

## RESEARCH

# Thermally resilient communities: creating a socio-technical collaborative response to extreme temperatures

Zoé Hamstead<sup>1</sup>, Paul Coseo<sup>2</sup>, Saud AlKhaled<sup>3</sup>, Emmanuel Frimpong Boamah<sup>4</sup>, David M. Hondula<sup>5</sup>, Ariane Middel<sup>6</sup> and Nicholas Rajkovich<sup>7</sup>

**Abstract**

Extreme temperatures claim more lives than any other weather-related event, posing escalating socio-technical and governance challenges that few urban communities have addressed in a systematic, coordinated and comprehensive way. Scholars have only recently begun to investigate the granular scales at which distributions of thermal risk are produced, people's individual subjective thermal experiences and environmental justice dimensions of the hazard. Advances in research pave the way for concomitant improvements in management and policies, but bridges are needed to connect the thermal vulnerability knowledge base with place-based protective practices that are climatically, politically and culturally appropriate. The research presented in this paper uses actor–network theory (ANT) to describe the planning phase framework of a socio-technical collaborative for managing thermal extremes. The Thermally Resilient Communities Collaborative (TRCC) is a framework for planning and test-bed design phases of a thermal management system. Drawing lessons from two case studies, the framework examines how socio-cognitive spaces for collaboration change with technical and policy disruptions, and provides a way to design experiments that test how technical and governance interventions can enable collective action around urban thermal management.

**Practice relevance**

Thermal extremes claim more lives than all other weather events and pose an escalating socio-technical challenge. Often the problem is exacerbated by lack of clarity about organizational responsibilities and coordination between local governmental departments or agencies. The TRCC framework can be used to understand current practices, identify data gaps and create opportunities to engage in cross-sectoral management. This approach engages actors in identifying built environments and societal practices that create hazardous indoor and outdoor thermal conditions, develops effective ways to convey microclimate information and peoples' subjective thermal experiences to responders and prevention planners, and elevates experiences of marginalized communities. The TRCC describes how governance networks are harnessed to solve collective action problems by integrating new data, technology, and governance capacities. Two case studies indicate how this process was used to create capacities to protect vulnerable people from the impacts of extreme temperatures in two US cities: Tempe, Arizona, and Buffalo, New York.

**Keywords:** cities; climate justice; cold vulnerability; collaborative governance; equity; hazard planning; heat vulnerability; public health; resilience; thermal conditions

<sup>1</sup> Department of Urban and Regional Planning, University at Buffalo, The State University of New York Buffalo, NY, US. ORCID: 0000-0003-4104-2373

<sup>2</sup> The Design School, Arizona State University, Tempe, AZ, US. ORCID: 0000-0002-0661-8309

<sup>3</sup> College of Architecture, Kuwait University, Adailiya, KW. ORCID: 0000-0002-8103-2842

<sup>4</sup> Department of Urban and Regional Planning, Community for Global Health Equity, University at Buffalo, The State University of New York at Buffalo, Buffalo, NY, US. ORCID: 0000-0002-6608-9170

<sup>5</sup> School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ, US. ORCID: 0000-0003-2465-2671

<sup>6</sup> School of Arts, Media and Engineering, School of Computing, Informatics, and Decision Systems Engineering, Arizona State University, Tempe, AZ, US. ORCID: 0000-0002-1565-095X

<sup>7</sup> Department of Architecture, University at Buffalo, The State University of New York Buffalo, New York, US. ORCID: 0000-0003-3592-728X

Corresponding author: Zoé Hamstead ([zoehamst@buffalo.edu](mailto:zoehamst@buffalo.edu))

## 1. Background

Thermal extremes pose an escalating socio-technical and governance challenge in cities across the globe. In the United States, prolonged periods of heat and cold claim more lives than all other weather-related events (Berko *et al.* 2014) and have significant impacts on urban ecosystems and infrastructure. Approximately 30% of the world's population is exposed to deadly heat and humidity for at least 20 days per year, and that percentage is expected to increase to 48–74% by 2100, depending on what emissions scenario occurs (Mora *et al.* 2017). Although heat and cold have long been considered environmental hazards, it is only in recent decades that scholars have begun to focus more closely on the spatial scales at which distributions of thermal risk are produced, the subjectivity of people's experiences with thermal (dis)comfort, and the multiple dimensions of vulnerability that relate to human physiology, the built environment, and social inequity. These scholarly advancements offer a knowledge base for more effectively reaching communities that are most at risk of temperature-related illness and death. However, bridges are needed to connect thermal vulnerability science and people's experiences with action in a way that integrates multiple dimensions of vulnerability. An overview of thermal vulnerability scholarship is first presented. Based on this, it is proposed that actor–network theory (ANT) can inform the design of the social–material processes underlying thermal management and other socio-technical systems.

### 1.1 Thermal vulnerability

Extreme cold and heat events can directly cause illness and injury, exacerbate existing health conditions or comorbidities, and lead to premature deaths. In the United States, studies consistently find that historically disenfranchised populations tend to be at greater risk of injury or death during heat events (Gronlund *et al.* 2015; Harlan *et al.* 2013; Hattis, Ogneva-Himmelberger, & Ratick 2012; Hondula *et al.* 2015b; Madrigano *et al.* 2015). Spatial variation in microclimates could account for part of this disproportionate vulnerability (Smargiassi *et al.* 2009; Voelkel & Shandas 2017), as can uneven access to resources and other social determinants of health.

As researchers' and practitioners' understandings of the mechanisms and inequities through which people experience heat-related risks is improving—and global and urban warming trends are increasing the frequency, intensity, duration, and adverse health risks of heat waves (Gasparrini *et al.* 2015; Hondula *et al.* 2015a)—governmental agencies have developed planning and emergency preparedness strategies to mitigate the impacts of heat-related risks (Larsen 2015; Stone 2012). At the same time, extreme cold is a persistent challenge that produces mortality rates greater than or equal to extreme heat (Berko *et al.* 2014), although it has received notably less attention in recent academic literature. Unlike other environmental hazards such as earthquakes and flooding which have obvious physical boundaries, thermal conditions are largely invisible atmospheric phenomena that leave little overtly observable physical damage and are less confined. Thermal conditions can also vary significantly at human-relevant scales. As regional, synoptic-scale air masses interact with local-scale urban built form, different microclimates are produced, and that microclimate variability impacts people's experiences with both extreme cold and heat. For example, dense urban forms and trees increase daytime thermal comfort at human-relevant scales through shading in summer (Middel *et al.* 2016, 2019; Middel and Chhetri 2014). Since the number of meteorological observing sites is limited, intra-urban variability of thermal conditions cannot be fully resolved. Thus, microclimates that place people at a disproportionate health risk may go undetected. Furthermore, outdoor conditions (especially when measured at only one or few locations) are not reflective of the conditions experienced by most residents as they go about their lives, which often involve a considerable portion of time spent indoors (Klepeis *et al.* 2001; Kuras *et al.* 2017). Observational studies of indoor (Quinn, Kinney, & Shaman 2017; Tsoulou *et al.* 2020) and individually experienced temperatures (*e.g.* Bernhard *et al.* 2015; Milà *et al.* 2020) indicate that the conditions experienced by residents can significantly diverge from those measured at outdoor, fixed-point weather stations.

While all hazards interact with human processes, such as policies that determine how and where we build (Coseo & Larsen 2014; Hamstead *et al.* 2016), evidence suggests that the risks posed by thermal extremes must be understood using approaches that recognize the unique difficulty of collective action. Given that thermal exposures and sensitivities are produced by broader systems of political economy, culture and infrastructure, individual action may be insufficient to reduce vulnerability to thermal extremes. Thermal risks are produced by properties of the hazard itself combined with multiscale (community, household and individual-level) processes that shape neighborhoods' physical and social environments, residents' and communities' access to cooling and other adaptive measures, and public health and well-being. All this suggests that professionals across a wide range of sectors (including housing, energy, design, planning and others in sectors that are not traditionally viewed as having explicit responsibilities in the management of thermal extreme-related hazards) may be crucial collaborators for mitigating thermal exposure. 'System of professions' approaches link professionals (*e.g.* public health officials, building scientists, social workers) to each other via the work they consider their jurisdiction, such as providing cooling and warming centers, increasing the energy efficiency of homes, or providing social services (Rajkovich 2016).

### 1.2 Local thermal governance as an actor network

As in other areas of urban sustainability and governance, lack of multisectoral collaboration can present a barrier to addressing vulnerability to thermal extremes. For instance, people who experience repeated health incidences during heat waves or cold spells may be living in inadequate housing, or might be experiencing thermal exposures during

commutes or in workplace settings. Yet, healthcare, energy and transportation providers are largely uncoordinated in planning for, responding to and evaluating solutions that address thermal resilience and climate action more broadly (Moser & Ekstrom 2010). ANT provides a way to understand how policy actors across social worlds or sectoral domains work together and evolve collaborative networks mediated through nonhuman actants.

ANT provides a conceptual vocabulary to describe how systems *emerge* and are (de)stabilized over time through formation of an *actor-network*, that is, the associations between human (social) and nonhuman (material) elements (Castree 2002; Latour 1987; Müller & Schurr 2016). In the field of science and technology studies, theorists of large technological systems (*e.g.* Coutard 1999; Summerton 1994) have borrowed ANT vocabularies to explain how the governance and technical aspects of a system seamlessly work together. Nonhuman actants—such as scientific knowledge, technologies, and policy-political processes—interact with human actants (Pineda 2010). The challenge for designers or innovators (*e.g.* scientists, planners, architects, and policymakers) is to be attentive to and offer a conceptually informed description of how large technological systems are designed via connections across social-material actants. Without addressing this challenge, designers are often limited in their ability to account for why systems fail when actants' interactions shift. For example, certain human actants (*e.g.* transportation managers) within a city's thermal management system may decide (not) to use or interact with nonhuman actants (*e.g.* thermal sensors installed at bus stops).

In dealing with this challenge, and specific to this paper, ANT provides two conceptual vocabularies to help unpack the socio-material associations involved in the design of urban thermal management systems. The case studies and conceptual framework, introduced below, illustrate how municipal agencies and researchers developing thermal management systems in Tempe, Arizona, and Buffalo, New York, are deploying ANT-informed design processes. First, ANT suggests that systems have 'arenas of development' (Jørgensen & Sørensen 2002: 198) or socio-cognitive spaces composed of actors, knowledge, vision, identity, power and spatial relations which work together and are (re) configured to solve socio-technical problems such as how to make cities thermally comfortable and resilient (see also Pineda 2010).

Second, in developing a system, actants within these arenas of development engage in a process of 'in-scription.' Borrowed from the field of semiotics to explain how people make and communicate meaning, inscription describes how systems are developed through 'scripts' written by designers to specify the technical, ethical, affective, legal, economic, political and cultural aspects (Akrich 1992: 208). For instance, the design of a thermal management system for a city will involve designing scripts in the form of technical specification of thermal sensors, procedures in collecting, analysing, and using data from the sensors, interpretation of public health data, spatial vulnerability assessments, and policy instruments that indicate how thermal managers, citizens, and others actors can interact with information generated by technology or other forms of data collection. This in-scription process reveals the actor-network or socio-material associations translated through human and nonhuman actants in the design of an urban thermal management system.

When designers are attentive to the in-scription process, they can 'de-scribe' a system by isolating and analysing its *scripts*. This process of 'de-description' in the planning of a system provides ANT-informed designers with concrete analytical tools, for at least two purposes. First, de-description allows designers to identify how scripts conform to or conflict with one another. For instance, technical specification of the system may clash with or conform to the legal and cultural values of particular actants (*e.g.* end users, planners, and policymakers). Second, where adaptation is needed, de-description allows designers to engage in radical innovations by building the capacities and competencies for writing new scripts, especially in cases where there is stagnation or *reverse salient* in the system (Hughes 1993, 1998).

While studies have employed ANT to explain the emergence of urban transportation, economic, cultural, and other types of systems (Hommels 2010; Tironi 2010, 2012; Zaloom 2010), there is limited application of ANT to climate governance, and a review of the literature revealed no instances of its application to thermal management of which the authors are aware. The few studies that have used ANT to understand climate governance have explored city-level carbon reduction policy (Rutland & Aylett 2008), low carbon commercial development (Rydin 2013), and global-scale carbon markets and trans-urban sustainability networks (Blok 2010, 2011). These studies examine and ascribe agency to nonhuman entities (*e.g.* hydropower) and materials (*e.g.* policy documents) that mediate relationships between actants (Dwiartama & Rosin 2014). Dwiartama & Rosin (2014) argue that ANT is compatible with social-ecological systems in the sense that both fields ascribe agency to nonhuman actors as they interact with human actors to influence the evolution of social-ecological (–technological) systems. Studies have also examined black and 'gray' boxes—such as energy and climate science models—that not only create commensurate meanings across different social worlds but also generate ambiguity and uncertainty that makes climate science contestable (Blok 2010; Rydin 2013). Actions around climate governance happen because actants with various goals share common interests that are aligned via climate change. For instance, Blok (2011) argues that carbon policy such as global carbon offset markets align the concerns of policymakers, economic interests and environmental nongovernmental organizations (NGOs). Similarly, policy actants in fields of energy, land use, environmental planning, health, emergency management, and transportation may all have similarly aligned concerns for people's well-being during adverse thermal conditions, and that technology, data, and capacity-building can act as mediators in their collaborations toward more effective thermal management.

This paper describes a framework used to implement in-scription processes in the planning phase of a thermal management system. During this planning phase, exploratory data collection and analyses revealed how visions for protecting people against thermal extremes create commensurate meanings across management sectors. These visions—along with frameworks for technological and governance capacity interventions—form a basis for the scripts of a test-bed thermal management system in which questions about how socio-cognitive spaces for collaboration change as a result of technological and capacity-building interventions which disrupt these spaces.

The authors draw upon ANT to propose a Thermally-Resilient Communities Collaborative (TRCC) framework for environmental management and to test hypotheses about the governance of socio-technical systems (**Figure 1**). Apart from some emergency responders and health providers, many managers in local governments and service providers do not conceptualize protecting people against impacts of thermal extremes as part of their professional role (Guyer *et al.* 2019; Mees, Driessen, & Runhaar 2015). In addition, thermal information is a new type of environmental data for many professions and generally not available at a scale that enables effective management. Thermal threats have emerged as a 21st-century climate governance challenge (Berko *et al.* 2014; Gronlund *et al.* 2014; Jenerette *et al.* 2016). These threats require a greater understanding of how technology and data influence policy learning, behavior, capacity, and collaborative networks among a constellation of actors within governance systems.

The TRCC approach posits that technology and microclimate data are required to provide objective 'eyes' in which to 'see,' and build capacities for using these observations to create convergent climate action across governance sectors. It is suggested that the linkage of community actors with streams of microclimate data (at appropriate scales and in usable formats) can advance climate governance and thermal equity practices, if coupled with policy development capacities aligned with social justice values. TRCC is a lens for integrative climate action planning and management that links many governance sectors across multiple jurisdictional scales. It engages practice and research around the question: How do socio-cognitive spaces for collaboration change with technical and policy disruptions?

## 2. Methods and data

Through a planning phase inscription process, the researchers and practitioners co-developed a framework for managing thermal extremes (**Figure 2**). This process involved policy document review, pre-interviews, and forum engagement. These three data-collection and analysis processes were used (1) to understand the state of thermal management in Tempe and Buffalo; (2) to produce a TRCC vision aligned across local government sectors; and (3) to use the vision to articulate technological and capacity-building scripts, which could serve as the backbone for designing a thermal management testbed. Here, the case selection and forum processes are described. The TRCC vision is then presented to develop and test questions about thermal governance. The methodology described in this paper relies on language, practices, and policies captured through verbal discourse and generative engagement processes.

Managers from Tempe and Buffalo partnered with local universities to co-develop a research/action agenda for thermally resilient communities. The team used engagement techniques to co-design a linked research/action approach that integrates data collection, analysis, and action on social and technological dimensions of urban infrastructure to build capacity for management of thermal extremes. Applying ANT to the implementation of this approach provides ways (1) to test hypotheses about how interactions happen across socio-technical systems; and (2) to develop effective socio-technical systems by articulating ways in which nonhuman actants facilitate collaborations between human actants, and how new scripts written in arenas of development conflict with or conform to existing scripts.

### 2.1 Case study selection

Buffalo and Tempe are ideal paired case studies for exploring the range of thermal extremes. One is traditionally associated with cold and the other with heat. Both grapple with how to build adaptive capacity for resilience to thermal extremes. Buffalo sits on the eastern edge of Lake Erie, surrounded by farmland and forests. Tempe sits toward the northern end of the Sonoran Desert, amidst the dramatic cactus-dotted basin and range region. It takes Buffalo about three months to receive the same amount of rainfall that Tempe does in an entire year. Buffalo's July daily average high temperature is similar to Tempe's March or November (NOAA 2019a, 2019b). In both cities, average temperatures are rising because of regional urbanization and global-scale greenhouse gas emissions. While the length and severity of the summer seasons are markedly different between Tempe and Buffalo, both cities face concerns about rising temperatures in the hottest months and an expanding season in which dangerous heat may occur.

The two cities also represent contrasting storylines of urban growth and decline over the last century. The City of Buffalo experienced a post-industrial population shrinkage from 580,100 (1950) to 256,304 (2018) people, while Tempe grew from 7684 (1950) to 192,364 (2018) (USCB 2019). While most of Tempe's housing was built after 1970, most of Buffalo's was built before 1940 and is now in need of energy-efficiency upgrades. Buffalo is experiencing an artistic and architectural resurgence along with new industry development in medicine and renewable energy, but it continues to lose population gradually. In Tempe, rapid growth fueled by expansion in the education, finance, and technology sectors brings pressures for urban development and consequent impacts on the local environment. These contrasting bioclimatic, economic, and infrastructure contexts span a broad spectrum of urban experiences in the United States and provide opportunities for rich comparisons to inform thermal management. Despite their geographic and historical differences, the cities share a common experience in that successful management of thermal extremes is, and will increasingly be, necessary to protect public health, quality of life, and economic growth.

## 2.2 Thermal management forums

To inscribe convergent research/action visions that integrate technology for thermal management across local government sectors, two-day forums (arenas of development) were convened in Tempe and Buffalo. These forums brought together key agency managers with academic partners for two days of meetings, workshops, and public presentations with a dedicated participatory workshop that included a broader audience of agency managers. Both events were designed (1) to identify connectivity and knowledge gaps across multiple management sectors; and (2) to develop visions for 'smart and connected management' of thermal extremes. The Smart approaches to thermal extremes would necessarily embed pragmatic technical systems into city interventions to inform policies and practices. Ultimately, values and priorities (*e.g.* increased walkability) drive those interventions, which are then informed by data to design policy and determine the efficacy of outcomes. 'Connected' approaches leverage a system of professions network (Rajkovich 2016) within cities and across regions, for learning exchange and socialized dissemination of findings. The forum model was intended to coordinate broad discussions using a peer city approach, which crosses scales of management, sectors, and jurisdictions to create a shared vision of the TRCC.

To prepare for the forums in Tempe and Buffalo, the authors first conducted a review of policy documents from each region (at city, county, and regional scales) over the last decade. Pre-meetings and forum design sessions with managers who would facilitate the engagements. The policy document review enabled informed conversations about the state of thermal management, and the forum agendas were structured through co-designed sessions. The authors deployed a priority mapping framework (**Table 1**) in pre-meetings with senior management. These pre-meeting listening sessions were intended to ensure that each department's priorities and values were represented and integrated into the forums' content:

- to make the sessions relevant and meaningful to cross sector participants;
- to enable discussions of synergistic approaches; and
- to identify pathways to address key gaps in policy and practice.

To build relationships of trust and begin to identify convergent narratives that could be built upon during the forums, the priority mapping questions were asked of department heads, city staff, and decision-makers in advance of the forum. For all three processes, inductive thematic coding (of policy documents or interview and forum notes) was used to identify existing data, strategies and collaborations that facilitate thermal extremes management, data and collaboration gaps, as well as visions for more effective management.

The forum model was first tested in Tempe with a participatory two-hour Extreme Heat Workshop where City staff, researchers, and other stakeholders engaged in conversations about thermal management. In Tempe, participants at the workshop were divided into working groups organized around: buildings; sites; public landscapes; emergency management; transportation and mobility policies and programs; and equity. Equity working group members floated between tables to ensure that equity issues were discussed in relation to each topic. The working groups discussed challenges with policies/programs, including code elements, budgets, and other practices or programs that prepare Tempe for extreme heat. During the workshop, city staff, researchers, and other experts discussed existing ways Tempe prepares for and responds to extreme heat and what weather data city staff use to inform decisions. Cross-departmental conversations enabled staff to identify successes and challenges related to the City's management of extreme heat and opportunities for improvement.

In Buffalo, the forum was organized around a morning 'Connected' World Café session and an afternoon Smart session. The authors adapted this approach to test how practitioners could work together across sectors and to gradually

**Table 1:** Questions posed for thermal extremes priority mapping.

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*Existing priorities and strategies*

What are your priorities for coping with extreme temperatures?

What are the adverse effects of temperature in your department?

What are the strategies you use to address heat/cold and any adverse effects of the strategies?

*Data streams*

What are your priorities for data around extreme temperatures?

What existing data do you use and why?

What new data are needed and how should data be used?

What data would make your job easier?

*Policy conflicts*

What do you prioritize when it comes to resolving conflict between departments?

As you see it, what are the key conflicts between policies or practices?

What are the synergies between policies or practices?

*Vision*

What do you think should be prioritized in order to address extreme temperatures more holistically?

What are other examples of visionary ideas in your opinion?

If you could change one policy or practice, what would that be?

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**Table 2:** Questions posed for World Café activities.

Round 1	Round 2
<p><b>Importance of the problem</b></p> <p>What is important to you and your agency about managing extreme cold/heat?            How does your organization address vulnerability to heat and cold?            What assumptions do we need to test or challenge in trying to address this problem?</p> <p><b>Naming what we don't know</b></p> <p>What is missing from our understanding of extreme cold/heat?            What are we not seeing?            Where do we need more clarity?            Who is missing from this conversation and how might that person see the problem differently?            What information would be useful for improving programs to address thermal vulnerability?</p> <p><b>Creating a vision</b></p> <p>How can academia and local government support each other in taking the next steps?            What is the unique contribution that each makes?            What would it take to better prepare for extreme cold/heat? How can technology support this?</p>	<p>In what way is the problem of heat and cold vulnerability important to the [health/energy/transportation/environmental] sector?            What is the unique contribution that the [health/energy/transportation/environmental] sector makes to managing heat and cold vulnerability?</p> <p>In what ways could your organization support [health/energy/transportation/environmental] organizations in protecting people against heat and cold (and <i>vice versa</i>)?            What is the unique contribution that the [health/energy/transportation/environmental] sector makes to managing heat and cold vulnerability?</p> <p>What could it take to work together?            What information could researchers provide to facilitate collaboration? How can technology support collaboration?            How can we support each other in taking the next steps?</p>

build toward specific visions for cross-sectoral collaboration. The World Café format is a creative process for sharing experiences, planning, and solving problems. During this activity, managers from multiple sectors of county and city government, nonprofit staff, and researchers worked together to describe the nature of the problems that heat and cold pose to communities and generate ideas for addressing those problems collaboratively. In the two-round World Café activity, participants generated collective knowledge about:

- problems that heat and cold pose to communities;
- information gaps that inhibit efforts to address the problem; and
- visions for collaborative action.

During the first round, participants engaged in discussions at sector-specific tables, depending on the sector with which they most closely affiliate: energy; environment; health and emergency services; and transportation. Facilitators from city or county government guided the discussion by posing three sets of questions. The first set was designed to focus collective attention around the problem; the second set helped participants dig deeper and name what is not known about the problem; and the third set focused on generating visions for collaborative approaches to managing thermal extremes (Table 2). During the second round, participants moved to a new table of their choosing, and the facilitators summarized the previous conversation before posing a set of questions that built on their previous conversation and encouraged visions for collaboration across sectors.

During the afternoon of the forum, participants engaged in Smart session discussions of data needs, and how data could be used in research and programs. The Smart session was divided into four groups, including: mapping data; communications data; budget and finance data; and utility data, and participants floated between the tables. During this session, participants discussed gaps in data content, as well as platforms that would enable data access, transfer, and compatibility.

The analysis focused on understanding the thermal management scripts that (1) are contained in policy documents, (2) were communicated through priority mapping, and (3) emerged from the forums, or co-designed arenas of development. Both *a priori* and *a posteriori* thematic coding were used to identify these scripts. *A priori* codes related to primary and secondary data sources on which management relies, sectors of management and collaborative strategies, and types of infrastructure (*e.g.* buildings, transportation) that are managed.

### 3. Findings

#### 3.1. Policy document review and priority mapping

Scripts that emerged from the policy document review and priority mapping analyses involved issues centered around: (1) shifts in the framing of thermal extreme impacts from personal responsibility to public quality of life and collective action; (2) building collaborative practices to bridge gaps in thermal management; and (3)

developing granular data to understand distributions of thermal risks. The policy document review revealed that both cities have engaged in the development of policy and guidance documents for thermal extremes. Between 2005 and 2018, Tempe developed at least nine and Buffalo developed at least 11 city, county, or regional-scale policy documents that address thermal extremes as a health hazard and convey management strategies. Both cities have long addressed heat (Tempe) and cold (Buffalo) as a hazard through policy, programs, and action. Yet, contemporary policy discourse may likely be transitioning from individual responsibility to public obligation, or collective action-based frameworks. Historically, thermal extremes were primarily seen through a frame of personal risk, with little to no public obligation or system of insurance to manage risk. That frame may still likely inform early policy to address thermal extremes. However, in both case studies, policymakers are beginning to craft documents that frame the impacts of thermal extremes in a way that is intimately connected to local government's public obligations to constituents.

The review of city and county policy documents in the region revealed that Tempe documents such as the Urban Open Space Plan (Project for Public Spaces 2007) frame thermal concerns around public safety, comfort, and public infrastructure. The City of Tempe General Plan 2040 describes sustainable design practices as a public benefit, which leads to '[o]verall environmental improvement, resulting from reductions in pollution and the urban heat island' effect' (City of Tempe, Community Development Department 2013: 20). However, at the county level, this shift has not yet occurred. The Maricopa County Multi-Jurisdictional Hazard Mitigation Plan (Fuller 2009: 401) indicates that Tempe's heat mitigation activities are:

[to p]articipate with outside agencies to distribute bottled water and provide education about hazards associated with extreme heat.

These actions place more responsibility on individuals rather than public agencies to be accountable for the health, welfare, and safety of residents related to heat.

In Buffalo, as in Tempe, a shift can be observed toward public responsibility to address thermal extremes. Buffalo's Green Code (City of Buffalo 2016: 42) aims to shift land use policies:

[to r]estore the citywide tree canopy and promote high-reflectance and pervious pavement systems to reduce heat islands and minimize effects on microclimates and human and wildlife habitats.

In much the same way as contemporary land use policy was developed in the 1960s and 1970s to address other collective hazards such as clean water and air (Rome 2001), Buffalo is creating a suite of policies that shifts the burden of health from an individual to collective concern. In Erie County (where Buffalo is situated) language in the County's Multi-Jurisdictional Hazard Mitigation Plan Update (Erie County Emergency Services & URS 2015) emphasizes the individual, rather than the community, minimizing impacts and excluding affordability and economic burdens on households.

Extreme temperatures are likely to result in relatively minor impacts in Erie County, with very few injuries (if any), minor and sporadic property damage, and minimal disruption on quality of life. [...] Common impacts associated with extreme heat in Erie County include: injuries associated with swimming to escape extreme heat, and individuals seeking medical treatment for heat related illness (i.e., for heat stress, exhaustion, heat stroke, etc.), and power outages from an associated strain on electrical networks. (3c-1)

However, the County is transitioning toward a collective view. Erie County's goal to reduce extreme temperatures include (1) outreach tools for property owners and (2) to 'review existing emergency response plans for enhancement opportunities' (6-3) with language around 'social support agencies, homeowners associations and general public' and a focus on the most vulnerable. The second objective is part of a perceptual transition toward a public imperative to protect vulnerable communities. Although progress had been made integrating community-oriented policy on thermal extremes into city and county policy, city and county officials in Tempe and Buffalo conveyed strong interest in advancing their capacity to plan and proactively enhance the effectiveness of their public and community-oriented response to thermal extremes.

### 3.1.1 Collaborative practices and gaps

In Buffalo, managers conveyed that the most important sectors for managing thermal extremes include environmental and land-use planning, health, emergency and social services, energy, and transportation. Staff expressed concern regarding the capacity of some service providers in local government agencies (*e.g.* social and senior services) who have regular contact with people who may be especially vulnerable to thermal health impacts. These service providers are the least connected to other departments and chronically under-resourced. They constitute an important missing link in efforts to undertake holistic thermal management. Missing links also exist in the energy sector. For example, providers of weatherization cannot address other fundamental housing–health issues, such as mold or roof repairs which are required to be remedied before weatherization. Moreover, awareness of weatherization programs is low, and

bureaucratic hurdles likely create an additional burden, as relatively few qualifying households are actually using the State's Weatherization Assistance Program.

Through a process of priority mapping conversations, Tempe managers identified important sectors for managing thermal extremes as sustainability, community development, transportation planning, parks, strategic management and diversity, and public works. As a rapidly growing city, the windows of opportunities for thermal management in Tempe involve: (1) public investment decision-making for city-owned buildings, rights-of-way improvements, and infrastructure; (2) private community development; and (3) hazard planning and emergency response. To advance their climate action planning process—of which heat resilience is a primary focus—the managers conveyed a need to address heat-related inequities of health, affordability, and transportation impacts.

### 3.1.2 Data use and data gaps

In Buffalo, the Department of Emergency Medical Services (EMS) routinely uses meteorological data as part of its normal operating procedures. Beyond temperature and humidity data, wind chill is also used to define thresholds for emergency warnings and emergency service deployment during cold winter days. At times, EMS has engaged in preventative initiatives by visiting people at their homes to deliver meals and visually assess wellness. However, coordinating such efforts with social services providers and developing a register of people with prior related medical incidents would make such efforts more effective. All partners conveyed that a lack of granular data to understand distributions of risk inhibits managers' ability to target interventions.

Similarly, in Tempe, emergency responders use common measures of air temperature and National Weather Service guidance on extreme heat days. However, other sectors do not commonly integrate weather data for decision-making in a formal manner. Officials reported that heat vulnerability maps exist, but do not adequately address the temporal (*e.g.* time of day) and contextual (*e.g.* rapid urban development and demographic shifts) issues specific to Tempe. There is a need to address systematically thermal inequities at multiple scales. At the macroscale, the City requires data for larger spatial scale planning to understand spatial inequities and to prioritize interventions. At the microscale, more detailed and experiential data are needed for targeted human-scale design projects. Staff reported that, despite a rich history of partnering with universities to study heat exposure, the format of data is not easy to use, and they lack 'desktop' ready informatic tools to integrate thermal data better into decisions.

## 3.2. Thermal management forums

The vision for thermally resilient communities that emerged from the Tempe and Buffalo forums or arenas of development consists of: (1) indoor and outdoor built environments that produce thermal conditions for residents to flourish; (2) institutions that enable adaptation to fluctuating thermal conditions; and (3) an equitable distribution of people's daily exposures, sensitivities, and capacity to adapt in ways that limit disproportionate injury from thermal-related impacts. A synthesis for both forums is presented below.

### 3.2.1. Importance of the problem

Conversations about the importance of the problem focused on the ways in which vulnerabilities to thermal extremes and thermal inequity are built into urban infrastructure, both indoors and outdoors. In particular, the Buildings group in Tempe and the Environment and Energy groups in Buffalo focused discussions on vulnerabilities in the housing stock and distribution of green infrastructure. Few residential buildings in Buffalo have central air-conditioning, and in some communities there is little central heating. Moreover, a lack of insulation and other types of weatherization make heating and cooling expensive, especially for low-to-moderate income households. Managers in Tempe pointed out that growing cities can engage in weatherization through new development. Buffalo may need to retrofit, but this is much more expensive and difficult to regulate, especially without the tax base of a growing city such as Tempe.

With respect to the outdoor built environment, participants pointed out that an overreliance on nonprofit or local volunteerism causes inequity. People in wealthy areas have the time and disposable income to invest in programs (*e.g.* volunteer urban forest management), whereas those in poorer areas lack resources for similar management. Programs from other cities (*e.g.* Cleveland, Ohio) provided a best practice model for green infrastructure management. The Cleveland Community Development Corporation represents every neighborhood in the city and plays a role in both traditional development as well as public space, green infrastructure management, and waterfront development.

Transportation managers discussed ways in which heat and cold present barriers to active transportation. Vulnerability to extreme temperatures are not systematically addressed with respect to infrastructure development and maintenance – such as siting and thermal comfort protection (*e.g.* tree shade) – and social vulnerability. Instead, decisions are currently based on ridership, budgetary limitations, and utility conflicts. At a larger scale, suburban sprawl in both cities has resulted in more infrastructure than is possible to maintain properly with existing budgetary and human resources. Capacity disparities exist between municipalities when it comes to maintenance and transportation needs, especially during emergency situations. Moreover, coordination across municipalities and agencies tends to be more reactive than proactive, although some existing partnerships exist. For instance, the Niagara Frontier Transportation Authority (NFTA) in Buffalo works with hospitals to ensure that people can make appointments when regular public transit is not functioning.

### 3.2.2. Naming what we don't know

Discussions about knowledge gaps focused on a lack of granular information about thermal lived experiences and the difficulty of cultural adaptation. Emergency managers were concerned with cultural sensitivities, *e.g.* the timing of Ramadan fasting in relation to heat events. Compounding cultural sensitivities is the challenge of reduced trust in public authority in some communities, which has emerged as a consequence of previous government initiatives. Environmental managers discussed a need for better information about microclimatic thermal variability of both cities, the diversity of day-to-day lived thermal experiences, and where people can be reached. Buffalo has a significant refugee and migrant population, and managers expressed uncertainty about how these populations experience heat and cold, as well as how resettlement agencies and other refugee-oriented service providers may be working with these communities to manage thermal vulnerability. Similarly, in Tempe, many seasonal visitors who travel for relief from colder climates may be ill-adapted to the hot weather. In both cities, residents identify as hardy to temperature extremes as a badge of honor and feel culturally defined by being able to endure cold and hot weather. This cultural pride also constitutes a form of risk attenuation that inhibits people's ability to acknowledge and address associated vulnerabilities of themselves or others.

Energy managers acknowledged that the older building stock in Buffalo presents vulnerabilities. The ability to conduct targeted weatherization or energy-assistance strategies is not possible without a detailed and comprehensive housing and health vulnerability assessment. Transportation managers were unsure of what people experience between their homes and transit stops, and how temperature stressors impact infrastructure materials. In aggregate, the participants expressed a confident understanding of the overall nature of the thermal vulnerability problem, but were less certain about how it is distributed and therefore were also less certain about how to prioritize resources or deliver them to the people, places, and circumstances where they are most needed.

### 3.2.3. Creating a vision

Strategies for thermal management that were co-created by the research–practitioner teams included: (1) a multi-agency sensing network and data repository that would facilitate cross sectoral and multi-city collaboration for targeting at-risk populations; (2) preventative and adaptive planning; and (3) developing cultural adaptations through storytelling. Emergency responders and health providers proposed mapping locations of vulnerable populations and buildings to connect first responders to people before emergencies arise, as well as collaboration with social service providers and others who have direct relationships with vulnerable people. The groups suggested that academic partners can bring capacity to data collection and analysis, and to utility commission policy decisions and the ratemaking processes. Reframing temperature as a potential vulnerability through storytelling may accelerate the cultural adaptation process and provide valuable experiential data to planners. The Environmental group suggested that people may better relate to the vulnerabilities that temperature poses to their pets; for instance, discourse strategies such as evoking imagery of dogs' paws on hot pavement may help concretize the problem for residents through empathy.

## 4. Discussion: socio-technical networks for thermal governance

The case study engagement processes reveal that, to various degrees, climate governance actors make efforts to address impacts of heat and cold via emergency services, building and energy programs, and landscape ordinances. However, these same actors lack tools to coordinate and evaluate solutions systematically, provide a framework for expanding adaptation and mitigation efforts, and foster resilience to growing thermal hazards. Unlike other public health hazards, regulatory structures such as flood control districts or the National Ambient Air Quality Standards are absent for urban thermal conditions. Even in cities where thermal management is taking place, managers may be uncertain about their role in those protective practices. For instance, participants of a 2018 Arizona Extreme Heat Planning Workshop conveyed differing perceptions about how (and by whom) extreme heat should be managed, as well as uncertainty about how heat preparation and response aligned individuals' official professional responsibilities (Guyer *et al.* 2019).

Drawing lessons from the Tempe and Buffalo case studies, the TRCC framework proposed here brings together social and technical networks for thermal governance. The TRCC is a linked research/action model that is both evaluative and hypothesis-driven. The primary question driving the TRCC is: How do socio-cognitive spaces for collaboration change with technical and policy disruptions? Governance networks are socio-cognitive spaces of collaboration consisting of actors, knowledge, visions, identities, power, and spatial relations (Pineda 2010). All these components constitute scripts through which thermal management takes form. The TRCC provides a way to evaluate how network disruptions—including technical and capacity-building interventions—improve thermal management and change socio-cognitive spaces for collaboration through processes of techno-policy inscription.

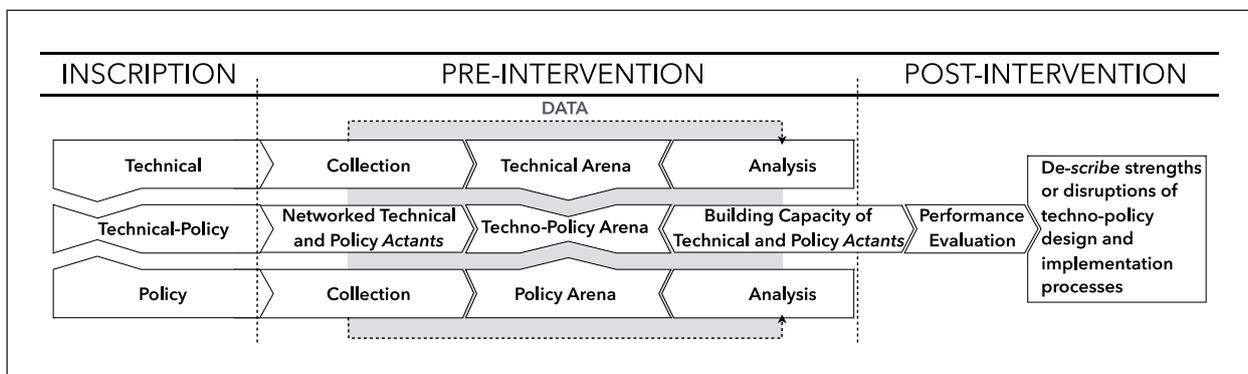
Sub-questions that can be tested in the implementation of a TRCC framework include:

- In what ways do new technology, policy, and techno-policy scripts conform or conflict with existing scripts? How do conflicts get resolved? How do new scripts lead to radical innovations and address reverse salient in the system?
- In arenas of development, what creates commensurate meanings across human actants? What generates ambiguity and uncertainty? Do data analysis scripts take the form of black or 'gray' boxes, and what translative tools do actants use to avoid those problems?

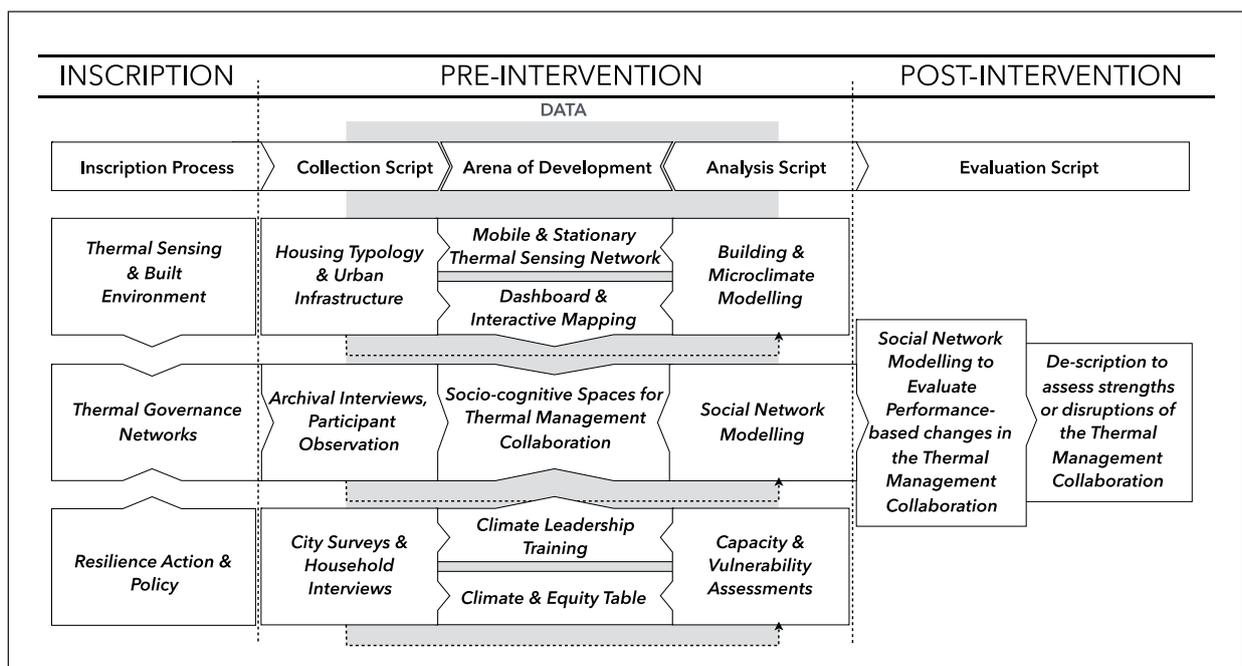
- In arenas of development, are there common interests and alignments across sectors? How do human and nonhuman actants interact in those spaces?

The questions must be asked in a way that is grounded in place; as learned from the case studies, indoor environments may be a primary thermal risk in one community with aging, substandard housing (*e.g.* Buffalo), whereas transportation infrastructure may be more important in another where even short wait times can expose riders to dangerous heat conditions (*e.g.* Tempe). Similarly, policy needs and windows of opportunity depend on many contextual factors, including the depth of existing climate planning and the extent to which vulnerable communities are visible in those existing planning frameworks. A TRCC that introduces new technical and governance capacity for managing thermal extremes can function as a co-produced experiment if pre- and post-intervention data are collected and analysed (**Figure 1**). Since thermal risk is produced by interacting social, ecological, and technical infrastructure, these are the systems from which baseline information must be collected; data collected from one domain alone are likely to be insufficient in fully contextualizing current conditions and understanding the processes contributing microclimate variability as well as systems that help people cope.

Based on the planning inscription processes in the Buffalo and Tempe case studies, participants of the TRCC have co-produced an experimental framework for designing a thermal management test bed that can be replicated across both cities (**Figure 2**). The technical inscription process of this test bed involves collecting thermal data from



**Figure 1:** The Thermally-Resilient Communities Collaborative (TRCC) framework showing the techno-policy inscription process pre- and post-intervention evaluations.



**Figure 2:** Application of the Thermally-Resilient Communities Collaborative (TRCC) framework to design of the Buffalo-Tempe Collaborative. Techno-policy inscription processes include arenas of development along linked thermal sensing, and action and policy themes in which pre- and post-intervention scripts are analysed.

classifiable built environments, modeling microclimates, and producing tools for communicating and visualizing granular data. The policy inscription process involves collecting data on thermal phenomenology—people's experiences with heat, cold, humidity, and wind—which can be characterized using social science methods such as interviews, surveys, focus groups, 'thermal walks,' and ethnographic participant observation methods (Kuras *et al.* 2017; Lau, Shi, & Yan-Yung Ng 2019; Tsoulou *et al.* 2020). In this regard, both the technical and policy inscription processes align with the concept of precision governance, an administrative capacity in which policy decisions are enhanced with information about individual and collective preferences and contexts (Hondula *et al.* 2018). These data can be used to develop capacity and vulnerability assessments, which then inform policy action. The technical and policy arenas of development create new thermal governance networks in which discourses of resilience and thermal management can be observed via policy and action venues, including formalized local government-level task forces, budgetary reviews, or steering committees that support climate action, as well as community organizations that engage in programs related to energy, housing security, and community resilience leadership training.

From an evaluative perspective, the Buffalo–Tempe TRCC identifies the built environments and societal practices that create hazardous indoor and outdoor thermal conditions, and ways in which microclimate information and peoples' subjective thermal experiences can be effectively communicated to responders and prevention planners. More broadly, the test-bed implementation phase of the TRCC addresses the following question and sub-questions:

*How are institutional structures around climate policy and action maintained and disrupted?*

- *Ethics:* Given that granular data—particularly health and place of residence information—raise privacy concerns, do data collection, analysis, and evaluation scripts conflict with existing ethical, legal, cultural, or other scripts? How do such conflicts get resolved?
- *Shared meanings:* In policy venues, do microclimate models, visualizations, and other technical tools create commensurate meanings across sectors such as health, transportation, energy, social services, and others? In what ways do data analytic and visualization scripts create ambiguity for some actants, and what translative tools do actants use to avoid these problems?
- *Aligned goals:* In policy venues, what alignments of values, identity, and vision happen across actants and sectors? In what ways do knowledge, power, and spatial relations play a role in inscribing thermal management?

The introduction of new informational, technological, policy, and governance capacities facilitates experimentation with how changes in these interacting systems structure the incentives, behavior, and capacities of actors within a governance network. Conceptually, (re)structuring actors' incentives, behavior, and capacities can lead to improved policy learning and collaborations among actors to act collectively in managing thermal extremes. Thus, it is suggested that the adoption of the TRCC would: (1) alter governance networks by making atmospheric phenomena and their impacts more visible and translational; and (2) disrupt institutions that maintain *status quo* conditions, enhancing governance capacities which make the experiences of marginalized and vulnerable communities visible (via thermal vulnerability assessments and initiatives such as climate leadership training in historically disenfranchised neighborhoods). Both types of interventions can restructure governance networks that solve collective action problems such as vulnerability to thermal extremes. The TRCC allows for these hypotheses to be tested by incorporating social network analysis and modeling (Robins 2011; Robins & Daraganova 2011; Robins *et al.* 2007) to examine, for instance, how the provision of microclimate information on populations at risk of thermal extremes can engender collective action among stakeholders (*e.g.* the building of new partnerships, the provision of technical and financial support) to address the thermal vulnerabilities of at-risk populations. Deploying TRCC concepts will lay the groundwork for collecting evaluation data on temperature interventions—including those which intervene in technological and governance systems—for which there is currently scant formal evaluation (Boeckmann & Rohn 2014).

One limitation of the TRCC is that it arose from collaboration with practitioners and is thus focused on professionals and managers. However, residents in vulnerable communities are key to managing thermal extremes. According to Kizzy Charles-Guzman, who led the development of New York City's first heat-resilience strategy:

Residents and organizations are usually first on the scene in a disaster, remain long after official services have ended, and often play vital roles in helping those affected to respond and recover. (Hamstead & Coseo 2020: 279)

Further, she argues it is crucial for leaders to support the capacity of community-based organizations, to build relationships with neighbors, and to have neighborhood gathering and resource centers. An expanded view of 'communities of resiliency practice' includes everyone as a first responder and preventative planner. Future iterations of the TRCC should experiment with ways of co-developing the framework in partnership with residents, particularly from historically disenfranchised and at-risk groups.

## 5. Conclusions

Compared with other weather-related hazards, extreme temperatures pose uniquely intractable socio-technical challenges. These events are largely invisible phenomena and existing objective measures of temperature are insufficient to capture people's lived experiences which are crucial predictors of health risk. Moreover, since individual action can be insufficient to reduce exposure, thermal vulnerability is a collective action problem. While cities are attending to thermal challenges, governance models and institutionalization of thermal management are still in their early stages of development. The thermal discourse tends to focus on physical rather than social elements of vulnerability, and that limits the effectiveness for residents' thermal safety, health, welfare, and experience. Within local government, the responsibilities for thermal management are often unclear and fall between different departments and different levels of local government. Coordination of these diverse actors is often missing.

A new practitioner/researcher engagement process was developed that generated visions for thermal management across local government sectors, identified a need to integrate across sectoral, informational and management gaps, and revealed technological and cultural gaps for locating and caring for people who are at risk. The two case studies presented in this paper revealed that (1) vulnerabilities to thermal extremes and thermal inequity are built into urban infrastructure and governance of the built environment; (2) there is a lack of granular information about people's thermal lived experiences; and (3) cities are in need of capacities for collecting and analysing integrative data, and frameworks for using that data to inform preventative planning and cultural adaptation.

The broader research/action framework that arose out of these activities—the Thermally-Resilient Communities Collaborative (TRCC) framework—can be used to hypothesize ways in which (re)structuring actors' incentives, behavior, and capacities can lead to improved policy learning and collaborations to act collectively in managing thermal extremes. In principle, the model can be extended to other challenges (*e.g.* pandemics) in which technology can be used for detection. It is complementary with emerging network science methods and actor–network theory (ANT), which allow for the rigorous testing of how thermally resilient technology and capacity-building interventions can be used to engender collective action among actors.

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The authors have no competing interests to declare.

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