorporating high-level variables which permit it to be

Table 1.
Definition and relevance of each term applied in STORM.

Term	Definition	Relevance in STORM
Coastal resilience	"…the capacity of the socioeconomic and natural systems in the coastal environment to cope with disturbances, induced by factors such as sea level rise, extreme events and human impacts, by adapting whilst maintaining their essential functions." — *Masselink and Lazarus* (2019)	Coastal resilience is shaped by the confluence of social factors, human decisions, and various environmental processes.
Hazard	"A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation." — *UNDRR* (2022)	Includes distinct events in time (e.g. hurricane, oil spill, harmful algal bloom) and longer-term evolving threats (e.g. erosion, sea level change, pollution) of either natural or anthropogenic origin.
Exposure	"The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas." — *UNDRR* (2022)	Assesses the array of assets (human, cultural, physical, monetary, etc.) potentially in harm's way.
Vulnerability	"The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." — *UNDRR* (2022)	Results in disparate hazard impacts and outcomes. Includes physical factors (e.g. building age, construction quality) as well as social factors (e.g. income, political power).
Adaptation	"…a process of adjusting to changes, which has to be sustained over very long periods of time." — *Barnett* et al. (2014)	Long-term strategies to respond to hazards that include scientifically defined adaptation pathways as well as social adaptations.
Mitigation	"The lessening or minimizing of the adverse impacts of a hazardous event." — *UNDRR* (2022)	Includes targeted engineering strategies (green and grey infrastructure) in addition to community development efforts (e.g. housing improvement and job placement programs)
Preparation	"The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters." — *UNDRR* (2022)	Includes critical infrastructure (e.g. alert system, shelters, public transportation) and social efforts (e.g. education programs, translation services, affordable access) that ensure community members of all backgrounds can meet their needs during crises.

applied in a variety of circumstances and locales. If applied alongside thoughtful engagement strategies, it can integrate structural or engineered approaches to resilience without neglecting the underlying causes of social vulnerability unique to individual communities.

Practical applications

Resilience is a complex, multidimensional concept that is difficult to measure. This is further complicated by diverse definitions of resilience and the justifiable urge to quantify resilience to track the effectiveness of policy decisions. Assessing and measuring resilience is an important task to evaluate current conditions and identify pathways for improvement. In response, numerical proxies are often employed to streamline resilience into a quantitative index but this approach is often heavily generalized, not locally specific, and challenging to validate. Overall, the selection of proxy variables can be highly subjective and often do not represent the unique needs and characteristics of individual communities.

To address the need for an inclusive assessment technique that can incorporate community input and thereby promote inclusion and procedural equity, STORM can serve as a baseline tool to help both define and measure resilience. The framework can offer a holistic understanding and representation of a community's sense and state of resilience. Since STORM is comprehensive yet easily understood and open, it is capable of exploring diverse perspectives. Depending on the application, it can account for various spatio-temporal scales and socioeconomic contexts.

STORM's bottom-up approach to exploring resilience can contribute to collaborative designs in response to coastal threats. One potential application is to apply STORM to understand and qualify community resilience through community events or town hall meetings. These events offer an opportunity to gather different stakeholders from the public and private sectors as well as different income, gender or racial groups within a community. The conceptual model (Figure 2) can be presented to the community members to identify their perceived state of resilience. This involves, firstly, providing definitions of each term listed in the conceptual model (Table 1) and illustrating how they can be flexibly interpreted to explore the various environmental and social factors that they find important. Then, they can be invited to identify the hazards they consider most disruptive to their state of resilience. This exercise can be followed by identifying their exposure and discussing their vulnerability to each selected hazard. Communities can also exchange dialogue between groups to propose potential adaptation and mitigation actions as well as discuss the status of their preparation to deal with the hazards.

As a visual aid, STORM can be used along with sticky notes to map ideas and thoughts in order to facilitate group conversations about current and future avenues towards promoting resilience. As a tool for negotiating resilience (Harris *et al.* 2018), it can help explore disagreements around the benefits and trade-offs of theoretical actions. If applied to the same community repeatedly over time, STORM can track the evolution of a community's overall sense of their state of resilience. This can help measure, for instance, the effectiveness of educational efforts or various policy measures.

The aforementioned exercise provides the community with a clear idea of the diversity of concerns and perceptions underlying perceived resilience, as well as potential avenues for solutions. While STORM is not a decision-making tool, when applied as an exploratory conceptual model, it enriches and organizes a collective understanding of the complexity of human concerns by integrating various locally-specific conditions. By highlighting differing experiences, resilience "winners" and "losers" cannot be overlooked (Meerow *et al.* 2019). Therefore, STORM offers an opportunity to discuss the underlying factors impeding resilience that are often excluded from quantitative assessments.

In one specific example, we look towards the completed work by Hemmerling *et al.* (2020) that designed and applied a novel combination of facilitated group conversations, live polling activities, and local knowledge mapping in tandem with geospatial modeling to explore community resilience in coastal Louisiana. Of note, they found, "…a general agreement between the results of the social valuation model and those of the ecological and hydrodynamic models demonstrating that coastal protection and restoration planning supported by the incorporation of reliable knowledge drawn from both the scientific community and from the local community results in more effective and sustainable outcomes." (Hemmerling *et al.* 2020). We offer that STORM can be incorporated into the engagement toolkit in similar community-informed resilience studies to facilitate and document conversations on local conditions, history, and the complexity of human experiences.

Communities not only have a strong sense of place attachment but also are in frontline facing local hazards in their daily life. STORM's approach aligns with multiple principles of locally led adaptation to climate change which urges collaboration between multiple actors, involvement of local communities in decision-making processes, and the identification of structural and non-structural inequalities existent within the community (Coger *et al.* 2021). Furthermore, given the increasing demand for multidisciplinary research, it can also facilitate interdisciplinary academic conversations to uncover unique avenues for research.

LIMITATIONS AND FUTURE NEEDS

STORM is a novel conceptual framework which can demonstrate how facilitated conversations amongst diverse actors can converge into a negotiated, accurate understanding of resilience. While theoretically grounded, STORM has not yet been tested in stakeholder engagement meetings and future work would include using STORM in a brainstorming session amongst a representative group of stakeholders. The framework should be applied in future test cases within U.S. coastal communities or areas with similar coastal hazards. The pilot application of the framework can be used as a baseline to facilitate conversations that ultimately aim to co-produce a locally specific framework and assess the perceived state of coastal resilience. In order to operationalize STORM, proactive steps would need to be taken to ensure marginalized groups were fairly included in all discussions and decisions. We acknowledge that this requires substantial resources but we hope the arguments laid out in this paper help justify the investment.

Additional research can improve the effective design and application of visual aids for facilitating community conversations. Future research can also enhance social equity by adding relevant factors or sub-factors within the framework before application. On the other hand, the current framework emphasizes the importance of community input to shape the model and thus requires individual input, local discussion, and negotiation to achieve a collective understanding of community coastal resilience. Therefore, STORM acts as a bridging framework to help communities account for their specific needs and culture to achieve consensus. This aspect is the strength of the framework as it is open to interpretation amongst diverse actors. However, this is also a limitation of the framework, which may be improved through future applications.

CONCLUSION

This paper makes the case for reconceptualizing coastal resilience with an intentional focus on community engagement and social equity. We began by summarizing the major social critiques of common interpretations of resilience, demonstrated the influence of social factors in coastal disaster outcomes, and emphasized the need for diverse stakeholder engagement. The evidence presented in this paper argues that if resilience is to be employed successfully as a boundary concept with equitable outcomes, there is a need for new interdisciplinary conceptual frameworks of resilience (Meerow *et al.* 2015). Moreover, visual models of resilience must be relevant, capable of ingesting qualitative data, and easily understood in collaborative settings in order to assess perceived community resilience. In response, we offered a new conceptual framework to explore, assess, and qualify the state of community resilience to coastal hazards.

The framework involves relevant factors related to coastal risk, including hazards, exposure, and vulnerability, as well as factors related to risk management, including adaptation, mitigation, and preparation. These variables are graphically represented and interconnected to offer a simple yet transparent assessment of resilience, which can be determined by negotiation amongst stakeholders within the community. When combined with intentional representative engagement (including diverse income, racial, and gender groups), STORM can be applied to define and assess an inclusive and collective understanding of a community's resilience to coastal hazards. While the framework is novel and has inherent limitations, this paper suggests that conceptual frameworks capable of ingesting qualitative information can help systematically reduce the biases that (a) alienate specific socioeconomic groups and (b) are inherent within purely quantitative methods.

We offer STORM not as a panacea to correct for antecedent historical injustices surrounding resilience efforts, but as an opportunity to facilitate open dialogue amongst diverse groups. STORM is a similarly abstract framework as panarchy and therefore avoids the pitfalls of false precision and encourages negotiation. The variety of meanings, perspectives, and goals behind resilience efforts will continue to persist as a result of the diversity of actors involved. As opposed to being a critique of "resilience," we argue that if adequate consideration of systemic inequality and uneven power distributions is given, diverse perspectives can be harnessed to improve system knowledge, community trust, and future outcomes. We hope that STORM can be applied as an adaptable, equitable, and transparent facilitator of new collaborations between various disciplinary experts, community members, and other stakeholders.

ACKNOWLEDGEMENTS

We thank Amber Leasure-Earnhardt and Janie Day Whitworth, as this work would not have been possible without their contributions to fruitful team science discussions and the development of this conceptual framework. We thank Dr. Mark Brush and Professor Elizabeth Andrews for their mentorship and support during the development of this framework. We thank Virginia Sea Grant for providing the professional support to engage in this research. We would also like to thank Drs. Stephen Fiore, Troy Hartley, Deborah Diaz Granados, and Samuel Lake for their continuous encouragement in conducting the "Science of Team Science" approach.

REFERENCES

Applied Insurance Research (AIR) Worldwide, 2016. "The Coastline at Risk: 2016 Update to the Estimated Insured Value of U.S. Coastal Properties." At: https://www.air-worldwide.com/SiteAssets/Publications/White-Papers/documents/The-Coastline-at-Risk-2016.

Adeola, F.O., and J.S. Picou, 2017. "Hurricane Katrina-linked environmental injustice: Race, class, and place differentials in attitudes." *Disasters*, 41(2), 228-257. https://doi.org/10.1111/disa.12204.

Aldrich, D.P., and M.A. Meyer, 2015. "Social capital and community resilience." *American Behavioral Scientist*, 59(2), 254-269. https://doi.org/10.1177/0002764214550299.

Allen, C.R., Angeler, D.G., Garmestani, A.S., Gunderson, L.H., and C.S. Holling, 2014. "Panarchy: theory and application." *Ecosystems*, 17(4), 578-589. https://doi.org/10.1007/s10021-013-9744-2.

Anderson, D., Dietrich, J.C., Spiegler, S., and C. Cothron, 2022. "Adaptation pathways for climate change resilience on barrier islands." *Shore & Beach* 90(1), 16-26. https://doi.org/10.34237/1009012.

Anguelovski, I., Shi, L., Chu, E., Gallagher, D., Goh, K., Lamb, Z., Reeve, K., and H. Teicher, 2016. "Equity impacts of urban land use planning for climate adaptation: Critical perspectives from the global north and south." *J. Planning Education and Research*, 36(3), 333-348. https://doi.org/10.1177/0739456X16645166.

Arlikatti, S., and S.A. Andrew, 2012. "Housing design and long-term recovery processes in the aftermath of the 2004 Indian Ocean tsunami." *Natural Hazards Review*, 13(1), 34-44. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000062.

Ash, N., Blanco, H., Garcia, K., and C. Brown, 2010. *Ecosystems and human well-being: a manual for assessment practitioners*. Island Press. 1-59726-711-2.

BaMasoud, A., and M.-L. Byrne, 2012. "The impact of low ice cover on shoreline recession: A case study from Western Point Pelee, Canada." *Geomorphology*, 173, 141-148. https://doi.org/10.1016/j.geomorph.2012.06.004.

Barlow, P.M., and E.G. Reichard, 2010. "Saltwater intrusion in coastal regions of North America." *Hydrogeology Journal*, 18(1), 247-260. https://doi.org/10.1007/s10040-009-0514-3.

Barnett, J., Graham, S., Mortreux, C., Fincher, R., Waters, E., and A. Hurlimann, 2014. "A local coastal adaptation pathway." *Nature Climate Change*, 4(12), 1103-1108. https://doi.org/10.1038/nclimate2383.

Barrett, C.B., and M.A. Constas, 2014. "Toward a theory of resilience for international development applications." *Proc. National Academy of Sciences*, 111(40), 14625-14630. https://doi.org/10.1073/pnas.1320880111.

Béné, C., Mehta, L., McGranahan, G., Cannon, T., Gupte, J., and T. Tanner, 2018. "Resilience as a policy narrative: Potentials and limits in the context of urban planning." *Climate and Development*, 10(2), 116-133. https://doi.org/10.1080/17565529.2017.1301868.

Bennett, L.M., and H. Gadlin, 2012. "Collaboration and team science: from theory to practice." *J. Investigative Medicine*, 60(5), 768-775. https://doi.org/10.2310/JIM.0b013e318250871d.

Bertin, X., Prouteau, E., and C. Letetrel, 2013. "A significant increase in wave height in the North

Atlantic Ocean over the 20th century," *Global and Planetary Change*, 106, 77-83.https://doi.org/10.1016/j.gloplacha.2013.03.009

Bolin, B., and L.C. Kurtz, 2018. "Race, class, ethnicity, and disaster vulnerability." *Handbook of Disaster Research* 181-203. https://doi.org/10.1007/978-3-319-63254-4_10.

Bonds, A., 2018. "Refusing resilience: the racialization of risk and resilience." *Urban Geography*, 39(8), 1285-1291. https://doi.org/10.1080/02723638.2018.1462968.

Borie, M., Ziervogel, G., Taylor, F.E., Millington, J.D., Sitas, R., and M. Pelling, 2019. "Mapping (for) resilience across city scales: An opportunity to open-up conversations for more inclusive resilience policy?" *Environ. Science & Policy*, 99 1-9. https://doi.org/10.1016/j.envsci.2019.05.014.

Chakraborty, J., Collins, T.W., Montgomery, M.C., and S.E. Grineski, 2014. "Social and spatial inequities in exposure to flood risk in Miami, Florida." *Natural Hazards Review*, 15(3), 04014006. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000140.

Coaffee, J., and J. Clarke, 2015. "On securing the generational challenge of urban resilience." *Town Planning Review* 249-255.

Coger, T., Corry, S., and R. Gregorowski, 2021. "Reshaping Monitoring, Evaluation and Learning for Locally Led Adaptation." World Resources Institute. https://www.wri.org/research/reshaping-monitoring-evaluation-and-learning-locally-led-adaptation.

Collins, J., Polen, A., McSweeney, K., Colón-Burgos, D., and I. Jernigan, 2021. "Hurricane risk perceptions and evacuation decision-making in the age of COVID-19." *Bulletin of the American Meteorological Society*, 102(4), E836-E848. https://doi.org/10.1175/BAMS-D-20-0229.1.

Cutter, S.L., 1996. "Vulnerability to environmental hazards." *Progress in Human Geography*, 20(4), 529-539. https://doi.org/10.1177/030913259602000407.

Cutter, S.L., Boruff, B.J., and W.L. Shirley, 2003. "Social vulnerability to environmental hazards." *Social Science Quarterly*, 84(2), 242-261. https://doi.org/10.1111/1540-6237.8402002.

Cutter, S.L., and C.T. Emrich, 2006. "Moral hazard, social catastrophe: The changing face of vulnerability along the hurricane coasts." *The Annals of the American Academy of Political and Social Science*, 604(1), 102-112. https://doi.org/10.1177/0002716205285515.

Dash, N., Morrow, B.H., Mainster, J., and L. Cunningham, 2007. "Lasting effects of Hurricane Andrew on a working-class community." *Natural Hazards Review*, 8(1), 13-21. https://doi.org/10.1061/(ASCE)1527-6988(2007)8:1(13).

Davoudi, S., Shaw, K., Haider, L.J., Quinlan, A.E., Peterson, G.D., Wilkinson, C., Fünfgeld, H., McEvoy, D., Porter, L., and S. Davoudi, 2012. "Resilience: A Bridging Concept or a Dead End?" *Planning Theory & Practice*, 13(2), 299-307. https://doi.org/10.1080/14649357.2012.677124.

Domingue, S.J., and C.T. Emrich, 2019. "Social vulnerability and procedural equity: exploring the distribution of disaster aid across counties in the United States." *The American Review of Public Administration*, 49(8), 897-913. https://doi.org/10.1177/0275074019856122.

Donaldson, A., Lane, S., Ward, N., and S. Whatmore, 2013. "Overflowing with issues: following the political trajectories of flooding." *Environment and Planning C: Government and Policy*, 31(4), 603-618. https://doi.org/10.1068/c11230.

Donner, W., and H. Rodríguez, 2008. "Population composition, migration and inequality: The influence of demographic changes on disaster risk and vulnerability." *Social Forces*, 87(2), 1089-1114. https://doi.org/10.1353/sof.0.0141.

Dow, K., 1992. "Exploring differences in our common future (s): the meaning of vulnerability to global environmental change." *Geoforum*, 23(3), 417-436. https://doi.org/10.1016/0016-7185(92)90052-6.

Fainstein, S., 2015. " Resilience and Justice." *International Journal of Urban and Regional Research*, 39(1), 157-167.https://doi.org/10.1111/1468-2427.12186.

Federal Emergency Management Agency (FEMA), 2021. "FEMA Resources for Climate Resilience." https://www.fema.gov/sites/default/files/documents/fema_resources-climate-resilience.pdf.

Fiack, D., 2022. "Governing for resilience: a new epoch in U.S. environmental policy and politics?" *J. Environmental Studies and Sciences*, 12(1), 43-80. https://doi.org/10.1007/s13412-021-00685-2.

Fiore, S.M., 2008. "Interdisciplinarity as teamwork: How the science of teams can inform team science." *Small Group Research*, 39(3), 251-277. https://doi.org/10.1177/1046496408317797.

Fothergill, A., and L.A. Peek, 2004. "Poverty and disasters in the United States: A review of recent sociological findings." *Natural hazards*, 32(1), 89-110. https://doi.org/10.1023/B:NHAZ.0000026792.76181.d9.

Fussell, E., Sastry, N., and M. VanLandingham, 2010. "Race, socioeconomic status, and return migration to New Orleans after Hurricane Katrina." *Population and Environment*, 31(1), 20-42. https://doi.org/10.1007/s11111-009-0092-2.

Goldsmith, L., Raditz, V., and M. Méndez, 2021. "Queer and present danger: understanding the disparate impacts of disasters on LGBTQ+ communities." *Disasters* https://doi.org/10.1111/disa.12509.

Gotham, K.F., 2014. "Reinforcing inequalities: The impact of the CDBG program on post-Katrina rebuilding." *Housing Policy Debate*, 24(1), 192-212. https://doi.org/10.1080/10511482.2013.840666.

Gourevitch, J.D., Diehl, R.M., Wemple, B.C., and T.H. Ricketts, 2022. "Inequities in the distribution of flood risk under floodplain restoration and climate change scenarios." *People and Nature* https://doi.org/10.1002/pan3.10290.

Grube, L.E., Fike, R., and V.H. Storr, 2018. "Navigating disaster: An empirical study of federal assistance following Hurricane Sandy." *Eastern Economic Journal*, 44(4), 576-593.https://doi.org /10.1057/s41302-017-0098-x

Harris, L.M., Chu, E.K., and G. Ziervogel, 2018. "Negotiated resilience." *Resilience*, 6(3), 196-214. https://doi.org/10.1080/21693293.2017.1353196.

Hartley, T.W., Hils, A., Lake, S., Rogers, S., and I. Vorster, 2018. "Virginia Sea Grant Strategic Plan 2018-2021." https://repository.library.noaa.gov/view/noaa/20681

Hartman, C.W., Squires, G. and G.D. Squires, 2006. *There is no such thing as a natural disaster: Race, class, and Hurricane Katrina.* Taylor & Francis. https://doi.org/10.4324/9780203625460

Hemmerling, S.A., McHugh, C.M., DeMyers, C., Bienn, H.C., DeJong, A., Parfait, J., and E. Kiskaddon, 2020. "A Community-Informed Framework for Quantifying Risk and Resilience in Southeast Louisiana." The Water Institute of the Gulf: Baton Rouge, LA, USA. https://thewaterinstitute.org/reports/a-community-informed-framework-for-quantifying-risk-and-resilience-in-southeast-louisiana.

Highfield, W.E., Peacock, W.G., and S. Van Zandt, 2014. "Mitigation planning: Why hazard exposure, structural vulnerability, and social vulnerability matter." *J. Planning Education and Research*, 34(3), 287-300. https://doi.org/10.1177/0739456X14531828.

Hill, Y., Den Hartigh, R.J., Meijer, R.R., De Jonge, P., and N.W. Van Yperen, 2018. "Resilience in sports from a dynamical perspective.", *Sport, Exercise, and Performance Psychology*, 7(4), 333. https://doi.org/10.1037/spy0000118.

Holling, C., 1985. *Resilience of ecosystems: local surprise and global change.* Cambridge University Press. 978-0521306706.

Holling, C.S., 1973. "Resilience and stability of ecological systems." *Annual Review of Ecology and Systematics*, 4(1), 1-23. https://doi.org/10.1146/annurev.es.04.110173.000245.

Holling, C.S., and L.H. Gunderson, 2002. "Resilience and adaptive cycles." *Panarchy: Understanding Transformations in Human and Natural Systems* 25-62.

Ingram, J.C., Franco, G., Rumbaitis-del Rio, C., and B. Khazai, 2006. "Post-disaster recovery dilemmas: challenges in balancing short-term and long-term needs for vulnerability reduction." *Environ. Science & Policy*, 9(7-8), 607-613. https://doi.org/10.1016/j.envsci.2006.07.006.

Islam, N., and J. Winkel, 2017. "Climate change and social inequality." *United Nations Department of Economic and Social Affairs*, https://www.un.org/development/desa/publications/working-paper/wp152

Jacobs, J.M., Cattaneo, L.R., Sweet, W., and T. Mansfield, 2018. "Recent and future outlooks for nuisance flooding impacts on roadways on the U.S. East Coast." *Transportation Research Record*, 2672(2), 1-10. https://doi.org/10.1177/0361198118756366.

Keeler, A., McNamara, D., and J. Irish, 2018. "Responding to Sea Level Rise: Does Short-Term Risk Reduction Inhibit Successful Long-Term Adaptation?" *Earth's Future*, 6(4), 618-621. https://doi.org/10.1002/2018EF000828.

Kench, P.S., Ryan, E.J., Owen, S., Bell, R., Lawrence, J., Glavovic, B., Blackett, P., Becker, J., Schneider, P., and M. Allis, 2018. "Co-creating resilience solutions to coastal hazards through an interdisciplinary research project in New Zealand." *J. Coastal Research* (85 (10085)), 1496-1500. https://doi.org/10.2112/SI85-300.1.

Kildow, D., Judith, T., Colgan, C.S., and P. Johnston, 2016. "State of the U.S. ocean and coastal economies 2016 update." https://cbe.miis.edu/noep_publications/18/.

Kirwan, M.L., and J.P. Megonigal, 2013. "Tidal wetland stability in the face of human impacts and sea-level rise." *Nature*, 504(7478), 53-60. https://doi.org/10.1038/nature12856.

Kombiadou, K., Costas, S., Carrasco, A.R., Plomaritis, T.A., Ferreira, Ó., and A. Matias, 2019. "Bridging the gap between resilience and geomorphology of complex coastal systems." *Earth-Science Reviews*, 198 102934. https://doi.org/10.1016/j.earscirev.2019.102934.

Kunkel, K.E., Easterling, D.R., Kristovich, D.A., Gleason, B., Stoecker, L., and R. Smith, 2010. "Recent increases in U.S. heavy precipitation associated with tropical cyclones." *Geophysical Research Letters*, 37(24), https://doi.org/10.1029/2010GL045164.

Lamb, Z., 2020. "Connecting the dots: The origins, evolutions, and implications of the map that changed post-Katrina recovery planning in New Orleans." In: *Louisiana's Response to Extreme Weather*, Springer, Cham, pp. 65-91,

Leichenko, R., 2011. "Climate change and urban resilience." *Current Opinion in Environmental Sustainability*, 3(3), 164-168. https://doi.org/10.1016/j.cosust.2010.12.014.

List, J.H., Sallenger Jr, A.H., Hansen, M.E., and B.E. Jaffe, 1997. "Accelerated relative sea-level rise and rapid coastal erosion: testing a causal relationship for the Louisiana barrier islands." *Marine Geology*, 140(3-4), 347-365. https://doi.org/10.1016/S0025-3227(97)00035-2.

Markman, G.M., and M. Venzin, 2014. "Resilience: Lessons from banks that have braved the economic crisis — and from those that have not." *International Business Review*, 23(6), 1096-1107. https://doi.org/10.1016/j.ibusrev.2014.06.013.

Masselink, G. and E.D. Lazarus, 2019. "Defining coastal resilience." *Water*, 11(12), 2587. https://doi.org/10.3390/w11122587.

McNamara, D.E., Gopalakrishnan, S., Smith, M.D., and A.B. Murray, 2015. "Climate adaptation and policy-induced inflation of coastal property value." *PloS One*, 10(3), e0121278. https://doi.org/10.1371/journal.pone.0121278.

McNamara, K.E., Westoby, R., and A. Chandra, 2021. "Exploring climate-driven non-economic loss and damage in the Pacific Islands." *Current Opinion in Environmental Sustainability*, 50 1-11. https://doi.org/10.1016/j.cosust.2020.07.004.

Meerow, S., Newell, J.P., and M. Stults, 2016. "Defining urban resilience: A review." *Landscape and Urban Planning*, 147 38-49. https://doi.org/10.1016/j.landurbplan.2015.11.011.

Meerow, S., Pajouhesh, P., and T.R. Miller, 2019. "Social equity in urban resilience planning." *Local Environment*, 24(9), 793-808. https://doi.org/10.1080/13549839.2019.1645103.

Mehring, P., Geoghegan, H., Cloke, H.L., and J. Clark, 2018. "What is going wrong with community engagement? How flood communities and flood authorities construct engagement and partnership working." *Environ. Science & Policy*, 89 109-115. https://doi.org/10.1016/j.envsci.2018.07.009.

Mentaschi, L., Vousdoukas, M.I., Pekel, J.-F., Voukouvalas, E., and L. Feyen, 2018. "Global long-term observations of coastal erosion and accretion." *Scientific Reports*, 8(1), 1-11. https://doi.org/10.1038/s41598-018-30904-w.

Morrow, B.H., and E. Enarson, 1996. "Hurricane Andrew through women's eyes." *International Journal of Mass Emergencies and Disasters*, 14(1), 5-22.

Morsut, C., Kuran, C., Kruke, B.I., Orru, K., and S. Hansson, 2021. "Linking resilience, vulnerability, social capital and risk awareness for crisis and disaster research." *J. Contingencies and Crisis Management* https://doi.org/10.1111/1468-5973.12375.

Ngo, E.B., 2001. "When disasters and age collide: Reviewing vulnerability of the elderly." *Natural Hazards Review*, 2(2), 80-89. https://doi.org/10.1061/(ASCE)1527-6988(2001)2:2(80).

Olshansky, R.B., and L.A. Johnson, 2017. *Clear as mud: Planning for the rebuilding of New Orleans.* Routledge. 1351179713.

Peacock, W.G., Van Zandt, S., Zhang, Y., and W.E. Highfield, 2014. "Inequities in long-term housing recovery after disasters." *J. American Planning Association*, 80(4), 356-371. https://doi.org/10.1080/01944363.2014.980440.

Pennington, D.D., 2011. "Bridging the disciplinary divide: Co-creating research ideas in escience teams." *Computer Supported Cooperative Work (CSCW)*, 20(3), 165-196. https://doi.org/10.1007/s10606-011-9134-2.

Pohl, C., Klein, J.T., Hoffmann, S., Mitchell, C., and D. Fam, 2021. "Conceptualising transdisciplinary integration as a multidimensional interactive process." *Environ. Science & Policy*, 118 18-26. https://doi.org/10.1016/j.envsci.2020.12.005.

Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., and C. Schleyer, 2018. "Understanding the role of conceptual frameworks: Reading the ecosystem service cascade." *Ecosystem Services*, 29 428-440. https://doi.org/10.1016/j.ecoser.2017.05.015.

Quinlan, A.E., Berbés-Blázquez, M., Haider, L.J., and G.D. Peterson, 2016. "Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives." *J. Applied Ecology*, 53(3), 677-687. https://doi.org/10.1111/1365-2664.12550.

Rezaie, A.M., Ferreira, C.M., Walls, M., and Z. Chu, 2021. "Quantifying the Impacts of Storm Surge, Sea Level Rise, and Potential Reduction and Changes in Wetlands in Coastal Areas of the Chesapeake Bay Region." *Natural Hazards Review*, 22(4), 04021044. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000505.

Rose, A., Porter, K., Dash, N., Bouabid, J., Huyck, C., Whitehead, J., Shaw, D., Eguchi, R., Taylor, C., and T. McLane, 2007. "Benefit-cost analysis of FEMA hazard mitigation grants." *Natural Hazards Review*, 8(4), 97-111. https://doi.org/10.1061/(ASCE)1527-6988(2007)8:4(97).

Schneiderbauer, S., and D. Ehrlich, 2004. "Risk, hazard and people's vulnerability to natural hazards." *A review of definitions, concepts and data. European Commission Joint Research Centre. EUR*, 21410 40.

Szczyrba, L., Zhang, Y., Pamukcu, D., Eroglu, D.I., and R. Weiss, 2021. "Quantifying the role of vulnerability in hurricane damage via a machine learning case study." *Natural Hazards Review*, 22(3), 04021028. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000460.

Tierney, K., 2014. "The social roots of risk." In: *The Social Roots of Risk*, Stanford University Press. https://doi.org/10.1515/9780804791403/html?lang=de

United Nations Office for Disaster Risk Reduction (UNDRR), 2022. "Terminology Online Glossary." https://www.undrr.org/terminology.

Vale, L.J., 2014. "The politics of resilient cities: whose resilience and whose city?" *Building Research & Information*, 42(2), 191-201. https://doi.org/10.1080/09613218.2014.850602.

van der Geest, K. and R. van den Berg, 2021. "Slow-onset events: a review of the evidence from the IPCC Special Reports on Land, Oceans and Cryosphere." *Current Opinion in Environmental Sustainability*, 50 109-120. https://doi.org/10.1016/j.cosust.2021.03.008.

Van der Lugt, R., 2002. "Brainsketching and how it differs from brainstorming." *Creativity and innovation management*, 11(1), 43-54. https://doi.org/10.1111/1467-8691.00235.

Van Holm, E.J. and C.K. Wyczalkowski, 2019. "Gentrification in the wake of a hurricane: New Orleans after Katrina." *Urban Studies*, 56(13), 2763-2778. https://doi.org/10.1177/0042098018800445.

Van Zandt, S. and W.M. Rohe, 2011. "The sustainability of low-income homeownership: The incidence of unexpected costs and needed repairs among low-income home buyers." *Housing Policy Debate*, 21(2), 317-341. https://doi.org/10.1080/10511482.2011.576525.

Walsh, K.J., McBride, J.L., Klotzbach, P.J., Balachandran, S., Camargo, S.J., Holland, G., Knutson, T.R., Kossin, J.P., Lee, T.C., and A. Sobel, 2016. "Tropical cyclones and climate change." *Wiley Interdisciplinary Reviews: Climate Change*, 7(1), 65-89. https://doi.org/10.1002/wcc.371.

White, E., and D. Kaplan, 2017. "Restore or retreat? Saltwater intrusion and water management in coastal wetlands." *Ecosystem Health and Sustainability*, 3(1), e01258. https://doi.org/10.1002/ehs2.1258.

Ziervogel, G., Pelling, M., Cartwright, A., Chu, E., Deshpande, T., Harris, L., Hyams, K., Kaunda, J., Klaus, B., and K. Michael, 2017. "Inserting rights and justice into urban resilience: A focus on everyday risk." *Environment and Urbanization*, 29(1), 123-138. https://doi.org/10.1177/0956247816686905.