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A System for Resilience Learning: Developing a Community-Driven, Multi-Sector Research Approach for Greater Preparedness and Resilience to Long-Term Climate Stressors and Extreme Events in the Miami Metropolitan Region

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There is a growing need for integrated approaches that align community priorities with strategies that build resilience to climate hazards, societal shocks, and economic crises to ensure more equitable and sustainable outcomes. We anticipate that adaptive management and resilience learning are central elements for these approaches. In this paper, we describe an approach to build and test a *Resilience Learning System* to support research and implementation of a resilience strategy developed for the Greater Miami and the Beaches or the *Resilient305* Strategy. Elements foundational to the design of this integrated research strategy and replicable *Resilience Learning System* are: (1) strong partnerships among community members, government and non-government organization leaders, and researchers from multiple academic institutions; (2) contributions of subject matter expertise and local knowledge to identify information and translational gaps, formulate metrics and evaluate outcomes of *Resilient305* Strategy actions from the community perspective; and (3) a comprehensive understanding of civic engagement activities, technological tools, and resilience-building capacities, including policy and financial innovations, from which to advance socio-technological, smart and connected regional-to-hyperlocal community translation through co-design/co-production. Initial results on co-produced metrics are provided. This work produces a new, replicable framework for resilience research that includes a comprehensive set of metrics, translation to communities through structured dialogues, a collaborative process involving all stakeholders and researchers, and evaluation of resilience actions to inform new investments and improve understanding and effectiveness over time.

Keywords: Resilience; integration; community; climate change; adaptive.

1. Introduction

Resilience is responding to change in ways that sustain both people and their environment, while maintaining the capacity for transformation (Moser *et al.* 2019) within and among interconnections of social, ecological and technological systems. Applied to conservation practice, Berkes and Turner (2006) suggest that how human and natural systems evolve to respond to change is rooted in the integration of learning both following the intervention of a resource crisis and with the elaboration of incremental knowledge by a group over time. The authors argue that adaptive management and resilience thinking (Folke *et al.* 2002), rooted in place-based participatory approaches for integrating within societies and between societies and their environment (Berkes and Folke 1998), are fundamental to advancing socio-ecological system resilience.

While an intentional focus toward advancing approaches for socio-ecological resilience has a strong basis in the literature, few examples of social learning to increase preparedness and build societal resilience to extreme events have been documented beyond the application to conservation practice and traditional ecological knowledge (see Johannessen *et al.* 2019). Slow-moving processes may result in incremental change imperceptible to the casual observer and, without a documented frame of reference, compounded over time as the baseline shifts, obfuscating opportunities for learning. Alternatively, the evolution of societal knowledge can come from rigorous documentation of interventions, experiences and experiments with subsequent change over time and harnessed as feedback learning and transformational change. Thus, a quantitative, integrated approach is needed to understand how diverse community priorities can be better aligned with resilience strategies to build more capacity to overcome climate hazards, support equitable and efficient recovery from societal shocks, embed adaptive management for resilience learning and to enable people and the environment to learn, transform and thrive.

A new framework for a *Resilience Learning System* fills this gap. Supported by comprehensive, multi-sector, data-driven research to quantify co-benefits of resilience investments and elicitation of hyperlocal community priorities, our approach strives to anticipate and overcome barriers, realize new innovations, and sustain civic engagement and participation for adaptive management and learning. Resilience learning outcomes also align with the federal process for disaster recovery (e.g., recovery support functions) to equip communities for greater preparedness and resilience. In this paper, we describe a research strategy to build and test a *Resilience Learning System* through the implementation of and research to support a regional resilience strategy developed for the Greater Miami and the

Beaches (GM&B) also referred to as the *Resilient305* Strategy (https://resilient305.com/).

2. Long-term Stressors and Extreme Events (Shocks) in the Miami Metro Region — The Case for Greater Preparedness and Resilience and Development of the Resilient305 Strategy

Impacts from extreme events including hurricanes, widespread flooding, and heat waves in coastal metropolitan areas illustrate how poorly equipped we are to protect life, livelihoods and well-being from these events that are increasing in both frequency and severity (Hayhoe *et al.* 2018). Since 1980, losses from extreme weather and climate events around the U.S. have exceeded $1 trillion (NOAA 2020). To address these impacts, cities are increasingly investing in climate resilience efforts. While challenges from shocks and stressors bring underlying issues to the surface, there is also the realization that unforeseeable circumstances and their consequences create new and diverse opportunities for innovation that can strengthen communities (Childers *et al.* 2015). The intersection of climate, along with other environmental, social and economic challenges calls for a more comprehensive approach to climate resilience that can increase the return on climate resilience investments in terms of equity, efficiency, and cross-sectoral benefits (Lempert *et al.* 2018). In fact, the Global Commission on Adaptation (2019) estimates that multiple benefits can be achieved from resilience investments, also referred to as triple dividends (Tanner *et al.* 2015), projected to return 4:1 over the next decade if we revolutionize adaptation by acting on the interconnections within and among systems to achieve societal resilience and prosperity. On the flipside of triple dividends are resilience trade-offs which are equally important and possible to anticipate with improved knowledge gained through a comprehensive, holistic approach to resilience (Chelleri *et al.* 2015).

South Florida's GM&B region is one of the places in the U.S. most vulnerable to compounding hazards of both acute shocks (hurricanes, heavy rain, and extreme heat) and chronic stressors (sea-level rise, sunny day flooding, saltwater intrusion, and warming) (Hallegatte *et al.* 2013). Motivated to address these challenges and with support from the Rockefeller Foundation's *100 Resilient Cities* program, civic leaders from across the GM&B region worked together over a 3-year period to create a resilience strategy (*Resilient305* Strategy) to safeguard homes and livelihoods and enable people and the environment to thrive in the face of uncertain climate shocks and stressors (Resilient GM&B 2019). The *Resilient305* Strategy (2019) put forward a plan to foster: (1) **resilient places** to address location-based social, environmental, and technological challenges; (2) **resilient people** to

improve the everyday lives of residents; and (3) **resilient pathways** to enhance collaboration and committed leadership. Following the framework outlined by the *100 Resilient Cities* Rockefeller Foundation program, the *Resilient305* Strategy aimed to address prioritized challenges through intergovernmental and community collaboration, driven by potential multi-sectoral synergistic outcomes (e.g., triple or resilience dividends; Rodin 2014; Tanner *et al.* 2015). The *Resilient305* Strategy identifies 59 actions, many of which are aligned with COVID-19 pandemic recovery and are being planned and implemented in a comprehensive, resilience approach.

With the release of the *Resilient305* Strategy, the GM&B set forth, a holistic plan for innovative science solutions, civic programs and policies, and governance approaches to preparedness and resilience for addressing climate hazards but also infrastructure failures, public health emergencies, crippling traffic, and substantial socio-economic inequities. The plan is closely aligned with Goal 11 of the UN Sustainable Development Goals to "Make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations 2015). In the GM&B region, nearly $1 billion in general obligation bond funding was approved in Fiscal Year 2018–2019 by voters in two (Miami and Miami Beach) of Miami-Dade County's thirty-four municipalities to invest in climate resilience (https://www.miamigov.com/Government/Departments-Organizations/Office-of-Capital-Improvements/Miami-Forever-Bond; https://www.gombinfo.com). In Fiscal Year 2020–2021, Miami-Dade County's operating budget included nearly $705 million in expenditures specifically targeted for resilience efforts and $3.285 billion of the total $3.335 billion in spending on capital projects dedicated to community resiliency in the capital plan. The stage is set for urban transformation toward resilience in the GM&B region (Kabisch 2019).

Despite significant community input in the development of the *Resilient305* Strategy, implementing its initiatives in the GM&B region of nearly 3 million residents representing a diversity of cultures, backgrounds, and socioeconomic strata, requires a robust and intentional approach for prioritizing and evaluating outcomes of actions set forth in the *Resilient305* Strategy. This presents an opportunity for civic organizations and academic institutions to accelerate research and civic engagement that: (1) secures resilient, efficient, and equitable adaptation investments in a hyperlocal context, (2) guides implementation toward transformative growth and prosperity, and (3) enables people to learn, transform and thrive in resilient environments. The ongoing COVID-19 pandemic and economic recession have only elevated the urgency to undertake this work. In this paper, we present a research strategy and system for resilience learning based on implementation and monitoring and understanding of whether and how actions resulting

from resilience investments are meeting their intended resilience outcomes and co-benefits of triple dividends. Rigorous, transparent adaptation science integrated with a co-design/co-production process is key to advancing replicable decision-support for translating the regional-scale resilience strategy to: (1) better meet hyperlocal community priorities, (2) accelerate societal resilience, (3) foster new social, ecological and technological innovations and workforce opportunities, and (4) enhance cross-sectoral benefits to help sustain and learn from resilience-building efforts.

3. A Resilience Learning System

Operationalizing resilience can foster a process for communities to live with uncertainty and harness diverse options and opportunities for evolving knowledge and increasing learning. It should also be flexible and coordinated to respond with new policies and institutions and institutional arrangements that build inertia along resilient pathways (Berkes 2007; IPCC 2014). These principles are central to dynamic adaptive management and decision-making under deep uncertainty (Haasnoot *et al.* 2013; Obeysekera *et al.* 2020). These enable adaptive decision-making by articulating science-informed pathways that help to manage uncertainty in physical, biological, climate, social, and economic systems against a shifting and non-stationary baseline. Importantly, if tolerance for different types and minimum levels of resilient outcomes can be defined, along with their thresholds, unintended negative tipping points and transformations that lead to positive tipping points can also support the basis for decision-making (e.g., Kopp *et al.* 2016; Tabara *et al.* 2018).

Put into local practice, the translation from resilience strategy (e.g., *Resilient305* Strategy) to resilience projects, programs, and policies through implementation and monitoring is the basis for advancing resilience learning. Contextualizing resilience by outcomes and opportunities that community members' value is both a process and an outcome of this translation. Elements foundational to the design of this integrated research strategy and replicable *Resilience Learning System* (Fig. 1) are (1) strong partnerships among community members, government and non-governmental organization (NGO) leaders, and researchers from multiple academic institutions; (2) contributions of subject matter expertise and local knowledge to identify information and translational gaps, formulate metrics and evaluate outcomes of *Resilient305* Strategy actions from the community perspective; and (3) a comprehensive understanding of civic engagement activities, technological tools, and resilience-building capacities, including policy and financial innovations, from which to advance socio-technological, smart and connected regional-to-hyperlocal

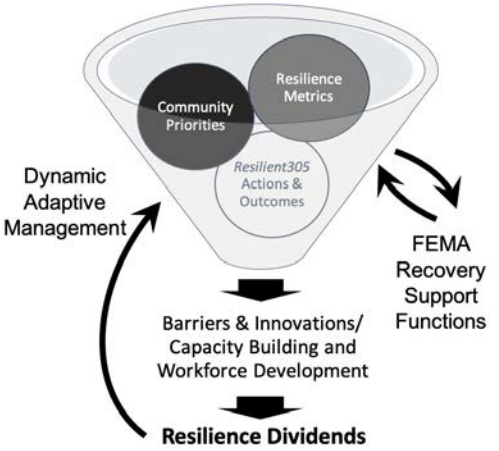


Figure 1. The *Resilience Learning System – the "Funnel" and Integrated Research-to-Action Pillars*. Social, ecological, technological resilience metrics are developed in work across five Core Areas: (1) Economy and Affordability, (2) Environment, (3) Health and Well-Being, (4) Shocks and Stressors, and (5) Technology and Infrastructure. Resilience metrics are refined with elicitation of community priorities at hyperlocal scale and *Resilent305* outcomes monitored and reported as *Resilient305* actions are implemented over time. This process and its outcomes funnel into Integrated Research-to-Action subgroups that operate as pillars for advancing resilience learning: (1) Barriers and Innovations, (2) Capacity Building and Workforce Development, (3) Dynamic Adaptive Pathways, (4) Resilience Dividends and (5) FEMA Recovery Support Functions.

community translation through co-design/co-production. Lessons learned will be leveraged to report on and enhance resilience outcomes and cross-sectoral benefits of *Resilient305* actions, develop new information to improve the translation of the *Resilient305* Strategy to help meet resilience priorities of the community, and replicate the research framework and strategy in other areas.

Our research is structured around four central questions:

(1) What is the local community context for resilience?
(2) What are the social, ecological, and technological metrics that enable baseline assessment, integration of community priorities, and evaluation of outcomes that build community resilience to climate hazards, and address other shocks and stressors important to communities?
(3) What are the cross-sectoral benefits of investments in climate hazard preparedness and resilience, the barriers to overcome, and new innovations that yield quantifiable benefits?
(4) How can this knowledge be integrated to translate regional-scale *Resilient305* Strategy to local-scale community resilience outcomes and sustain engagement for resilience learning?

3.1. *Comprehensive, multi-sector, data-driven metrics to measure, evaluate and track resilience outcomes over time — Basis for a research strategy*

Our research strategy is based on comprehensive, multi-sector, data-driven metrics to measure, evaluate and track resilience outcomes over time and support a replicable, *Resilience Learning System* responsive to changes in a hyperlocal context (e.g., shocks and stressors, community priorities, and social, economic and cultural diversity). The comprehensive, multi-sector approach integrates features of the ARUP and Rockefeller Foundation (2014) and social-ecological-technological systems (SETs) framework (e.g., Markolf *et al.* 2018; Chang *et al.* 2021) with the *Resilient305* Strategy (2019) as its basis. The overarching objectives of the research are to: (1) Identify where we are now (baseline "community state"), how shocks (like the COVID-19 pandemic) affect the social, ecological, and technological systems of our community, and define where we want to be in order to document success against that baseline "community state"; (2) Create a resilience learning tool; (3) Highlight both near-term outputs and short- and long-term successes toward achieving resilience outcomes; and (4) Define, develop, and assess resilient adaptation along social, ecological, and technological pathways, including new approaches for cost–benefit analyses that avoid unintended consequences that may exacerbate social inequities and environmental degradation. To do this, we need information that enables "benchmarking" (Cutter *et al.* 2010) of our baseline "community state" in social, ecological and technological dimensions applying historical information available before the onset of the pandemic, now, and over time. Benchmarking needs to occur at an appropriate temporal frequency and spatial scale in order to assess how interventions through resilience projects, programs, and policies are transforming our community — to be better prepared for the next shocks and better mitigate stressors in order to thrive.

3.2. *Framework and methodology*

3.2.1. Resilient305 Collaborative

The *Resilient305* Collaborative is a joint GM&B academic-government resilience research partnership among Florida International University (FIU), Miami-Dade College (MDC), University of Miami (UM), government entities Miami, Miami Beach, and Miami-Dade County and collaborating non-government organizations (NGO) including our local community foundation (The Miami Foundation), The CLEO (Climate Leadership Engagement Opportunities) Institute, Catalyst Miami, and Miami Waterkeeper (Fig. 2). It began as an outgrowth of a memorandum of understanding (MOU) signed in 2016 to support comprehensive resilience

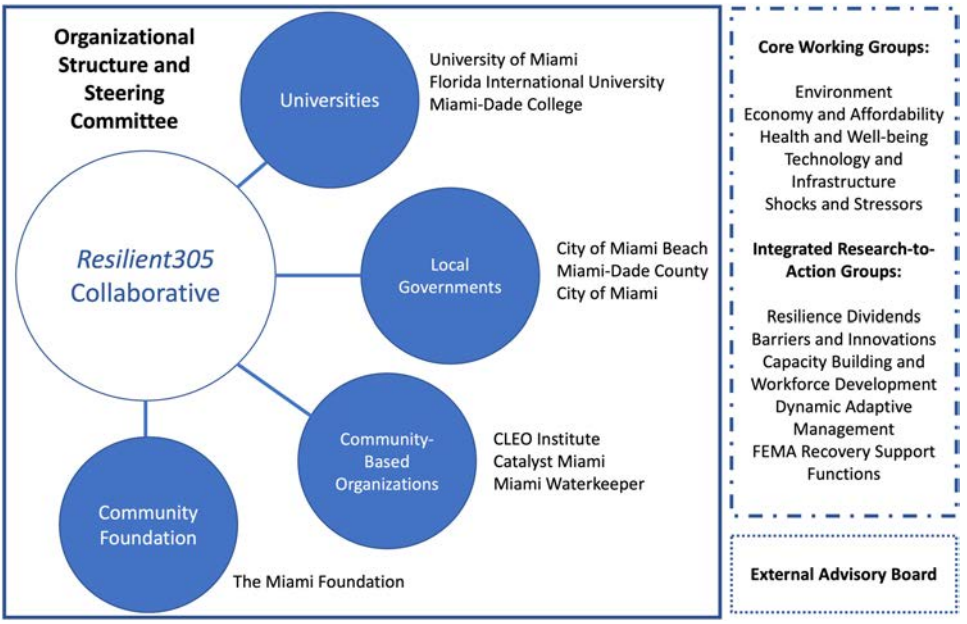


Figure 2. The *Resilient305* Collaborative Organizational Structure

research as part of the MetroLab Network. Our work has evolved from a set of bilateral partnerships to a collaborative, integrated network to support implementation of the *Resilient305* Strategy and evaluate how *Resilient305* actions are contributing to the resilience of our social, environmental, economic, and infrastructure systems. The Miami Foundation is a central partner which facilitates the Progress, Innovation, and Vision for Our Tomorrow (PIVOT) team, the *Resilient305* Strategy implementation team on which the civic leaders of our *Resilient305* Collaborative serve. Within our universities, the *Resilient305* Collaborative includes faculty across disciplines of physical, environmental, health, and social sciences, including public, primary, and mental health, information technology, communications, disaster risk management, adaptation science, engineering, architecture, planning, and community engagement. The *Resilient305* Strategy is the foundation and common platform upon which the *Resilient305* Collaborative operates. The *Resilient305* Strategy provides a guiding framework for communication, cohesiveness and coordination among group members, grounds the work in a collective sense of shared purpose and fosters team collaboration. Leads from each academic institution co-developed the emergent *Resilient305* Collaborative with civic team members, each committed to bringing research and civic engagement activities to decision-makers and the general public. Our *Resilient305* Collaborative structure follows the multi-sector,

interdisciplinary approach established in the *Resilient305* Strategy. Its design enables a replicable *Resilience Learning System* for implementing resilience strategies in other cities within the GM&B region and beyond.

Community partner organizations are critical to this effort. Each brings unique skillsets, programs, and expertise that provide meaningful community engagement, they are trusted among community members and deeply connected within communities across the region. CLEO's mission is centered on climate literacy and advocacy with numerous programs throughout Miami-Dade County. These programs provide transformative learning opportunities for the local student population, comprised of one of the greatest concentrations of Hispanic and Black non-Hispanic students in the country. Catalyst Miami is focused on serving vulnerable populations in the county. Through their Community Leadership on the Environment, Advocacy, and Resilience (CLEAR) program, Catalyst Miami has established strong engagement through networks in vulnerable communities. Miami Waterkeeper is strongly engaged in water quality advocacy, education and community outreach through their numerous programs.

We organized the *Resilient305* Collaborative into workgroups supporting five Core Areas and five Integrated Research-to-Action cross-cutting areas. Each team member supports both types of workgroups. The five Core Area workgroups focus their social, ecological, and technological subject matter expertise on synthesizing data, identifying data needs, and refining metrics to quantify multi-sector outcomes of *Resilient305* Strategy actions. These workgroups are (1) Health and Well-being, (2) Economy and Affordability, (3) Environment, (4) Technology and Infrastructure, and (5) Shocks and Stressors. We formulated these groups based on anticipated data needs supporting resilience metrics. The five Integrated Research-to-Action workgroups were designed to directly support key pillars of the *Resilience Learning System* (Fig. 1): (1) Resilience Dividends, (2) Barriers and Innovations, (3) Capacity Building and Workforce Development, (4) Dynamic Adaptive Management, and (5) FEMA Recovery Support Functions.

3.2.2. Place-based — Little River to North Beach Resilience District

In order to develop our research strategy and create the *Resilience Learning System*, we focused on the GM&B's "Little River to North Beach Resilience District" (LRNB Resilience District; Fig. 3). We selected this project area based on key criteria that included: (1) communities with varying degrees of climate hazards, social and economic conditions, and technological capacities, (2) ongoing projects, programs, and policies supporting *Resilient305* Strategy actions by civic partners and research or other activities by each of our academic partners in the area, (3) delineation as a hydrologic sub-basin in the Biscayne Bay watershed, and

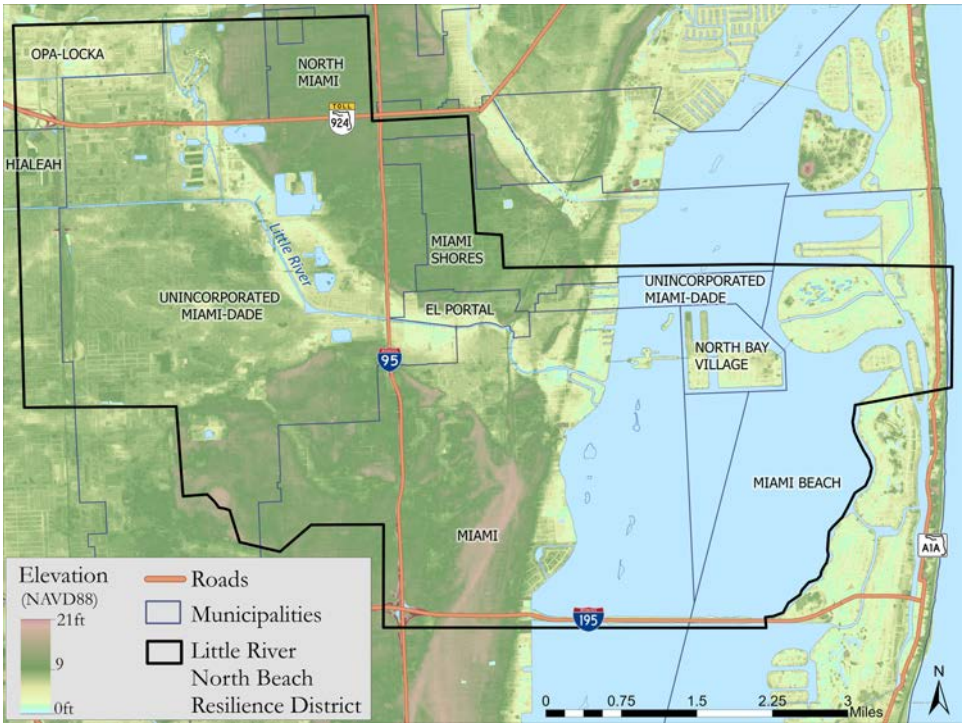


Figure 3. The Little River to North Beach (LRNB) Resilience District

(4) inclusion of multiple jurisdictions in addition to the City of Miami, City of Miami-Beach and Miami-Dade County. The LRNB Resilience District includes portions of eight municipalities as well as areas of unincorporated Miami-Dade County. The boundary follows the hydrologic drainage system of the Little River or "C-7 basin", with an elevation range 0–21 ft. Climate hazards include extreme heat, flooding, storm surge, saltwater intrusion, sea-level rise, and heavy rainfall. The LRNB Resilience District also encompasses an area of northern Biscayne Bay experiencing declining water quality with recent large seagrass die-off (Miami-Dade County 2018a) and unprecedented fish kill. The 2010 population of the LRNB Resilience District was 192,000, with racial composition 52% Black, 36% Hispanic, 9% White and 2% other races (US Census Bureau 2010). There is significant social and economic inequity (median household income range at the census block group level: $10–300 K) within communities across the LRNB Resilience District. Between 2011 and 2015, commercial and residential repetitive losses (paid claims) exceeded $1.5 M (Bouwer *et al.* 2017). Further, the LRNB Resilience District is the site of intensive planning and design efforts to launch significant investments in new resilience projects, programs and policies.

These include preliminary State-led flood protection level of service assessment (Bouwer *et al.* 2017) and transportation projects, State-funded Adaptation Action Area planning by Miami-Dade County, periodic, isolated or course-scale resilience outreach by academic, municipal and NGO partners, and County-led Biscayne Bay recovery efforts and local flood mitigation projects. To initiate the development of our research strategy in the LRNB Resilience District pilot area, we selected seven pilot actions identified in *Resilient305* Strategy because they exemplified the breadth and diversity of the objectives and outcomes of the *Resilient305* Strategy across goal areas of resilient places, people and pathways (Table 1).

3.2.3. The "Funnel"

3.2.3.1. *Social, ecological and technological metrics for resilience outcomes*

Our approach emphasizes research-government-NGO co-design/co-production of social, ecological and technological metrics and knowledge in a first step we refer to as the "Funnel" (see Fig. 1). Faculty were paired with government and NGO partners across the five Core Area groups and tasked with developing social, ecological and technological resilience metrics to evaluate resilience outcomes that relate to their Core Area group's expertise. The basis for these metrics is a crosswalk among *Resilient305* actions, objectives they address and outcomes they are intended to achieve (Table 1).

Working within the five Core Area groups, members were asked three questions: (1) What are the resilience metrics (direct and indirect) that can support establishing a baseline in the LRNB Resilience District in this Core Area? (2) How do the metrics enable evaluation of *Resilient305* outcomes (primary and co-benefit) in social, ecological and technological dimensions? (3) How are these metrics and outcomes responsive to one or more shocks and stressors and types of resilience interventions (e.g., projects, programs and policies)? The approach we employed served to both establish relationships among Core Area group members and to provide meeting time to discuss a broad array of potential metrics and available data within the subject matter expert groups unhindered by the specific outcomes articulated in the *Resilient305* Strategy. The groups were then asked to take a deeper dive to refine the metrics discussed based on how they could be used to evaluate intended (*primary*) outcomes of the seven pilot actions (Table 1) and identify those co-benefit outcomes that could be measured with other metrics identified to be responsive to resilience-building in social, ecological and technological dimensions. In other words, of the forty total resilience outcomes articulated in and intended with the *Resilient305* Strategy, the seven pilot actions of *Resilient305* Strategy addressing the four objectives corresponded with nineteen

Table 1. Set of Initial *Resilient305* Strategy Objectives and Actions Across the Three Goal Areas to Initiate Development of Resilience Metrics used to Monitor *Resilient305* Strategy Outcomes

Goal Area	Objectives	Actions	Primary Outcomes
Places	Enhance Natural Systems	Expand Nature-Based Infrastructure	Reduces sea-level rise and coastal flooding impacts, Restores coastal ecology, Restores natural habitat and Increases understanding of resilience
People	Cultivate Financial Stability	Build an Inclusive Economy	Stimulate economic growth, Creates job opportunities, Provides youth employment, Lifts residents out of poverty, Improves industry/job diversification
		Buy Local	Stimulates economic growth, Creates job opportunities, Improves industry/job diversification
		Expand Youth Career Opportunities	Reduces neighborhood violence, Lifts residents out of poverty, Provides youth employment, Improves youth graduation rates, Improves industry/job diversification
	Strengthen Community Response	Prepare your Property	Reduces sea level rise and coastal flooding impacts, Improves natural disaster preparedness, Protects against storm-related impacts, Improves communication with residents
		Support Resilience Hubs	Improves natural disaster preparedness, Enhances community-based interventions, Improves community cohesion, Improves communication with residents, Expedites disaster recovery
Pathways	Cultivate Resilience Expertise	Resilient 35 in the 305	Reduces sea level rise and coastal flooding impacts, Improves water quality, Improves natural disaster preparedness, Improves community cohesion, Increases understanding of resilience, Streamlines government processes

Note: Information presented here is reproduced from the *Resilient305* Strategy (2019).

outcomes of the *Resilient305* Strategy. Following the mapping of intended outcomes with Core Area metrics, the Core Area groups then reviewed the forty outcomes a second time to map metrics to evaluate potential unintended (*co-benefit*) outcomes of those actions (e.g., to enable comprehensive evaluation of potential value-added triple dividends and unintended consequences that may elicit outcomes in other aspects of social, ecological and technological systems).

Once the initial set of key metrics was identified, groups reviewed available data based on criteria that included the history and continuity of datasets, at what spatial scales and temporal frequency they were available and could be applied, data accessibility and additional effort needed to apply data as the basis of those metrics. The group's approach did not differentiate among direct and indirect metrics which emerged as an important knowledge need and refinement to the approach. Discussions in Core Area groups among the research, government and NGO members revealed a large number of readily available datasets for baseline assessment of community state in the LRNB Resilience District pilot area. Review of available data also revealed gaps in available information that serves as the basis for new, co-produced knowledge. In particular, the process fostered mutual understanding and coordination of priority research topics and projects requiring new investment that support the overarching *Resilient305* Collaborative goal of applied resilience research that creates and sustains learning, innovation, and new education, technological and workforce opportunities.

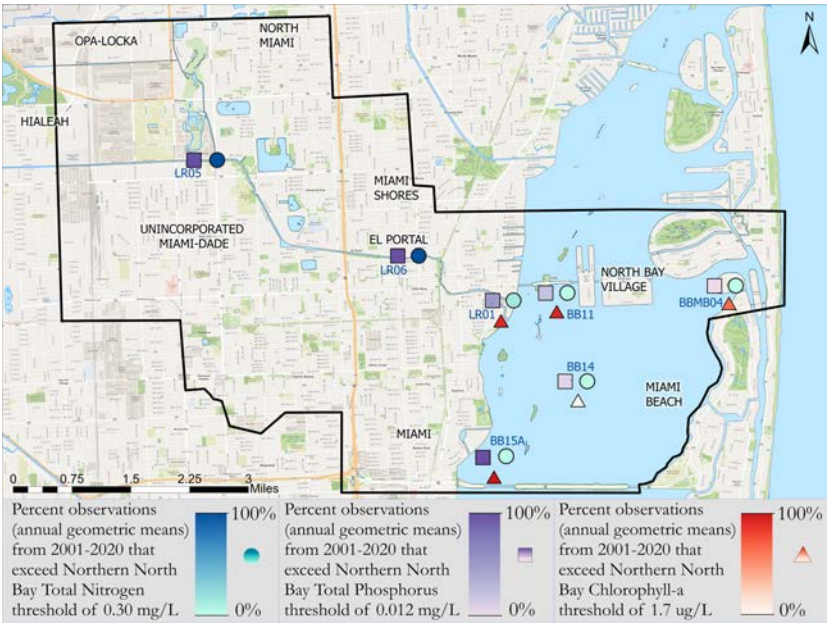
As an example of metrics developed by the Environment Core Area group, the five *Resilient305* Strategy outcomes articulated and intended (primary *Resilient305* Strategy outcomes) by "expanding nature-based infrastructure" were: (1) reduces sea-level rise and coastal flooding impacts, (2) restores coastal ecology, (3) increases understanding of resilience, and (4) restores natural habitat. The group aligned vetted metrics followed by discussion that resulted in a number of additional metrics to assess these outcomes for a total of eleven metrics. The group then reviewed the other metrics that had been identified based on outcomes they thought, based on their subject matter expertise, would be important environment metrics, and aligned those with the remaining outcomes. This process resulted in seven unintended outcomes (co-benefit *Resilient305* outcomes) and 21 additional metrics.

For example, the Environment Core Area group identified a *direct* metric of "depth, length and number of flooding events" to measure the *primary* outcome of "reduces sea-level rise and coastal flooding impacts". City or county flood mitigation projects intended to reduce impacts of flooding would be directly assessed by measuring the change in the "depth, length and number of flooding events" pre-COVID, now, and over time. A gap identified is the limited number of local flood

monitoring stations and the lack of elevation data at appropriate spatial resolution to directly assess this outcome. Furthering this example, one of the *Resilient305 co-benefit* outcomes identified by the Environment group was "improves water quality". A recent Miami-Dade report (2018) and publication by Millette *et al.* (2019) suggested that water quality has been declining in Biscayne Bay, and in particular the North Bay area of the LRNB Resilience District, for at least the last 20 years. A recent, unprecedented fish kill in this area lends support for the hypothesis of Millette *et al.* (2019) that the North Bay has reached a critical tipping point. A number of land-based pollutant sources have been identified that are conveyed by stormwater runoff discharging into canals and into the Bay, direct stormwater runoff discharging into the Bay, and groundwater seepage from the Little River (C-7) Basin. Another recent Miami-Dade report attempted to clarify the potential influence of rising groundwater levels with increasing sea level on the functioning of septic systems (Miami-Dade County 2018b). Data presented in that report suggest that there are approximately 17,000 septic systems in the LRNB Resilience District and that, applying 2020 simulated groundwater levels, the function of 8,000 of those systems is compromised at least part of the year. The Environment group thus identified four metrics to evaluate how a *Resilient305* Strategy action produces the *co-benefit* outcome of "improves water quality": (a) % years total phosphorus (TP), total nitrogen (TN), chlorophyll *a* (Chl), dissolved oxygen (DO), turbidity and fecal indicator bacteria criteria are exceeded (Fig. 4(a), Miami-Dade County Department of Environmental Resource Management, unpublished data); (b) total number and number of compromised septic systems (Fig. 4(b), Miami-Dade County 2018b); (c) funds spent on National Pollution Discharge Elimination System (NPDES)-related activities; and (d) type and frequency of stormwater maintenance.

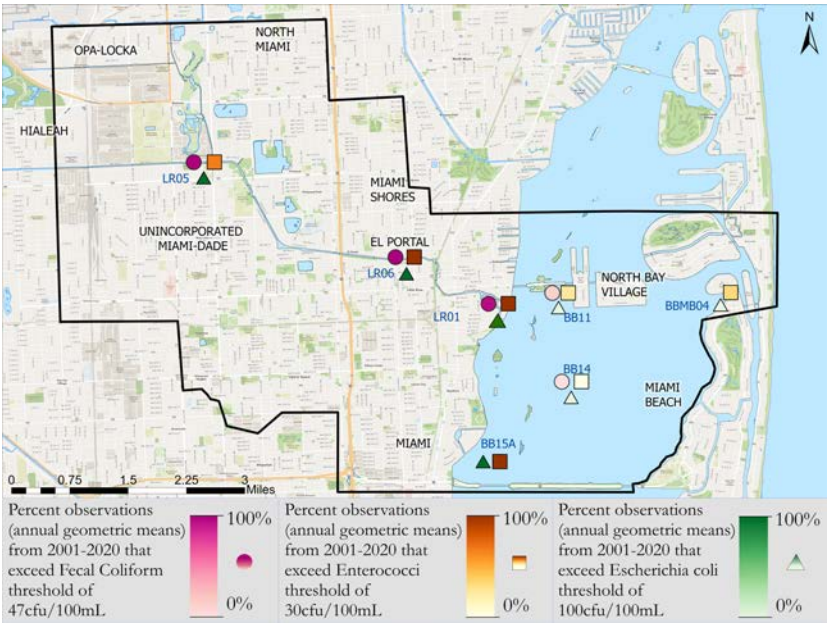
Another example is related to heat, with a focus on metrics that emerged from both the Environment and Health and Well-being groups. One of the primary adaptations to extreme heat, which lasts throughout the summer in South Florida, is air conditioning. Barriers to air conditioning access can include median household income (Fig. 4(c)). Discussions in the core area groups identified a major data gap in that there is no readily available data on who across Miami-Dade County has reliable access to air conditioning. There are a number of ways to monitor this, but additional research is required. Examples of research that could be developed include applying machine learning techniques to big data on energy usage and survey instruments to determine the "energy burden" at the household level. Moving forward, researchers are expanding their partnerships with NGO and government staff to develop ways to deliver these data, an example of an emergent co-designed and co-produced research activity.

Co-developed research-government-NGO metrics were then synthesized and distilled into a common set of metrics for comprehensive assessment of *Resilient305* Strategy outcomes (Table 2). The initial set of metrics were vetted across different sets of subject matter expert groups to broaden perspectives on gaps, seed new ideas and conduct informal peer-review of metrics. Very few resilience outcomes were deemed missing from the *Resilient305* Strategy, however the approach led to a number of gaps in *direct* metrics for both primary and co-benefit outcomes that required further refinement of metrics to differentiate *direct* and *indirect* metrics for the *primary* and *co-benefit* outcomes identified.

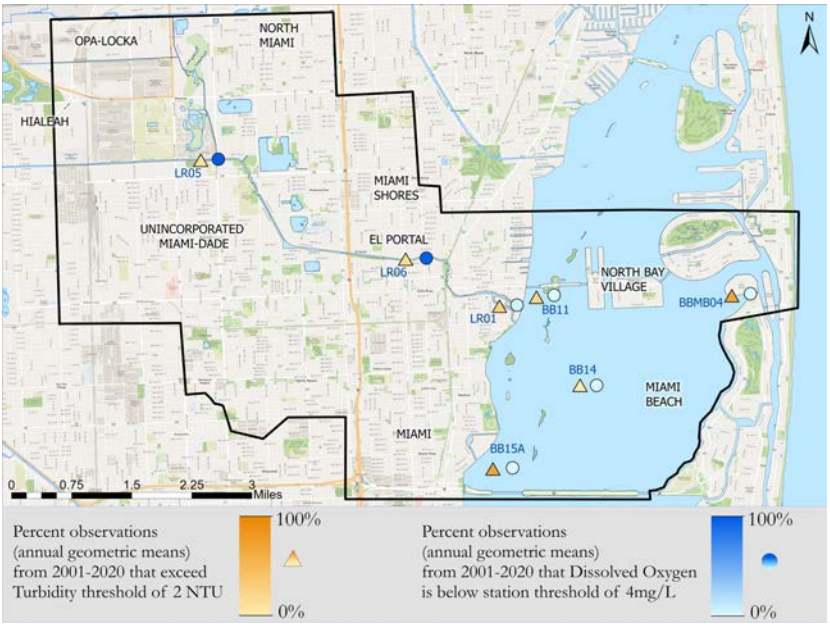


(a1)

Figure 4. The Little River to North Beach Resilience District with Preliminary Example Metrics and Resilience Outcomes for Baseline Assessment: a) Environment Metrics [e.g., % Years TP, TN, Chl (1), Fecal Indicator Bacteria (2), and Turbidity and DO (3) Criteria are Exceeded; Data Source: Miami-Dade County Department of Environmental Management] to Assess Change in Water Quality; (b) Infrastructure/ Technology Metrics [e.g., Number of Septic Systems (1) and Number of Compromised Septic Systems using 2020 Projected Groundwater Levels with Sea Level Rise (2) by CBG; Miami-Dade County 2019] to Assess Change in Aging Infrastructure; (c) Economy and Affordability Metrics (e.g. Median Annual Household Income; American Community Survey data) to Assess Change in Residents in Poverty and Community Wealth.

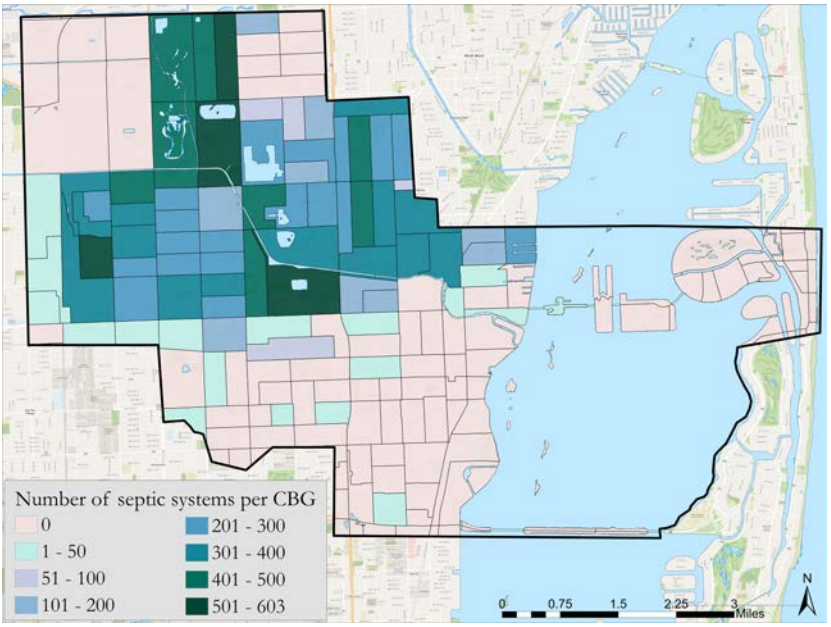


(a2)

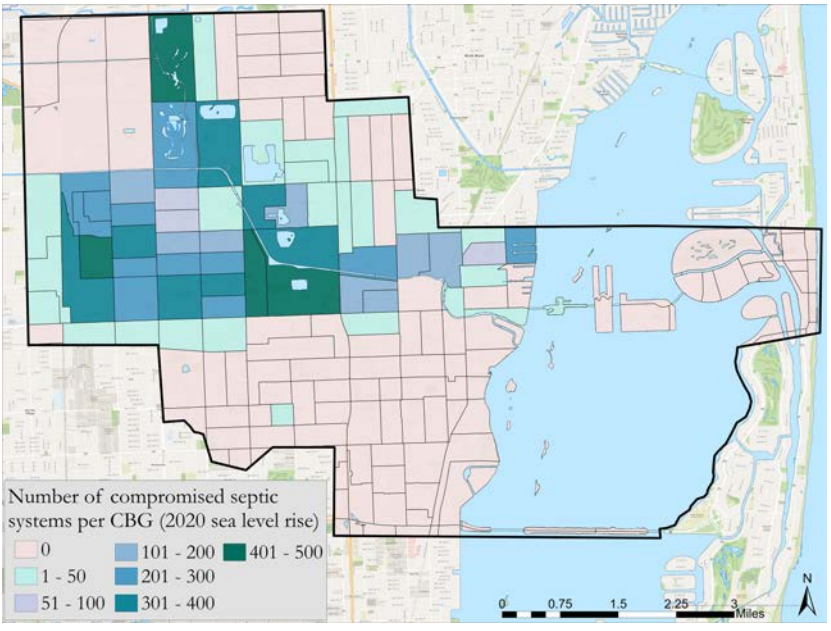


(a3)

Figure 4. (*Continued***)**

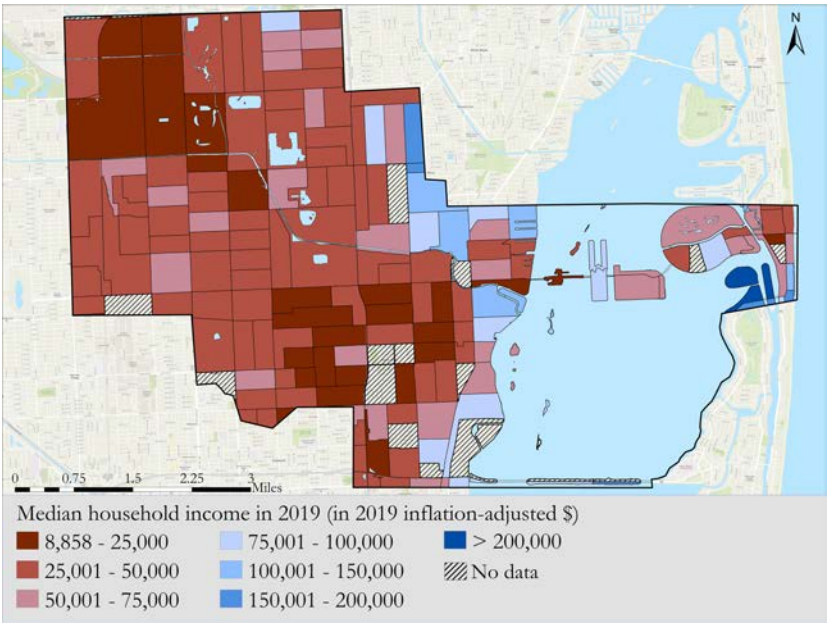


(b1)



(b2)

Figure 4. (*Continued*)



(c)

Figure 4. (*Continued*)

3.2.3.2. *Community priorities*

Critical to our approach is to bring the priorities of communities (the general public) forward to foster diverse, just and inclusive participation, and thus their collective stakes, to align the resilience outcomes that local communities value with research supporting their evaluation. Populations most vulnerable to the impacts of climate change, including low-income, communities of color, the disabled, persons with persistent mental illness, the homeless, undocumented residents, and the elderly, may also be underrepresented in climate adaptation and mitigation efforts (Walsh-Russo 2016; Schlosberg and Collins 2014; Bullard 2008; Ikeme 2003). By bringing communities' priorities forward, we seek to better understand how to enhance the legitimacy and efficiency of resilience actions (Ban *et al.* 2013), diversify decision-making power and increase buy-in to sustain participation in the resilience-building process (Biedenweg *et al.* 2017). Thus, the second ingredient in the "Funnel" is community priorities that will be used to vet research-government-NGO co-designed/co-produced metrics. To accomplish this, we are developing a series of regular, iterative community dialogues supported by our civic partners. The structure of these dialogues is based on alignment across a

Table 2. Types of Local Resilience Interventions, Intended Outcomes and Examples of Metrics Differentiated by Core Area Groups Economy and Affordability (E&A), Environment (ENV), Health and Well-Being (H&WB), Shocks and Stressors (S&S), Technology and Infrastructure (T&I)

Types of Resilience Interventions Underway in LRNB Resilience District	Example Resilient305 Strategy "Intended" Outcomes	Example Metrics Proposed*
• King tide Action plan (City of Miami) • Flood alert system (City of Miami) • Little River Adaptation Action Area Planning (MD County) • Heat and flood citizen science (all) • CLEO's Empowering Resilient Women Program (NGO) • CLEO's Climate Resilient Schools (NGO) • Catalyst CLEAR program (NGO) • Climate Ready Strategy Outreach (City of Miami)	• Reduces impacts of sea-level rise and coastal flooding	*E&A*: NA *ENV*: (1) Flood frequency and extent — depth, duration, and number of flooding events at individual properties; (2) Depth, duration, and number of flooding events in "natural" areas; (3) Cover, type and quality of coastal/bay ecosystems; (4) Stormwater maintenance/cleaning frequency. *H&WB*: NA *S&S*: (1) Disaster/relief metrics — flood extent (City of Miami Comprehensive Stormwater Master Plan, updated FEMA flood maps, Office of Emergency Management); (2) Home resilience (is the home equipped to withstand shock); (3) Disaster relief: Small Business Association (SBA), FEMA National Flood Insurance Program (NFIP) disaster loans/payments/grants. *T&I*: (1) Flooding assessment — lowest habitable finished floor elevation; (2) Living shoreline versus seawall; (3) Water supply (possibility of saltwater intrusion; number of contaminated wells; number of water shortage declarations; age of pipes).
	• Improves natural disaster preparedness	*E&A*: (1) Percentage of cost-burdened households (owner/renter occupied). *ENV*: (1) Elevation of buildings; (2) Cover, type and quality of coastal/bay ecosystems. *H&WB*: (1) Community resources — mutual aid groups; (2) Utility/energy burden — weatherization program access and participation; (3) Heat — hospitalizations and ER use.

Table 2. (*Continued*)

Types of Resilience Interventions Underway in LRNB Resilience District	Example Resilient305 Strategy "Intended" Outcomes	Example Metrics Proposed*
		S&S: (1) Emergency evacuation centers; (2) Vulnerable groups registry: number of registrants in the Emergency and Evacuation Assistance Program (EEAP); (3) Response capacity — Certified emergency response teams (CERT crews/ volunteers; (4) Home resilience (is home equipped to withstand a shock). *T&I*: (1) Flooding assessment — lowest habitable finished floor elevation; (2) Flooding and hurricane impact assessment (losses), distance to water body.
	• Improves communication with residents	*E&A*: (1) Ethnic/racial distribution, diversity, and entropy. *ENV*: (1) Green space access — distance to neighborhood/transit hub/work; (2) Collaboration (e.g., Memorandums of understanding (MOU) between organizations, community-based organizations (CBO) collaboration, network mapping); (3) Green space access and park use — new green spaces/parks. *H&WB*: (1) Community resources — number of social associations/organizations per 10,000 population; (2) Survey — social capital measures; (3) Community resources — mutual aid groups. *S&S*: (1) Vulnerable groups registry: Number of registrants in the Emergency and Evacuation Assistance Program (EEAP). *T&I*: (1) Broadband adoption rate; (2) Broadband availability.
	• Improves water quality	*E&A*: NA *ENV*: (1) Stormwater maintenance/cleaning frequency; (2) Water quality (total phosphorus, total nitrogen, chlorophyll a, dissolved oxygen, turbidity, fecal indicator bacteria), Groundwater quality. (3) Access to clean drinking water (quality of water coming out of the tap including perfluoroalkyl and polyfluoroalkyl substances (PFAS)). *H&WB*: NA *S&S*: NA *T&I*: (1) Water supply (possibility of saltwater intrusion; number of contaminated wells; number of water shortage declarations; age of pipes).

Table 2. (*Continued*)

Types of Resilience Interventions Underway in LRNB Resilience District	Example Resilient305 Strategy "Intended" Outcomes	Example Metrics Proposed*
	• Enhances financial stability	*E&A*: (1) Poverty rate; (2) Employment rates; (3) Labor force participation rate; (4) Percentage of employees making less than $15/h; (5) Percentage of people with a bachelor's degree or higher. *ENV*: (1) Affordability of water; (2) Access to clean drinking water. *H&WB*: (1) Urban agroecology — proximity to community gardens; (2) Social capital measures; (3) Utility/energy burden — weatherization program access and participation. *S&S*: (1) Transportation access/availability; (2) Utilities assistance (cost burden, utilities debt, water/sewer data county wide) such as water bill assistance. *T&I*: (1) Water usage per capita; (2) Estimate risk of infrastructure failure.

Note: *Examples of metrics co-developed by partners of *Resilient305* Collaborative.

matrix of four features: (1) identified census block groups that show low overall resilience across the three Goal Areas applying initial metrics assembled into a baseline assessment, (2) conducted in locales where municipal staff or other *Resilient305* Collaborative partners have already launched initial community engagement activities to build awareness of the *Resilient305* Strategy, (3) leverages ecogeographic variation that describes different typologies supporting the basis for implementation of *Resilient305* actions (e.g., inland, coastal, barrier island typologies) and (4) ensures representation of disadvantaged and under-represented the groups at census block group scale). In these dialogues, we will elicit specific priorities in communities (neighborhood to census block group scale) of jurisdictions overseen by the three CROs on our team serving City of Miami, City of Miami Beach and Miami-Dade County, while simultaneously working to deepen partnerships with civic leaders across the nine jurisdictions of the LRNB Resilience District to prepare for replicating our *Resilient305* Collaborative process in other localities.

Our approach is to integrate hyperlocal context, specific priorities, and existing information on civic engagement activities, technological tools, and resilience-building capacities in community dialogues to feed work across our academic and civic leader team members (Core Area and Integrated Research-to-Action workgroup) and to support design of the *Resilience Learning System* (Fig. 1). A key to the success of our research approach is aligning low-barrier/high-benefit opportunities with communities' priorities supporting *Resilient305* Strategy actions. We intend to address this using a simplified, science-based, community-driven Multi-Criteria Assessment (MCA). The MCA is an evaluation that integrates qualitative and quantitative data and has been applied to address a wide range of sustainability challenges (Ness *et al.* 2007; McPhearson *et al.* 2016), including ecosystem-based approaches (e.g., green infrastructure; Meerow and Newell 2017; Alves *et al.* 2018; Heckert and Rosan 2018). Based on the *Resilient305* Strategy objectives (Table 1), resilience outcomes will first be weighted and scored to identify community priorities. Second, metrics used to track each of those prioritized resilience outcomes, and initially qualitative targets, will be weighted and scored. Third, an elicitation exercise to identify other priority metrics for each prioritized resilience outcome and for other potential resilience outcomes will be conducted. This information will be assembled by the *Resilient305* Collaborative team to crosswalk *Resilient305* actions with metrics and *Resilient305* outcomes identified with the MCA (Department for Communities and Local Government 2009). The outputs from these three iterative steps of the MCA and crosswalk with *Resilient305* actions will be presented back to communities for refinement. Next steps will include development of automated curation with a publicly accessible visualization

interface queryable by and tailored to the census block group level to display progress against targets for each prioritized resilience outcome.

Our initial planning with NGO partners for these dialogues has revealed two key factors for consideration. First is the perception that there is very little community awareness of local efforts to advance resilience, and even less awareness of the *Resilient305* Strategy. This is coupled with another factor that our partners called "survey fatigue". There is a perception that community members have been asked on numerous occasions (as part of local planning efforts) what they would like to see done to improve resilience (green infrastructure is often at the top), but there is rarely any follow up to demonstrate how community priorities are advanced. This clearly demonstrates the need to (1) capitalize on the survey data that already exists, (2) engage community members meaningfully throughout the process and (3) produce an accessible, intuitive, and non-intrusive means by which community members can evaluate progress against prioritized resilience outcomes using metrics and communication tools that are valuable to them. These exemplify just some of the barriers and innovations that we intend to address in the Integrated Research-to-Action phase of the *Resilience Learning System*. The formation of the *Resilient305* Collaborative was a significant first step in addressing these needs. We anticipate that sustained engagement with greater access and transparency linking resilience actions to progress in a more accessible and localized format will be another major step forward.

3.2.4. Integrated Research-to-Action pillars

Increasing regional adaptive capacity to sustain function of social-ecological systems, defined here as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, take advantage of opportunities, or to respond to the consequences" (IPCC 2014), can be a daunting effort as knowledge gaps, social barriers, under-representation, and limited resources often hamper the effectiveness of community resilience efforts (Whitney *et al.* 2017). The *Resilience Learning System* addresses these potential pitfalls in resilience-building through integration of lessons learned through five **Integrated Research-to-Action pillars**. These pillars are informed by work to apply co-design/co-production (e.g., Childers *et al.* 2015), baseline community assessment and resilience metrics (e.g., Cutter *et al.* 2010), urban ecosystem services (e.g., Childers *et al.* 2019), design experiments (e.g., Felson and Pickett 2005), adaptive management (e.g., Melis *et al.* 2015), and positive developmental outcomes (e.g., Ungar 2011) among features of resilience learning. As resilience programs, policies and projects are implemented, what is learned through monitoring of prioritized community outcomes and co-benefits across social, ecological and technological dimensions and

emerge as critical gaps in knowledge, will inform new understandings that are integrated among each pillar to improve resilience outcomes. Integrated Research-to-Action workgroups are designed to directly support these key pillars of the *Resilience Learning System* (Fig. 1): (1) Resilience Dividends, (2) Barriers and Innovations, (3) Capacity Building and Workforce Development, (4) Dynamic Adaptive Management, and (5) FEMA Recovery Support Functions.

3.2.4.1. *Barriers and innovations*

Eliminating barriers and realizing innovations are hallmarks of resilience learning (Rosenzweig and Solecki 2018). This basis for knowledge is delivered through the "funnel" by way of discovery of the gaps between research and knowledge, regional resilience strategy and local community context, researcher-government-NGO metrics and local community priorities. Even when there is clear evidence of the benefits of resilience actions, there are often social or technical barriers to implementation (Childers *et al.* 2014; TetraTech 2014; Kabisch *et al.* 2016; Wamsler *et al.* 2016). Such barriers include: (1) economic: existing livelihoods, economic structures, and economic mobility; (2) social/cultural: social norms, identity, place attachment, beliefs, worldviews, values, awareness, education, social justice, and social support; (3) human capacity: individual, organizational, and societal capabilities to set and achieve adaptation objectives over time including training, education, and skill development; (4) governance, institutions, and policy: existing laws, regulations, procedural requirements, governance scope, effectiveness, institutional arrangements, adaptive capacity, and absorption capacity; (5) financial: lack of financial resources; (6) information, awareness, technology: lack of awareness or access to information or technology and (7) physical and infrastructure (IPCC 2012). Specifically, we have found that communities had weak engagement with these resilience activities — they were either unaware of these activities, or tired of being asked about problems ("survey fatigue") without seeing results. Interestingly, our initial findings point to a number of persistent barriers operating at once. With our approach to resilience learning, we intend to close the gap between community needs and decision-maker interests.

Innovations can be achieved by nurturing and maintaining the relational and network aspects of interdisciplinary research collaboration, through momentum built by evidence of progress within the community, by an improved understanding of community and other resources, and through acknowledgment and support for resilience activities already underway. Innovations in processes are also sought, in particular, through more equitable decision-making processes whereby members of communities living in the most vulnerable conditions, who can most benefit from

resilience actions, are leaders and partners in the process, and not simply recipients of actions driven by others (Brown 2017).

Disruptions to both progress on overcoming barriers and realizing innovations can come with climate hazards, elections, and shifts of political trends that can dramatically change resources available, but these events can also open windows of opportunity (e.g., Tabara *et al.* 2018). Engaging barriers as openings to innovate can be advanced by understanding and mapping the relational aspects of the research approach, process and anticipated resilience outcomes including internal and cross-institutional collaboration and co-production, identifying opportunities for nurturing those cross-sectional/cross-institutional relationships, and leveraging social network analysis or other approaches to understand changes over time.

3.2.4.2. *Capacity building and workforce development*

Overcoming barriers to create innovations can also create new capacity building and workforce opportunities. For example, examination of vulnerabilities in a coal mining community of China identified transformative opportunities for sustainability-focused workforce development (Tai *et al.* 2020). Social learning builds human and cultural capital alongside ecosystem benefits and in turn can encourage more holistic and effective regional adaptation (Bunch *et al.* 2011; Keys *et al.* 2014). Continuous monitoring of resilience outcomes over time and across sectors can reveal gaps in knowledge or skills that translate to new discoveries for building capacity and developing a new workforce to fill those gaps. This new knowledge can develop capacity and jobs that can be exported elsewhere to build a new resilience-based economy. Given the comprehensive and holistic approach of the *Resilient305* Strategy, these opportunities extend beyond sustainability and climate resilience to sectors of education, food systems, technology, transportation and health.

3.2.4.3. *Resilience dividends*

Quantifiable outcomes elicited through resilience investments lead to innovative cost-benefit assessment that enhance understanding of the value-added benefits, help avoid unintended consequences or other resilience trade-offs that can exacerbate social inequities and environmental degradation and promote new actions that lead to further innovation (Boyd and Shabman 2019). These triple dividends are also critical for informing policy decisions and prioritizing future projects and can enhance and expand investment impacts. Comprehensive, cross-sectoral and ongoing monitoring of outcomes vetted against community priorities are key. On the flipside of triple dividends are resilience trade-offs that are equally important and possible to anticipate with improved knowledge gained through a

comprehensive, holistic approach to resilience (Chelleri *et al.* 2015). In particular, gaps in understanding community priorities can also lead to unacceptable resilience trade-offs. Using approaches like MCA and scenarios of resilient futures with the local community context can help to demonstrate how a potential project could avoid/mitigate future losses and damages (to our economy, housing stock, infrastructure, etc.). This pillar adds a new capacity to the resilience-building process that is not typically available within the many demands of government work, and also a transparency that helps to sustain public participation in the resilience journey.

3.2.4.4. *Dynamic adaptive management*

Dynamic Adaptive Management enables objective and adaptive decision-making by articulating science-based pathways that help to manage uncertainty in physical, biological, climate, social, and economic systems against a shifting and non-stationary baseline (Haasnoot *et al.* 2013; Obeysekera *et al.* 2020). However, decision points are more commonly defined by engineers for physical infrastructure (e.g., damages avoided) rather than social and ecological resilience outcomes defined by community priorities. Developing a structure and process that guides holistic, comprehensive decision-making that takes into account not only cross-sectoral resilience trade-offs but fosters resilience learning that enables people and the environment to thrive is a fundamental challenge. Engaging the community to understand and co-design/co-produce tipping points toward different pathways can help to overcome these pitfalls. Historical information could also be used to define potential community tipping points that could then be vetted through community members. Identifying metrics that are more suitable for dynamic phasing of adaptive pathways, overcoming challenges brought by temporal frequency of underlying available datasets (e.g., census data challenge — available only every five years) and advancing cross-sectoral approaches for tipping points and pathways are existing challenges that the *Resilience Learning System* is designed to address and overcome.

3.2.4.5. *FEMA recovery support functions*

With the onset of COVID 19, the need for science-based pathways to recovery that foster holistic community resilience has never been more urgent (Lloyd's 2020). The federal government established The National Disaster Recovery Framework which introduces six Recovery Support Functions (RSF) — Community Planning and Capacity Building, Economy, Health and Social Services, Housing, Infrastructure Systems and Natural and Cultural Resources (FEMA) — that are led by designated federal coordinating agencies at the national level and partners in the

local, state and tribal governments and private and nonprofit sectors who may not typically be involved in emergency support functions but are critically needed in disaster recovery. Federal partners also may include public and private organizations experienced in permanent housing financing, economic development, advocacy for underserved populations and long-term community planning. The processes used for facilitating recovery are more flexible, context-based and collaborative in approach than the task-oriented approach of the response phase of an incident. Recovery processes should be scalable and based on demonstrated recovery needs.

The federal process for recovery support can also model a process to better prepare individuals to thrive in the face of the next set of extremes (and hazards) and foster near-term recovery more quickly. Further, the identification of relevant data and metrics can help us track recovery to discover and embed new insights that feed back to the *Resilience Learning System*. The underlying economic and employment status of individuals offers an example of how this can work. For instance, in Miami-Dade County, small businesses (fewer than 500 employees) employ over 50% of the workforce and are exceedingly vulnerable to climate-related risks, with a 40% failure rate associated with natural disasters (FEMA 2018). This level of impact in Miami-Dade County would result in more than 200,000 jobs lost and nearly $8.5 billion in lost employment income (FIU 2018). Miami-Dade County experienced major financial disruptions for families, with cash inflows and outflows dropping over 20% and 30%, respectively, in the week of Hurricane Irma's landfall. Drops in healthcare, bill and debt payments in Miami were evident 10 weeks later (Farrell and Greig 2018). Fostering a supportive infrastructure to assist small business survival also can encourage growth and the creation of higher wage opportunities for the workforce.

Focusing federal dollars and programs to increase investment in pre-disaster mitigation in areas dependent on small business is just one example. Other impact sensitive industries such as hospitality and tourism pose similar challenges. An application of federal Recovery Support Functions to resilience planning can provide a framework to support individuals and businesses to be able to withstand both chronic and episodic conditions.

4. Conclusion

Greater Miami and the Beaches (GM&B) is one of the most vulnerable places in the country to intersecting climate hazards of both acute shocks (hurricanes and extreme heat) and chronic stressors (sea-level rise, sunny day flooding, and warming). Motivated to address these challenges and with support from the

100 Resilient Cities program, civic leaders and academics from across the GM&B region worked together over a 3-year period to create a resilience strategy. The strategy identified a number of early-stage actions. A quantitative, integrated approach is needed for understanding how diverse community priorities can be better aligned with resilience strategies to build resilience to climate hazards, support equitable and efficient recovery from other societal shocks, and embed adaptive management and resilience learning to enable people and the environment to recover, learn, and thrive. Several questions guiding our thinking include: How will we know if our resilience investments are achieving the resilience outcomes intended and potential multi-sectoral co-benefits? How can we feed back this information into a learning process that improves our ability to build resilience across social, ecological and technological dimensions with each new investment in a project, program, or policy?

We have designed an integrated research strategy supporting a *Resilience Learning System* that intends to close potential gaps between the regional *Resilient305* Strategy and community priorities to enhance resilience to climate hazards while creating and enhancing triple dividends of resilience investments. Critical objectives for initiating the work included: (1) Building on existing partnerships to create collaborative workgroups; (2) Developing metrics to evaluate outcomes of actions in the *Resilient305* Strategy from the community perspective; (3) Integrating existing activities and information to advance socio-technological, smart and connected regional-to-hyperlocal community translation through co-design/co-production; and (4) Designing an integrated research strategy that supports a replicable, *Resilience Learning System* responsive to changes in a hyperlocal context.

In order to elicit resilience outcomes across sectors, actions established in the *Resilient305* Strategy address shocks and stressors including COVID-19 pandemic-related recession, sea-level rise and coastal flooding, storms, increasing heat, aging infrastructure, income inequality, youth violence, community health, environmental degradation, and lack of education/awareness. We anticipate that co-design/co-production of climate resilience projects, programs, and policies driven by community priorities, comprehensive metrics and resilience learning will yield triple dividends of resilience investments. Metrics of social, ecological, and technological systems are designed to enable effective assessment of the process and outcomes that build community resilience to climate hazards.

We are building the scientific basis for resilience investments using these metrics to develop a smart and connected *Resilience Learning System* that translates regional resilience strategy to hyperlocal-scale resilience outcomes. Our approach to a *Resilience Learning System* puts community first via a co-design/co-production process to quantify what civic leaders desire to better understand,

addressing key questions that include how we can equip communities for greater preparedness and resilience to climate hazards while addressing basic community priorities of poverty, youth violence, industry and job diversification, youth employment, and environmental benefits. The intersection of these outcomes can yield significant innovations and provide value-added social outcomes from increased access to and quality of recreational spaces, decreased time to recovery for small businesses, enhanced life satisfaction, social connectedness, fewer hospitalizations, decreased damage or job loss after an event, to reduced flood insurance rates. Our research strives to generate new, transformational knowledge that can fundamentally change social, ecological, and technological systems and policies to enhance quality of life across the socioeconomic and cultural diversity of coastal communities responding to climate hazards. The interdisciplinary education, technological and training opportunities for our students and all community members in the future sustainable urban systems workforce will be built on these collaborative approaches and emerging social, technological, environmental, and infrastructural innovations. The *Resilience Learning System* will also provide transformative learning opportunities that support individual, community and regional resilience for our local student population, which comprises one of the greatest concentrations of Hispanic and Black non-Hispanic students in the country.

Acknowledgments

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