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Critical Lines of Action for Vulnerability and Resilience Research and Practice: Lessons from the 2017 Hurricane Season

Hallie Eakin*

School of Sustainability, Arizona State University, P. O. Box 875502, Tempe, AZ 875502, USA

Tischa A. Muñoz-Erickson

International Institute of Tropical Forestry, USDA Forest Service, 1201 Calle Ceiba, San Juan, Puerto Rico, 00926-119, USA
tamunozerickson@fs.fed.us

Maria Carmen Lemos

School for Environment and Sustainability, University of Michigan, 440 Church Street, Ann Arbor, MI 48109, USA
emos@umich.edu

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The unprecedented number of devastating disasters recently experienced in the United States is a clarion call to revisit how we understand our vulnerability in the face of global change, and what we are prepared to do about it. We focus on the case of Hurricane María's impact in Puerto Rico to underscore five critical concerns in addressing vulnerability and adaptation planning: (i) vulnerability as a product of flows; (ii) how our beliefs about the capacities of ourselves and others affect local vulnerability; (iii) the role uncertainty, politics, and information access play in amplifying vulnerability and complicating adaptation; (iv) the need for a better distribution of risk and responsibility in adaptation; (v) and the challenge of seizing the opportunity of disasters for transformative change. These five issues of concern were particularly evident in the case of Puerto Rico where Hurricane María's 155 mph winds exposed existing infrastructural vulnerabilities, institutional incapacities, and socio-economic disparities. We argue that addressing these issues requires fundamental shifts in how we prepare for environmental change and disasters in the 21st century. We discuss promising approaches that may assist researchers and practitioners in

*Corresponding author's email: Hallie.eakin@asu.edu

addressing some of the underlying drivers of vulnerability, stemming from cross-scalar dynamics, systemic interdependencies, and the politics and social relations associated with knowledge, decision-making and action. We argue that society needs to broach the difficult topic of the equity in the distribution of risk in society and the burden of adaptation. Addressing these challenges and response imperatives is a central task of this century; the time to act is now.

Keywords: Vulnerability; adaptation; resilience; hurricane impacts; Puerto Rico.

1. A Need to Think Differently About Vulnerability

On September 20, 2017, María made landfall in Puerto Rico. Loss of life is now estimated to be 2975 (Milken Institute of Public Health 2018), and many services are still not restored in parts of the island. The National Oceanic and Atmospheric Administration estimates that the costs for Hurricanes Harvey, Irma and María together inflicted as much as $265 billion in damages; other estimates are higher (AccuWeather 2017). Households and businesses are still recovering from the devastation of Harvey, and María has evolved into an ongoing humanitarian crisis for 3.4 million U.S. citizens (Park and Hanna 2017). The 2018 Atlantic hurricane season for the United States and the Caribbean is now upon us. While the destructive path of extreme weather exposes the fragility of our infrastructure and social institutions, they also provide valuable opportunities for learning, adaptation, anticipating, and avoiding future shocks.

It is time to address the underlying drivers of our vulnerability to extreme events. Doing so requires novel approaches to vulnerability assessment and adaptation planning. In colloquial terms, vulnerability is the propensity to suffer harm from shocks and stress. More technically, vulnerability is function of a population's exposure to risk, and the specific attributes of that population that make it particularly sensitive to impacts and that affect its resilience. Thus vulnerability is not simply a result of being in the way of these massive storms. Rather, it is shaped over time through investments (or lack of) in infrastructure, decisions over the locations of settlements and economic activities, cultural perspectives on risk and responsibility, and the politics and practices of resource access, distribution and use (Eakin *et al.* 2017). Hurricanes Harvey, Irma and María together illustrated how our patterns of urbanization, our love affair with coastal views and recreation, and our critical dependence on networks of fragile infrastructure amplify risk (Plumer 2017; Kimmelman 2017).

Using the lessons from Hurricane María as a springboard for discussion, in this article we focus on five concerns in addressing vulnerability and adaptation planning that have been repeatedly raised by the scientific community, but which have yet to be adequately integrated into the practice of vulnerability assessment

and reduction. These five issues of concern were particularly evident in the case of Puerto Rico where Hurricane María's 155 mph winds exposed existing infrastructural vulnerabilities, institutional incapacities, and socio-economic disparities. We argue that current approaches to analyzing vulnerability, through for example, the use maps that overlay population, environmental and infrastructure attributes of a place, are no longer sufficient. While this approach has been useful in the past, it now constrains the capacity of researchers and practitioners to address some of the underlying drivers of vulnerability, stemming from cross-scalar dynamics, systemic interdependencies, and the politics and social relations associated with knowledge, decision-making and action.

2. Five Concerns: Where Vulnerability and Adaptation Planning is Falling Short

2.1. *Vulnerability is a product of flows*

In practice, researchers and practitioners alike talk about vulnerability as if it were contained in specific places and populations. We rely on vulnerability maps to combine specific geographic attributes — e.g., the income level of census blocks, the number of homes insured, the area representing the 100-year flood plain — to communicate the spatial patterns of vulnerability to decision-makers (Preston *et al.* 2011). This helps in communication because it speaks to the spatial mandates of particular decision-makers, however, vulnerability cannot be assigned neatly to administrative and geographic boundaries. Vulnerability is partly a product of flows: financial transactions, the movement of goods and services, circulation of information and knowledge, and the movement of people, flora, fauna, dust, pollutants, and other material across political boundaries and spatial divides (Adger *et al.* 2009; Eakin 2010). This fact introduces significant uncertainty into the efforts of local actors — state governors, municipal leaders, local businesses — to anticipate and ultimately act to reduce risk.

In Puerto Rico, some of the most important flows (in this case commodity flows) to the island are governed by the 1920 Jones Act. This century-old law, requiring all cargo entering Puerto Rico's ports to arrive on US ships with US crews, impeded effective response to the Hurricane by blocking aid flows and increasing the cost of badly needed imports. But it also affected the island's initial economic susceptibility to María: Puerto Rico's financial crisis — which inhibited investments in critical infrastructure such as the electricity grid — is in part a result of being economically crippled by the Act for nearly a century (Bloomberg View 2017). Because the island's electric system depends almost entirely on oil imports, its vulnerability is also connected to other places, such as Houston, where

the oil industry was also affected by the unprecedented hurricane season. With cellular and electric grids dysfunctional, the social networks that connect the Puerto Rican diáspora to the island were disrupted, constraining the use of such networks to fill in gaps where more formal relief systems were failing.

The networked nature of vulnerability puts a high demand on governance: it exposes the need for coordination, communication and synergistic actions across different sectors, levels of government and private and public actors. In Puerto Rico, confusion over local agency responsibilities, delays in responses from federal authorities, and the complexity of Puerto Rico's territorial status impeded the delivery of relief to the island and into the interior. Nevertheless, vulnerability assessments tend to focus more on defining who and what is vulnerable, rather than how vulnerability should be governed — e.g., who should be at the table, what flows and networks of knowledge, finance, information, institutional ties are salient to vulnerability in specific locations and how these should be managed, and what are the scopes of influence and decision priorities of specific agencies and organizations, given their respective mandates (Wellstead *et al.* 2013; Gall *et al.* 2015). While there is evidence that investments in adaptation prioritize "soft" issues such as management, institutions and capacity building (Berrang-Ford *et al.* 2011; Biagini *et al.* 2014), it is not clear the extent to which the networked, cross-scalar and cross-sector concerns of vulnerability are being addressed in such investments.

2.2. *What we think about our own capacity to manage risk, and what we believe about the capacities and responsibilities of others, matters*

Second, what we think about our own capacity to manage risk, and what we believe about the capacities and responsibilities of others, can significantly affect conditions of local vulnerability. Our willingness to take action, as private individuals, communities, organizations or businesses, in response to, or in anticipation of, some external threat is not only an issue of our capacities: our wealth, our assets, or our knowledge. Our capacities to manage and proactively prepare for extremes is also circumscribed by the tension between what we each feel we have a responsibility and capacity to do and influence; what we expect the agencies that serve public purposes are responsible for doing; and what such agencies *can actually* do at any moment in time. Thus, what we think others — government agencies, businesses, or our neighbors — are doing to manage risk affects the actions we take to reduce our vulnerability, even if these perceptions are inaccurate or unfounded by fact.

In essence, this implicit appraisal of what we think others are doing on our behalf is a critical part of what makes us willing and able to adapt (Grothmann and

Patt 2005). If we are well-buffered from risk in our day-to-day existence, we may grow complacent, relying on assumptions that others — managers of public agencies and programs, insurance markets — have our exposure to risk covered. This is the "safe development paradox" (Burby 2006). However, should these safety-nets fail, and if we haven't made the necessary individual investments and preparations to reduce our risk, trusting that others — typically the public sector, but increasingly also private commercial entities — have our best interest in mind, can make us quite vulnerable.

Alternatively, we may have little trust and confidence in the public sector and find risk management resources such as insurance inaccessible. This is how much of the most vulnerable lives: those living on the economic margins, and in conditions where public institutions are weak and where private sector mechanisms for risk management are unavailable (Eakin *et al.* 2014). In these circumstances, we would likely spend significant amounts of time and energy preparing for the worst, putting our "safety first." Here, our outlays and preparations come often at significant personal expense, for example, trading off other valuable investments in our health, our jobs or our pleasure and recreation (Eakin *et al.* 2014).

In both these circumstances, having good knowledge of the risk you face and the potential limits of public or private resources to protect you is increasingly important. The rising frequency and intensity of climatic extremes is now testing both the limits of conventional risk management strategies, as well as the ability of individual households to manage such extremes on their own (IPCC 2012). *Shared* and *fair* responsibility for coping and adapting to environmental change is now essential.

2.3. *Uncertainty, politics, and information access complicate adaptation*

In part what defines a system's vulnerability is its proximity to a threshold that would define an undesirable state (Luers 2005). For example, a household's vulnerability to a disaster is in part determined by whether the household is near financial crisis *prior* to the event. For a city, vulnerability is influenced by how close a sewage canal is to a risk of rupture, or the electricity grid to failure. But is the public informed about how close they or their communities are to such thresholds? While disaster risk specialists and experts in public relations have identified transparency, honesty and candor as essential for effective risk communication with the public (Seeger 2006; Palttala *et al.* 2012), the incentives for such transparency, particularly about the level of uncertainty inherent in that risk, may be lacking among those with the authority to disseminate information that is

available. A public agency's acknowledgment of vulnerability and uncertainty is often interpreted in the media as an acknowledgement of lack of control over, or even failure in, the provision of public security. Nevertheless, in the current context of global change, it is increasingly clear that this idea is outdated: no organization, agency, individual or enterprise alone can adequately know and buffer society from the risks that now characterize human existence.

Lack of sufficient transparency and problems in information dissemination became acutely clear in the aftermath of María when it became apparent just how fragile Puerto Rico's electricity grid and road infrastructure were prior to the hurricane. A year prior to María's arrival, PREPA, the Puerto Rico Electric Power Authority, had been externally evaluated and found to be in crisis. The report by Synapse Energy Associates, published in 2016, stated "PREPA is failing at the basic mandate of an electric utility, which is to safely and reliably supply electricity to its customers. Neither the Commission, other governmental authorities, nor the public should be misled about PREPA's current state, which is unambiguously one of crisis" (Synapse Energy Associates 2016: 18). While local newspapers were reporting on the critical financial straits of the agency, the delicate political and economic circumstances of Puerto Rico in the months prior to María likely gave the government little incentive to be entirely forthcoming about the physical state of the island's electric grid. In other cases, politicians were accused of exaggerating the vulnerability to justify privatizing public infrastructure over public opposition.

As a result of failures in information flows, the politics of knowledge management and the inevitable myopia of the vulnerable, households and businesses were unprepared for the impacts of María. Lack of emergency preparation at the household level is common across hazard zones and not unique to Puerto Rico. But in Puerto Rico, the disjuncture between the knowledge and expectations held by public agencies and private actors had particularly severe and lasting consequences.

2.4. *Reducing the vulnerability of any system — A city, a coastline, an island territory — is not something that any one agency or administration can accomplish*

Vulnerability reduction typically requires contributions from individuals, households, businesses and others who may or may not see the salience of their actions. As more and more resources and assets are privatized, even highly capable public-sector agencies and well-managed and maintained public infrastructure can only go so far in reducing social vulnerability. Achieving more system-wide adaptation at multiple scales requires the collaboration and specific contributions of individuals, households, businesses, and civil society organizations. For example, residents

with property along a coastline may need to be willing to have their view obstructed by a sand dune in order to improve hurricane resilience over a swath of territory. Giving up one's view from a property — when the view was why you purchased it to begin with — can be an unwelcome cost. And the individual benefits from making such contributions to reduce public vulnerability are often elusive or only indirectly apparent after a hazard strikes (Tompkins and Eakin 2012). Thus, while there is ample evidence of solidarity *following* impacts, when it is clearly apparent that public infrastructure provisioning has failed, there is less evidence that individuals will collaborate to anticipate and prepare for highly uncertain (in space and time) events, particularly if it entails that individuals bear specific costs for an uncertain, and often intangible public benefit.

A case in point is the complex relationship between urbanization and associated land use change, and the implication of these processes for cumulative risk and regional resilience. Cities and counties govern land use zoning and building permits; individuals and enterprises respond to the institutional incentives and disincentives to build their homes and businesses. In this complex process, individual actions satisfying individual aspirations not only create individual vulnerabilities but also alter terrestrial, climatic, and hydrological processes to collectively produce aggregated, amplified risk (Cook *et al.* 2012; Milman and Warner 2016).

How to motivate individual property owners to contribute to reducing the sensitivity of the landscapes in which they reside is an increasingly important policy challenge (Tompkins and Eakin 2012). While zoning and building standards are intended to incentivize developers and home owners to take risk into account, the case of Houston — where urban development was permitted to expand into known flood plains — illustrates that these incentives are not always used effectively. And in Puerto Rico, inequity, poverty and lack of affordable housing stock created conditions in which as much as 55 percent of all housing units (Torres Gotay 2017) lacked building permits or property titles, and thus were "irregular" in construction. This fact not only suggests that any building codes that might have made them more resistant to flooding or wind would not apply, but it also makes them ineligible for FEMA support in recovery. No homeowner likes additional regulation, yet, in the face of increasing privatization of land and other resources, mobilizing the support of such resource managers to reduce vulnerability at broader scales is critical.

2.5. *Disasters represent opportunities for initiating more sustainable development trajectories, but such transformations face significant barriers*

This issue is by no means new: disaster management practitioners have for some time argued that disaster recovery offers opportunities for communities to

"leap-frog" or "bounce-forward" to more desirable states in the substance and direction of rebuilding (Pelling 2011; Glantz and Jamieson 2000). Nevertheless, implementing this ideal is challenging, particularly considering the urgency of restoring key infrastructure, services, and capacities. Sustainability transitions following disaster are more likely when there is an enabling political and economic environment, an articulated vision or idea of alternative development prior to the disaster, and a social network of people willing to carry forward the ideas even in the midst of significant hardship and loss (Brundiers and Eakin 2018).

In Puerto Rico, prior to María's landfall, efforts were already underway to envision alternative energy supply structures and delivery systems. Academic institutes, non-governmental actors and the public sector were exploring alternatives involving renewables and increased energy independence. After María threw the island into a severe and lasting energy crisis, the governor of Puerto Rico recognized the opportunity presented to transform the electric power system to one that is "hardened, smarter, more efficient, cleaner and less dependent on fossil fuel imports" (Puerto Rico Energy Resiliency Working Group 2017: 5). A report by a conglomerate of US energy utility companies and leading organizations and laboratories in the energy industry offered the governor a vision and plan to rebuild Puerto Rico's grid towards more sustainable energy pathways in the future (Puerto Rico Energy Resiliency Working Group 2017). However the governance processes, rules, and cultural values and norms — the so-called "socio-political infrastructure" that can facilitate or inhibit transformative change (Eakin *et al.* 2017) — was not central to the analysis. Rebuilding "differently" but expeditiously implies that the vision and associated alternative development trajectories have been discussed and vetted with affected communities, the forces that maintain the status quo have been identified, and the political will to change has been ignited. This is typically not the reality, and the combination of immediate social need, political pressure, and infrastructure path dependency works against efforts for transformation and towards restoring infrastructure back to prior conditions.

3. Critical Lines of Action in the Face of Vulnerability Challenges

There is clearly a need for new approaches to managing vulnerability this century if we are going to overcome the challenges described above. First, if we acknowledge that vulnerability emerges from social, political and economic relationships among people, technology and the environment (Tschakert *et al.* 2013), and is subject to interdependencies across trade routes, administrative boundaries and information flows (Adger *et al.* 2009; Eakin 2010), we also need to create new metrics to account for these relations along with multiple spatial and temporal scales (Lim-Camacho *et al.* 2017).

Again, vulnerability maps that overlay population, environmental and infrastructure attributes of a place are perhaps no longer sufficient (Preston *et al.* 2011). Instead, more dynamic and spatially complex models are needed (Coetzee *et al.* 2016). Rather than focus on describing the current state of assets and capacities, we need to be more proactive about identifying the critical thresholds and our proximity to them (Luers 2005), and how linkages across systems — dependency, for example, on imported energy sources, or the political will for action by a distant government body — affects the probability of crossing such thresholds. Assessments of vulnerability, for example, could highlight indicators of critical material (finance, energy, water, food, labor) and non-material (information, values, trust, social/cultural) flows that sustain a system, their interactions and interdependencies, and the potential for their disruption.

Researchers are developing the tools and skills to do this: advances in the modeling of complex system dynamics can simulate unexpected interactions among, for example, population mobility, transport infrastructure conditions and energy supply networks (Murray 2013). More intangible flows, such as knowledge, social capital, and political influences, are much harder to quantify and model, but may be critically important in the dynamics of vulnerable systems. A further challenge is to capture the responses of distinct actors within a system — residents, businesses, public sector representatives — to these collective dynamics, and how these responses in turn affect the evolution of vulnerability over time.

To cope with lack of data, and the need to capture dynamics that are qualitatively understood but poorly measured or monitored, techniques based on local expert knowledge can help. Established decision analysis tools such as the Analytical Network Process, for example, can help communities understand what drives vulnerability, evaluate the state of critical variables, and how these factors interact to create undesirable states (Eakin and Bojórquez-Tapia 2008; Saaty 2005). Qualitative and quantitative scenario planning and "serious games" that allow for the simulation of decision-making in complex emergencies can also address this challenge (Birkmann *et al.* 2015; Loreto *et al.* 2012). And participation in the development and deployment of such tools can be instructive for decision-makers and citizens in that it can illustrate critical system nodes, and how risk can be amplified or reduced through specific social relationships and biophysical networks and connectivity.

And yet, even when such approaches to knowledge are widely available, the solutions are not. Reducing the vulnerabilities that result from systemic interdependencies typically entails enhancing redundancy and diversity in a system: having a backup system for energy production, alternative supply chains, multiple agencies and social groups participating in overlapping knowledge

networks. Maintaining such redundancy is expensive and can seem inefficient for individuals and communities, until a crisis hits. Diversity in trade relations and flows, diversity in economic profiles of places, diversity in modes of energy, water and food production, diversity in social relationships and organizational ties, in times of crisis, are fundamental to resilience, diffusing shocks and enabling multiple response channels. Of course, diversity entails costs: in "normal" times, maintaining diverse and decentralized relationships can seem to create inefficiencies and unnecessary complexity. But our "normal" times are changing. Planning for risk and uncertainty now, more than ever, needs to be the new normal.

Anticipating the impact of connectivity and interdependency in vulnerability implies a greater role for cross-scale, multi-stakeholder and even international coordination of risk governance. The costs and perceived inefficiencies may seem less when shared among households, or across communities and sectors that have a common interest in diminishing the risk of crossing critical thresholds of vulnerability. While we have made some progress in these hybrid and flexible forms of governance in relation to, for example, supply chain sustainability and land change (see, for example, Round Table on Sustainable Palm and other such multi-stakeholder initiatives), it is not yet clear what such governance arrangements should look like in relation to managing vulnerability (Engle and Lemos 2010).

Addressing the problem of incomplete, inaccurate or misinformed decision-makers — from the household to higher level public administrators — is challenging, but not impossible. Society is more than ever connected via social media, the Internet and a variety of novel forms of information and economic communication mechanisms. In the months after María hit Puerto Rico, residents were able to find out about their relatives through amateur radio hackers, Facebook and other grassroots networks. New forms of communication — so called "Information Communication Technology" — also can result in enhanced public accountability and wider possibilities for participating and influencing conversations of public interest (Eakin *et al.* 2014; Heeks and Ospina 2018). Public documents are increasingly made available through leaks to news outlets or directly on the Internet, through avenues such as Wiki-leaks. Nevertheless, these horizontal flows of information are often incomplete and inaccurate and often politically motivated, thus communicating only partial information about the state of the systems on which we all depend. Thus, as citizens, we need to be more involved in producing and accessing the knowledge about our own vulnerability, and thus more responsible about evaluating this information, and demanding transparency and accountability. We need to be more integrated into the knowledge networks organized by public and private sector entities about risk and system threats, and such entities need to be more transparent and forthcoming about what knowledge

is available and how it was generated, based on what data, rather than suppressing it when it does not meet short term political goals. In the new era of extreme events, risk should be front and center in all areas of government and civil life. Public agencies have a responsibility on only to effectively manage early warning systems but also to responsibly communicate the fragility of the different systems on which citizens depend.

To achieve this, researchers, decision-makers, and practitioners need to "upgrade" the knowledge systems through new sets of tools and practices for collecting, analyzing, and applying data to anticipate risk and empower people to see their own vulnerability, act where possible, and demand more just and equitable access to adaptation support for those who need it. Climate models and scenario processes that imagine future trajectories, while not perfect, can provide useful anticipatory knowledge for addressing unprecedented extreme events (Miller and Muñoz-Erickson 2018). Scenario planning can help in this regard, particularly if such planning builds on an analysis of the interdependencies and "flows" that are driving vulnerability in particular places. Adaptation pathways analysis (Haasnoot *et al.* 2013; Wise *et al.* 2014) has shown promise in helping decision makers identify the future circumstances in which a particular intervention to manage risk may become ineffective and where alternatives might be needed. Such analytical tools also may be constructive in anticipating opportunities for altering the course of development towards more sustainable trajectories should disasters occur. Critically, involving diverse segments of society in such planning efforts, and anticipating the potential barriers to change, can be instrumental for communities to take advantage of such opportunities in the wake of crisis. If a broad segment of society is involved in developing such alternative development plans they will be more likely to have the relevance, credibility and legitimacy necessary for implementation in contexts of duress.

Finally, none of the above will make a difference unless we engage in new conversations about sharing risk and sharing the burden of adaptation *equitably.* We do not live in an era in which the state alone can provide and protect. All segments of society need to participate in assuming the burden of risk management and adaptation to achieve more sustainable and resilient communities. To accomplish this, society — particularly people residing in more wealthy settings — needs to begin to accept the real limits of existing systems of risk management. The reality is that no one is immune, and all have responsibility for both producing and addressing vulnerable conditions. We must also simultaneously address the fact that the conditions of vulnerability are unevenly and unjustly distributed (Cole 2016). In Puerto Rico, this may mean debt forgiveness and facilitating investments in education, health care and basic infrastructure. In other

places, individual residents and private businesses may need to confront the uncomfortable fact that the public sector, and associated private and public financial services, are no longer able to buffer them from rising sea levels and hurricane force winds. Incentives for luxury development on attractive coastlines, for instance, will need to change such that the burden of adaptation falls more squarely on those who are choosing to put themselves (and others) at risk.

We are now confronted with an opportunity; the losses experienced in Puerto Rico, Houston and Miami underscore the need for embracing a new perspective on vulnerability. We cannot wait for the next major event to begin a process of individual and system adaptation. The time is now.

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