GUIDING DESIGN FOR SEA-LEVEL RISE: AN ITERATIVE METHODS FRAMEWORK

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1 ABSTRACT

Climate change poses immediate challenges for human populations worldwide. Coastal areas in particular face sea-level rise and storm surge issues. Several artificial designs, including seawalls and surge barriers, have been used to manage the effects of sea-level rise, but these options often require ongoing upkeep and fail to offer long-term solutions. Nature-based solutions offer an alternative for coastal resilience and adaptation strategies relevant to both urban areas and other coastal areas such as national parks. Identifying design procedures for nature-based design could promote successful implementation and long-term sustainability. Based on existing literature, a set of design criteria is formed to guide the implementation of nature-based design in response to projected sea-level rise in the context of East Potomac Park in Washington, D.C., but endeavors to be widely applicable to other coastal areas facing sea-level rise and storm surge. The design criteria address socio-ecological factors of landscape, planning and design for adaptation and resilience, communicating climate change, and design performance evaluation. The goal is to provide an iterative methods framework, composed of the design criteria, for climate change design projects and to connect research with practice by creating a design-science feedback loop. The framework provides a platform for innovative solutions in climate change design and furthers dialogue on nature-based design.

1.1 Keywords:

Climate change, sea-level rise, coastal resilience, nature-based design, national parks

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2 INTRODUCTION

Designing for climate change, and specifically for sea-level rise, is one of the biggest challenges facing designers today. Fair weather flooding is now common among coastal cities and considerable resources are going into planning and design for a variety of mitigation measures. Traditional methods of shoreline protection, including seawalls and dikes, can still leave coastal areas vulnerable to sea-level rise, threatening infrastructure, local economy, and community fabrics. Research articles, agency reports and other documents identify important strategies for studying and addressing these problems, but typically focus on a narrow set of issues relevant to local problems in need of solutions. The benefit is the richness of detail and depth of consideration in each situation. The drawback is the lack of broader coordinated procedures that can bring in additional stakeholders, experts, and ideas from an increasingly comprehensive viewpoint. Overall, services to adapt and mitigate climate change effects will likely become progressively more important, but current strategies remain fragmented locally and globally.

The research presented here draws from multiple sources of published information that each encapsulate one or more parts of the design and planning process. Together, the research brings into focus a more fully developed set of actions and objectives that could improve the decision-making processes for communities affected by climate change issues such as sea-level rise. The results of the study offer a framework, supported by a diverse collection of literature that is organized by triangulation, into a set of actions and objectives for identifying and addressing issues relevant to climate change design. To manage the complexities of designing in the context of climate change, with a focus on sea-level rise, the framework provides a guide to engaging social and environmental factors critical to the long-term sustainability of climate change design projects. The framework translates widespread literature into an applied method informing and strengthening adaptation responses to coastal climate change issues that support socioecological needs.

2.1 Literature Review

2.1.1 Climate Change

Climate change poses significant challenges in human-made environments and natural systems worldwide (IPCC, 2014). More than half of the world's population lives in urban areas and urbanization is expected to continue in the future (Revi et al., 2014). Many cities lack measures for climate change adaptation planning, while those that do not are mostly located in high-income countries (Araos et al. 2016). Moreover, growing populations of people are living less than 10 m above sea level, creating significant risks from climate change issues related to sea-level rise, including elevated tides, increased flooding, erosion and groundwater salinization (Oppenheimer et al., 2019)

Global average sea-level rise since the late 19th is around 210 mm, with a linear trend of 1.7-1.9 mm per year (Church & White, 2011), and global average sea level is likely to increase in the future, with some studies reporting a possible global sea-level rise increase of 2 m by 2100 in a high emission scenario. However, likely sea-level rise projections for global mean sea-level rise range from 0.24-0.32 m by 2050 and 0.43-0.84 m by 2100, with a 17 percent chance of 0.59-1.1 m by 2100. Moreover, sea-level rise is not uniform, and some regions could see up to 30 percent higher sea-level rise than the global average due to factors such as ocean dynamics and subsidence (Oppenheimer et al. 2019).

In the United States, the North Atlantic Coast is extremely vulnerable to sea-level rise, especially considering the region's population density and coastal hazards such as hurricanes and severe storms. Based on climate models from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), Yin, Schlesinger, & Stouffer (2009) project sea-level rise ranging .36-.51 m in New York City; .37-.52 m in Boston; and .33-.44 m in Washington, D.C. by the end of the 21st century. Moreover, the region has regularly experienced severe storms in the past. Hurricane Sandy in 2012, for instance, brought widespread economic damage, where storm surges reached 9.4-12.65 ft above normal high tides in the New York Metropolitan area. The event revealed an immediate need to address sea-level rise and storm surge issues in coastal areas (US Army Corps of Engineers New York District, 2019).

Tide gauges along the East and Gulf coasts have also been used to extrapolate on storm surge and flooding. Dahl, Fitzpatrick, & Spanger-Siegfried (2017) studied 52 locations along the U.S. East and Gulf Coasts, with projections indicating that Washington, D.C. will experience up to 337 tidal flooding events per year by 2045, the most of all the study cities. Moreover, Washington, D.C. ranked in the top 10 for number of flooding events that received a Coastal Flood Advisory in 2012-2013, with almost 70, and in the top three for average tidal flood events between 2001-2015. The National Capital Region is susceptible to multiple flooding risks, including riverine, coastal, and interior flooding. Tidal flooding and storm surge, which can be caused by hurricanes, have the potential to produce extremely high water when occurring at high tide in the Washington, D.C. (National Capital Planning Commission, 2018). In fact, Washington, D.C. has around a 50 percent chance of experiencing a record-breaking flood by 2040. For a 100-yr flood, this would be 11 ft above the high tide line. For comparison, previous high floods were 7.9 ft in 1942 during torrential rains; 7.4 ft in 1936 due to storm water; and 7.1 ft in 2003 during Hurricane Isabel. Under the highest sea-level rise scenarios, floods exceeding these records would become annual events by 2080-2100 (Strauss et al., 2014).

Furthermore, the National Capital Region is estimated to have the highest rate of sea level change in the National Park System by 2100, with an average of 0.8 m sea-level rise. U.S. national parks are important in preserving cultural and natural resources. Yet, with more than one quarter of lands managed by the National Park Service falling on ocean coastlines, many National Parks are vulnerable to the effects of climate change, especially issues resulting from sea-level rise (Caffrey, Beavers, & Hoffman, 2018). Peek and Beavers (2015) estimate that with 1 m of sea-level rise, over $40 billion of National Park assets will be at risk. For the National Mall in Washington, D.C. the effects of sea-level rise alone may not cause significant damage, but in combination with storm surge, the area could face serious issues (Caffrey, Beavers, & Hoffman, 2018). Economic costs of 0.1 m and 5 m of sea-level rise for Washington, D.C. stand at approximately $2 billion and $24.6 billion, respectively (Ayyub, Braileanu, and Qureshi, 2012), while sea-level rise threatens $4.6 billion in property value less than 6 ft above the high tide line, with the amount increasing to $9 billion at 10 ft above high tide level (Strauss et al., 2014). The Washington, D.C. tide gauge 8594900, which is located near the Tidal Basin in the Washington Channel, has experienced an annual mean change of 3.09 mm from 1959-2008, with the area projected to experience 0.33m by 2050. (Tebaldi, Strauss, & Zervas, 2012). In 2019, the National Trust for Historic Preservation named the National Mall Tidal Basin as one of America's most endangered historic places, largely due to flooding issues. The Tidal Basin experiences regular flooding during high tide, creating accessibility issues and possibly adverse effects on the Tidal Basin Cherry Trees, which attract 1.5 million visitors during the National Cherry Bloom Festival. Similarly, in nearby Annapolis, Maryland, Hino et al. (2019) found that visitation numbers to historic downtown Annapolis are likely to drop by 37,506 visits, or approximately 24%, during high tide flooding with 1 ft of sea-level rise.

2.1.2 Nature-based Solutions

A number of protective design solutions based on natural systems have been proposed to combat the effects of sea-level rise, including seawalls, floodwalls, tide gates, levees and surge barriers. However, many of these options require ongoing upkeep, may not be cost-effective, create ecological problems, and fail to offer long-term solutions (Hirschfeld & Hill, 2017). Hinkel et al. (2014) estimate the cost of maintenance and upkeep of dikes managing coastal flooding range $12-31 billion in a low emissions scenario and $27-71 billion in a high emissions scenario by 2100. Moreover, adaptation requires directed, long-term solutions. In the Gulf of St. Lawrence in Canada, Jolicoeur and O'Carroll (2007) observed how ad hoc adaptation strategies alongside coastal roads, including seawalls and riprap, contributed to the loss of coastal habitat and, ultimately, additional coastal armoring.

Alternatively, nature-based design and ecosystem-based adaptation is receiving increasing attention as a strategy for adapting to sea-level rise, storm surge, and flood risks (Oppenheimer, 2019; Bridges et al. 2018). In New York City, for instance, wetland and dune restoration have been suggested as methods of shoreline protection (Rosenzweig et al., 2011). Nature-based design incorporates natural features that improve coastal protection (Pontee et al., 2016). For instance, coral reefs and salt marshes can reduce wave height up to 70 and 72 percent, respectively (Narayan et al., 2016). Tidal wetlands can even offer a level of coastline protective capacity against storm surge during hurricanes, with larger wetlands providing increased protection from flooding damage and storm surge (Highfield, Brody, & Shepard, 2018). Related to Hurricane Sandy, wetlands were found to protect against $625 million in direct flood damages from North Carolina to Maine (Narayan et al., 2017). Coastal wetlands have been shown to provide additional benefits such as providing erosion control, sequestrating carbon, and maintaining fisheries (Barbier et al., 2011). Moreover, nature-based solutions can often be more cost-effective than traditional infrastructure solutions. Salt marshes and mangroves were shown to be 2-5 times cheaper than a submerged breakwater for waves up to 0.5 m, and the habitats become more effective than breakwaters at increasing depth (Narayan et al. 2016). In addition, Hirschfeld and Hill (2017) observed that a shift from using walls to protect vulnerable coastlines to earthen systems reduces the cost of adaptation to coastal flooding.

2.1.3 Implementation Examples

SCAPE Landscape Architecture's *Living Breakwaters* project in New York City provides an example of integrating nature-based design. The design incorporates breakwaters off of Staten Island to help absorb wave energy and reduce coastal flooding, while also making habitat for fish, oysters, and other species. In China, Turenscape's Sanya Mangrove Park works to restore damaged habitat and the protect coastline against storm surge. And in response to flooding and projected sea-level rise, the National Mall Ideas Lab in Washington, D.C. has identified five landscape architecture firms—DLANDstudio, GGN, Hood Design Studio, James Corner Field Operations, and Reed Hilderbrand—to imagine a redesign of the threatened Tidal Basin (National Trust for Historic Preservation, 2019).

A nature-based design approach opens a route for weaving scientific experiment into the design process, complimenting the "designed experiment" method proposed by Felson and Pickett (2005). With an ecological base, design can offer a route for collecting quality ecological data in urban settings. Furthermore, designed experiments encourage partnerships among urban designers, landscape architects, and architects that enables ecologists and researchers to weave experiments into the urban setting. Similarly, Ahern et al. (2014) propose an adaptive urban planning approach that includes "safe-to-fail" designs, which enable pilot testing of innovative, experimental design solutions in small spatial extents and low risk contexts. The approach offers an opportunity to further integrate design and science, and a method for incorporating ecosystem services into the planning and design process. Mutually beneficial for designers, planners, and researchers, such collaborative efforts work to integrate design into science. Nassauer and Opdam (2008) argue that design can be a vehicle used by scientists and practitioners to include scientific knowledge in the decision-making process related to landscape change, contending that through transdisciplinary collaboration, scientists and practitioners of many fields enhance landscape science and knowledge. Therefore, design can act as common ground between researchers and professionals, connecting science and society by informing the design process and bolstering the outcomes of landscape projects.

3 RESEARCH OBJECTIVES

The primary purpose of this research is to review journal articles, agency reports, and other written documents addressing design and planning concerns related to climate change, particularly sea-level rise, and identify a common set of procedures across professions. The study aims to develop an iterative methods framework based on triangulation of relevant literature sources. The goal of the framework is to pull together diverse thinking on the topic of design for sea-level rise into a comprehensive, organized reference source for designers, planners, researchers, community organizers, and stakeholders. The research-based framework informs and formulate a set of pre- and post-evaluation guidelines that provide recommendations for directing decisions throughout the design process, and later, to evaluate the success of a design.

Furthermore, the project seeks to present a process integrating science and design, and aspires to further connect research and design throughout the design process in a manner that is informative to future design projects addressing issues of climate change. Although the iterative methods framework was developed to address issues of sea-level rise in an urban land area managed by the National Park Service, the study aims to be widely applicable to other study sites by furthering dialogue on the applicability of nature-based design for climate change and by contributing to management approaches in preserving natural and cultural resources at risk from climate change issues.

4 METHODS

To accomplish these goals, the study pulls on literature from interdisciplinary fields and studies addressing climate change to form a framework meant to guide design related to sea-level rise and storm surge. A search for journal articles, agency reports and other documentation on design for sea-level rise was conducted using large online journal databases, such as Science Direct and U.S. Department of the Interior Integrated Resource Management Applications data repository. Search terms broadly fell into topic categories of climate change, nature and ecosystem-based design, parks and places, and communication. For instance, 'nature-based design,' 'coastal resilience,' 'coastal planning,' 'sea-level rise,' 'storm surge,' 'flooding,' and 'national parks' were among the search terms. Supporting literature was identified from journal articles (JA), National Park Service reports (NPS), and documents from other institutions (O) such as government or non-profit entities. These materials were organized based on the actions involved and the people engaged in the actions into the appropriate Action category of the framework. Triangulation was used to determine how strongly the literature supported the categories of action and engagement identified in the documents reviewed.

The iterative methods framework was formed in the context of addressing design for sea-level rise using nature-based design solutions in Washington, D.C., an urban area where much of the parkland is managed by the National Park Service. The content of each Action and Objective, for instance, was developed and informed by considering social and environment dimensions—e.g., human activities, bathymetric and hydrological characteristics, and topographic features—specific to the study site at East Potomac Park in Washington, D.C. (Figure 1). Thus, although the review includes global and regional (Atlantic/Gulf coast) perspectives, and is meant to be applicable to other areas, the primary strength is related to the Chesapeake Bay and Washington D.C. area

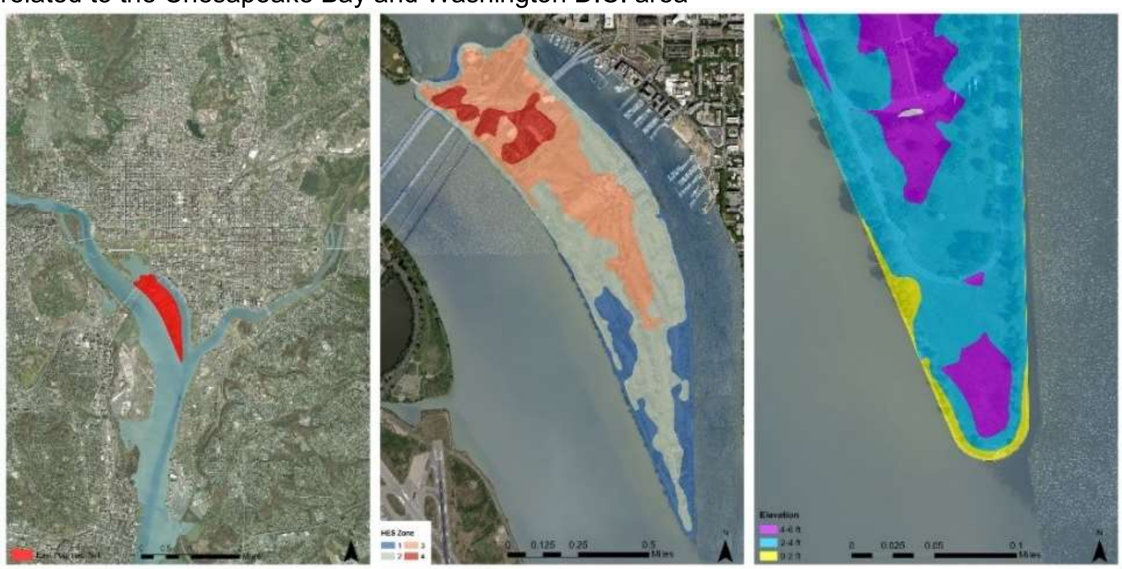

Figure 1. Examples of studies related to sea-level rise for East Potomac Park, Washington, D.C. East Potomac Park (left) encompasses four hurricane evacuation study zones (center), while the southern point is below 6 ft of elevation (right), making it vulnerable to sea-level rise.

4.1.1 Framework Development

The framework is based on supporting literature. Triangulation identified relevant research from journal articles (JA), National Park Service reports (NPS), and documents from other institutions (O) such as government or non-profit entities. Research broadly fell into topic categories of climate change, nature and ecosystem-based design, parks and places, and communication. The framework text is based on a review of more than 40 research papers in these categories. The framework includes Action and Objective columns with text developed to reflect and summarize information from the review of the research literature. For brevity, the framework includes 15 examples from the identified literature (JA, NPS, O; Table 1). The supporting literatures that appear in the table were selected for relevance, instructiveness, and accessibility to a wide audience of academics, practitioners, and communities. The aim was to include literature approachable to more than a single audience. Although the remaining articles were critical to the development of the framework (Table 2), providing additional insight on resilience and adaption topics, the authors felt the 15 chosen best encompassed the framework content and provided the most opportunity for further instructiveness. Each Action and Objective section correspond to examples from the supporting literature, with one example from each identifier in every section, to support the directives of the proposed framework method, the main result of the study.

Table 1. The iterative methods framework identifying actions, objectives, and triangulated supporting literature (JA: journal article; NPS: National Park Service; O: Other)

Action	Objective	Supporting Literature	Type
Explore	*Identify the Issue and Key Players*	*Sources grouped for relevance to the Action, and are not linked to a single directive only	
Study site history and context	Locate natural and cultural resources		
Determine users and community relationship	Connect decision-makers and information users	High-tide flooding disrupts local economic activity Hino, M. et al. (2019)	JA
Consider opportunity for innovative and creative solutions	Collaborate to define the issue	Coastal Adaptation Strategies Handbook Beavers, R. et al. (2016)	NPS
Engage social scientists and stakeholders	*Ex: Social media postings for site use*	Designing With Water: Creative Solutions From Around The Globe Aiken, C. et al. (2014)	O
Acclimate	*Define Socioecological Factors*		
Assess vulnerability to climate change	Identify vulnerable experiences and ecosystems	Nature-based solutions: Lessons from around the world Pontee, N. et al. (2016)	JA
Specify adaptation and resilience strategies	Determine habitat type of nature-based design	Climate Change Response Strategy National Park Service (2010)	NPS
Evaluate appropriate nature-based designs and ecosystem services	Balance user needs, coastal services, and design solution	When Rising Seas Hit Home Spanger-Siegfried, E. et al. (2017)	
Engage ecosystem scientists and allied researchers	*Ex: Mapping and projections to study site*		O
Plan & Design	*Implement Adaption, Mitigation, and Resilience*		
Integrate culture and nature	Design solutions that provide multiple socio-eco benefits	The shore is wider than the beach: Ecological planning solutions to sea level rise for the Jersey Shore, USA Burger, J. et al. (2017)	JA
Consider time horizons and scenarios	Use scenario planning and phasing for uncertain futures		
Strengthen preparedness, adaptation, and resilience	Encourage local and regional preparedness and adaptation	Climate change scenario planning: A tool for managing parks into uncertain futures Weeks, D. et al. (2011)	NPS
Engage planners and designers	*Ex: Plan two alternative futures*		

		Engineering with Nature Bridges, T.S. et al. (2018)	O
Communicate	*Promote Dialogue and Idea-sharing*		
Bring attention to place identity and meaning	Advance the local context and a sense of place	Climate change impacts in Missouri State Parks: Perceptions from engaged park users Groshong, L. et al. (2018)	JA
Provide educational and engagement opportunities Encourage curiosity and discussion	Use site to demonstrate climate change Develop public dialogue between science and design	Using social science in National Park Service climate communications: A case study in the National Capital Region Campbell, E. (2020)	NPS
Engage communicators and end users	*Ex: Past and present photographs for context*	Climate Change Communication Campaign Planning: Using Audience Research to Inform Design Thompson, J. et al. (2013)	O
Monitor	*Study Design Outcome*		
Research and evaluate pre-post site performance for long-term sustainability	Identify relevant metrics and indicators	Designed experiments: new approaches to studying urban ecosystems Felson, A.J. & Pickett, S. (2005)	JA
Make findings accessible and instructive	Examine design contribution to cultural and ecological goals	Coastal Adaptation Strategies: Case Studies Schupp, C.A. et al. (2015)	NPS
Connect research and practice *Engage all relevant parties*	Create a practice-science feedback loop *Ex: Baseline and outcome data for comparison*	Site Commissioning White Paper U.S. General Services Administration (2017)	O

Table 2: Additional Supporting Literature Informing Iterative Methods Framework

Authors	Title
	Journal Article (JA)
Ahern, J. et al. (2014)	The concept of ecosystem services in adaptive urban planning and design: A framework for supporting innovation
Brown, S et al. (2014)	Shifting perspectives on coastal impacts and adaptation
Campbell, L. et al. (2016)	A social assessment of urban parkland: Analyzing park use and meaning to inform management and resilience planning
Frantzeskaki, N. et al. (2019)	Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice Communities for Evidence-Based Decision-Making
Hinkel, J. et al. (2014)	Coastal flood damage and adaptation costs under 21st century sea-level rise
Hino, M. et al. (2017)	Managed retreat as a response to natural hazard risk
Hurlimann et al. (2014).	Urban planning and sustainable adaptation to sea-level rise
Jarrat, D. et al. (2019)	Planning for climate change impacts: coastal tourism destination resilience policies
Kirsehn, P. et al. (2008)	Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies
Le Cozannet, G. et al. (2017)	Sea Level Change and Coastal Climate Services: The Way Forward
Mitchell, M. et al. (2019)	Embracing dynamic design for climate-resilient living shorelines
	Climate Change Response Strategy
Monahan, W. et al. (2014).	Climate Exposure of US National Parks in a New Era of Change
Molinaroli, E. et al. (2019)	Do the Adaptations of Venice and Miami to Sea Level Rise Offer Lessons for Other Vulnerable Coastal Cities?
Nassauer, J. et al. (2008)	Design in science: extending the landscape ecology paradigm
Narayan, S. et al. (2016)	The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences
Rosenzweig, C. et al. (2011)	Developing coastal adaptation to climate change in the New York City infrastructure-shed: process, approach, tools, and strategies
Siders, A.R. et al. (2019)	The case for strategic and managed climate retreat
Spalding, M. et al. (2014)	Coastal Ecosystems: A critical element of risk reduction
Van Dolah, E. et al. (2020)	Marsh Migration, Climate Change, and Coastal Resilience: Human Dimensions Considerations for a Fair Path Forward
Van Wesenbeeck, B. et al. (2016)	Coastal and riverine ecosystems as adaptive flood defenses under a changing climate
Woodruff, S. et al. (2018)	Fighting the inevitable: infrastructure investment and coastal community adaptation to sea level rise
	National Park Service (NPS)
National Park Service (2010)	Inventory of Coastal Engineering Projects in Coastal National Parks
National Park Service (2010)	Climate Change Response Strategy
National Park Service (2014)	Dyke Marsh Wetland
National Park Service (2015)	Adapting To Climate Change in Coastal Parks
	Estimating the Exposure of Park Assets to 1 m of Sea-Level Rise
National Park Service (2018)	Sea Level Rise and Storm Surge Projections for the National Park Service
	Other (O)
National Capital Planning Commission (2018)	Flood Risk Management Planning Resources for Washington, DC
NOAA. (2017)	Global And Regional Sea Level Rise Scenarios For The United States
Strauss, B. et al. (2014)	Washington, D.C. and the Surging Sea: A vulnerability assessment with projections for sea level rise and coastal flood risk

5 RESULTS

An iterative methods framework (Table 1) is developed to inform and guide a design process for coastal resiliency. The framework is populated with an Action and Objective column supported by relevant literature from three different source types. The Action column is organized by the following sections: Explore, Acclimate, Plan & Design, Communicate, and Monitor (Figure 2). The process begins at Explore and follows through to Monitor. However, the process is iterative and a section can, and should, be revisited as needed at any point while using the framework.

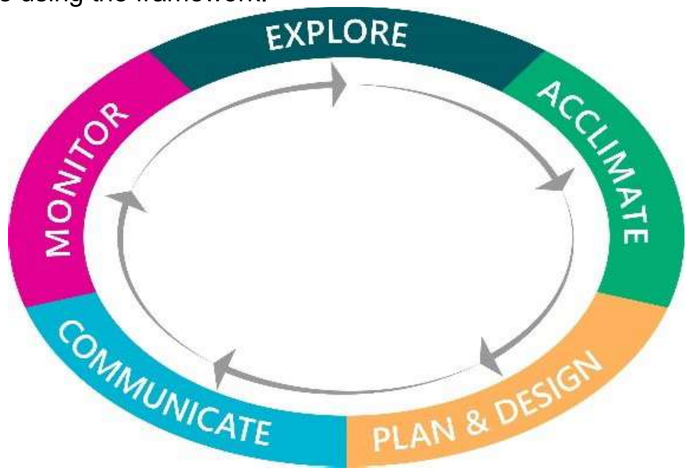

Figure 2. Conceptual layout of the iterative methods framework

Each section contains a directive to address in achieving the related Objective. For instance, the Action "Explore" aims to achieve the Objective "Identify the issue and key players." Recommendations of useful steps in going through the process are included in each section. Continuing the Action "Explore" example, the directive to "study site history and context" is to "locate natural and cultural resources," while the directive to "determine users and community relationships" is to "connect decision-makers and information users," and finally, the directive to "consider opportunity for innovative and creative solutions" is to enable "collaboration in defining the issue." This process is repeated for each Action section. Additionally, each Action and Objective describes relevant parties to be involved at a given stage of the process and a concrete example enabling progress toward the Objective. The Action "Explore" suggests engaging social scientists and stakeholders at this stage, while using social media is listed under the Objective column as one potential route in working to achieve the Objective "Identify the issue and key players."

A third and fourth column attaches supporting literature to the corresponding Action and Objective columns. The supporting literature informs and is directly related to the directives in the Action and Objective columns. Each section contains supporting literature from three source types: journal articles (JA), National Park Service reports (NPS), and Other (O), lending multi-source support to the directives in the Action and Objective columns. Although these literatures were situated in the Action "Explore" category, information within the literature could overlap in other Action categories. Therefore, the literature associated with each Action category should not be misinterpreted as only contributing a single directive to a single category. However, the literature identified in each category did contribute significantly to the category it is tagged within compared with the other categories. For instructive and organizational purposes, therefore, the authors grouped literature in the most relevant categories.

Using the Action "Explore" as an example, Hino et al., 2019 (JA), Beavers et al. 2016 (NPS), and Aiken et al. 2014 (O) each contain content that supports the directives in the Action "Explore" column and the Objective "Identify the issue and key players" column. The directive "study site history and context" is to "locate natural and cultural resources," with suggestions of engaging social scientists and stakeholders and proposed example of exploring social media for site uses. The process described is followed likewise for each Action. For instance, the Action "Acclimate" aims to achieve the Objective "Define socioecological factors." The directive "specify relevant adaptation and resilience strategies" is to "determine habitat type of nature-based design," encouraging users to engage ecosystem scientists and allied researchers and consider using mapping and projections for studying the site. Similarly, the Action "Plan & Design" aims to achieve the Objective "Implement adaptation, mitigation, and resilience measures." The directive "strengthen preparedness, adaptation, and resilience" is to "encourage local and regional preparedness and adaptation," with planners and designers engaged at this stage and a potential method of planning alternative futures. The Action "Communicate" aims to achieve the Objective "Promote dialogue and idea-sharing." The directive "provide educational and engagement opportunities" is to "present the site as a demonstration of climate change." At this stage, the Action "Communicate" suggests engaging communication professionals and end-users, and recommends using past and present photograph comparisons as one potential example in achieving the Objective "Promote dialogue and idea-sharing." Finally, the Action "Monitor" aims to achieve the Objective "Study design outcome." The directive "connect research and practice" is to "create a practice-science feedback loop." Here, the Action "Monitor" suggests engaging all relevant parties and recommends comparing baseline and outcome data as one potential example in achieving the Objective "Study design outcome."

Together, the Action, Objective and Supporting Literature columns form the iterative methods framework. The directives capture perspectives from three types of literature largely related to climate change or sea-level rise adaptation, though the JA and O articles in the Action "Monitor" were selected for their instructiveness on integrating science and design. The literature also serves to provide further reading and context for those using the iterative methods framework for climate change design related to sea-level rise.

6 CONCLUSIONS

The study presents an iterative methods framework for informing coastal resilience design and planning projects. The framework is constructed in the context of national park land in Washington, D.C., but endeavors to be widely applicable to other coastal areas facing similar issues. The text within the framework reflects interdisciplinary thinking to provide a cohesive method to work from in the design process for sea-level rise issues.

A number of studies address the design process. Many even seek to understand design and planning adaptation strategies specifically in response to or preparation for sea-level rise and coastal change (Kirshen, Knee, & Ruth, 2008; Hurlimann et al. 2014; Burger et al. 2017; Woodruff, BenDor, & Strong, 2018; Molinaroli, Guerzoni, & Suman, 2019). Given the many disciplines involved in addressing sea-level rise issues, however, a comprehensive methods framework attempting to bring together and structure relevant interdisciplinary information might promote an informed, effective, collaborative, and sustainable design and planning process to address climate change issues such as sea-level rise. The iterative methods framework proposed here aspires to differentiate itself from other similar frameworks by focusing on climate-adaptive approaches, specifically for sea-level rise. The content in each Action and Objective provides a pathway to informing and guiding design in the context of coastal resilience, offering steps of when to engage interested parties and examples of strategies useful in adaptation design and planning. Furthermore, the framework includes literature with the potential for additional instruction and inspiration for users of the framework.

Attempting to bridge the gap between science and design, the framework develops a set of Actions and Objectives across diverse disciplines and takes initiative to involve stakeholders before, during, and after design. Engaging and empowering communities is an essential and informative part of the design process, or a project might risk unsuccessful adaptation or create inequity. Therefore, collaborating with communities in the design process, as encouraged by the framework, can inform and strengthen adaptation responses to climate change that support socioecological needs. Each Action pertains to an Objective meant to contribute to strengthening resiliency and sustainability. Ultimately, the framework aspires to improve the decision-making processes for communities affected by climate change issues such as sea-level rise. The iterative methods framework could be useful as a foundational tool and case study for park managers, policy-makers, and communities concerned with sea-level rise and storm surge issues.

However, the framework is meant to act as a guide for design related to climate change, specifically sea-level rise, and it is encouraged to use the framework as a foundation rather than canon. The proposed iterative methods framework is unlikely to be applicable in every instance of climate change design. Moreover, the framework may need to be appropriately adjusted for use on a case specific basis.

Additional limitations of the study include the extent of the literature review the framework is built on. A number of other studies and works could further inform and specify the framework. Literature was selected for its relevance and topic area, but the process was somewhat subjective. The authors hope that the triangulation of multiple sources for each section of the framework alleviates some of the subjectivity involved in the development of the framework, and advocate that users of the framework adopt additional relevant literature as necessary.

Finally, future study should evaluate the effectiveness, fluidity, and transferability of the iterative methods framework in multiple contexts and timescales. Whether the framework has applicability in both urban and rural contexts, for instance, provides an interesting route of future study, as does how well the framework stands up to issues of climate change beyond sea-level rise. The framework's ability to connect multiple nature-based design projects in a shared area into a larger functioning system that provides numerous ecosystem services presents another interesting route of study. Overall, the study is not attempting to promote a single solution for sea-level rise and storm surge issues. But what the authors do hope the iterative methods framework does achieve, is furthering dialogue on design for climate change and offering a way forward in using nature-based design to increase community and ecological resilience in the context of sea-level rise and storm surge.

7 DISCUSSION

Unlike previously in history, human centers and coastal areas of interest have not been managed or planned for in an era of rapid sea-level rise and climate change. Large urban centers are likely to be the hotspots needing adaptation and coastal resiliency plans. But other areas of human interest, such as coastal national parks, are also primed to benefit from considering adaptive strategies addressing climate change issues like sea-level rise. Nature-based design offers an innovative and exciting approach in adapting to climate change and may serve as a vehicle for exploring and reinvigorating a research-design feedback loop. Tackling the complexities of sea-level rise, for instance, transcends any single discipline, presenting an opportunity for interdisciplinary collaboration and breaking down communication barriers across disciplines.

The interdisciplinary nature of the content informing the iterative methods framework in this study has implications for coastal resiliency and adaptation efforts, and the study may be useful in designing to buffer against the effects of climate change on the coastal front. The framework provides a step in promoting dialogue on design for climate change and connecting science and design as well as serving as a tool for coastal communities enacting resilience planning measures. Although the future of coastal areas seems tenuous, never has there been such urgency in developing sustainable, resilient, and innovative paths forward to preserving—and reimagining—human connections with coastal zones.

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