AN ASBPA WHITE PAPER:

U.S. community perspectives on coastal flooding

By

Science & Technology Committee
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ABSTRACT

Coastal flooding, from both extreme events and sea level rise, is one of the top management challenges facing U.S. coastal stakeholders today. The intensity of coastal flooding is expected to increase with global sea level rise. This paper focuses on flooding challenges from the perspective of coastal communities. The myriad of flood mitigation strategies that have been implemented across the U.S. vary based on a multitude of factors including spatio-temporal scale of the coastal flooding hazard. ASBPA administered a survey of 106 coastal stakeholders from around the U.S. to assess specific community challenges and needs related to coastal flooding in late 2021. A majority of respondents indicated that their community includes an underserved population or neighborhood (54%) or nearby communities do (25%). While the vast majority of survey respondents indicated that flooding was a major challenge, only 24% of respondents' communities have a coastal flooding adaptation plan. Improvements to drainage systems are the most commonly implemented gray infrastructure strategy in the Southeast and Gulf coast regions. Respondents from all regions noted that beach and dune restoration has been the most widely implemented nature-based flood mitigation strategy. Interest is now high in other nature-based solutions with application in low-lying, vulnerable coastal areas such as thin-layer placement on marshes, living shorelines, and hybrid projects on estuarine shorelines. This paper does not provide an exhaustive review of the science, forcings, or policies on coastal flooding in the U.S.; rather, it captures the perspectives of coastal communities and aims to inform and prioritize future research investments related to coastal flooding.

The American Shore and Beach Preservation Association (ASBPA) has polled coastal stakeholders (i.e. practitioners) to identify their top coastal management challenges (Elko and Briggs 2020). Informed by two annual surveys, a multiple-choice online poll was conducted in 2019 to evaluate stakeholders' most pressing problems and needs, including what they felt most ill-equipped to deal with in their day-to-day duties and which tools they most need to address these challenges. Overall, the prioritized coastal management challenges identified by the survey were:

- *Deteriorating ecosystems* leading to reduced (environmental, recreational, economic, storm buffer) functionality,
- *Increasing storminess* due to climate change (i.e. more frequent and intense impacts),
- *Coastal flooding*, both: sea level rise and associated flooding (e.g. nuisance flooding, King tides); and combined effects of rainfall and surge on urban flooding (i.e. episodic, short-term), as well as flooding from changes in lake levels along the Great Lakes coastline,
- Chronic *beach erosion* (i.e. high/increasing long-term erosion rates), and
- Coastal *water quality*, including harmful algal blooms (e.g. red tide, *Sargassum*).

The goal of this paper is to address some of the issues surrounding the management challenge of coastal flooding, and to share challenges that coastal communities face with regards to flooding. The information provided may be helpful in prioritizing research investments in the topic area.

Flooding commonly occurs in coastal areas of the United States as a result of astronomical tides, storm surge, wave overtopping, local winds, and/or seiching. Coastal flooding induced by storm surge and waves is primarily caused by severe wind events including extratropical and tropical cyclones, cold fronts, and long-period swells. In addition to storms, tsunamis and tectonic activity can cause coastal flooding in Hawaii, Alaska, and the West Coast. Along some estuaries and particularly the Great Lakes shorelines, flooding may be triggered by seiches or meteotsunamis formed by winds from certain directions and/or magnitudes. Such flooding is exacerbated by sea level rise as waves and storm surges can penetrate through the coastal zone and have extended impacts inland.

Highly localized coastal flooding events are often referred to as nuisance

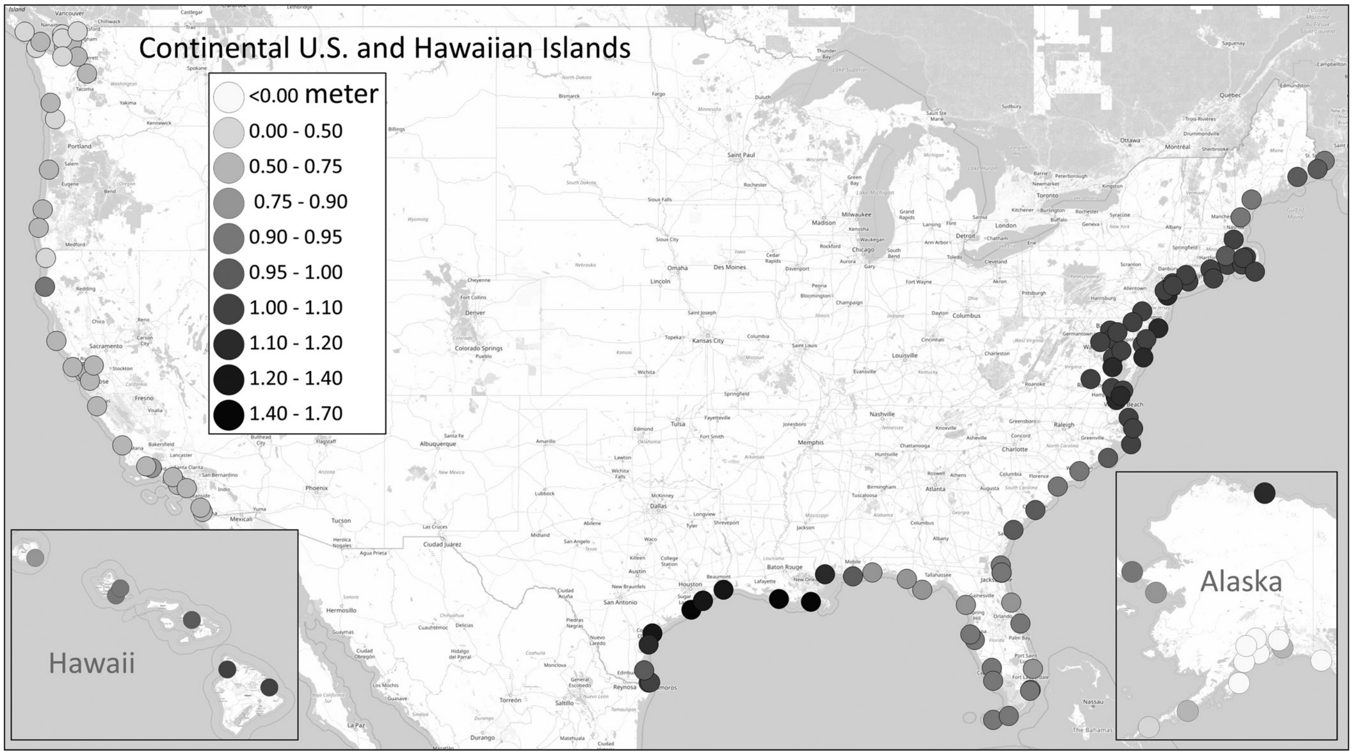

Figure 1. Median (50th percentile) projection of local sea-level rise (meter) at the location of tide gauges. Projections are shown for the end of 21st century under the high emission, fossil-fueled development scenario "Shared Socio-economic Pathway 5-8.5" medium confidence. The figure is generated based on data from the IPCC AR6 (Fox-Kemper *et al.* 2021).

flooding, high-tide flooding (Sweet *et al.* 2018, 2019, 2020, 2021, 2022), or colloquially, King tides, and are all driven by increased flooding due to relative sea level rise (Douglass and Webb 2020). These terms are sometimes used interchangeably, but can represent subtle differences in process and impact. High-tide flooding occurs when water levels exceed mean higher high-water level for a particular location (Sweet *et al.* 2020). Nuisance flooding generally represents low levels of inundation (e.g. 3 to 10 cm depth) that disrupt daily activities (Moftakhari *et al.* 2018) and includes fluvial, pluvial, and oceanic flooding. King tides represent the highest astronomical tides in a given year (Roman-Rivera and Ellis 2018). Differences in interpretation and meaning between these terms may affect mitigation strategies. While interpretations may vary, all describe similar processes; for many locations, water levels relative to local ground elevations are higher now than in recent history and continue to rise.

In contrast to more intense forms of flooding, high-tide flooding is often not dangerous but can cause public inconveniences due to road closures, overwhelmed storm drainage systems, and contaminated water. High-tide flooding does not lead to immediate major damage to infrastructure but in the long-term the seawater salinity could lead to costly damages to public infrastructure as well as private property.

Coastal flooding as it relates to sea level, described above, is especially noticeable along estuarine and ocean-facing coasts, and is influenced by flash flooding exacerbated by impervious surfaces, historic stormwater infrastructure that have become a tidal water flooding delivery system, and/or channelization that increase runoff during rainfall events. Impervious surfaces impede infiltration of rainwater into the shallow subsurface, which increases the residence time for waters within a particular flooded area. This may hamper rescue and relief efforts during flooding events. Channelization of coastal streams leads to higher slopes and velocities within the stream channel, which can deliver more water to a particular storage basin (i.e. flood-protection impoundments, wetlands, etc.) than that system may be able to handle.

The causes and nature of coastal flooding in the Great Lakes differs from those along ocean coasts. Long-term lake level rise has not been shown to be occurring in the Great Lakes, but water level extremes — both highs and lows — are occurring more commonly in the Great Lakes, with increasing precipitation and evaporation competing as offsetting effects (Norton *et al.* 2019; Do *et al.* 2020; Groenwald *et al.* 2021). For example, Lake Michigan water levels increased nearly 2 m between 2013 and 2020, a range that essentially spans the entire range of lake levels experienced in recorded history, from record low to record high waters. In addition to causing widespread coastal damage from coastal erosion (e.g. Volpano *et al.* 2020, Troy *et al.* 2021, Theuerkauf *et al.* 2021), prolonged, multi-year high water periods can render low lying Great Lakes coastal areas persistently susceptible to flooding from regularly occurring processes such as large rainfall events, storm surge, seiches, and meteotsunamis (Melby *et al.* 2012; Bechle *et al.* 2016; FEMA, 2014; Huang *et al.*, 2022).

The combination of heavy rains with impervious surfaces and channelized streams has notably exacerbated a number of coastal flood events in recent years. Flooding around the Houston region during Hurricane Harvey was related to ineffective drainage systems within a heavily urbanized landscape (Zhang *et al.* 2018). Hurricanes Dorian and Florence led to widespread flooding across North Carolina, particularly in Lumberton where

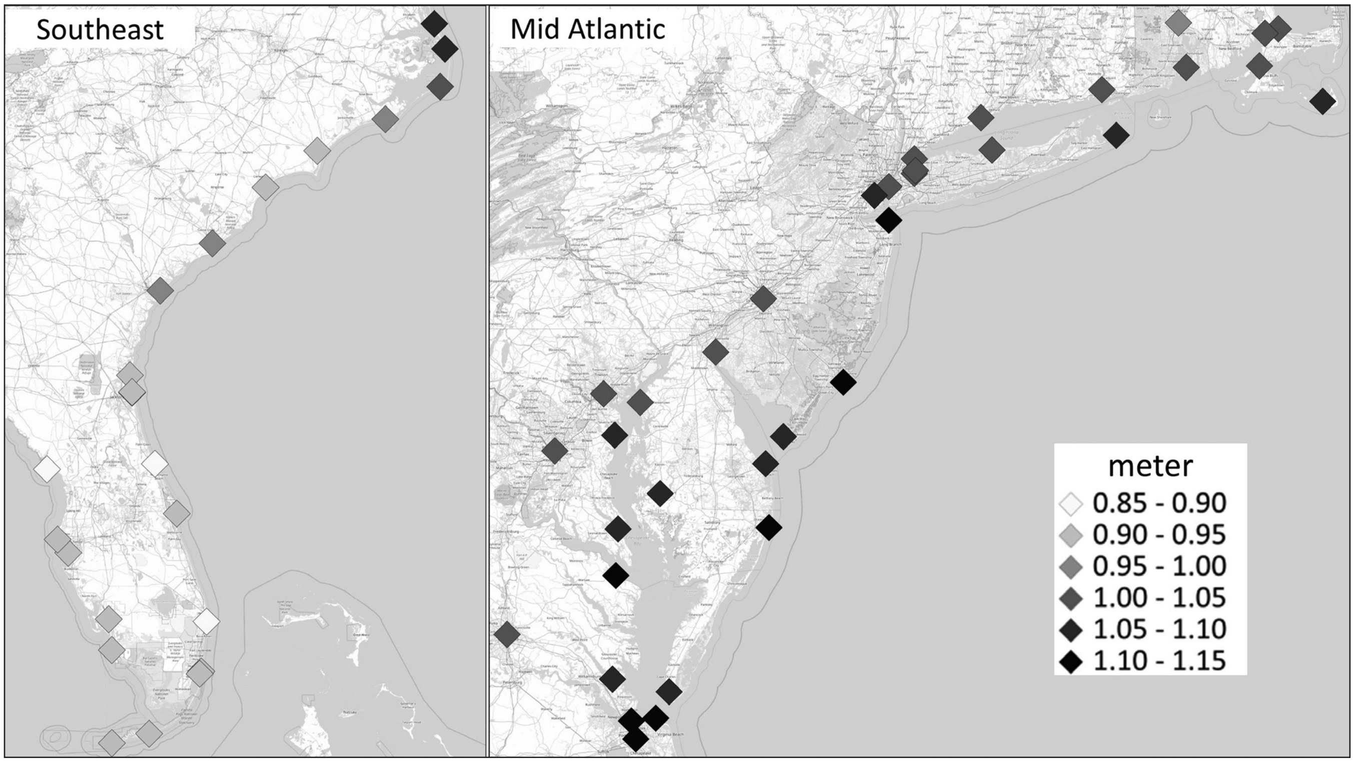

Figure 2. Median (50th percentile) projection of local sea-level rise (meter) at the location of tide gauges in the Southeast and Mid-Atlantic regions. Projections are shown for the end of 21st century under the high emission, fossil-fueled development scenario "Shared Socio-economic Pathway 5-8.5" medium confidence. The figure is generated based on data from the IPCC AR6 (Fox-Kemper *et al.* 2021).

officials assert Interstate 95 and levees served to funnel floodwaters towards the town (see *Edwards v. CSX 2020*). Across the United States, historical development patterns followed water-borne commerce along coasts, estuaries, and rivers. Today, many developed areas are especially vulnerable to a suite of flood impacts from different sources, different directions, and at different magnitudes.

Regional variability in forcing parameters

The intensity of coastal flooding is expected to increase with global sea level rise (Sweet *et al.* 2014; Buchanan *et al.* 2017; Wang and Marsooli 2021). The degree to which that occurs is less clear, but the IPCC AR6 (Intergovernmental Panel on Climate Change Sixth Assessment Report; Fox-Kemper *et al.* 2021) offers more information than previous reports on the probabilities of various future temperature and sea level scenarios.

The report outlines five main scenarios of future emissions known as "Shared Socioeconomic Pathways" (SSPs). These include a low-emissions scenario SSP1-19, which assumes deep cuts in carbon emissions by 2025, a high-emissions scenario SSP5-8.5, which assumes continued increases and a doubling of annual emissions by 2100, and three more moderate scenarios.

Each scenario is projected to trigger likewise sea level rise. Furthermore, each scenario includes a median project sea level rise as well as a range of possible values. Diversity and uncertainty inherent in some of the climate models used to project warming lead to a range of values rather than a single figure for each scenario. The median sea level rise projections for SSP1-1.19 and 0.38 m by 2100, while SSP5-8.5 projects 0.77 m by 2100, compared to a 1995-2014 baseline. Accounting for the range of values within all scenarios, global sea levels are expected to increase anywhere from 0.28 to 1.02 m by 2100.

Here, as an example to demonstrate the regional variability of sea level rise, we focus on the high emission, fossil-fueled development scenario "Shared Socio-economic Pathway 5-8.5" medium-confidence. Under this pathway, the median estimated projection of global mean local sea level rise (i.e. the level that has 50% chance to be equaled or exceeded) in 2100 is 0.77 m, relative to a 1995-2014 baseline.

Regional sea level rise could differ substantially from the projected global mean sea level rise, due to local factors such as vertical land motion and ocean dynamics (Figure 1). Overall, regional projections for the United States show that relative sea level rise along the West Coast would be smaller than the global sea level rise, especially in higher-latitude regions. In contrast, the projected local sea level rise for the East and Gulf Coasts would exceed the global sea level rise (Sweet *et al.* 2022). Along the East Coast, the local sea level rise for the mid-Atlantic region is larger than that for the New England and Southeast regions (Figure 2). In the Gulf of Mexico, the local sea level rise along the northern and western coasts (e.g. Texas to Alabama), would exceed that along the eastern Gulf Coast (e.g. Florida).

The largest and smallest projections of local sea level rise in the contiguous United States are, respectively, in the northern region of the Gulf of Mexico and the high-latitude region of the West Coast. According to the IPCC AR6, median estimated projections of local sea level rise (i.e. the level that has 50% chance to be equaled or exceeded), are 1.6 m in Louisiana and 0.29 m in Washington by the end of 21st century relative to a 1995-2014 baseline. Under the same high emission scenario, the largest and smallest projections for

Table 1.
Different categories of adaptation strategies and examples of strategies in each category; examples that are considered green are shaded.

Protection	Accommodation	Managed relocation
Beach and dune restoration	Elevate buildings/ infrastructure	Limit expansion of development
Berm-building	Flood-proof buildings/ infrastructure	Limited or no rebuilding after disasters
Living shorelines/ Oyster bed restoration	Elevate land and roadways	Property acquisition/ buy-outs
Marsh or mangrove restoration	Increase new construction setbacks	Prohibit hard shoreline structures
Sandbags	Increase density of salt-tolerant vegetation	Phased replacement of hard structures with green infrastructure
Seawalls/bulkheads/ revetments		

Hawaii are, respectively, about 1 m for the Island of Hawaii and 0.89 m for Kauai. Projections for Alaska show local sea level falling for the southern region, reflecting tectonic uplift. Local sea level rise is projected for the northern region of Alaska, where a broader coastal plain and lack of tectonic activity led to enhanced flood vulnerabilities (Figure 1).

Localized trends calculated specifically for the United States show a similar suite of relationships between RSLR between regions, with perhaps a higher magnitude of change occurring as a result of vertical land motion and changes to oceanic circulation (Sweet *et al.* 2022).

In addition to sea level rise, coastal flood hazards are influenced by changes in storm climatology related to global warming. Storm surge is a frequent cause of major damages along the East and Gulf Coasts. While storm surge flooding by extratropical cyclones occurs more frequently, the costliest storm surge flood events have been associated with tropical cyclones (TCs). Storm surge hazards due to TCs will increase in the coming decades, given that a warmer climate will lead to an increase in the intensity of TCs (Knutson *et al.* 2013; Gutmann *et al.* 2018; Knutson *et al.* 2020) and the frequency of very intense TCs (Knutson *et al.* 2015; Walsh *et al.* 2016; Sugi *et al.* 2017). These expected changes together with the effects of SLR will result in a substantial increase in coastal flood hazards along the East and Gulf Coasts (Lin *et al.* 2012; Marsooli *et al.* 2019; Marsooli and Lin 2020). For example, under the highest emission scenario by the end of 21st century, the combined effect of SLR and TC on flood hazards associated with climate change would result in TC-induced 100-year flood levels to become a 1-year flood level along the New England and mid-Atlantic coasts and a 1-to-30-year flood level along the Southeast Atlantic and Gulf coasts (Marsooli *et al.* 2019).

River and flash floods due to heavy precipitation or snowmelt are other types of flooding that frequently occur in coastal areas. According to the IPCC AR6 (Arias *et al.* 2021), it is very likely (90%-100% probability) that heavy precipitation events will intensify and become more frequent in the 21st century. Along the Gulf and East Coasts, heavy rainfall from TCs has historically resulted in river and flash flooding as most recently exemplified by flash floods in New York and New Jersey caused by heavy rainfall from the remnant of Hurricane Ida in 2021. This dual-source flooding is called compound flooding (Wahl *et al.* 2015). The amount of TC-induced rainfall is inversely proportional to the translation speed of TCs so that a more severe river/flash flooding could be caused by slow-moving or stalled TCs (e.g. Hurricanes Harvey in 2017 and Dorian in 2019). Historical data suggest that TCs in the North Atlantic have become slower (Kossin 2018) and more likely to stall near the coast (Hall and Kossin 2019), which could increase the potential of river and flash flooding. Wahl *et al.* (2015) found that changes in the joint distributions of storm surge and heavy rain events associated with climate change will result in an increase of flood potential during TCs.

Along the Pacific Coast of the U.S., "Atmospheric Rivers" (AR), narrow corridors of water vapor transport, contribute to extreme precipitation and flooding (Ralph *et al.* 2006). For example, on 9 January 2018 a 200-year rainstorm event caused massive, locally focused debris flows in creeks and streams in the coastal community of Montecito, California. Hundreds of residential, commercial and community structures were damaged or destroyed and more than 20 lives were lost (SBCOEM 2021). It is estimated that well over 1,000,000 cubic yards of debris inundated public and private properties, and/or flowed to the nearshore ocean waters. According to Oakley and Ralph (2018): "This (Montecito Debris Flow) event featured a north-south oriented atmospheric river with two moisture bands interacting with a closed low pressure system."

Goals of this white paper

This white paper aims to share flooding challenges that coastal communities face. The paper does not intend to provide an exhaustive review of the science, forcings, or policies on coastal flooding in the U.S.; rather, it aims to capture the perspectives of coastal communities. A broad overview of community impacts, perspectives, and select case studies are presented. The methods and results of a survey administered to coastal stakeholders are then presented to summarize current challenges, needs, and recommended next steps. The information provided may be helpful in prioritizing research investments in the topic area.

Community impacts

Coastal disasters can result in high fatalities and economic losses (Newton and Weichselgartner 2014). Population growth in the coastal zone combined with climate-change-induced flooding is leading to greater impacts to coastal communities in terms of damage to and loss of infrastructure, cultural resources, and ecosystem function that communities rely on for tourism and recreation. These impacts are generally greater in more vulnerable communities, which tend to exist in places with a history of disenfranchisement, large low-income or minority populations, or in regions with exceptionally high physical risk and lower economic development (Qiang 2019; Collins *et al.* 2018). Because SLR and climate changes will likely exacerbate these issues, contemporary studies on coastal flooding based in the United States often consider environmental and social justice components of hazard risk reduction and other improvements to resilience (Cutter 2012; Burton and Cutter 2008). These collective properties of vulnerabilities within certain communities have been studied in greater detail over the past few decades than any other time in modern coastal science, and are collectively known as social vulnerability (Stafford and Abramowitz 2017; Collins *et al.* 2018; Cutter *et al.* 2003)

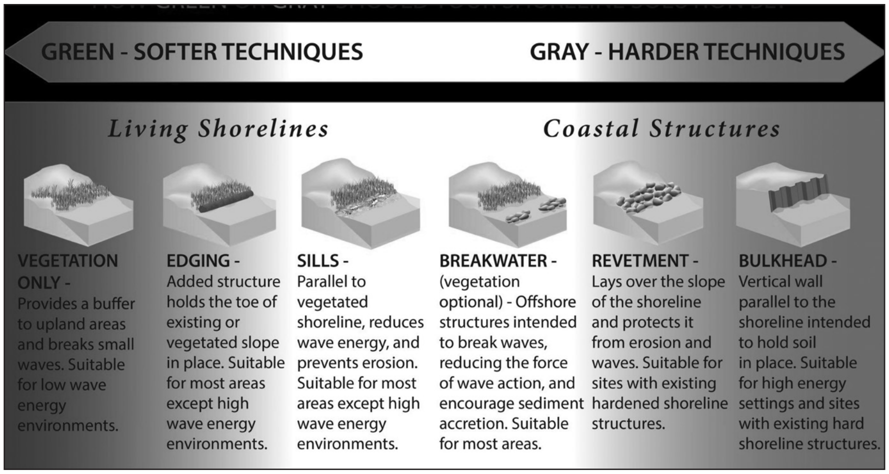

Figure 3. Adaptation choices can range from green to gray to hybrid, which are combinations from elements of both green and gray approaches (NOAA 2022b).

Flood mitigation approaches

Flood mitigation options range from policy and regulatory changes to individual adaptation projects to mitigate impacts from storms and sea level rise (NOAA 2022a). Adaptation strategies typically fall into four categories: protection, accommodation, managed relocation (or retreat), and do nothing (Table 1). Protection involves defense/protection actions to mitigate loss of natural or developed resources (e.g. hard or soft solutions). Accommodation changes to structures, infrastructure, or policies to allow for natural hazards to occur while minimizing their impact. Managed relocation or retreat either prevents or gradually removes development from the coast, whereas do nothing is a no action approach. Most strategies have varying long-term adaptive capacity and potential SLR accommodation (e.g. how flexible is the approach and how much SLR can it accommodate). Adaptation strategies will vary substantially due to the variable land uses, coastal typology, exposure to waves, erosion potential, and community staff capacity and funding.

Engineered project-based strategies can be soft, nature-based, or green (e.g. beach and dune restoration, wetlands, living shorelines) as opposed to hardened or gray structures (e.g. seawalls, storm barriers) (Figure 3). Hybrid approaches that combine the two are also increasingly common. Policy changes can also be considered a form of adaptation. The intention of adaptation strategies can be to restore ecological habitat, mitigate flooding, and/or manage erosion and damage to natural resources and public/private property.

Adaptation planning evaluates which measures can be used to alleviate vulnerability in each sector and their secondary impacts that affect the rest of the community. An interwoven tapestry of measures is needed to develop a sustainable community adaptation plan (Figure 4). In considering secondary impacts, it is also important to ensure that adaptation strategies are socially equitable and do not benefit one population to the detriment of another, or reinforce existing environmental and societal inequities. Good adaptation planning is collaborative and considers the interconnected ecological, social, political, and economic systems, including adjacent jurisdictions. Social and geomorphological problems can arise if disparate shoreline policies (e.g. protect vs. retreat — see below) are adopted between neighboring communities.

FLOOD MITIGATION PROGRAMS AT THE FEDERAL AND STATE LEVELS

Several federal and state agencies have established or funded programs that address coastal flooding and flood mitigation strategies (FEMA, NOAA, and New Jersey, among others). The programs from the U.S. Army Corps of Engineers and the Florida Department of Environmental Protection highlighted emphasize extensive scientific and planning approaches to reducing flood impacts to coastal communities.

Example: Federal

The U.S. Army Corps of Engineers (USACE) has led successful nationwide efforts to develop comprehensive, systems-based approaches to coastal flood control for decades. In addition to levees, Coastal Storm Risk Management (CSRM), or federal beach nourishment and dune restoration, projects are an important nature-based flood mitigation strategy that involve USACE and state and local managers/sponsors. Over 1.5 billion cubic yards of sand have been placed along U.S. beaches by both federal and non-federal entities to reduce beachfront flood risk during the last century (Elko *et al.* 2021). Since 2000 in South Carolina, for example, storm surge and tides are not attributed to damages nor injury nor deaths (Table 2); compared with the 1989 landfall of Hurricane Hugo which caused 13 impact fatalities (mostly drownings) and $8 billion to $10 billion in damages (CDC 2022; NOAA 2022c). Since the passage of Hugo, there has been a significant federal, state, and local investment in many coastal management policies (mandatory evacuation orders; more robust coastal building codes) and projects (beachfront flood mitigation) (SC DHEC 2022). These large-scale beach and dune restoration projects are attributed at least in part to the reduced flood risk along the South Carolina beachfront (Kana and Kaczkowski 2019). A similar national flood risk reduction investment is needed on the backside of barrier islands and along estuarine shorelines to increase coastal resilience to future sea level rise.

To begin to address this need, USACE has developed the concept of Engineering With Nature (EWN) which calls for an ecosystem-based approach, whereby USACE, in collaboration with partners and stakeholders, seeks to understand and use natural processes in order to achieve project objectives within coastal systems (Bridges *et al.* 2021; Banks *et al.* 2013). Historically, institutional constraints, such as the challenges associated with interagency coordination, required

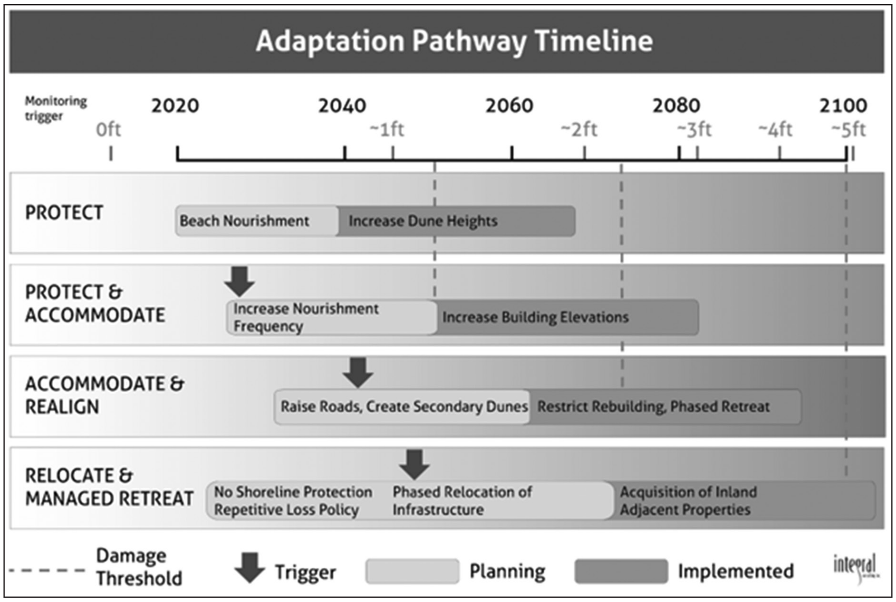

Figure 4. Example of an adaptation pathway that is intended to aid coastal communities in long-term planning for adaptation. The pathway lays out a timeline that identifies triggers and thresholds when a change of strategy will be required, giving the communities time to plan in advance (Hapke *et al.* 2021).

studies for project implementation, and lack of trust between the USACE and relevant stakeholders, may have further constrained the timing and scope of projects. However, recent efforts are improving interagency coordination building coastal resilience.

In 2013, the Coastal Engineering Research Board (CERB) recommended a three-tiered system for an assessment of the resilience of coastal engineering, environmental, and community infrastructure to coastal storms and long-term evolutionary processes such as population dynamics and climate change (Larkin *et al.* 2015; Rosati *et al.* 2015). The tiers include a framework to assess overall coastal community resilience, a targeted assessment of the community, ecological, and engineered coastal protection structures, and a detailed model of interconnected physical infrastructure evaluated under various simulated disturbance scenarios to understand expected performance (Schultz *et al.* 2012). Most projects are designed to provide flexibility through adaptive management, ensure redundancy of resilient features, and support creative incentives to promote the use of resilience measures.

Example: State

The Florida Resilient Coastlines Program (or "Resilient FL"), administered by the Florida Department of Environmental Protection (FDEP) Office of Resilience and Coastal Protection, produced an Adaptation Planning Guidebook and a grant program (FDEP 2018). Communities and regional entities have utilized this process to undertake various stages of adaptation planning, examining vulnerabilities and risks associated with flooding from storms, tides and combinations thereof (Figure 5). In 2021, the Florida Legislature passed Senate Bill 1954, allocating $1 billion to establish the Resilient Florida Program, intended to comprehensively prepare both coastal and inland Florida for the impacts of climate change. As part of the Resilient Florida Program, a statewide coastal vulnerability analysis dataset will be compiled. The community vulnerability analyses can be undertaken by individual communities using grant funding, and are required to follow specific requirements, including evaluating the risk to critical assets. The assessments must evaluate the vulnerabilities at both the NOAA (2017) intermediate-low and intermediate-high scenarios and include two planning horizons, 2040 and 2070.

Table 2.

Flooding synopsis in South Carolina by type from January 2000 to September 2021 (NOAA 2021).

Event type	Deaths	Injuries	Property damage	Crop damage	Event type count
Coastal flood	0	0	$450,000	0	56
Flash flood	22	39	$163,908,390	$24,879,720	470
Flood	2	1	$37,430,500	$5,009,600	195
Storm surge/tide*	0	0	0	0	12
Total	24	40	$201,788,890	$29,889,320	733

*Storm surge statistics may be underrepresented because it is occurring in conjunction with other types of flooding and/or because of investment in beachfront flood mitigation.

Select community studies

Many large U.S. cities are investing in projects focused on improving or installing infrastructure to reduce coastal flooding. Post-Katrina (2005) improvements to the New Orleans and South Louisiana levee systems cost approximately $14 billion, but only renovated an existing system. In addition to raising the East River Park in New York City by 8-10 feet, 2.4 miles of seawalls, floodgates, and other barriers are expected to be constructed by 2025 along the East River to protect Lower Manhattan from scenarios of catastrophic flooding, such as from Hurricane Sandy (2012), with integrated flood protection for the dense network of above- and below-ground infrastructure and over 110,000 residents of the area (Thomson Reuters 2021). Along the Texas coast, a system of levees, flood gates, and improved drainage networks designed by USACE following Hurricane Ike (2008) would provide multiple lines of defense and mimic the models enacted by Louisiana as well as the Netherlands at a price tag of nearly $30 billion (TXGLO 2022).

The common thread between these examples is the sheer value of assets exposed to coastal flooding. For instance, Miami-Dade County (MDC) is one of the most affluent flood-vulnerable jurisdictions in the United States (Hanson *et al.* 2011; Ghanbari *et al.* 2020). During the 21st century, at least one severe storm has impacted MDC every two years. As a result, the county has spent more than $326 million for on-site adaptation projects from 2012-2016 (Kim 2020). MDC employs a variety of flood adaptation approaches spanning from traditional hard "gray" infrastructure (e.g. seawalls, storm barriers) to nature-based or green infrastructure (e.g. wetlands, living shorelines), as well as hybrid adaptation strategies that incorporate both green and gray features. The City of Miami Beach plans to invest $500 million in the coming years for sea level rise adaptation that include raising roads, installing pumps, and upgrading sewer line connections (Fu and Song 2017).

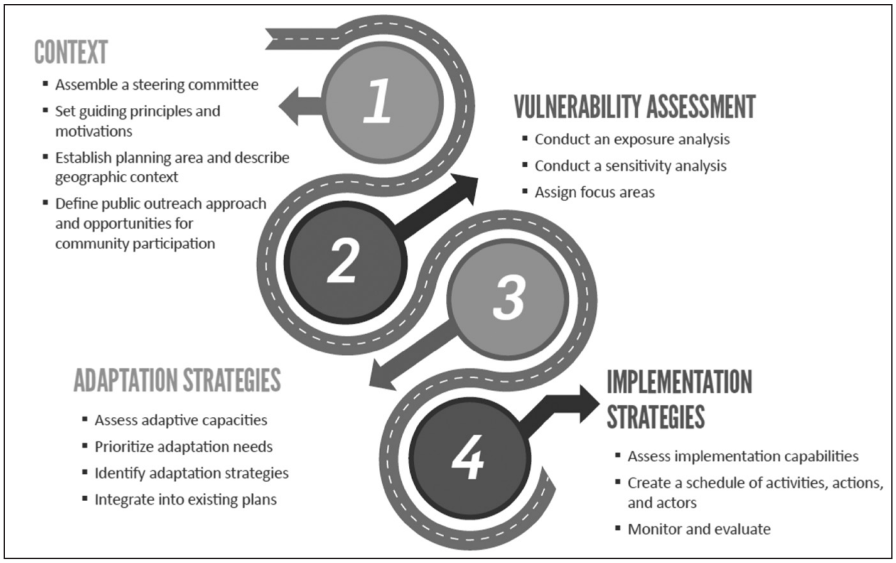

Figure 5. Florida's steps to develop adaptation plans (from FDEP 2018).

A typical coastal flood mitigation strategy is beach and dune restoration, which relies on the ability of systems to protect coastlines from hazards while also providing benefits such as habitat enhancement and increased recreational space, and are more aesthetically pleasing than hard structures (O'Donnell 2017). For example, along Hatteras Island, North Carolina dune restoration projects have been used to maintain foredune continuity and help reduce overwash frequency and mitigate damages to NC 12 — a main thoroughfare connecting Cape Hatteras National Seashore to the mainland (Sciaudone *et al.* 2016). Beach nourishment is one of the most commonly implemented soft-adaptation options on the oceanfront, as it adds sediment within the littoral system and allows natural forces to continue to operate (Elko *et al.* 2021). In locations with low to moderate rates of beach erosion, nourishment can be used to mitigate flooding as well as bolster recreational value of oceanfront shorelines. At Myrtle Beach, South Carolina, a low background erosion rate (e.g. < 1 m horizontal shoreline recession per year) means nourishment volumes can outpace the removal of sand from the active beach-dune system. To this point, multiple rounds of nourishment completed from the 1980s to present day have advanced the high-water line in portions of Myrtle Beach over 50 m seaward over the same period (Kana and Kaczkowksi 2019).

California has adopted a number of different strategies to address coastal flooding across various environments. For example, wetland restorations are analogous to beach nourishments in that they can reduce flood frequencies and re-establish ecological connectivity within diminished systems. The low-lying South Bay region is at risk of flooding due to sea-level rise, however restoration efforts in this region potentially conflict with new levee standards that threaten to further disconnect existing and restored wetlands from natural freshwater seepage characteristic of tidal wetlands in the region. To combat this potential issue, horizontal levees (Battalio *et al.* 2013) have been designed combining a traditional flood-control levee core with a seaward ecotone slope grading smoothly to a low marsh elevation. The slope is planted with native wetland and transitional species, restoring degraded habitats while providing adaptive capacity to allow wetlands to adjust landward as sea levels rise. Some designs allow the ecotone slope to undulate slightly, creating microhabitats within the slope that can increase overall habitat diversity.

However, horizontal levees may have limited application in some areas due to the larger area required. In the San Francisco Bay area of California, wetland restoration is of particular interest given a >90% loss of all wetland areas largely from development (USGS 2022). In consideration of the climate of the San Francisco Bay region, many of the proposed horizontal levees are paired with freshwater discharge points from wastewater treatment facilities. Clean wastewater is discharged along an infiltration trench near the top of the slope, re-establishing the lost freshwater seepage that many wetlands in the region rely on. Officials in the Montecito community in California acknowledge that "the impacts of changes in climate and weather contributing to extreme rainstorm events affecting flooding, need to be taken into account in multiple plans and planning efforts, including coastal hazard mitigation, Climate and SLR Adaptation, and regional sediment management plans" (Local Government Commission 2019).

Some communities are also adapting nonstructural solutions to coastal flooding, such as planning, building codes, zoning, setback, and buyouts. Since 2015, when high-tide flooding became a major concern for the City of Folly Beach, this small South Carolina beachfront community adopted six long-term plans which establish goals and objectives to manage the effects of climate change and sea level rise. In 2018, the Folly Beach City Council approved an unprecedented nine-month coastal building moratorium on the development of properties on either the beach or the marsh while dune and marsh management plans were adopted. This proactive planning process resulted in the adoption of 25 new land use regulations including ordinances for setbacks, buffers, septic tanks, marsh-island development, dune protection, seawalls, increased freeboard and other regulations related to increasing resilience along the beach and marshfront (Elko 2019). Many other coastal communities in South Carolina have also begun the adaptation planning process for anticipated future sea level rise-related impacts (Watson *et al.* 2021).

A myriad of strategies is available and implemented across the U.S. and can vary based on a multitude of factors including spatio-temporal scale of the coastal flooding hazard. A national-scale understanding of perspectives and challenges that coastal communities face due to flooding will to help identify gaps in knowledge and disseminate information on potential strategies for communities, managers, and stakeholders.

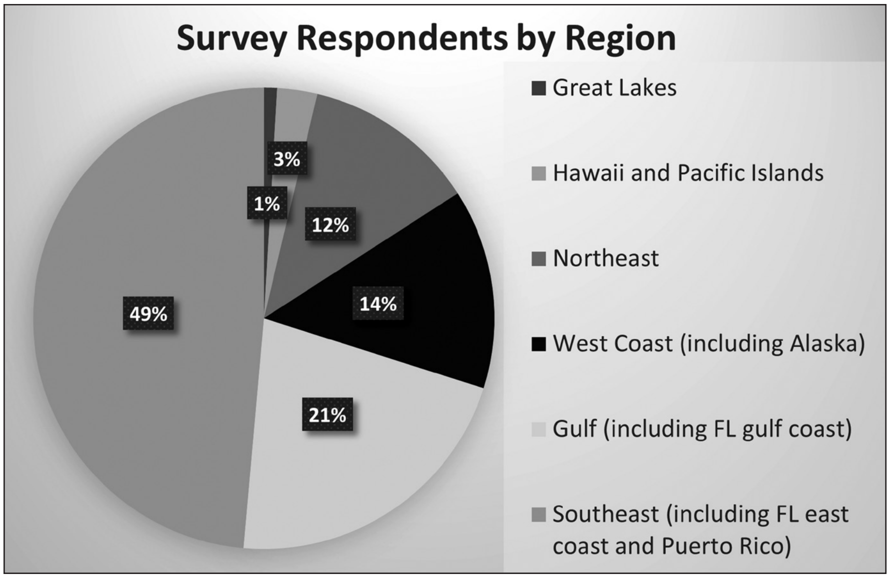

Figure 6. Geographic distribution of the 106 survey respondents.

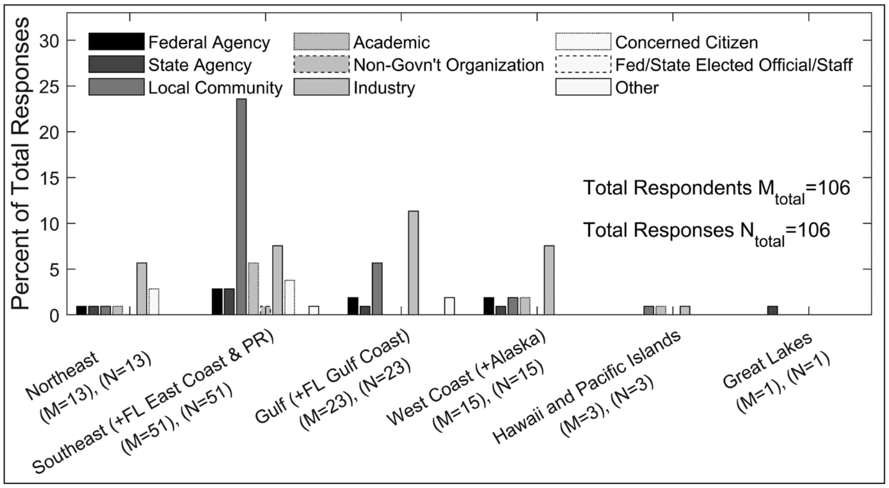

Figure 7. Affiliations of the survey respondents.

SURVEY METHODOLOGY

In late 2021, ASBPA administered a survey of coastal stakeholders to assess specific community challenges and needs related to coastal flooding. The survey targeted coastal professionals from the local, regional, state, and federal levels. Respondents included local planners, managers, engineers, administrators, and elected officials, as well as representatives of coastal organizations, consultants, and academics with a focus on coastal research. The survey was promoted to and taken by members of organizations with a coastal and, more specifically, often beachfront perspective. Traditionally, for example, the ASBPA has focused on beach and shore preservation via beach nourishment and dune restoration.

The first section of the survey aimed to understand respondents' demographics, organization and job roles and responsibilities and included questions to categorize the respondents' affiliation, organization name, title, department, and job duties. The next section contained general questions about coastal flooding challenges. This was followed by a series of questions as to whether the communities were 1) implementing, or 2) interested in, flood mitigation approaches described in previous sections, such as infrastructure, natural or nature-based features (NNBF), policies and plans, data and research, and funding solutions. Examples of some question phrasing included: "Which of the following natural or nature-based flood mitigation strategies is of interest, but has not yet been implemented by your community?"

SURVEY RESULTS

The survey yielded 106 total responses, with the typical respondent completing the survey in 7.5 minutes. This section characterizes the survey population, reviews answers to general questions about coastal flooding, and details responses to flood-mitigation strategy implementation questions.

Surveyed population

Survey participants were asked to answer several questions to describe their affiliation, job duties and title, and region of the U.S. The geographic location of survey respondents illustrates the representation of a national scale survey with regional perspectives (Figure 6). The majority of respondents were from the Southeast (including the Florida east coast and Puerto Rico, 49%) and the Gulf (including the Florida Gulf coast, 21%). About 14% were from the U.S. west coast and Alaska, and 12% were from the Northeast. A few respondents were also from Hawaii and the Great Lakes.

Most responses were from industry and local community representatives (34% each), followed by the academic sector (10%) (Figure 7). Federal (8%) and state (6%) agency staff also represented 13% of respondents. Except in the Southeast region where most participants of the survey were from local communities (county, town, homeowners' assoc.), most participants from other regions were affiliated with industry. Most participants from the Southeast region self-identified as administrators or planners; whereas Program/Project Manager was the most common job duty in other regions (Figure 8). Together these characterizations suggest a group of survey respondents that represent coastal practitioners.

A majority of respondents indicated that their community includes an underserved population or neighborhood (54%) or nearby communities do (25%). Overall, the survey populations' affiliations, job duties, and region of the U.S. indicate that survey results represent the opinions of coastal practitioners on a national scale. This basic characterization of the respondents provides the appropriate perspective for the substantive analysis of U.S. communities' coastal flooding challenges.

Overview of survey responses

In general, survey respondents indicated that flooding is either challenging (>60%) or extremely challenging (>20%) relative to other coastal management challenges they face. Less than 3% of respondents indicated that flooding was not very or not at all challenging. Despite this, only 24% of respondents' communities had a coastal flooding adaptation plan, 30% were developing one now, and <20% were planning to develop one in the future. The remainder were either not supported by their community to pursue an adaptation plan, didn't have one, or weren't sure whether they had one.

• *Flood mitigation strategies:* In terms of gray infrastructure approaches, a common implemented strategy in all regions is "improving drainage systems (prevent saltwater backflow, manage stormwater with retention areas, etc.)." In the Southeast and Gulf coasts, this strategy dominates the other gray-mitigation strategies (Figure 9). In contrast, the Northeast and West Coast respondents selected public and private seawalls/bulkheads. "Improving drainage systems" is also the most desired gray mitigation strategy among the survey participants from the Southeast and Gulf regions (Figure 10). "Erosion control structures" is the most common strategy of interest for West Coast respondents but the least interesting strategy to respondents from the Northeast.

In terms of nature-based strategies, all regions selected "beach nourishment and dune restoration" as the most commonly implemented green flood mitigation strategy (Figure 11). Across all regions, both living shorelines and vegetative buffers were selected as the next tier of strategies implemented. "Beach nourishment and dune restoration" was the strategy of least interest among survey participants (Figure 12). Most regions identified thin layer placement on marshes, living shorelines, and hybrid projects on estuarine shorelines as flood mitigation strategies of interest. This may imply that the majority of flooding in coastal communities is occurring on the estuarine shorelines rather than on the beachfront.

• *Data and research:* Except in Hawaii and the Pacific Islands — where respondents indicate "citizen science" as the most commonly conducted research in the region (Figure 13) — responses from other regions indicate that most research has aimed to develop infrastructure improvements. Few respondents indicated that no research has been conducted.

Additionally, survey respondents indicated that the most common data or research being collected/conducted by the communities are engineering analysis for infrastructure improvements (e.g. drainage studies) and specialized data sets (e.g. local water level measurements). Many of the survey respondents from the southeast are part of a water level observations partnership between ASBPA and the Southeast Coastal Ocean Observing Regional Association (SECOORA 2022).

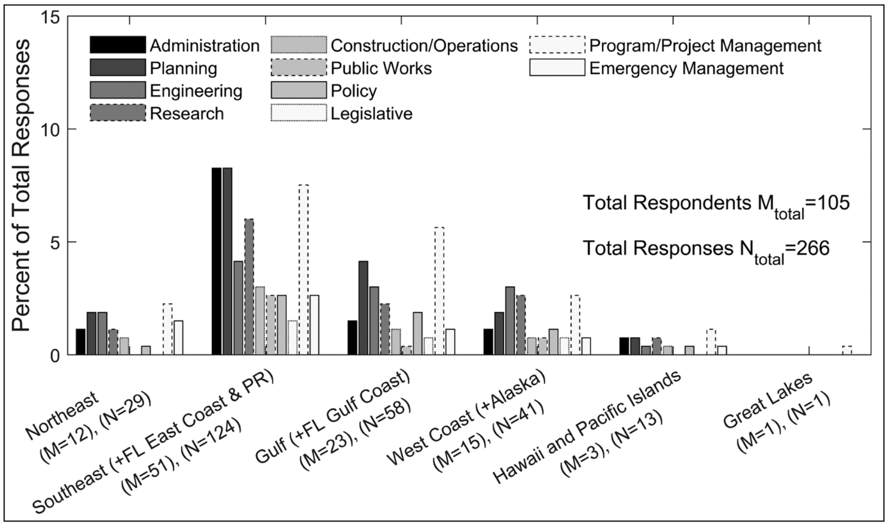

Figure 8. Self-identified primary job duties of respondents.

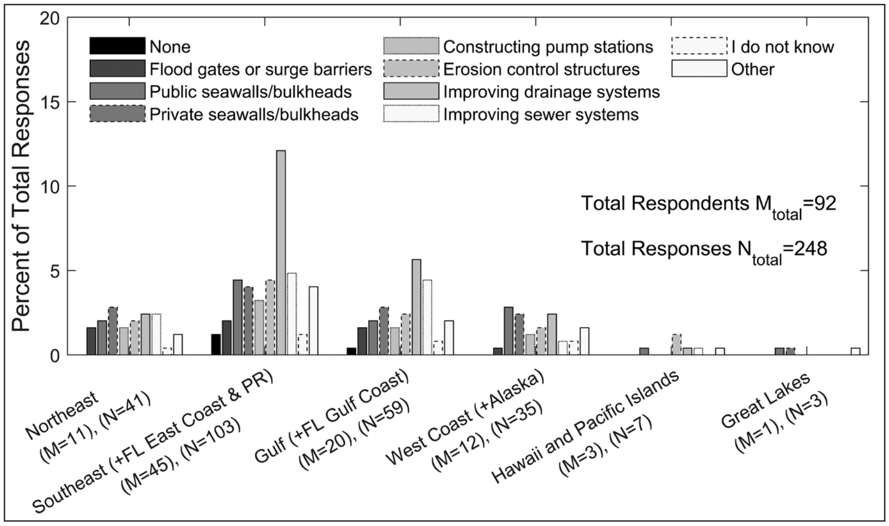

Figure 9. Gray infrastructure flood mitigation strategies implemented by region.

NOAA funding and tools such as the Sea Level Rise Viewer have also been helpful in addressing coastal flooding. NOAA's Digital Coast was developed to meet the unique needs of the coastal management community and the website provides not only coastal data, but also the tools, training, and information needed to make these data truly useful. Datasets range from economic data to satellite imagery with visualization tools, predictive tools, and tools that make data easier to find and use. Training courses are also available online or can be brought to the user's location. However, site- or regional-specific implementation will vary depending on the extent and/or cause of flooding, funding, and community support.

• *Funding for coastal flood mitigation*: Finally, survey respondents indicated that they had attempted to utilize the following funding and/or financing solutions for coastal flood mitigation: federal grants (e.g. FEMA hazard mitigation), state-level grants (e.g. coastal management programs), private foundation and/or non-profit grants (e.g. The Nature Conservancy), public-private partnership (defined as a cooperation between a public-sector agency and a private-sector entity that allows government and businesses to work together to provide a service to the community), voluntary surcharge (defined as a small charge (~1%) or fee (~$2) added to a customer's retail, hospitality, or lodg-

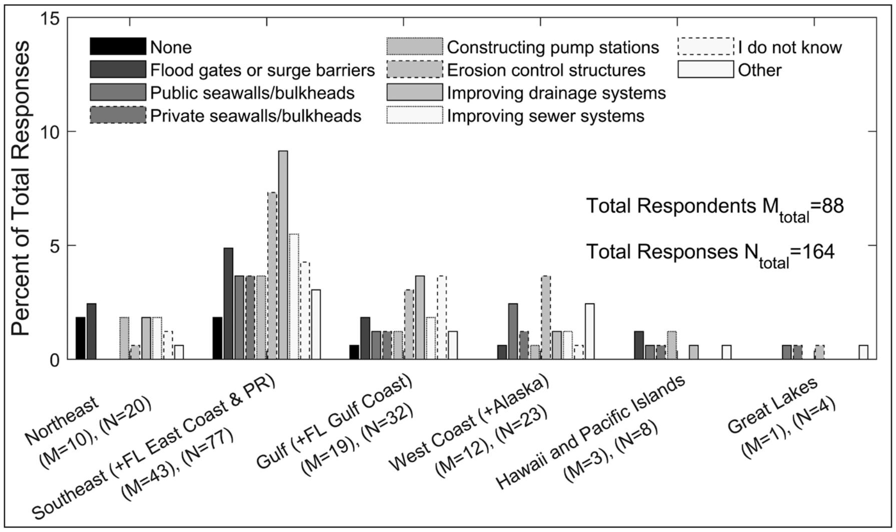

Figure 10. Gray infrastructure flood mitigation strategies of interest to respondents by region.

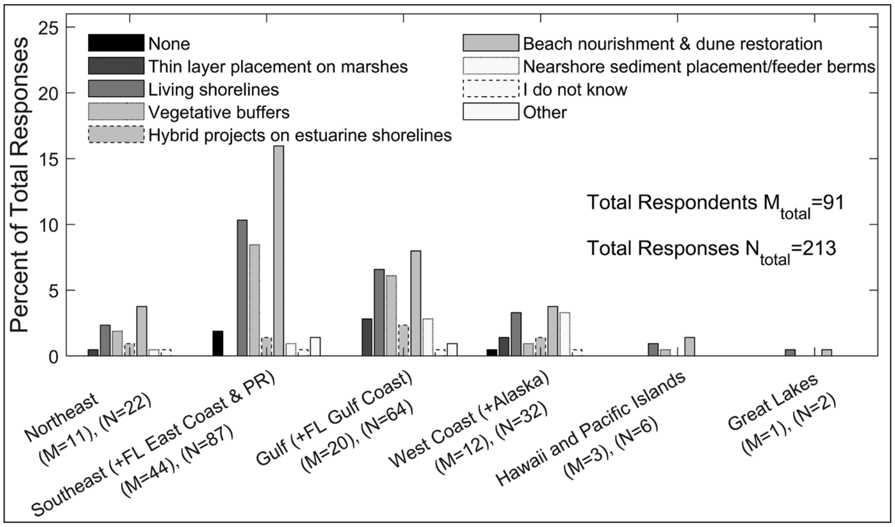

Figure 11. Nature-based flood mitigation strategies implemented by region.

ing bill), loans from a private banking, philanthropic source, or state/federal government (including state revolving funds), and bonds (e.g. environmental impact bonds, green bonds).

The Federal Emergency Management Agency (FEMA) Building Resilient Infrastructure and Communities (BRIC) is one of FEMA's Hazard Mitigation Assistance Grants programs. FEMA defines hazard mitigation as any sustainable action that reduces or eliminates long-term risk to people and property from future disasters. BRIC guiding principles are supporting communities (states, local communities, tribes and territories) through capability- and capacity-building; encouraging and enabling innovation; promoting partnerships; enabling large projects; maintaining flexibility; and providing consistency. The program provides technical guidance to local communities to promote the use of nature-based solutions for flood mitigation (FEMA 2021).

Additional resources for information and funding include (but are not limited to) the National Fish and Wildlife Federation (NFWF) National Coastal Resilience Fund, State Coastal Programs, Coastal Zone Management Act Grants, NFWF Great Lakes Fund, U.S. EPA Great Lakes Restoration Initiative Grants, Ecological Impacts to Sea Level Rise Grants, the 2021 Bipartisan Infrastructure Law (BIL), Community Development Block Grants (CDBG), and Housing and Urban Development.

DISCUSSION

The co-benefits that result from restoration of marsh or wetland ecosystems, like flood mitigation as well as biodiversity benefits are of great interest to communities and funding entities. Some of these benefits include improved water quality, habitat enhancement, and perhaps even carbon storage.

Large-scale beach and dune restoration projects have reduced flood risk on a national scale through the placement of over 1.5 billion cubic yards of sand by over 465 U.S. beach communities during the last century (Elko *et al.* 2021). A notable shift in priorities of coastal communities from beach erosion to water-related challenges was recorded in a previous ASBPA survey on coastal management challenges (Elko and Briggs 2020). A similar and more specific shift was revealed through the survey conducted with this white paper.

In terms of nature-based strategies, survey respondents from all regions selected "beach nourishment and dune restoration" as the most commonly implemented green flood mitigation strategy. Beach nourishment and dune restoration was the future strategy of least interest to the survey respondents. Thin-layer placement on marshes, living shorelines, and hybrid projects on estuarine shorelines were the flood mitigation strategies of most interest. This shift in priorities is enlightening given that the respondents to both surveys are members of organizations with a focus on beachfront management. Perhaps the shift is not surprising given that beachfront erosion challenges have an accepted and well-funded mid-term solution in beach nourishment, and fairly well documented and recognized co-benefits of recreation, tourism/economics, and habitat restoration in addition to flood mitigation. Until recently, flooding challenges in low-lying, non-beachfront coastal areas have not yet been prioritized or systematically addressed with a similar large-scale, replicable solution that has been implemented by hundreds of coastal communities.

Although a comprehensive analysis of the causes of flooding was beyond the scope of this paper, certain questions need to be addressed to best support communities in the development of various adaptation strategies. For example, what are the projected futures for existing and new (created or restored) natural and nature-based features? Research and data products that directly inform decision making are critical at all levels. Addressing coastal hazard mitigation, coastal climate change, and sea level rise adaptation should be integrated into comprehensive plans for flood mitigation. Furthermore, communities should adapt strategies with equity considerations, amplify local and/or indigenous perspectives into their plans, and ensure funding is available at the state and local level with direct technical assistance to under-resourced coastal communities.

SUMMARY

Coastal flooding, from both extreme events and sea level rise, is one of the top management challenges facing U.S. coastal stakeholders today. The intensity of coastal flooding is expected to increase with global sea level rise with disproportionate impacts likely in vulnerable, underserved communities. This paper focuses on flooding challenges from the perspective of coastal communities. Flood mitigation approaches typically fall into four categories: protection, accommodation, managed relocation (or retreat), and do nothing. Options exist to incorporate green or soft approaches such as beach or marsh restoration in all four categories.

Federal- and state-level programs now exist to increase the resilience of coastal communities. The myriad of flood mitigation strategies that have been implemented across the U.S. vary based on a multitude of factors including spatio-temporal scale of the coastal flooding hazard. A national-scale understanding of perspectives and challenges that coastal communities face due to flooding will help identify gaps in knowledge and disseminate information on potential strategies for communities, managers, and stakeholders.

ASBPA administered a survey of 106 coastal stakeholders from around the U.S. to assess specific community challenges and needs related to coastal flooding in late 2021. A majority of respondents indicated that their community includes an underserved population or neighborhood (54%) or nearby communities do (25%). While the vast majority of survey respondents indicated that flooding was a major challenge, only 24% of respondents' communities have a coastal flooding adaptation plan. Improvements to drainage systems are the most commonly implemented gray infrastructure strategy in the Southeast and Gulf coast regions. Respondents from all regions noted that beach and dune restoration has been the most widely implemented nature-based flood mitigation strategy. Interest is now high in other nature-based solutions with application in low-lying, vulnerable coastal areas such as thin-layer placement on marshes, living shorelines, and hybrid projects on estuarine shorelines.

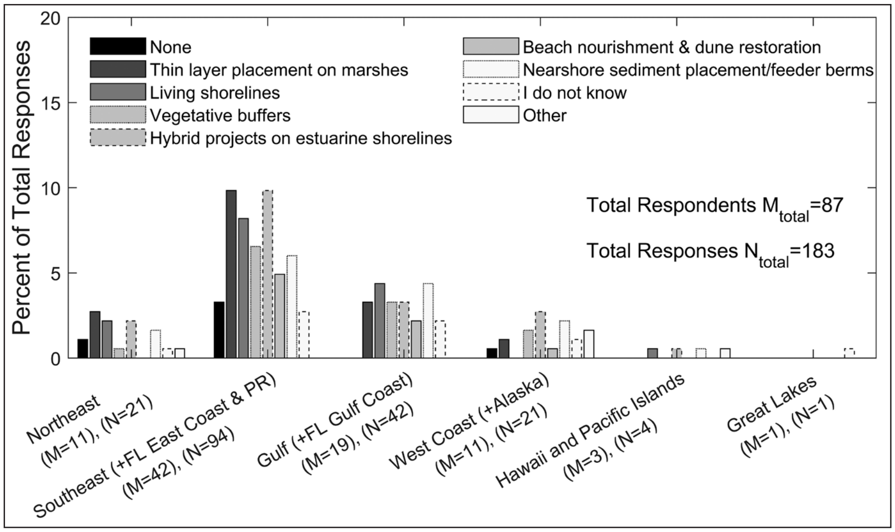

Figure 12. Nature-based flood mitigation strategies of interest by region.

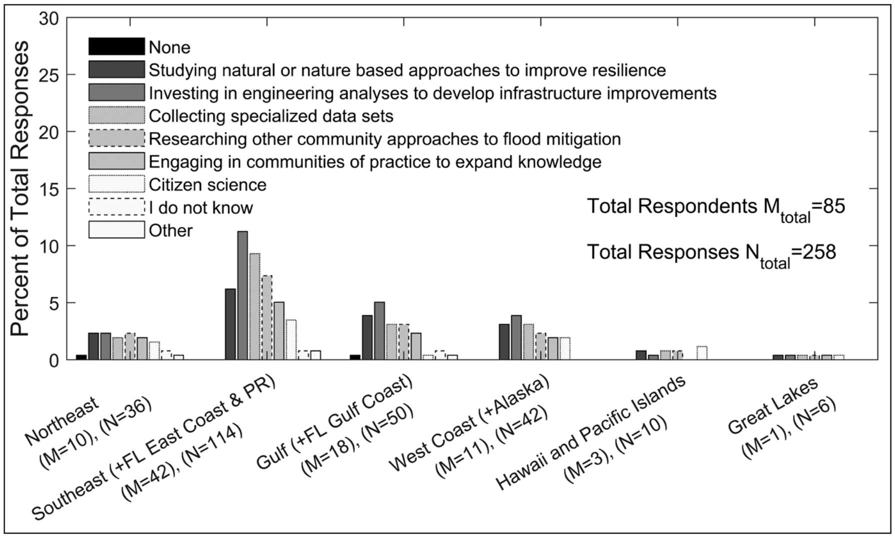

Figure 13. Research conducted related to flooding and mitigation strategies.

This paper does not intend to provide an exhaustive review of the science, forcings, or policies on coastal flooding in the U.S.; rather to capture the perspectives of coastal communities and to inform and prioritize future research investments related to coastal flooding. To support communities in the development of adaptation strategies, research is needed to understand, for example, the combined water threats and impacts from increasing storm intensities, watershed precipitation and runoff, and increasing coastal wave and run-up forces. Research and data products on the nature-based flood mitigation strategies of greatest interest, thin layer placement on marshes, living shorelines, and hybrid projects on estuarine shoreline, should be translated and disseminated to coastal decision makers. Addressing coastal hazard mitigation, coastal climate change, and sea level rise adaptation should be integrated into comprehensive plans for equitable flood mitigation.

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