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ADVANCED REVIEW

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Explaining differential vulnerability to climate change: A social science review*

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The varied effects of recent extreme weather events around the world exemplify the uneven impacts of climate change on populations, even within relatively small geographic regions. Differential human vulnerability to environmental hazards results from a range of social, economic, historical, and political factors, all of which operate at multiple scales. While adaptation to climate change has been the dominant focus of policy and research agendas, it is essential to ask as well why some communities and peoples are disproportionately exposed to and affected by climate threats. The cases and synthesis presented here are organized around four key themes (resource access, governance, culture, and knowledge), which we approach from four social science fields (cultural anthropology, archaeology, human geography, and sociology). Social scientific approaches to human vulnerability draw vital attention to the root causes of climate change threats and the reasons that people are forced to adapt to them. Because vulnerability is a multidimensional process rather than an unchanging state, a dynamic social approach to vulnerability is most likely to improve mitigation and adaptation planning efforts.

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KEYWORDS
access, culture, governance, knowledge, vulnerability

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[Correction added on 14 December 2018, after first online publication: The affiliation of Dr. Robert Winthrop has been updated.]

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1 | INTRODUCTION

When the Intergovernmental Panel on Climate Change issued its First Assessment Report in 1990, research on climate change vulnerability primarily framed the issue in terms of exposure to physical impacts on particular sectors (e.g., water, agriculture), regions (e.g., the Andes, Southeast Asia), and countries, but offered little by way of analysis of the social drivers of climate change vulnerability or the uneven distribution of risk. Much has changed since. In the intervening years, a vast number of social scientific investigations has generated methodological approaches, empirical findings, and theoretical insights that have transformed how we think about climate change vulnerability. Despite these significant developments, scientific and technical approaches to climate change continue to dominate, leaving the underlying social drivers of vulnerability largely unaddressed. We therefore draw crucial attention to social scientific approaches to climate change vulnerability by identifying and synthesizing signal contributions to the field.

We start with the observation that while nobody can escape the impacts of climate change, some social groups experience greater loss of resources and greater impacts to livelihoods and cultural identity than others. This differential vulnerability to comparable levels of physical change is primarily a function of social rather than physical factors. In this review, we focus on these crucial but often neglected aspects of vulnerability. We ask: who is most affected by weather- and climate-related impacts, and why? We highlight social scientific evidence, which indicates that access to resources and the ability to reduce exposure to climate hazards are not randomly distributed across society but are the drivers of uneven vulnerability across social difference. Social science modes of investigation improve our understanding of the reasons that uneven vulnerability exists and offer practical insights into how to minimize it before hazards become disasters.

Vulnerability, rather than an unchanging state, is a multidimensional process affected by social, political, and economic forces interacting from local to international scales (Bohle, Downing, & Watts, 1994; Ribot, 1995). In this paper, we define vulnerability as a function of exposure, sensitivity, and adaptive capacity (Figure 1; Engle, 2011; Smit & Wandel, 2006). Recognizing that many factors influence vulnerability, we identify four broad themes as particularly helpful for understanding the social aspects of vulnerability and structure our review around these themes: resource access, governance, culture, and knowledge. We bring to our analysis multiple disciplinary perspectives—cultural anthropology, archaeology, human geography, and sociology. The four themes capture prominent theoretical framings found in each of these disciplines, but they do not map exclusively to any one discipline. Together they provide a more comprehensive, interdisciplinary social science framework for analyzing and understanding uneven vulnerability across social difference. Any effort to reduce uneven vulnerability requires understanding why it exists in the first place, a subject for which these disciplines, with their established approaches to examining issues of power and social difference, are especially well suited.

Interventions can reduce harm and mortality that extreme weather events cause in socially vulnerable groups. Such interventions are far more effective when they account for the ways that this review's four themes—resource access, governance, culture, and knowledge—interact with the three components of vulnerability—exposure, sensitivity, and adaptive capacity. Cases of maladaptation indicate that it is also necessary to account for potential unintended negative effects of adaptation interventions on people and places situated beyond the geographic and temporal scale of a given project. Attention to these

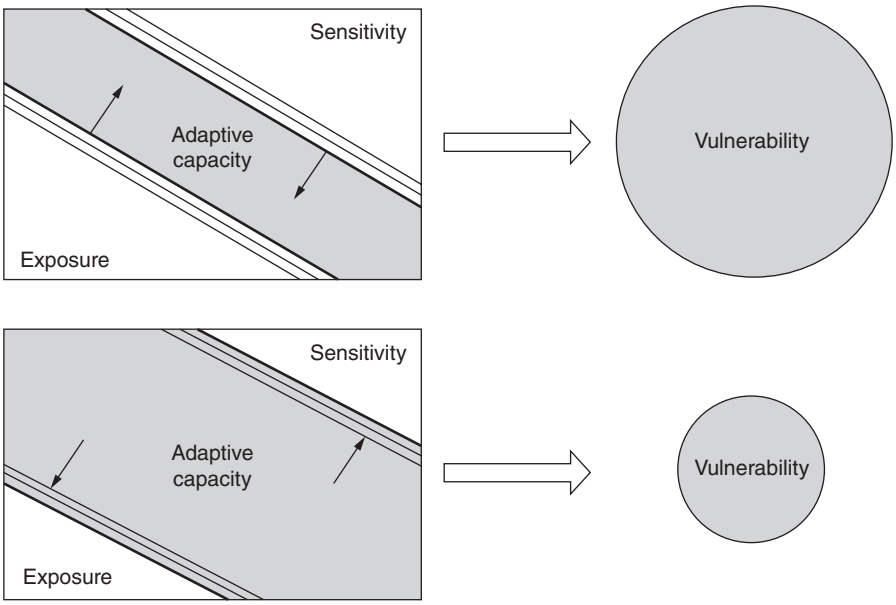

FIGURE 1 Vulnerability is a function of exposure, sensitivity, and adaptive capacity. Adaptive capacity that is low, relative to exposure and sensitivity, contributes to high vulnerability (top). By contrast, higher adaptive capacity helps reduce the effects of exposure and sensitivity, and in turn reduces vulnerability (bottom). (Reprinted with permission from Engle (2011). Copyright 2011 Elsevier Science)

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issues will support the development of emergency responses and longer-term adaptation strategies that minimize exposure and sensitivity, and that elevate adaptive capacity under a changing climate.

2 | FOUR THEMES OF VULNERABILITY

Within the four thematic sections that follow, we first examine access to resources, considering how access varies in society and how disparities drive differential sensitivity to climate impacts. Social processes of marginalization and disenfranchisement play important roles in creating patterns of unequal access to resources. Simultaneously, climate change will increase the exposure of populations to environmental hazards, exacerbating the existing unevenness in vulnerability across axes of social difference such as race, class, ethnicity, and gender (Denton, 2002; Leichenko & Silva, 2014; Shepherd & Binita, 2015). Designing and implementing effective disaster risk reduction and adaptation interventions require attention to these inequalities in the context of ongoing social changes.

Second, we consider how governance affects vulnerability to climate change: how local governments, private firms, and civil society plan for and manage climate change risk. Representation and empowerment are fundamental parts of why there are such stark differences in the vulnerability of different social groups. Power differentials drive who receives the benefits of government policies and who may be disenfranchised by them (Watts & Bohle, 1993). Many effective approaches for addressing vulnerability focus on multilevel governance and developing cobenefits for a diverse range of groups. Connecting expert science with local organizations through knowledge networks increases both knowledge sharing between government and communities, and related benefits, including trust and stakeholder engagement (Bidwell, Dietz, & Scavia, 2013; Phadke, Manning, & Bardaglio, 2016; Tschakert & Dietrich, 2009).

Third, we explain the role of culture in shaping vulnerability. Culture frames how individuals perceive and explain their environments and affects who is sensitive and exposed to environmental change and how they experience exposure. As it informs perceptions of risk, culture also affects the adaptive capacity of those exposed and shapes the ways in which related equity and environmental justice issues are weighed. Because the impacts of climate change are experienced where people live, many aspects of exposure, sensitivity, and adaptive capacities are context-specific (Crate & Nuttall, 2009). Communities have developed complex ways to adapt to climate risks, including robust bodies of place-based knowledge and practice. Recognizing such local adaptation practices will help communities prevent the next hazard from becoming a disaster.

Fourth, we examine the multidimensional nature of knowledge and information about climate risk. We advocate moving beyond the knowledge-deficit model because it implies that emergency management and climate risk agencies need only share more information, such as by presenting scientific findings on climate change-related threats and hazards. Instead, we emphasize that information is necessary but not sufficient for reducing vulnerability. We explore different types of knowledge and information that affect vulnerability, arguing that including diverse forms of knowledge can improve mitigation and adaptation planning (McNeeley, Even, Gioia, Knapp, & Beeton, 2017). We highlight examples that show the importance of social networks and boundary organizations for facilitating the creation and two-way sharing of knowledge.

3 | ACCESS TO RESOURCES

Climate change effects arrive on an already-complex social landscape populated by groups with different access to resources (Kasperson & Kasperson, 2001). Access to resources—or, the ability to derive benefits from natural and human resources (Ribot & Peluso, 2003)—influences vulnerability by augmenting or reducing exposure, sensitivity, and adaptive capacity (Figure 1). Relevant resources comprise tangible and intangible, and private and public goods. These include private capital, liquid assets, disaster warning systems, emergency response, alternative housing, insurance, food stores, migration support, durable infrastructure, transportation, and information and communication networks (e.g., Cinner et al., 2018). However, the availability of these resources in any one place does not necessarily mean that people have access to them or that they may be utilized to reduce vulnerability (Sen, 1984). Access to these resources entails complicated social relationships and power structures, many of which marginalized and poor populations struggle to navigate (Watts, 1983).

Inequalities in access to resources can be seen across regions of even the wealthiest countries and across communities and neighborhoods within the same city (e.g., Shearer, 2012a). In this context, a hazard such as a hurricane or drought only becomes a disaster when some groups lack the adaptive capacity to protect themselves from it. In other words, "natural" disasters are actually human disasters (Gaillard et al., 2014; O'Keefe, Westgate, & Wisner, 1976; Wisner, 2001). When Superstorm Sandy hit New York and New Jersey in 2012, over 100 people were killed (Kunz et al., 2013). These deaths were concentrated among the elderly in part because they lacked access to healthcare and transportation (Kunz et al., 2013). By comparison, Hurricane Katrina killed about 1,800 people in the relatively impoverished coastal areas of Louisiana and Mississippi.

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Here too, a majority of the victims were elderly, but in New Orleans a large group was also poor and black, especially in the Lower Ninth Ward, close to where the levees were breached (Brunkard, Namulanda, & Ratard, 2008; Diakakis, Deligiannakis, Katsetsiadou, & Lekkas, 2015; Jonkman, Maaskant, Boyd, & Levitan, 2009). Hurricane Katrina only became a disaster because the neglected infrastructure failed, poverty and segregation were common in New Orleans, and many people lacked the resources to prepare for, avoid, and recover from the storm. Comparing the devastation caused by Hurricane Maria in Puerto Rico with that caused by Hurricane Harvey in Texas in 2017 provides another stark example of the social nature of disasters (Weiss, Lebrón, & Chase, 2018). Puerto Rico was devastated and remained so several months later, while Texan communities were able to recover much more quickly.

There are similar inequalities in adaptive capacity: some communities recover more quickly than others from hurricanes or floods (Logan, Sukriti, & Xu, 2016). Recognizing and understanding these differences requires scientists and policymakers to better understand what access to resources and adaptive capacity entail. The crucial point in understanding both is that they do not reflect a lack of resources, but rather an unequal distribution of available resources (Gaillard, 2010; Ribot, 1995; Sen, 1984). The inability of groups of people to secure access to resources and the capacity to adapt to climate-related impacts directly results from their inability to control their daily life (Gaillard, 2010), to choose the location in which they live, and how and where they secure livelihoods (Blaikie, 1985). Following from this, climate-related impacts and the suffering incurred by subsets of the population "reflect development failure where the root causes of vulnerability merge with the origins of other development-related crises" (Gaillard, 2010, p. 222). These development failures stem from issues related to different types of social hierarchies based on racial, caste, and gender discrimination; poverty; and power differentials.

3.1 | Race, caste, and gender

Rather than through overt acts of racial discrimination, structural racism creates racial disparities in educational attainment, income, and wealth in more subtle ways by perpetuating uneven access to resources (Bonilla-Silva, 1997; Lopez, 2003; Omi & Winant, 2015; Shearer, 2012b). Structural racism, involving "the totality of the social relations and practices that reinforce white privilege" (Bonilla-Silva, 2013, p. 9), contributes to increased vulnerability among U.S. nonwhite populations. In the United States, white households earned 65% more income and possessed 13 times greater wealth in 2014 than African American households (Pew Research Center, 2016), which were more likely than white households to suffer home foreclosure following the 2009 recession (Rugh & Massey, 2010). Such disparities can lead to color-blind adaptation planning in practice, which, in the United States, further exacerbates inequalities in access to the resources needed to adapt to a changing climate (Hardy, Milligan, & Heynen, 2017). On the Eastern Shore of the Chesapeake Bay, the social and political isolation of three African American communities reduced their access to resources that could be used to adapt to frequent flooding, as well as their representation in government decision making (Miller Hesed & Paolisso, 2015). Efforts to reduce vulnerability, therefore, can benefit from attention to differences of populations along lines of race, class, gender, ethnicity, and other axes of social difference. In non-U.S. contexts, similar but regionally specific social processes can lead to inequitable adaptation planning (Graham, Barnett, Fincher, Mortreux, & Hurlimann, 2015; Sultana, 2017).

In several countries, people experience social discrimination along endogamous, hereditary, and hierarchical groupings known as castes. Although such social categories are not always officially recognized, they can still have profound implications for people's exposure to climate-related impacts, as well as access to food, water, land, education, and government services, including disaster relief (Mustafa, Ahmed, Saroch, & Bell, 2010; Ray-Bennett, 2009). In India, caste is increasingly understood to be flexible, dynamic, and contested. However, one study in Orissa found that upper-caste women were able to cope with multiple disasters more effectively than low-caste women, who lacked stable housing and neighborhood networks that could buffer them from the impacts of floods, cyclones, and droughts (Ray-Bennett, 2009). These studies highlight how caste, class, gender, and other social categories overlap to create unique vulnerabilities only discernible by such intersectional analysis (Bosher, Penning-Rowsell, & Tapsell, 2007; Onta & Resurreccion, 2011; Ray-Bennett, 2009; Sultana, 2014, 2017).

Gender is a potent factor explaining vulnerability to climate-related impacts. Factors such as lack of access to and control over basic resources and lack of entitlements amplify women's vulnerability and undermine their ability to cope with effects of disasters (Denton, 2002; Sultana, 2014). One study in coastal Bangladesh examined the immediate impacts of cyclone Aila in 2009, as well as more gradual and longer-term changes, like working the fields in worsening heat, retrieving water from seawater-contaminated wells, and repairing infrastructure damaged by recurrent tidal flooding (Al Nahian, Islam, & Bala, 2013). These situations increased hardships in daily resource acquisition tasks for women, in turn driving increased hunger. They also found that due to restricted gender roles, women were unable to attend nongovernmental organization (NGO) trainings or income generating activities without their husbands' permission (Al Nahian et al., 2013). Perhaps the most striking example of women's extreme vulnerability comes in cases where women are unable to evacuate from rising flood waters due to religious and cultural restrictions on their traveling without male chaperones (Crate & Nuttall, 2009; Sultana, 2014).

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Addressing vulnerability therefore requires understanding of and attention to gender and its interactions with race and caste, but also class.

3.2 | Poverty

Poor people and poor nations regularly suffer the greatest losses from climate-related disasters (Roberts & Parks, 2006). Poverty affects access to resources, and in turn vulnerability, in several complicated ways (Blaikie, Cannon, Davis, & Wisner, 1994; Leichenko & Silva, 2014; Peacock, Morrow, & Gladwin, 1997). Vulnerability is determined by economic, institutional, and political capacities of different people affected by climate-related impacts (Bohle et al., 1994). If access to resources is limited by income or wealth, vulnerability results from a lack of *economic capacity.* If resources simply do not exist in a place inhabited by a certain group, vulnerability stems from a lack of *institutional capacity* in that group. Finally, if access to resources is limited by processes of exploitation or surplus appropriation, vulnerability must be considered to result from a lack of *political capacity* to obtain or retain resources. In each case, the marginalized group may be considered poor, but solutions to limit or reduce vulnerability may differ widely.

Many groups may face combinations of insufficient economic, institutional, and political capacity. For example, disaster preparedness typically involves developing disaster plans, assembling supplies, obtaining insurance, preparing defenses, and seeking information. In many places, it is more difficult for poor households and communities to prepare for climate threats because they lack the required income, time, language abilities, and knowledge of resources and how to access them (Mileti, 1999). Vulnerability among these households reflects both limited wealth to prepare for climate-related impacts and limited institutional capacity to ensure that disaster preparation resources exist in a form that is useful to them.

A second example explains why standard disaster warnings are often less useful to poor communities. A number of disastrous floods and cyclones in Bangladesh led the government to shift from an emphasis on disaster relief and recovery to early warning and evacuation systems, resulting in a remarkable reduction in fatalities associated with such events (Ribot, 2010). However, Bose (2015, p. 5) notes that protective benefits do not necessarily accrue to those living in Dhaka's informal settlements, due in part to "an inability to notify residents who do not have legal title to property or residence, and a general impermanence of community." These households are made vulnerable by a lack of institutional capacity to ensure that they are included in disaster warning initiatives. In addition, they are not able to claim legal status that would legitimize their communities, which reflects a lack of political capacity.

A third common example of the relationship between poverty and vulnerability draws attention to the built environment. The locations in which poor people reside are often less resistant to the impacts of weather and climate change. Cheaper, less-desirable housing sites such as floodplains and unstable hillsides are often more exposed to climate hazards (e.g., Wisner, 2001). Buildings may be poorly constructed, thereby increasing sensitivity to climate impacts (Austin & Schill, 1994; Bolin, 1986; Greene, 1992; Hallegatte, 2012; Phillips, 1993). This renders poor people vulnerable to climate change in and of itself, but it also broadens their vulnerability because recovery becomes more difficult. For example, after Hurricane Andrew, although the Federal Emergency Management Agency (FEMA)—the primary disaster response agency in the United States—opened disaster-assistance centers, poor victims were disproportionately impacted by the storm but received less relocation assistance because it was difficult to get transportation and childcare, and to take time off work to make claims (Dash, Peacock, & Morrow, 1997). In recovering from climate-related disasters, the biggest challenges the poor face are often to secure safe housing and to relocate (Fothergill & Peek, 2004). This reflects a lack of economic, institutional, and political capacity among poor households, which are all capacities tied to power.

3.3 | Power differentials

The ability to influence or coerce different groups—social power—is derived from and reproduces the social hierarchies that create inequalities in access to resources, which in turn engender differential vulnerability among communities. In this way, power differentials may be conceptualized as a synthesis of the other two sets of issues described above. Vulnerability occurs not only because of the marginalization or poverty of particular social groups but also through the processes that perpetuate or expand marginalization and poverty, potentially including adaptation planning (Anguelovski et al., 2016; Atteridge & Remling, 2018; Warner & Kuzdas, 2016). Groups with more political power are more likely to secure funding to plan for, cope with, and respond to climate-related impacts. It is possible to increase inequalities in adaptive capacity by enabling "powerful geographical groups of people to minimize negative environmental externalities and appropriate positive environmental externalities in particular places, with unjust socio-environmental consequences" (Collins, 2010, p. 265; see also Anguelovski et al., 2016; Shi et al., 2016).

In the case of coastal impacts of climate change, such inequalities are increased financially through the unequal expenditure of adaptation funds, and physically through the construction of sea walls or other coastal protections that literally shift the problem down the road or across the river (Adger, Arnell, & Tompkins, 2005). In many cases of coastal hazards, the construction of sea walls, dikes, flood channels, and other "gray infrastructure" may protect land and life for target populations while

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deflecting risk elsewhere (Atteridge & Remling, 2018). In Southeast Asia, flood risk management strategies heavily reliant on structural measures prioritize the protection of high-value property and land uses that benefit local elites over the ecological services of productive fisheries, wetlands, and floodplains that primarily benefit rural farmer and fisher households (Lebel & Sinh, 2007). A recent study in eight cities around the world found two main ways that efforts to reduce vulnerability could increase inequality (Anguelovski et al., 2016). First, "infrastructure investments, land use regulations, or new protected areas disproportionately affect or displace disadvantaged groups" (Anguelovski et al., 2016, p. 334). A second set of impacts were from "plans that protect economically valuable areas over low-income or minority neighborhoods, frame adaptation as a private responsibility rather than a public good, or fail to involve affected communities in the process" (2016, p. 334).

Beyond heterogeneous urban environments, the traditional dichotomy between "rural" and "urban" inadequately represents the diversity of relationships between people and the landscapes that strongly affect vulnerability (Lerner & Eakin, 2011). In areas of high population density, even if most people are affected similarly by exposure to a given local climate impact, various activity spaces—defined as, "a geographic extent in which people move in the course of their daily activities" (Ren, 2016; see also Kwan, 2013; Kwan & Schwanen, 2016)—will be affected differently. These discrepancies were clearly revealed by the effects of the Maharashtra Floods of 2005 in Mumbai, India and Hurricane Sandy, for example (Chatterjee, 2010; Schmeltz et al., 2013).

In low population density areas, the livelihoods of people engaged in agriculture, forestry, and fisheries depend directly on the environment. Climate impacts threaten not only their health and safety but also their ability to earn a living (Berkes, 2007; Watts et al., 2015). People in these areas also may have less access to medical care and disaster-response resources than people in higher-population-density areas (Morrow, 1999). In areas with lower population densities, diminishing resources are associated with the privatizing of public services and with limited social-service delivery, although these trends may vary (Lobao, Adua, & Hooks, 2014).

Whether in high or low population density areas, daily activity spaces affect health and exposure to environmental toxins (Perchoux, Chaix, Cummins, & Kestens, 2013), food accessibility (Widener & Shannon, 2014), and the capacity for both short- (Faber, 2015) and long-distance travel (Silm & Ahas, 2014). Programs to reduce vulnerability to climate change should therefore be designed for specific social contexts (see examples from the Navajo Nation and Southern Appalachia, below). More research is needed to understand what combination of capacities, those that address specific climate-related impacts (specific capacities) and those that address the structural deficits (e.g., lack of income, education, and political power; i.e., generic capacity) that create vulnerability, are needed in different places (Lemos, Lo, Nelson, Eakin, & Bedran-Martins, 2016). Building these capacities and addressing issues of power, poverty, race, caste, and gender will require transforming climate change governance practices.

4 | GOVERNANCE

The processes of governance—how societal problems are addressed by governments and other organizations—both shape and respond to climate change vulnerability. The concept of governance extends well beyond formal governmental institutions, encompassing "the relationships between government and society including the means through which private actors, markets, and interest-based networks influence policy decisions" (Chaffin et al., 2016, p. 401). Climate change presents both acute and chronic challenges for effective governance, requiring responses to both sudden "pulse" events such as Cyclone Nargis, which killed over 130,000 people in Myanmar, in 2008 and gradual "press" events such as sea-level rise (Collins et al., 2011). It is difficult to overstate the different governance styles and institutions needed for these vastly different situations.

Representation is a foundational issue. Representation is the ability of different groups to participate in the political processes that establish procedures and influence outcomes, which is crucial for human security in the face of climate-related stressors. Building upon Sen's (1984) work on capabilities and the roots of hunger, Watts and Bohle describe a "space of vulnerability" at the intersection of command over resources (such as food), class-based patterns of social reproduction, and the totality of rights. "A reduction in vulnerability demands a promotion of entitlements...[which is] prima facie political" (Watts & Bohle, 1993, p. 49). Famine (and equally, the devastating impacts of climate-related disasters) hits three different and overlapping groups of people: the resource poor, the powerless, and the exploited. This social map of types of vulnerability, they argue, also "has its geographic or spatial counterpart," as different regions and parts of the world rank higher or lower on each of these variables (Watts & Bohle, 1993, p. 56). This perspective helps us see how limitations in representation (governance with power biased to favor certain groups) are critical in creating and maintaining patterns of vulnerability; and addressing governance is fundamental in reducing vulnerability.

NGOs can help reduce climate change vulnerability. Organizations that speak for vulnerable populations may challenge governmental policies on climate change and whether they can reach the poor, for example, while partnerships between governments and local NGOs can significantly increase the capacity for effective social action. The rise of climate issues on local governments' agendas is promoting new kinds of partnerships across sectors. For example, climate change has significant

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impacts on health (Watts et al., 2015), such as the increased incidence of asthma (Shea, Truckner, Weber, & Peden, 2008). As these causal relationships become better understood, hospitals, universities, and state health departments increasingly partner with social action organizations, labor unions, and environmental groups to develop programs addressing health and other aspects of environmental well-being (Rudolph, Gould, & Berko, 2015).

Scientifically sound and socially robust approaches to adaptation involve community groups in every stage of the process: identifying issues, designing responses, implementing actions, and evaluating results. The Centers for Disease Control and Prevention (CDC) uses a community-based participatory research model, which was developed for understanding and addressing health issues, that approach could be adapted to building resiliency (Simonds, Wallerstein, Duran, & Villegas, 2013). Other institutions have conducted numerous programs, similarly using iterative engagement, on issues such as disaster management in the Philippines and water and crop management in Ghana (Allen, 2006; Tschakert & Dietrich, 2009). As the cases we discuss here show, relationship building promotes accountability among experts and policy-makers and helps overcome the deficiencies of top-down decision-making.

4.1 | Public and private governance

Vulnerability reduction is a necessary goal of most organizations as they seek, on behalf of themselves and the populations they serve, to avoid threats of harm, to lessen damage if harm arrives, and to improve their response to threats. Governmental institutions, private firms, and NGOs, working separately or jointly, all engage in efforts to reduce vulnerability to climate change. Their activities involve establishing priorities for action, allocating resources, and developing and implementing plans, as well as ongoing operations for reducing vulnerability, which stems from multiple interacting drivers. But many organizations allocate few or no resources to vulnerability reduction because its potential future benefits cannot compete with immediate needs and short-term goals. These factors present challenges to the development and implementation of plans, which often focus on a subset of the sources of vulnerability (Weber, 1997).

Climate change adaptation activities vary from locally autonomous endeavors to government-led projects. Regarding flood risk management, in many peri-urban communities, homeowner associations, and other local groups are responsible for maintaining storm-water retention ponds and green infrastructure facilities that reduce flooding and protect local waterways. Associations often lack the funds and technical expertise for proper management of these features; such lack increases both vulnerability to water hazards and risks for downstream communities. Many groups, ranging from individual municipalities to complex social organizations comprised of neighbors along shorelines, have self-organized to construct coastal defenses such as breakwaters, seawalls, and revetments. Regardless of the degree of self-organization, financial and decision-making capacity may limit community-based project development (Allen, 2006). Cities and provinces by necessity may assume final responsibility for funding adaptation measures, such as implementing costly improvements to coastal roads threatened by sea-level rise (Moser, Williams, & Boesch, 2012; Ruppert & Deady, 2017).

Governance challenges are obvious in many municipal efforts to reduce climate change vulnerability, particularly in relation to hazards and extreme events. Cities often operate within longer time frames than those of other organizations because urban stakeholders are closely tied to officials and because city governments have important investments in long-lasting infrastructure projects. Hazards and disasters can prompt cities to take resources from ongoing activities and allocate them to vulnerability reduction; gradual trends, though equally serious, often do not attract attention. In Chicago, a severe heat wave in 1995 prompted the city to develop outreach programs to particularly vulnerable populations, such as the elderly; after the programs were implemented, fewer people died during subsequent heat waves (Klinenberg, 2002).

The Chicago example notwithstanding, cities tend to invest in visible, tangible, hard infrastructure rather than soft vulnerability reduction measures, often generating unintended consequences in the process. After a major flood in 1962, Norfolk, Virginia built a large sea wall rather than reduce residents' exposure by using buyouts and insurance to encourage them to relocate away from low-lying areas, which remain highly vulnerable to sea-level rise (National Research Council, 2004; Norfolk, Virginia, City of, n.d.). This is an example of the "safe development paradox," where "increased safety induces increased development leading to increased losses" (Kates, Colten, Laska, & Leatherman, 2006, p. 14653; see also Adger et al., 2005).

Governance of climate risks, therefore, can fail to reduce vulnerability if projects are too narrow in defining the population, geographical area, issues, or time scale of concern. Addressing climate hazards and other environmental issues thus often requires large-scale action across an ecosystem or landscape. Such action in turn requires public engagement within and between countries.

4.2 | Civil society engagement

In addition to public and private institutions, civil society often comprises a third dimension of governance. Incorporating the efforts of diverse civil society groups, from sports clubs and churches to social service organizations and protest movements,

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can enhance communities' capacity to prepare for and respond to climate-related extreme events. Increased public engagement depends on people's understanding that climate risks are relevant to their own lives and challenges. How are heat waves and flooding, for example, connected to poor health and social isolation? Building community adaptive capacity requires efforts at multiple scales.

The array of civil society institutions and initiatives involved in building adaptive capacity include climate action social movements, such as the People's Climate March; faith-based organizations, such as ActionAid, Islamic Aid, and Interfaith Power and Light; national and international networks, such as Local Governments for Sustainability (formerly International Council for Local Environmental Initiatives, ICLEI); the Climate Action Network; and numerous indigenous groups. The last include the Institute for Tribal Environmental Professionals; the Indigenous Environmental Network; and the Arctic Circumpolar Council, which is composed of representatives from Eskimo Inuit in Canada, Greenland, and Russia.

The work of Local Governments for Sustainability and the Rockefeller Foundation's 100 Resilient Cities provide important examples of shifting governance in addressing vulnerability. Begun as a nonprofit to help cities reduce their CO_2 emissions, Local Governments for Sustainability has expanded into providing technical assistance to cities in developing vulnerability and adaptation plans and influenced a global "Compact of Mayors" to reduce emissions and vulnerability (ICLEI, 2015). The Rockefeller Foundation launched its major 100 Resilient Cities initiative creating a network for sharing knowledge and experience, supporting the hiring of Chief Resiliency Officers in each, and supporting the creation and implementation of resiliency plans (https://www.rockefellerfoundation.org/blog/100-resilient-cities/). The initiative, along with international organizations such as the World Bank that fund urban investments, has had a major influence on how climate vulnerability is conceived and addressed around the world (Chu, Anguelovski, & Carmin, 2016). While modes of public engagement and inclusion differed markedly, depending upon local histories and contexts, one study concluded that "broadly inclusive planning processes that involve a wide variety of actors and institutions can contribute to higher procedural justice and equitable outcomes in the near term" (Chu et al., 2016, p. 387).

The Local Governments for Sustainability and the 100 Resilient Cities examples reflect a highly "multiscalar" approach to governing the issue of vulnerability to climate change and resilience (Bulkeley & Betsill, 2005; Shi et al., 2016). States alone are no longer seen as the sole solution to the problem; effective governance to reduce climate change vulnerability now engages a range of actors encompassed by governments, civil society, and the private sector. Important issues for social scientists include: What are the bases of involvement in these groups and organizations? How do such institutions influence the negotiation, legislation, and implementation of adaptation plans at various scales? When does climate emerge as an issue that is taken up by existing social movements, and when does it create new social movements? How does consciousness about climate issues shape agenda setting and coalition formation (Caniglia, Brulle, & Szasz, 2015; McCright & Dunlap, 2015)? Each question raises issues of justice and equity in climate governance, including procedural justice and fair procurement and distribution of adaptation resources (Ciplet, Roberts, & Khan, 2015; Grasso, 2010).

5 | CULTURE

Culture—the shared and patterned meanings held by members of social groups—is vital to understanding climate change vulnerability. The human experience of nature and environmental change is mediated by culture. "Nature is seen by humans through a screen of beliefs, knowledge, and purposes, and it is in terms of their images of nature, rather than of the actual structure of nature, that they act" (Rappaport, 1979, p. 97). This applies with particular force to climate change adaptation and vulnerability, for in adaptation, "the identification of risks, decisions about responses, and means of implementation are all mediated by culture" (Adger, Barnett, Brown, Marshall, & O'Brien, 2013, p. 112).

Yet "cultures" are not distinct entities, like planets or grapefruits. If cultures are systems of meaning, these are fuzzy rather than clearly bounded systems: evolving, transacted, and largely tacit (Winthrop, 2002, p. 163). While cultures only exist in and through social life, cultural systems lack a definitive membership. Individuals participate in multiple cultural frames. Thus, the cultural understandings through which watermen on Chesapeake Bay, for example, whose livelihood depends on crabbing, view the threatened blue crabs both overlap with and diverge from the perspective of marine scientists who study the bay's ecosystem (Paolisso, 2002).

Culture and social organization shape vulnerability to climate change in terms of who and what are exposed and how they are sensitive. When a hurricane hits a poor community in a developing country, for example in Mexico's Yucatan Peninsula, women are three to four times more likely than men to die (Crate & Nuttall, 2009; Watts et al., 2015). This drastically different fatality rate is partly explained by disparities in men's and women's learning and expected behavior. Many women are excluded "from survival skill learning, such as tree climbing and swimming, which help during floods; [and] restrictions on women's movement in times of crisis…[dissuade] women from leaving the home without a male's permission" (Crate & Nuttall, 2009, p. 15; see also Watts et al., 2015).

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A cultural lens also helps clarify adaptive capacity, including the ways in which environmental change is understood and what responses are considered feasible. Social practices such as forging close kin-based or neighborhood networks can increase the capacity to cope with a threat, as network members share access to information, transportation, or other resources.

5.1 | Tangible and intangible factors

Social vulnerabilities to climate change are both tangible and intangible. Consistent with disaster preparedness, assessments of climate change vulnerability tend to focus on the tangible: infrastructure, such as roads and dwellings, and the material bases for survival and health, such as food supply and clean water. But climate change also indirectly disrupts life's intangible aspects, including social systems, cultural knowledge, and the practices of daily life, by modifying the material conditions that support them.

Daily practices are critical to learning and transmitting cultural knowledge (Wagner, 1981). In many societies, hunting, fishing, and gathering not only provide for material needs but also help maintain social groups and networks through acts of exchange. Such subsistence practices likewise preserve critical bodies of knowledge about plants' and animals' characteristics, mythic associations, and spiritual significance; and the attributes of the cultural landscapes where they are found (Winthrop, 2002). These bodies of knowledge are often locally specific. "The most important dimension of local knowledge may not even be specific information per se but particular strategies for learning about the natural world and applying the resulting insights—practices which may themselves differentiate indigenous from scientific knowledge" (Kirsch, 2001, p. 173).

Preserving and transmitting the intangible aspects of social life often depend upon conserving the tangible–including natural, built, and historic environments. The devastating 2011 earthquake and tsunami in the northeast region of Japan prompted renewed interest in the lessons of tsunami memorials or "tsunami stones," markers placed at elevations above the devastating flooding from previous tsunamis. For Itoko Kitahara, a specialist in the history of environmental disasters, "'tsunami stones are warnings across generations, telling descendants to avoid the same suffering of their ancestors'" (quoted in Fackler, 2011; see also Suppasri et al., 2013).

Similarly, historical and archaeological research in Pensacola, Florida helps connect early settlement experiences with hurricanes and other environmental stresses and broader cultural forces of political and military power (Laracuente, 2008, 2010). Taken together, individual monuments and the heritage record of communities demonstrate that vulnerability is not solely a condition of the present, but rather a product of cultural forces acting over time. Understanding the environmental and occupation history of places and landscapes by recovering and investigating the physical evidence of past experiences (sites, curated artifacts, and their contexts) therefore is an important component of reducing vulnerability.

The loss of tangible cultural heritage involves the related loss of cultural and social significance that is often invisible to those calculating climate change impacts (Adger et al., 2009). "Expert-only politics runs the risk of excluding the knowledge of individuals who do not prioritize scientific explanations, who in some cases might also be the most vulnerable" (Rice, Burke, & Heynen, 2015, p. 260). Such undervaluing can be redressed through local engagement. For example, physical and social scientists funded by Louisiana Sea Grant worked with local indigenous communities to develop a coastal resource management plan based on a combination of natural sciences and traditional ecological knowledge, organized through a geographic information system (Bethel et al., 2014). The resulting information—which incorporated local community priorities and values—informs project planning and implementation for coastal restoration. When culture is considered central to reducing vulnerability, efforts are more likely to succeed.

5.2 | Risk and culture

A shifting climate heralds changes to the hazardscapes in which people dwell. Culture shapes which risks people attend to, which risk management strategies they prefer, and why. Similarly, social memory—both a backbone and product of culture—informs how people will think about and address hazards, including new ones born of climate change. Perceptions of risk, based on knowledge and previous experience, and the values attributed to place highlight some of the ways in which culture intersects with the causes of vulnerability and the sources of adaptation and adaptation planning (Adger et al., 2009).

Culture underpins how people perceive risks, make protective decisions, and respond to and recover from threats. Failure to identify risk increases vulnerability: if people do not initially perceive risk from climate impacts, then they will not put measures in place to reduce potential harm or otherwise change their behavior. Risk is the product not only of the likelihood and potential magnitude of loss but also of relationships and interactions between people and nature (Rayner & Cantor, 1987). People tend to perceive risks when their ideal social organization or worldview is threatened (Douglas & Wildavsky, 1982).

Risk is not simply an objective quality out in the physical world; instead, people see nature and its associated risks through their cultural lenses, including their beliefs, knowledge, and needs. Worldviews and risk perceptions influence whether, for example, people evacuate from a hurricane (Morss et al., 2016). Protective actions, adaptation plans, and projects are more

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likely to succeed when they match the risk perceptions of those who will live with them. In California in 2010–2011, the Oakland Climate Action Coalition's work with local coastal communities succeeded because it incorporated community risk perceptions by engaging community stakeholders throughout the 18-month planning process (Garzon et al., 2012). Adaptation options that include "clumsy solutions," in which a diversity of people can see their own cultural worldviews, perceptions of risk, and experiences reflected, may be less politically tidy but more likely to be agreed upon and enforced (Lazrus, 2015, 2016; McNeeley & Lazrus, 2014; Verweij & Thompson, 2006).

Risk denial, political inertia, and social status can constrain individual and collective decision-making, while valuing local social memory and encouraging people to use experiential knowledge tend to increase community action. An example of valuing social memory is the Coweeta Listening Project in southwestern North Carolina, which "seeks to listen to residents of Southern Appalachia, integrate social and ecological science through the coproduction and democratization of knowledge, and build useful and meaningful connections between scientists and the public" (Rice et al., 2015, p. 256). The project recorded personal observations such as recollections that,

> Clothes worn on the first days of school indicate changes in summer and fall weather. The depth at which one buries water pipes, the (in)ability to bury dead bodies, the fate of overwintering insects, and the extent to which snow remains on the ground all indicate the depth of hard frosts. (Rice et al., 2015, p. 257)

which revealed changes in weather across the years and connected them to concrete experiences.

5.3 | Vulnerability and well-being

Tangible and intangible aspects of vulnerability converge in the phenomenon of place. Capitalist economic systems treat land as fungible and alienable, merely a factor of production (Pritchard, Folke, & Gunderson, 2000, p. 38). From this perspective, if climate change results in a loss of access to significant places there will be some action that can make affected populations whole, through relocation or by other means gaining an equivalent level of ecosystem services. But often such losses and displacements cannot be made good: there may be no equivalents to the territory with important mythic associations, the fishery that supported culturally salient livelihoods, or simply the sense of place that provided an emotional and spiritual foundation for multiple generations. For these reasons, cultural heritage is now listed by the United Nations Framework Convention on Climate Change as a component of noneconomic loss and damage (UNFCCC, 2013).

Similarly, studies of food security and health under climate change typically focus on physiology and nutrition, "while other aspects of individual and community health that are met by food and food culture, such as psychological and psychosocial needs, remain understated or absent" (Loring & Gerlach, 2009, p. 471). As store-bought foods replace wild foods in the diets of many Alaska Native communities, for example, an emphasis on nutritional adequacy (while important) risks masking important features of health vulnerability. In rural Alaska, securing, preparing, and sharing wild foods provide a means not only of nutrition but of cultural transmission, celebration, and strengthening social ties (Loring & Gerlach, 2009).

The common element in these examples is a gap, found in many conventional analyses of climate change vulnerability: the failure to assess the effects of environmental and social change against a standard of culturally relevant well-being or flourishing, rather than mere physical survival. The contemporary exploration of this theme draws heavily on Aristotle's account of *eudaimonia*, generally translated as *well-being*. "Aristotle argued that it is the actions, content and processes of an individual's life that matter, rather than transitory and subjective mental states. Accordingly, eudaimonic accounts focus on the activities, abilities, or 'functionings' (rather than goods) that constitute a well-lived life" (Lamb & Steinberger, 2017, p. 3). But we cannot identify "concrete ways of life that would be good, much less best, for every human being" (Perry, 1998, p. 63). The "well-lived life" is in significant measure culturally defined and is likely to find a different realization among Alaska Natives, Chesapeake Bay watermen, and Oakland urbanites. In assessing differential vulnerability to climate change, this is critical and is strongly connected to how people know and understand their environments.

6 | KNOWLEDGE AND INFORMATION

Knowledge and information intersect with vulnerability to climate change in myriad ways, directly and indirectly shaping peoples' adaptive capacity, exposure, and sensitivity. Knowledge and information arise from within situated contexts (Haraway, 1988), and differential "access to knowledge… [shapes] who can benefit from resources" (Ribot & Peluso, 2003, p. 168). However, different types and sources of information and modes of knowledge transmission affect how people understand, perceive, and act on information. Additionally, understanding the sociocultural context in which vulnerability is being addressed is essential for the successful use of social-scientific, local, and/or coproduced knowledge. In addition to processes of governance and culture (reviewed in the previous sections), the ability to mitigate vulnerability is also affected by various aspects

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and types of knowledge, including knowledge transmission, social memory, traditional ecological knowledge, deep time knowledge, and knowledge coproduction.

6.1 | Transmission of environmental knowledge

Information about weather forecasts and climate predictions is communicated, received, and interpreted through multiple channels, including interpersonal communication, television, radio, the Internet, and social media (Morss et al., 2017). People combine information from these multiple sources before they make decisions (Sadri, Ukkusuri, & Gladwin, 2017). Social networks importantly help people access, personalize, and perceive the relevance of information. The phrase "social amplification of risk" describes the fact that people are more likely to attend to a threat about which others in their social network express concern (Kasperson et al., 1988). When Hurricane Sandy approached the U.S. East Coast, people with robust social networks, who tended to have greater access to relevant information and better understanding of the risk, were more likely to evacuate, which limited their exposure to the physical hazards (Lazrus, Wilhelmi, Henderson, Morss, & Dietrich, 2017; Sadri et al., 2017). As social networks bolster adaptive capacities, they help people receive and evaluate information that can enable protective decision-making. Perception of risk within social networks also plays a critical role in vulnerability mitigation, linking information transmission, social context, and the cultural factors that contribute to risk perception.

Perception affects the application of information to mitigate harm and reduce vulnerability, of oneself or others. Scientific information that public and private agencies produce may be disseminated broadly to the public or directed to specific users; one instance of the latter is the release of climate predictions to Colorado city park managers who incorporate them into long-term decisions about optimal flood-control plantings (Lazrus et al., 2017). Whether produced by public or private agencies or by community traditional knowledge holders, weather- and climate-related information is subject to assessment about its *salience*, or relevance to the decision at hand; *credibility*, in terms of believability and accuracy; and *legitimacy*, or production with the decision maker in mind (Cash et al., 2003). The importance of such factors is well illustrated by the case of Cyclone Gorky, which caused 140,000 deaths in Bangladesh in 1991 (Ribot, 2010). While nearly all surviving households had been aware of official cyclone warnings, 78% of them failed to seek shelter before the storm, in large part because false alarms in the previous year made residents distrust the warning (Thomas et al., 2011). Such social memory, however, may also contribute to vulnerability reduction.

6.2 | Social memory

Humans must learn their environments: knowledge of environmental cycles and hazards is not innate (Rockman, 2003). Such knowledge shapes the very concept of "hazard," informs decision-making, and supports the identification of risks. Environmental knowledge does not require first-hand experience but its accumulation and usefulness do depend on effective social transmission (Crumley, 2002). The effective response to the 2004 Asian tsunami on Simeulue Island, Indonesia drew on oral history of a 1907 earthquake and tsunami that killed as much as 70% of the island's population. Because most residents knew this history, in 2004 they headed to higher ground within minutes of the earthquake and so escaped the tsunami (McAdoo, Dengler, Eeri, Prasetya, & Titov, 2006). This case demonstrates how a single event can generate a useful memory that outlasts a single lifetime and can help shape public response to hazards. When local environmental knowledge extends beyond direct, individual experience, communities may draw on this knowledge to identify potential risks and implement innovative local adaptation and mitigation strategies faster and more effectively than if they wait for larger, nonlocal institutions to act (Evans, Milfont, & Lawrence, 2014; McDowell, Ford, & Jones, 2016).

The pace of environmental learning depends on both environmental cycles and a community's capacity for remembering risks and responses. When knowledge transmission is robust, strategies for adapting to environmental change can persist for thousands of years, as shown by practices of foraging societies in the Levant and landscape memories of aboriginal societies in Australia (Nunn & Reid, 2015; Rosen & Rivera-Collazo, 2012). In other cases, economic or political factors may disrupt or override the use of established environmental knowledge. Drought management strategies that arose during the Dust Bowl, for instance, were abandoned after only a few decades. This occurred due to high crop prices and several good weather years leading people to shorten crop rotation cycles and to reduce vegetation planted as wind buffers (Orlove, Roncoli, Kabugo, & Majugu, 2010). Such social memory shapes not only communities' exposure to hazards but also their sensitivity to those exposures and their ability to mitigate vulnerability.

Intracommunity processes of knowledge production and dissemination may privilege certain types of knowledge, such as scientific knowledge, or official discourses may be imposed; both tendencies may reduce or prevent transmission of local, environmentally relevant knowledge (Gilmartin, 1994). Shortening the depth of social memory, perhaps to only a few decades, may reduce the capacity to identify local risks, and thereby increase vulnerability (Bone, Alessa, Altaweel, Kliskey, & Lammers, 2011). In Puerto Rico, local environmental knowledge about hurricanes or tsunamis has traditionally been sustained via oral transmission within families and other networks. However, local knowledge has been eroded by outmigration and the

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failure to record and preserve the older generation's memories (Duany, 2010). Moreover, social memory plays a critical role in shaping local knowledge.

6.3 | Local, indigenous, and traditional ecological knowledge

Local, indigenous, and/or traditional environmental knowledge (TEK) of communities includes information about weather and climate phenomena and their impacts. Collected over generations, and continuously refined through transmission, TEK withstands the test of time. Often very place-specific, it may also connect the natural environment with social and cosmological processes (Anderson, 2014; Basso, 2007; Berkes, 1999). Indigenous communities are often the first and most drastically affected by climate change due to their displacement to marginal environments and their limited political power. Such communities may have systematic environmental knowledge, including knowledge of processes that can enhance their adaptive capacity. Collaborative analysis of combined TEK and mainstream science can yield critical insights into climate change and adaptation (Bennett et al., 2014). Collaborations must be based on relationships of trust; follow cultural, ethical, and legal protocols; and recognize that TEK is embodied in cultural practices and beliefs that are inseparable from deep cultural contexts (Maldonado et al., 2016).

TEK that is based on individual and collective experience, and employs indicators based on direct observation, is an important element of weather and climate forecasting. One such indicator is the parhelia, or sundogs, that are produced by humid air at high altitudes; these are often considered signs that storms will arrive within a day or two. Such knowledge can be incorporated into developing adaptations to ecosystem changes (Berkes, Colding, & Folke, 2000; Naess, 2012). For example, the Navajo Nation's adaptation efforts are hindered by a severe shortage of meteorological data and other scientific observations that could supplement traditional knowledge. To provide additional information and promote adaptive responses that would be consistent with cultural priorities, more than 50 Navajo elders shared their observations about changing environmental conditions (Redsteer et al., 2013). As their observations agreed with point observations, the resulting data helped extend the observational record of changes in water availability, weather, and sand and dust storms (Redsteer, Kelley, Francis, & Block, 2010). In addition to TEK, archeological studies can also provide routes to mitigate vulnerability via accessing deep time knowledge about climate change transitions.

6.4 | Deep time knowledge

The archaeological record provides paleoenvironmental data and evidence of contemporaneous human behavior that can be connected to broader environmental events and trends at multiple temporal scales (Minc & Smith, 1989; Rick, Kirch, Erlandson, & Fitzpatrick, 2013; Schwadron, 2000). That information can be particularly useful for recovering detailed, locally relevant examples of past climate impacts and corresponding human responses. Together with climate scientists, other social scientists, and local communities, archaeologists can generate data and bring together local and traditional knowledge to develop culturally and locally sensitive adaptation or mitigation strategies (d'Alpoim Guedes, Crabtree, Bocinsky, & Kohler, 2016).

Archaeology extends place-based knowledge of adaptation as it recovers memories lost due to colonial rule, forced displacement, and outmigration (Gullapalli, 2008; Nelson et al., 2016). Climate change, however, threatens the archaeological record as environmental change increases erosion rates and intensifies or accelerates the effects of flooding, wildfires, invasive species, and drought (e.g., Marzeion & Levermann, 2014). These stresses add to ongoing pressures from development (Morgan, Rockman, Smith, & Meadow, 2016).

In the Arctic, archaeological sites and sacred places—which serve as reminders of seal-hunting techniques, historical weather patterns, and community and family identity—are sensitive to damage by reductions in sea ice and permafrost. For example, Walakpa, Alaska is a modern hunting location where there are also preserved traces of human use extending back at least 4,000 years (Hollesen et al., 2018). After storms destroyed approximately half the recorded area of the site in 2014, a salvage excavation team collected samples the next year, but additional sections of the site were eroded away shortly after the team's visit (Kintisch, 2016). Many types of cultural heritage (including archaeological sites, historic structures, and cultural landscapes) across multiple ecosystems are now being damaged or destroyed at a greater rate than in the past (Hollesen et al., 2018; Morgan et al., 2016). Beyond archaeology's ability to recover lost knowledge, recent studies in social science have shown how knowledge transmission and buy-in is improved when that knowledge is coproduced.

6.5 | Knowledge coproduction

Knowledge production, with overlapping local and scientific forms (Agrawal, 1995), is an iterative process that engages local stories, narratives, and formal and informal institutions. Creating a productive space through coproduction of knowledge removes barriers to climate change adaptation (Dilling & Lemos, 2011; Engle & Lemos, 2010; Moser & Ekstrom, 2010; Rice et al., 2015). For example, the NOAA-funded, Great Lakes Integrated Sciences + Assessments (GLISA) Center acts as a boundary organization (Guston, 2001) connecting science and researchers to end users and policymakers via knowledge networks and boundary chains (Bidwell et al.,

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2013; Lemos, Kirchhoff, & Ramprasad, 2014). Because climate change impacts usually disproportionately affect low-income communities and people of color (Shonkoff, Morello-Frosch, Pastor, & Sadd, 2011), who are underrepresented in climate change-adaptation planning, GLISA implemented the Ready and Resilient project for these communities in Saint Paul, MN, USA (Phadke et al., 2016). The project "aimed to meet [its resilience] goal via two pathways: first, to reinvigorate community networks in the city and second, to eliminate barriers to participation that members of minority and low-income communities face" (Phadke et al., 2016). The project team created chains of boundary organizations that linked GLISA to local social networks via multiple community partner organizations that were working in four Saint Paul neighborhoods (Phadke et al., 2016). This approach facilitated trust and built on existing social networks that included community partners and local residents.

Another example of knowledge coproduction comes from the Quinault Indian Nation village of Taholah, Washington where the Quinault River joins the Pacific Ocean. Because of climate change and its proximity to the Cascadia Subduction Zone, the village is highly vulnerable to tsunamis, storm surge, and riverine flooding (Quinault Indian Nation, 2017a). In planning for climate change, village leaders drew on not only climate change projections provided by the State of Washington (2012) but also a variety of other information sources, including community perspectives, before proposing to relocate to a higher location inland (Environmental Protection Agency, n.d.). "Village-wide meetings were convened, along with completion of door-to-door and online surveys, to gain an understanding of conditions, community aspirations, and perceptions of risk" (U.S. Global Change Research Program, n.d.). The results are captured in the Relocation Master Plan (Quinault Indian Nation, 2017b). While uncertainty over future climate change may constrain government action, this example shows that climate change predictions are only one of several sources of knowledge that guide adaptation measures.

7 | CONCLUSION

Populations are not uniformly vulnerable to climate change. The reasons for vulnerability are largely social and economic, not merely a matter of different exposure to climate-related and environmental hazards. We have identified several factors responsible for differences in local-scale vulnerability to climate change and suggested a number of actions to reduce it. Access to resources is one critical factor that shapes communities' ability to plan for and respond to the impacts of climate change. Addressing unequal access to resources involves a twofold challenge: it requires both action on a community or project basis, and larger-scale structural change to reduce poverty and political marginalization. Climate change presents both acute and chronic challenges for effective governance. The successful examples of environmental governance discussed here demonstrate the benefits of partnerships among governments, social movements, and organizations. Cultural systems shape how people understand environmental change, while at a local or regional scale culture and history may constrain the feasible responses to climate change threats. Valid and timely information about weather and climate are necessary but not sufficient to promote effective action at a community scale. Putting into practice an iterative process in which researchers and community residents jointly shape the availability, dissemination, and use of knowledge increases the likelihood that the information will meaningfully contribute to adaptive responses to climate change.

Stemming from this review, we identify three promising areas of research on differential vulnerability: mobility, uncertainty, and incremental change. Conventional analyses of the spatial extent of vulnerability are usually based on residence and ignore *short-term mobility* among different populations. Further research is needed about daily activity spaces as they affect health and exposure to environmental toxins, food accessibility, and the capacity for short- and long-distance travel. Regarding *uncertainty*, climate change predictions are only one of several sources of knowledge guiding adaptation. Despite uncertainty over climate change predictions, which may constrain governmental action, effective adaptation planning is nonetheless feasible. Additional research on the most effective frameworks for fostering effective adaptation decisions, that are interpretable by different populations, in the face of uncertainty will benefit planning. Finally, with respect to *incremental change*, climate change presents both acute and chronic challenges for adaptation and requires responses to both pulse events, such as Typhoon Haiyan, and press events, such as sea-level rise. While the threat of pulse events can prompt governments to reallocate resources from routine activities to vulnerability reduction, gradual environmental change, though equally serious, less often provokes a significant response. Identifying strategies that can promote more effective engagement around the press aspects of climate change offers an important topic for interdisciplinary work.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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