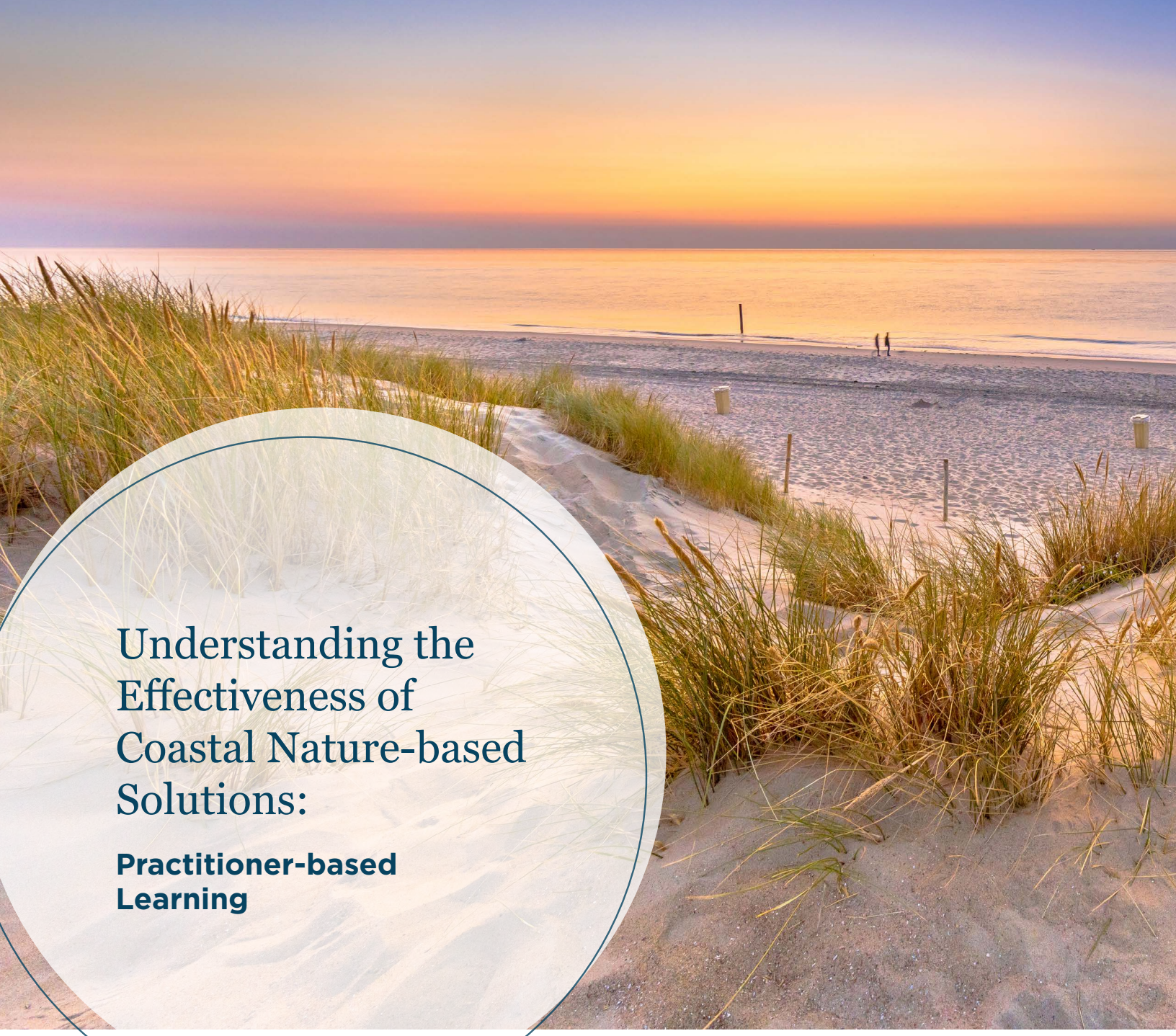

Understanding the Effectiveness of Coastal Nature-based Solutions:

Practitioner-based Learning

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Highlights

Nature-based solutions (NbS) use nature and natural processes to address societal challenges and protect ecosystems. More specifically, they provide physical risk reduction benefits, they create or maintain habitat and biodiversity, and they provide social and equity benefits to the communities that interact with and maintain them.

This report summarizes the state of knowledge of this topic in the context of coastal climate adaptation in the United States and identifies numerous challenges and opportunities. Findings are useful for practitioners, non-governmental organizations (NGOs), climate service providers, state regulators, federal agencies, and myriad institutions and researchers engaged with NbS. We address two main Action Areas for NbS implementation: understanding and evaluating effectiveness, and identifying the challenges that can be overcome to accelerate coastal adaptation with NbS.

EVALUATING EFFECTIVENESS OF NBS

What does it mean for a nature-based solution to be "effective?" To answer this question, we asked people working on NbS across the US states and territories and sovereign Native Nations what it takes for an NbS to thrive, conducted a literature review, and asked a group of NbS experts to provide feedback throughout our inquiry. From a synthesis of the literature and these conversations, we found that effectiveness comes down to four simple pillars: physical, ecological, economic, and social. Without considering each of these, a project will ultimately not have the support it needs to fulfill its goals.

ADDRESSING CHALLENGES IN NBS IMPLEMENTATION

We identified three specific bottlenecks where action is constricted and can be facilitated with specific and actionable measures.

First, **GOVERNANCE** is the most critical opportunity for accelerating applications of NbS. Practitioners need governance structures that meet ongoing systemic needs and address historical, current, and future contexts. This includes supporting Indigenous knowledges and practices, and moving planning from preserving a past baseline to flexibly managing for an adaptive future. Systems-based approaches can support adaptive management, but are only possible where regulations and institutions support them.

- At the federal level, this could require changing the approach to Benefit Cost Analysis (BCA) to reflect and value the vast and varied co-benefits of NbS–including those that cannot be assigned a monetary value.
- At the state level, the agencies that permit coastal infrastructure projects need political and data-driven support to change regulations and rules to integrate and support NbS where such solutions are appropriate.
- At the local level, NbS need to be integrated into municipal planning processes and documents such as comprehensive plans and hazard mitigation plans. Municipal decision makers also need information on why and how to request and implement NbS projects.

At every level of planning, a fundamental shift needs to occur in both spatial and temporal scales. Ideally, planning for coastal protection and environmental enhancement needs to happen at the landscape scale: individual projects need to be coordinated to understand and evaluate impacts and opportunities. And planning needs to integrate an adaptive baseline to adjust for future climate conditions. Shoreline habitat will disappear in the coming decades: planning has to enable humans AND ecosystems to relocate as waters rise.

Second, we cannot address governance without better **COMMUNICATION** and **COLLABORATION**. Collaboration is frequently the unpaid and invisible labor of NbS — it is a critical ingredient for success and lack of collaboration is often cited as a significant limitation to progress.

- At the federal level, agencies can explicitly fund collaboration, community-building, and convening across climate service organizations.
- Cross-sectoral education and training needs to happen at the state level in universities and colleges to cross-pollinate engineering and ecological knowledge. NbS training should also include landscape architects, engineers and planners who are providing the first draft of solutions to towns, cities, and private landowners.
- At the local level, stakeholders are not convinced by the plethora of existing projects around the world–they need local social proof. Clear and achievable goals that address the co-benefits of NbS from project inception are central to uniting diverse stakeholders around projects.

Across scales, monitoring and evaluation and maintenance require more funding and training. Ongoing monitoring and assessment of effectiveness relative to stated goals should be a funded aspect of projects without creating

an excessive burden. There is a long list of research needs associated with NbS, including addressing 1) groundwater implications, 2) NbS-relevant carbon sequestration opportunities, 3) documentation of effectiveness of NbS in the context of hazard events such as catastrophic storms, 4) impacts of thin-fill sedimentation projects, 5) assessment of social impacts and ecosystem services, and 6) developing a system for monitoring across scales in support of ongoing projects and programs. Maintenance, which encompasses a different set of actors from monitoring and evaluation, can benefit from regional certification programs for landscape architects and maintenance businesses, which have proven successful in both maintaining projects and spreading awareness.

Finally, **EQUITY** is at the heart of effective NbS, and using an equity lens to evaluate effectiveness provides important framing to ask *effectiveness for whom (or what), at what cost to whom?* Naming and valuing the co-benefits of NbS and hybrid projects are critical to advancing equity in this space.

- At the federal and state level, supporting outcome-based standards can better integrate community visions and goals.
- At the local level, if a community does not drive projects from the beginning, it will not survive the long process of implementation and maintenance over time. Some communities may not want NbS; communities need to be in the driver's seat.

NbS bear an unfair burden of proof when compared with gray infrastructure in a system that perpetuates a false apples-to-apples comparison between green and gray. Explicitly addressing tradeoffs and recognizing a spectrum of possible solutions that move from green to gray were two key methods identified for moving beyond the green versus gray positioning.

These three key areas–governance, communication, and equity– encompass the current challenges for NbS, and addressing them will allow acceleration of NbS implementation in coastal adaptation efforts. This will require both incremental and transformative change, but we hope that having benefited from experience of practitioners across the US, our framework can help mobilize research, climate services, funding, and other support for the army of dedicated practitioners doing this critical work to adapt to change on the coasts.

Summary

Nature-based solutions (NbS) are approaches that use nature and natural processes to address societal and environmental challenges. More specifically for US coasts, they provide interlinked benefits in hazard risk reduction, natural habitat, and social and equity needs (*see* Main Concepts). NbS are part of a suite of adaptation options to meet increasingly dire coastal adaptation needs (*see* Motivation; Broader context: Coastal risk). NbS encompass a wide range of interventions with design lives spanning from decades to centuries: they include projects from marshes, living shorelines, and "horizontal levees", to coral reefs and clam gardens, and they can integrate gray infrastructure such as breakwaters and groins (*see* Main Concepts). However, no comprehensive effort to understand the state of knowledge *and practice* has been made to identify the effectiveness of NbS to meet these growing coastal adaptation needs. Consequently, we addressed three research questions that structure this report using qualitative social science methods (*see* Methods): (Q1) what knowledge and capacity already exist for NbS implementation; (Q2) what makes NbS "effective"; and (Q3) can we use practitioner-based learning to better integrate multiple knowledges into a sustained national approach to assessing effectiveness (*see* Objectives and Questions).

QUESTION 1 | What knowledge and capacity already exist for NbS implementation?

First, we **identify NbS knowledge and capacity**. There is strong interest in NbS across the US, and projects are being implemented in a piecemeal fashion

across all regions. Despite wide-ranging differences across US regions, there were multiple shared barriers and opportunities (*see* Part II: National Findings). These include sixteen areas of knowledge and capacity. While each of these sixteen aspects of NbS implementation each stand alone, to support their recognition and implementation, we grouped them into five key areas, all of which are interlinked with equity: governance, valuation, communication, planning, and capacity.

Governance: Governance, or the interdependent policies, programs and regulatory efforts of government and other related actors, was identified as a foundational issue for enhancing NbS effectiveness. Suggestions included examining and streamlining power/decision structures and policies, especially those related to social and economic/funding systems. It includes identifying and addressing underlying systemic and equity issues, and leads to the questions *NbS for whom, at what cost to who else?*

- Regulatory challenges: Multiple and conflicting regulatory policies and frameworks at the local, state, and federal levels are a primary impediment to NbS implementation.
- Native Nations and Indigenous Leadership: Native nations and Indigenous peoples are often at the front lines of climate impacts and have extensive local knowledge of sustainable practices, but NbS can sometimes co-opt Native practices while simultaneously disempowering Native people and solutions. Cross-sectoral collaboration with Native nations helps to support NbS.
- Systems-based Approach: Systems thinking and practice leads to more successful long-term outcomes based on understanding landscape-scale interactions and changing physical and social conditions.

Communication and Collaboration: Communication and collaboration are crucial factors in successful NbS projects, but this invisible labor is often uncompensated. Without well-articulated, collaborative framing of goals, benefits, limitations and uncertainty, projects are vulnerable to an array of potential roadblocks.

- Messaging and Credibility: It is essential for practitioners to clearly communicate the limitations, uncertainties, and benefits of NbS. There is a disproportionate burden of proof for green versus gray infrastructure, because gray infrastructure is the status quo option for many decision makers.

- Social Proof: Despite a plethora of case studies from around the world, what most influences the decision to choose a green solution is local proof of concept from neighbors and regional projects.

Valuation and Co-benefits: Our current valuation systems do not properly value the vast and varied co-benefits of NbS; economic valuation is set up for more traditional gray infrastructure, and gray to green is not an apples-to-apples comparison.

- Cost Benefit Analysis (under Valuation and Co-benefits)
- Standards: Many practitioners desired performance-based standards that could account for context and co-benefits. Standards already exist in international frameworks and documents, and these could be used to build cross-sectoral national or regional standards.

NbS Planning Processes: Where NbS are deliberately integrated into key planning documents and processes, investment can more easily flow to NbS projects.

- Human and Ecological Relocation: Relocation of both people and habitat is a critical discussion that needs to be better integrated into NbS understanding, engagement, planning, and implementation. Issues related to "incremental" vs. "transformational" changes need to be addressed in the context of multiple time frames.
- Green to Gray Spectrum: Everyone loses when gray and green infrastructure are presented as competitive alternatives. Instead, experienced practitioners approach project alternatives as a spectrum moving from green to gray, starting on the green end and including combined approaches.

Capacity: Interdisciplinary knowledge is required for NbS: disciplines, such as civil engineering and biology, could each benefit from education about the other, and certifications and trainings for maintenance of NbS have been shown to support project longevity. There are not enough people employed at the national, state, and especially the local level to support NbS needs from planning through implementation and maintenance. There are often community leaders willing and able to take on NbS implementation, but only limited climate services and expert advice to support them.

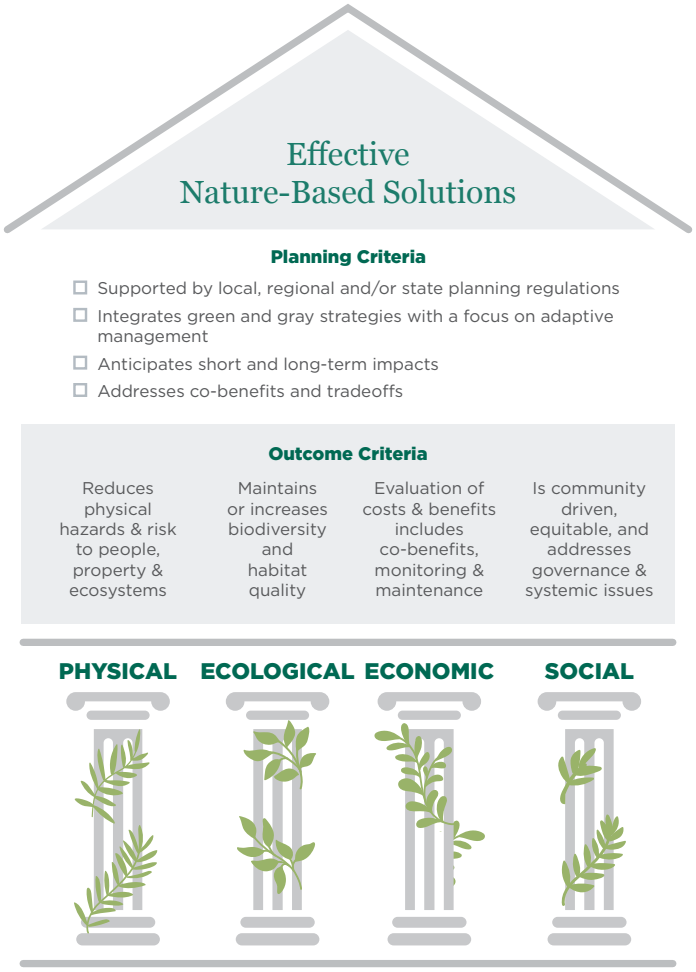
- Monitoring and Maintenance: Monitoring, if it occurs at all, is typically conducted by the initial project implementers, while maintenance is

an entirely different group of people such as landscapers and grounds crews. Both are necessary for the short and long term success of a project and for scaling NbS regionally.

Equity and Power: Equity and institutional power dynamics influence all aspects of NbS implementation. One concern that frequently emerges is that investment in NbS can lead to gentrification in areas currently underserved by natural areas. Other equity issues shared with gray infrastructure include Western science being valued over other knowledges, and economic practices that keep marginalized communities from opportunities for coastal protection.

QUESTION 2 | What makes NbS "effective"?

Next, to **understand effectiveness**, we provide a simple framework (*see* "effectiveness" Framework). Four pillars support NbS "effectiveness:" physical, ecological, economic, and social.



Physical effectiveness:

- The ability of an NbS project to mitigate physical risk depends on the functionality and persistence of habitat type and its historic and current degradation, the climate hazards at play, the geology of the region, and specific biological factors.
- The wider the NbS buffer, the more hazards can be mitigated–and most areas do not have the miles of habitat and/or feet of elevation necessary to mitigate storm surge associated with extreme events. There is very little documentation of the real impacts of catastrophic storms on NbS.
- Coastal wetlands do not eliminate risk but do significantly reduce property damage.

Ecological effectiveness:

- Ecological effectiveness means increases to habitat quality and quantity, ability to provide ecosystem services, and benefits to ecosystem biodiversity.
- Biodiversity is critical to ecosystem function and for providing human health and wellbeing ecosystem services (e.g., recreation).
- Considering and planning adaptively for future conditions is critical to preserving associated habitat and biodiversity, and this may come with tradeoffs for current habitat.
- Natural systems used to protect infrastructure and habitat can be damaged by storms, and species-specific research and monitoring can support better outcomes.

Economic effectiveness:

- NbS clearly and irrefutably reduce the damages and costs from sea level rise and catastrophic storms.
- Current valuation systems do not name nor value the many co-benefits of NbS that are critical for coastal economies.
- Monitoring and maintenance, which require different people and areas of expertise, need to be included in NbS projects from the outset to measure and understand hazard mitigation and co-benefit effectiveness (*see* Monitoring).

- This report does not explore the role of insurance and reinsurance in promoting and protecting NbS, but this is an important future research space.

Social effectiveness:

- Governance and regulatory challenges are cited as the most critical gap in NbS implementation.
- Where NbS are integrated into local and state planning processes and documents they are much more likely to reach implementation and meet goals.
- Research gaps exist in understanding cultural norms around how we think about green and gray infrastructure, compare them, and see them as related assets (or not).
- NbS do not exist in isolation and need to be considered in broader social systems and contexts, with more focus on adaptive management that integrates contexts and future, (changing) baselines.

Building on these pillars, practitioners consistently identified six **Leading Practices for NbS effectiveness**:

1. **Community-driven Processes**
2. **Clear and Achievable Goals**
3. **Plan at Landscape Scale**
4. **Plan for an Adaptive Baseline**
5. **Explicitly Address Tradeoffs and Hybrid Options**
6. **Link the Four Effectiveness Pillars and Name and Integrate Co-benefits**

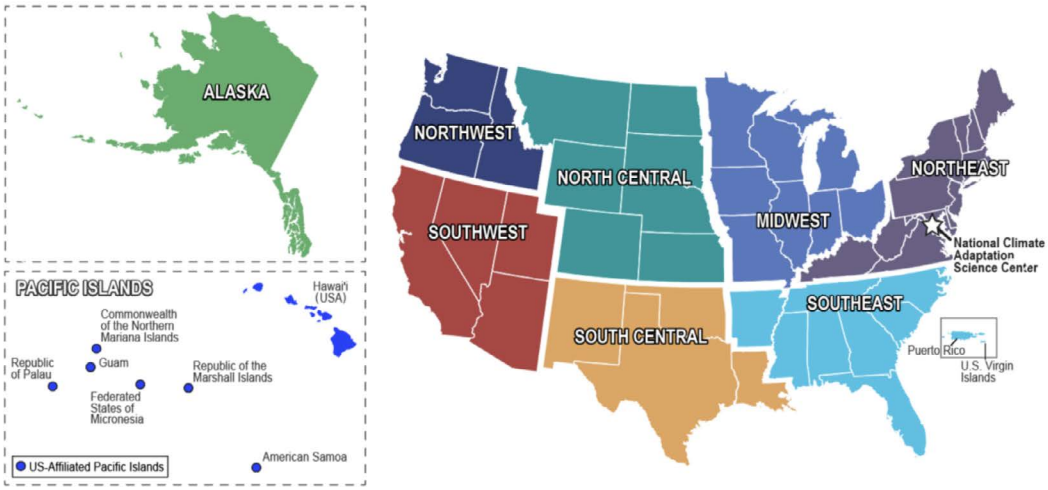
Based on the findings from Question 1 (knowledge and capacity) and 2 (effectiveness), we provide research and climate services **National Opportunities** for NbS:

- **Build Relationship Capacity**: build capacity for peer-to-peer (P2P) learning, especially among and between state regulators, and engage and build partnerships with international communities.

- **Design Interdisciplinary Training to Build Capacity**: Work with state universities and colleges to include NbS design and basic ecological understanding into engineering programs, and include engineering coursework for environmental land management programs; design and implement training and certification programs for landscape architects, landscape maintenance businesses, and municipal and county employees; provide training exchanges between engineering and environmental sciences at the state level; and provide adaptive management training and support for planners and managers.
- **Develop Practices for Centering Equity in NbS**: Fund relationship building and facilitation of collaborative processes, address tensions between Western and Indigenous science and practices, compensate community leadership, and document historical contexts while promoting the "full community" approach.
- **Develop Outcome-based Standards that Account for Context**: Rather than a one-size-fits-all approach, adaptive metrics should be developed for projects that integrate all relevant sectors and are based on local objectives.
- **Enable Incremental and Transformative Valuation Innovation:** Support new approaches to BCA and research better ways of valuing co-benefits.
- **Monitor NbS in the Context of Natural and Social Systems:** Monitoring needs include groundwater implications, documentation of NbS effectiveness in the context of hazard events such as catastrophic storms, impacts of thin-fill sedimentation projects, assessment of social impacts and ecosystem services, and perhaps most importantly, developing a system for monitoring across scales in support of ongoing projects and programs
- **Support Ongoing and New Carbon Sequestration Research:** For example, this can include marshes, seaweeds, and dunes and dune vegetation.
- **Pursue Public-Private Partnerships:** Partnerships could support work that otherwise is not funded, keeping NbS on the table in the planning process.
- **Fund Social Science Research on Social and Economic Aspects of NbS:** Research ways to support state regulatory changes, develop new valuation practices and outcome-based standards, understand perceptions of risk in coastal contexts, and identify tradeoffs between co-benefits.

- **Enable State Legislation that Supports NbS:** There is a dramatic difference in NBS implementation rate in states that support NbS, either through legislation or through streamlined approval of NbS projects, vs. those without explicit support for NbS.
- **Focus on Strengthening Adaptive Governance:** Develop projects from a landscape scale perspective, valuing co-benefits, monitoring for effectiveness, and educating practitioners and the public, would all benefit from a more adaptive and innovative approach to governance.
- **Focus on Incentives, Especially for Relocation:** Individuals and local governments, as well as ecosystems, need support to make challenging transitions.
- **In NbS Conversations that Include Relocation, Recognize the Trauma:** These ongoing conversations need professional support to handle and process trauma and grief (in addition to political and economic considerations).

As expected, there are regional differences in NbS approaches and practitioner experience; consequently, we assembled a **Regional Synthesis** to showcase specific regional NbS directions and examples that may be useful to other national practitioners or stakeholders from other regions.



We based our regions on the USGS CASC regional boundaries, and included Northeast, Southeast, South Central, Southwest (California), Northwest, Alaska, and the Pacific Islands. The key takeaways from each region include:

ALASKA

- Rapid coastal erosion and major storms make NbS such as living shorelines less viable for exposed coasts.
- Siloed federal grant making systems burdens already overloaded human capacity in communities.
- Alaska needs additional baseline monitoring and assessment, particularly of coastal erosion and harmful algal blooms (HABs), done in partnership with communities.
- A full community approach, in which diverse interests come together to share experiences and receive training, has proven effective for designing NbS applications in multiple communities, and is a practice from which other regions could benefit.
- The definition of effectiveness or success for adaptation projects should be led and determined by affected communities, especially Alaska Natives.

NORTHEAST

- The disparity between rural and urban areas is significant, and rural regions struggle with capacity to support NbS, even as there is growing interest.
- Significant areas of the coast are already hardened, and many areas are experiencing even further coastal development ‘squeeze’, making efforts to evaluate and integrate ecosystem retreat with human retreat critical.
- Living shorelines are one of the most common initial pilot projects, but can suffer damages in high energy conditions.
- Significant areas of the coast are private, and state regulations, local examples, and experienced coastal engineers all play a critical role in the successful implementation of NbS.

NORTHWEST

- Native nations provide leadership and experience in NbS, including key collaborations.
- Like the Alaskan coast, erosion and significant storms make NbS such as living shorelines less viable for exposed coasts; instead, dynamic revetments (cobble berms that mimic natural cobble) and sandbags with planted vegetation are solutions that offer protection and habitat benefits.
- Regional estuaries could benefit from sediment augmentation, and the region could learn from and partner with other regions, such as the Southwest, that are pioneering these solutions.
- Urban areas need funded interagency relationship-building to move NbS projects forward, especially in complicated legacy contamination sites that could be transformed to support ecological systems and environmental justice communities.

PACIFIC ISLANDS

- Indigenous groups often take an integrated approach to NbS that includes traditional practices and engagement, which may clash with a Western science approach that separates people from the landscape. Native peoples-led framing and approaches could support implementation and sustained projects.
- Coastal adaptation is extremely costly, and the islands, especially US-affiliated, are deeply dependent on federal funding to meet adaptation needs, yet struggle to meet the required federal agency BCA ratios.
- Despite local interest and support, funding deficits prevent communities from pursuing alternatives to gray infrastructure.
- Research that demonstrates and clearly communicates the co-benefits of NbS would support practitioners who work to have local and territorial governments prioritize NbS.
- As in Alaska, this region integrates NbS concepts and practices into broader and more comprehensive adaptive planning for sustainability.
- As in the Southeast (USVI and Puerto Rico), US territories have limited funding, making them especially important to support in this space.

SOUTH CENTRAL

- Sea level rise, subsidence, and increasingly powerful storms are forcing this region to actively address planned relocation at a significant scale, and existing equity issues persist in these actions, especially for Indigenous groups.
- The region has the mixed blessing of significant funding from the Deepwater Horizon disaster, but that funding has yet to manifest as an implemented NbS project in Texas.
- Well-organized state level planning processes support a landscape level view of adaptation, but communities can feel left out of decision making.
- Integrated hybrid strategies preferred: research shows the economic benefits of NbS in the region, but the memory of highly impactful storms such as Katrina deter the use of green infrastructure as a solo strategy.

SOUTHEAST

- Coastal squeeze and development are a constant threat not only to existing natural ecosystems on the coast, but to migration corridors for these systems. Continual coastal development is heavily incentivized in the region.
- According to practitioners, many in the region are willing to increase their hazard risk exposure to not live behind concrete walls, and there is significant interest in NbS.
- Understanding groundwater implications and impacts is a pressing concern when considering potential NbS roles for current and future sea level rise.
- This region has regulatory and planning leadership, with Virginia's first-in-the-nation laws requiring the use of coastal NbS unless proven otherwise, and the City of Charleston's Comprehensive Plan that centers water in its structure.
- USVI and Puerto Rico have small existing and potential equity-driven projects, but there is concern about their risk mitigation capabilities for severe storms, and practitioners stressed ongoing systemic governance challenges that need to be addressed in NbS planning.

SOUTHWEST (CALIFORNIA)

- California has already undertaken significant coastal NbS projects, and now looks to better integrate long term planning into projects with broader scopes and land areas and with a greater attention to equity, but is severely hampered by state regulations.
- Developing and maintaining partnerships was highlighted in this region: cross-agency and sectoral relationships were needed to support the implementation of larger scale projects, and public-private partnerships present significant opportunities.
- Outside of the region's significant estuaries and related thin-fill sedimentation and horizontal levee projects, dune restoration and beach nourishment has seen success in both protecting coastal infrastructure and preserving recreation and habitat on exposed coasts.
- Key planning documents that integrate adaptation at the intersection of coastal and inland ecosystems provide an excellent opportunity for integrating NbS into regional planning.
- Despite relatively strong governance, the region still lacks regulations to support NbS implementation, which complicates and slows NbS permitting. As in the Northeast and elsewhere, existing regulations designed to protect habitat now impede progress.

QUESTION 3 | Can we use practitioner-based learning to better integrate multiple knowledges into a sustained national approach to assessing effectiveness?

Our primary objective in this project has been to develop and test a framework for identifying common experiences, leading practices, and transferable learning that can accelerate NbS in diverse locations. To address integrating practitioner knowledge and on-the-ground practices into a national assessment, we suggest a next step for building a Sustained Assessment of effectiveness of NbS by funding a national Community of Practice (CoP) for practice-based learning. We discuss the potential foci, CoP process, and capacity building associated with the CoP.

We wrap up the report with **Next Steps for NbS**, a brief summary and review of the National Opportunities.

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The authors would like to thank the United States Geological Survey (USGS) Climate Adaptation Science Centers (CASCs), for their support of this research and their continued engagement with the research. We also thank the institutional homes of the report authors: the Aspen Global Change Institute, the University of Arizona, and Princeton University.

In the process of writing this report, we are continually astonished by the dedication of the practitioners who made time to talk with us. They were generous with time and ideas to support our efforts to include the perspectives of practitioners in assessments and to accelerate climate adaptation (risk management) and mitigation (emissions management) efforts. They are the backbone of and the inspiration for this report.

We are also indebted to our talented and experienced Advisory Committee members, whose insights and suggestions were critical to the success of this project.

PART I

Introduction and Background

OVERVIEW

Purpose: This report examines the current state of knowledge and practice for nature-based solutions across the coastal US states and territories; it outlines a simple framework to characterize key aspects of "effectiveness" based on physical, ecological, economic and social features; and it tests the use of practitioner-based learning to advance knowledge of nature-based solutions (NbS) as a climate adaptation strategy. It is designed to be a national assessment that serves as a primer or resource to provide basic information for coastal NbS implementation and methods for integrating practitioner knowledge into climate assessments; to elevate the current voices and knowledge of NbS implementers and provide a list of opportunities for research and climate services that reflect their needs; and to support an integrated, equity-centered approach to NbS implementation in national and regional contexts. By identifying key national findings that apply regardless of region, we aim to illuminate the topics and strategies to support accelerated adaptation across locations. We also highlight regional similarities and differences to illustrate the textured contexts across the US, and to provide information about each region and its current projects, approaches, and needs. The report suggests ways forward in research and climate services that support nature-based solutions as a promising component of a set of approaches to coastal adaptation that also include risk reduction measures, hard infrastructure, and in some cases planned relocation.

Audience: The report is not meant to be exhaustive, but to illuminate current and future work in science and practice for coastal nature-based solutions as well as practitioner-based learning processes. Our work aims to be policy-relevant but not policy-prescriptive, for an audience of scientific researchers, policymakers and planners, and practitioners implementing NbS. Our audience can be envisioned as two independent sets of concentric circles, with the core of the first including our funders, the USGS Climate Adaptation Science Centers (CASCs), and other science and research institutions interested in coastal adaptation. The next layer includes federal, state and local agencies interested in learning more about and anticipating the barriers and opportunities to accelerate NbS projects in their jurisdictions. The outer

layer includes private and philanthropic funders, non-profit organizations and conservation groups, and climate service providers interested in understanding where to focus time, energy, and funds. Finally, while much of this information will not be news to practitioners implementing projects, the national findings may confirm shared challenges and opportunities and spur further regional and national collaborations.

The second layered circle is for a targeted audience interested in creating an ongoing national assessment process that gives local knowledge and experience a seat at the table in national climate assessment processes. This may include federal agencies and funders interested in an equity-driven and practical framework for better integrating science and practice to accelerate adaptation, but is explicitly concerned with inclusion of reliable, peer-reviewed information that supports adaptation and mitigation decisions and helps to promote resilience.

This project is structured around three broad questions:

1. *What interest, knowledge and capacity is there for different approaches to coastal nature-based solutions in different regions?*
2. *What can we conclude about the effectiveness of coastal NbS and how it is evaluated?*
3. *How could a "practitioner-based learning" process advance knowledge and implementation of coastal NbS and climate risk management more broadly?*

MOTIVATION

Managing climate-related risks along coasts is a massive challenge for all of the US coastal states and territories (Fleming et al., 2018). Nature-based solutions (NbS) are part of a continuum of coastal adaptation approaches and can help to manage these risks by safeguarding, restoring, or building ecosystems to help human communities respond to the impacts of climate change (Jones et al., 2012). There is significant public and private interest in using nature-based solution approaches to conserve critical ecosystems in coastal watersheds, estuaries, and intertidal zones, and to protect man-made infrastructure and human and ecological communities that are at risk within the coastal zone (e.g. Bridges et al., 2015; USGAO, 2019). However, to date there have been relatively few efforts to collect and compare the lessons learned from on-the-ground experience with implementing NbS, and these efforts have generally not included project evaluation to understand the climate adaptation outcomes and effectiveness (Milman and Jagannathan, 2017).

Considering the fast pace of change in coastal zones, the trillions of dollars of investment in human communities in coastal areas, and the myriad ecosystem services provided by natural coastal environments, answering questions about both the costs and the benefits of alternative adaptation strategies in the near term is critical to taxpayers, decision-makers, and the biodiversity of the planet. There are many potential NbS approaches, and effectiveness depends on the characteristics of the local ecological and human systems, as well as the unique context for implementation, including laws, customs, economic interests, and other factors (Donatti et al., 2020). In other words, all adaptation solutions are local, which means that generalized, one-size-fits-all approaches may be unsuccessful. However, there are common experiences that can be shared to accelerate the tailoring of local adaptation solutions.

Our primary objective in this project has been to develop and test a framework for identifying common experiences, leading practices, and transferable learning that can accelerate NbS in diverse locations. The framework articulates the current state of knowledge and practice of NbS and supports the evaluation of NbS across spatial and temporal scales. The findings also support the development of a research agenda for future investments in NbS.

Because the experience of practitioners is critical, we explicitly sought to learn from the practice of implementing NbS in the context of coastal engineering, ecosystems management, cultural resource protection, regional planning, social and environmental justice, and other professional areas, in addition to evaluation of standard scientific sources.

These findings build on existing assessments and reviews by other federal agencies and non- governmental organizations (NGOs). This underlying work includes vulnerability assessments of specific species, habitats, and systems (e.g., Hutto et al., 2015; MARCO, 2018; Myers et al., 2017) as well as a smaller number of cross-cutting projects on issues such as the design of ecosystem-based adaptation (NbS) options for protected areas (e.g. TNC, 2010; USCCSP, 2008), hybrid adaptation strategies that combine ecosystem-based and hard infrastructure (e.g., Sutton-Grier et al., 2015; ULI, 2016), decision support studies (e.g., Beavers et al., 2016; Narayan et al., 2016; US GAO, 2019) and tools (e.g., NOAA Climate Resilience Toolkit, NOAA Coastal Inundation Toolkit, NOAA Coastal Planning Advisor), valuation of the benefits of NbS in relation to its costs (e.g., DOI MEG 2015), and other topics. In addition, there are extensive international efforts to support NbS, including through the UN Environment Programme (UNEP, 2016).

BROADER CONTEXT: COASTAL RISK

Across the U.S. and territories, coasts face multiple and increasing hazards that put people, property, and ecosystems at greater risk (Arkema et al., 2013; Nicholls et al., 1999). These include the hazards associated with catastrophic storms, namely storm surge and inland flooding, and the current and future impacts of sea level rise (SLR), including "sunny day" flooding and infiltration of groundwater supplies. These hazards then translate to physical and social vulnerabilities. Failure to adapt proactively has resulted in increasingly dire consequences: recent catastrophic storms have been the costliest disasters in U.S. history, and SLR combined with increased intensity and severity of inland flooding has caused overwhelming damage within some municipalities.

Many of our discussions with coastal practitioners focused specifically on the coastal natural infrastructure that addressed the seaward hazards: the storm surge and catastrophic flooding associated with increasingly powerful storms, and the tidal and "sunny day" flooding associated with SLR. However, the intersection of inland flooding and management of runoff and wastewater figured prominently in many discussions because the effect of storms does not stop at the coast. For example, San Francisco Bay is at the mouth of the San Joaquin and Sacramento rivers, draining forty percent of California's land area, while also facing significant threats from current and future sea level rise. Consequently, while this report focuses largely on the shore and near-shore natural and nature-based features such as dunes, marshes, mangroves, and coral and oyster reefs, this is not in any way a judgment of critical inland green infrastructure such as rain gardens, retention ponds and other stormwater and wastewater management strategies.

BROADER CONTEXT: PRACTITIONER-BASED LEARNING AND SUSTAINED ASSESSMENT

The Biden administration has recommended that federal agencies prioritize research, innovation, and adaptive learning for nature-based solutions (CEQ et al., 2022). Testing an approach to ongoing, adaptive, practitioner-based learning about NbS (which we refer to as "sustained assessment") in this context explicitly addresses this recommendation. It also builds on the CASC network's interest in research to understand, measure, and verify the effectiveness of nature-based solutions; identify and fill knowledge gaps; and accelerate the pace of NbS implementation.

By "sustained assessment" we refer to an ongoing, credible, well-documented process that engages researchers, professional practitioners, and stakeholders to share and apply knowledge and experience relevant to adaptation and mitigation solutions. The concept of sustained assessment was developed in the context of the third U.S. National Climate Assessment (Melillo et al., 2014; Buizer et al., 2013) as an approach to improving assessment outcomes and addressing expanding needs for decision-relevant information. The approach includes sustained dialogue with users regarding information needs and decision contexts, diversification of products and communications strategies beyond reports and static data sets, and capacity building. Because of its emphasis on ongoing engagement and evaluation, sustained assessment has the potential to promote learning about climate risk management strategies and sources of knowledge needed to tailor their design and implementation in particular environmental, socioeconomic, and cultural contexts.

In early 2016 a federal advisory committee was established to provide additional guidance to federal agencies on implementation of a sustained assessment. The committee was discontinued by the Trump administration but the group reformed as an independent body and published a report (Moss et al., 2019) with input from "practitioners" – individuals in state/local/tribal governments, private-sector firms, non-governmental organizations (NGOs) and other groups who were attempting to plan and enact adaptation and mitigation measures. In response to the needs of practitioners, the advisory committee continued to evolve and refine the sustained assessment concept to (1) focus on how to plan and implement climate action using available scientific and practice-based knowledge and (2) engage a wider range of experts, including relevant professionals and stakeholders.

The committee's recommendations included establishing "a civil-society-based climate assessment consortium" to support "communities of practice" in which practitioners interact with professional groups (e.g., engineers, architects, public health experts, conservation professionals) and the academic groups historically involved in assessments (e.g., researchers at universities, government laboratories, and research centers). Through this process, the practice-based knowledge of practitioners and professional groups would be assessed and synthesized with research and other knowledges (e.g., Indigenous) to identify leading practices in adaptation and mitigation. This would include identifying standards for quality assurance and providing authoritative data in climate services to support multiple stages of adaptive management. Because practitioners indicated that their efforts were stalling, the committee suggested structuring Communities of Practice to

evaluate information needs and tools in a stylized "adaptive management" implementation process (Figure 1). Climate services inputs are needed for all phases of adaptive management. While the citizens' climate assessment network has not yet been established, one of the motivations for this project is to further explore how such a process could be used to support practitioners, evaluate practical applications of climate and global change science, identify leading practices, and accelerate risk management. Our practitioner-engaged approach builds on these ideas about sustained assessment and underlying knowledge from decades of research and application that emphasize the need for a new approach to incorporating experience-based knowledge.

An additional major motivation for this work is to support broader efforts to escalate science-based adaptation and mitigation action. Effective adaptation requires constant evaluation of progress and effectiveness, which is why adaptation processes are often depicted and operationalized as an iterative, circular process (ie., Pathak et al., 2022, Gardiner et al., 2022). We propose to make more explicit the relationship between on-the-ground adaptation and assessment, in order to promote adaptive learning more generally and adaptation action specifically. To translate from this limited pilot study to a much broader set of applications and questions, it is essential to study the assessment process itself and to provide guidance on ways to use the lessons from this pilot across adaptation efforts generally.

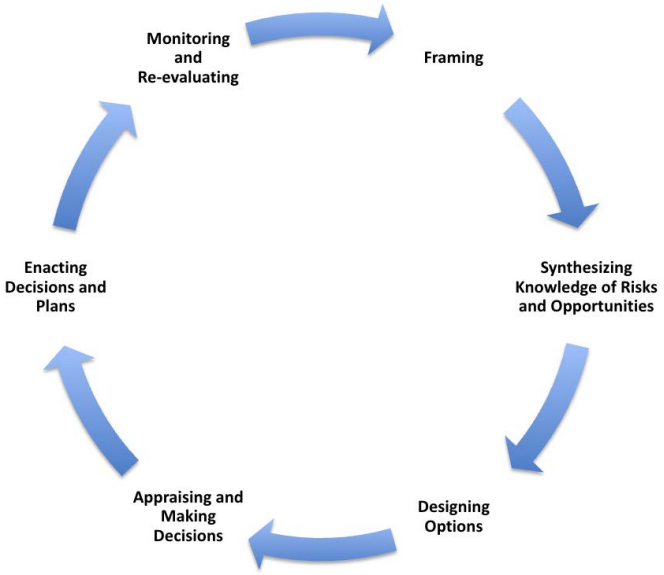


FIG 1.

An iterative adaptation process incorporates evaluation and learning, from Moss et al., (2019). The figure focuses on identifying information and methods needed to understand problems, design and select options to address them, and finance and enact these measures.

A realistic appraisal of coastal NbS and the potential to scale these approaches up needs to engage representative individuals and groups who have experience with it, because understanding of how to plan and develop NbS options and overcome barriers to implementation does not rest primarily in the academic literature (nor can it be represented in full by a project report). To build momentum for coastal adaptation using nature to protect people and valued attributes of the environment, we need ongoing assessment processes that continually engage practitioners. This is because practitioners have knowledge of the uses and limitations of NbS and challenges in implementing it garnered through experience, knowledge that is not often incorporated into academic studies.

An example of a path towards sustained assessment and shared knowledge is communities of practice (CoPs). When driven by their members to tackle the most practice-relevant questions, CoPs can expand the overall knowledge base of a domain beyond the research literature and published studies (Wenger et al., 2002). CoPs and other methods of practitioner-based learning build on case studies and individual experience, aggregating knowledge beyond an individual project scale. Translating and enacting practitioner-engaged assessment has the potential to identify leading practices and improve adaptation and mitigation support at larger scales.

METHODS

Our methods prioritized learning from the on-the-ground knowledge of NbS practitioners. Practitioner-based learning integrates concepts and practices of knowledge coproduction, a process that brings together diverse groups to iteratively create new knowledge and practices (Jagannathan and Arnott et al., 2020). We utilize methodologies and methods that correspond with the four predominant principles of knowledge coproduction: the research is context-based, situating the process in a particular place or issue; pluralistic, in recognizing the multiple ways of knowing and doing; goal-oriented, defining shared and meaningful goals that are related to the challenge at hand; and interactive, allowing for ongoing learning among actors through active engagement (Nörstom et al., 2020). Following the interest in creating new knowledge about NbS practices and also generating useful information on practitioner-based learning and sustained assessment practices, we have designed this research to support the CASC's understanding of nature-based solutions, and the methods that can be used to build a broader effort to engage with and coproduce knowledge with stakeholders about specific climate questions and topics.

Our methodology is based in *grounded theory*, a set of inductive methods used for qualitative research to build new theories. In our case, we use it to build a framework for analysis and synthesis of our topic (Strauss and Corbin, 1997). We use traditional social science research tools (coded interviews), while also recognizing the researcher's reflexivity, biases, and engagement (Klenk, 2018). Specific methods used to complete this project included:

- **Literature review**

At the project outset, we conducted an extensive literature review. For scientific and academic publications, we used Web of Science and Google Scholar to search key terms and cited materials in key articles. This approach, without specific context, initially proved challenging. We found more readily accessible literature through reports, white papers and gray literature, conference proceedings and recordings, webinars, and podcasts. See Appendix I for all references cited.

We conducted a second literature review following the completion of interviews, building on resources shared by practitioners to inform both the national and regional findings. With the recommended literature from practitioners and their associated sectors or discipline-specific terminology, we were better able to locate additional useful resources for this report from the scientific literature. While the literature search was not exhaustive, we identified a representative set of research, reports, and other sources to inform our approach, corroborate practitioner experiences, discover gaps between practitioner experience and published findings, and highlight opportunities for further research.

- **Interviews**

We conducted semi-structured interviews using a key informant and purposive sampling technique (Creswell, 2014). Initial scoping interviews (n = 5) were used to test, validate, and better integrate practitioner context and knowledge into questions. We first conducted interviews with the CASC leadership from all applicable coastal regions (n = 13), then conducted interviews with practitioners (n = 51) across institutions and scales for a total of 69 interviews. Potential interview participants were contacted via email, with a 92% response rate. We speculate this high response rate was due to multiple factors, including purposive sampling methods, individualized emails, consistent follow up, and a pervading culture in which participants support nature-based-solutions-related work. The majority of our non-responses came from the

Pacific Islands and Alaska, which we speculate is related to severe capacity constraints in those regions, among other factors discussed in the Regional Findings. All responses are confidential and protected in compliance with the Advarra Institutional Review Board (IRB).

Participants represented a range of geographies, sectors, and tiers of engagement, documented in the table below:

Practitioner representation	Total number interviewed
SECTOR	
Municipal	22
State	16
Federal (includes CASCs)	29
Native nations and Indigenous	9
Research	9
Nonprofit	9
Business / for profit	5
REGION	
Alaska	5
Northeast	13
Northwest	8
Pacific Islands	5
South Central	9
Southeast	11
Southwest	13

The interview protocol is included in Appendix III.

- **Advisory committee**

After the initial literature review and a series of interviews, we selected potential advisory committee members based on their broad and specific knowledge of coastal adaptation processes across geographies and experiences, along with sectoral expertise with nature-based solutions. 100% of practitioners contacted agreed to serve on the advisory committee. These experts provided ongoing input from different fields essential to coastal

adaptation generally, and NbS specifically. The committee convened via video conference 4 times in the course of the research, and provided additional guidance via email. A list of advisory committee members can be found in Appendix II.

Representing Indigenous Nations and Voices

Throughout our process, we sought the input and perspectives of Native nations as well as federally-unrecognized tribes. We recognize that asking for time from representatives of traditionally under-represented communities can increase stress where resources and people are already stretched thin. Consequently, we sought the input of liaisons and practitioners who could be compensated as part of their regular work to speak with us, as we were unable to offer compensation. Throughout this report, we strive to use the language and terminology that Native nations and Indigenous peoples use to represent themselves, while we recognize that "the process of decolonizing language surrounding Indigenous peoples is not finished; terms, names, and styles continue to evolve" (Baker, Little Elk, Pollard and Red Bird, 2021).

- **Analysis**

We used QSR International's NVivo qualitative data analysis software to analyze all primary data collected in this project. Following our modified grounded theory approach (Glaser and Strauss, 1967; Strauss and Corbin, 1990), analysis was completed using multiple rounds of data coding, followed by additional research as necessary to better understand and articulate the themes that emerged in the analysis. During and following the analysis, our advisory committee served to ground-truth our findings.

- **Quotations**

Our practitioners were selected based on their expertise and extensive knowledge of nature-based solutions. How they verbalized information frequently represented important evidence regarding a topic. From an epistemological standpoint, because this is practitioner-based learning, we find it integral to our research to illustrate how practitioners talk about this topic.

Multiple ways of knowing and doing are represented in this research, and we use direct quotes to engage the reader more explicitly and directly with the knowledge creation process, simultaneously respecting the hundreds of years of experience represented by our participants.

MAIN CONCEPTS

Like the term 'resilience' in the context of climate change, nature-based solutions can encompass a broad range of meaning, understanding, and actions. In the synthesis below, we discuss the specific challenges and potential pathways for addressing this broad lack of shared common understanding, but we take this opportunity to acknowledge here that "nature-based solutions" means a multitude of different things to different people. There is meaning, power, and opportunity in the diversity of knowledges and subsequent approaches (Soden et al., 2015). However, clarity of language is critical to assessment processes; consequently, we establish shared language based on our findings.

On the ground, practitioners often use terms interchangeably depending on their intended audience, but the origins and nuance can still be useful and help us begin to capture the nuanced nature of this topic. That said, some overlapping definitions are dissimilar enough that the terminology occasionally caused confusion during the research. Consequently, we will define a key set of terms that are often used in various sectors to describe coastal adaptation through natural or nature-based approaches.

- **Nature-based Solutions (NbS)**

Nature-based solutions (NbS), defined broadly, are approaches that use nature and natural processes to address societal and ecological challenges (Seddon et al., 2019). The International Union for Conservation of Nature (IUCN), the World Bank Group, and the World Resources Institute (WRI) define nature-based solutions as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (from Luedke, 2019).

Given the centrality of National Fish and Wildlife Foundation (NFWF) in engaging with and advancing NbS in the U.S. (through the National Coastal Resilience Fund (NCRF)), we find their conceptualization a simple and elegant way to think about nature-based solutions: "constructing or restoring coastal

habitats to increase the capacity of communities and habitats to withstand and recover from disruptions and adapt to changing environmental conditions." Put simply, this includes (1) risk reduction benefits and (2) habitat benefits. In the US context, as reflected frequently in our interviews, the social and equity considerations have often been overlooked in coastal adaptation, including in NbS projects. Therefore, a more holistic definition might explicitly include (3) social and equity benefits.

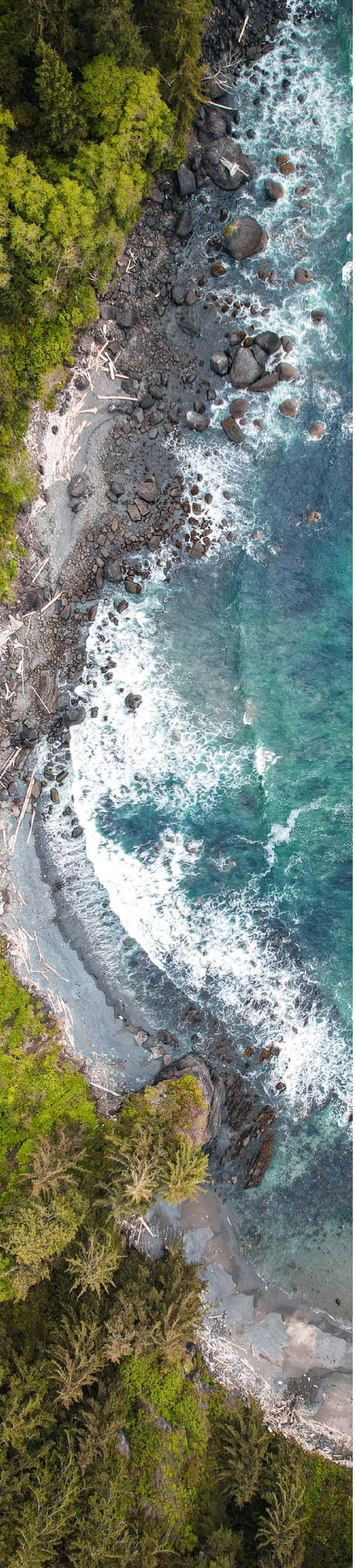
We chose the term 'nature-based solutions' because this is one of the more commonly used terms among practitioners, and it is the term used extensively by the current Biden administration and federal agencies, including the CASCs. We use 'nature-based solutions' or 'NbS' to include a wide variety of projects driven by a diverse range of practitioners and stakeholders, from federal engineers to local emergency management, with the acknowledgment that it is not a perfect term, particularly in that the term does not immediately convey an understanding of its focus or context to a lay audience, and may not capture all aspects of other terms listed next.

- **Other terms and definitions**

There are multiple terms related to this concept of providing risk protection to communities while restoring, creating, or maintaining natural ecosystems. These terms, listed here followed by the sectors in which they are most commonly used, include:

- biodiversity-focused adaptation (conservation);
- climate-smart conservation (conservation);
- ecosystem-based adaptation (international, academic research);
- ecosystem-based disaster risk reduction (insurance, international);
- ecosystem-based management (coastal and marine);
- engineering with nature 'EWN' (USACE);
- green infrastructure (urban and stormwater);
- living shorelines (vegetated coast or marsh-specific);
- nature-based adaptation (conservation);
- natural and nature-based features 'NNBF' (infrastructure and engineering);
- natural infrastructure (infrastructure, engineering and conservation); and
- resilient infrastructure (state agencies).

'Nature-based solutions' is not only used in the context of climate adaptation:



it is a term shared by the climate mitigation community to represent natural carbon sequestration, which caused some initial confusion for practitioners during our research. Nature-based (climate) solutions in a mitigation context are conservation and management practices that remove carbon from the atmosphere and/or generate carbon credits by avoiding or sequestering greenhouse gas emissions. While NbS for adaptation (reducing risk, benefiting ecosystems, growing social equity) may include nature-based climate solutions, such as blue carbon accounting in seaweeds and aquatic plants (that calculates the carbon sequestered by plants and substrates), these two uses and contexts are often not considered together in the U.S., although interest in carbon accounting for marine vegetation and sequestration, and the implementation of ocean renewable energy, may push these two spheres closer together.

RESOURCE

The University of Oxford's Nature-based Solutions Initiative (**https://www.naturebasedsolutionsinitiative.org/**), whose mission is to "enhance understanding of the potential of nature-based solutions to address multiple global challenges whilst supporting the health of ecosystems and respecting the rights of Indigenous Peoples and local communities," examines nature-based solutions across mitigation and adaptation contexts, and provides advice for countries and corporations seeking nature-based solutions projects. Their work includes guidelines for successful and sustainable nature-based solutions, highlighting the serious concerns about the expansion of forestry framed as climate change mitigation at the cost of disrupting carbon rich and biodiverse ecosystems and harming local people and resources (Seddon et al., 2021).

We did not select specific types of coastal NbS to assess. The NbS that our practitioners discussed included:

- barrier islands,
- beach (re)nourishment,
- beneficial (re)use of dredged material,
- bioswales,
- clam gardens,
- coastal impoundments,
- coastal forests,
- cobble mattresses (for dunes),
- coral reefs,
- culvert replacement,
- dunes and dune restoration,
- dynamic revetments,
- eelgrass,
- kelp beds,
- greenways,
- horizontal levees,
- land conservation and easements,
- living shorelines,
- mangroves,
- marsh creation,
- oyster reefs,
- preservation and restoration,
- rain gardens,
- retention ponds,
- sandbags with vegetation,
- sea grapes,
- sea oats,
- shellfish reefs,
- thin-fill or thin-layer sediment augmentation.

- **For future investigation**

While this report broadly focuses on nature-based solutions that meet coastal adaptation needs, it does not examine all opportunities to apply NbS. For example, other hazards in which nature-based solutions may have a significant measure of mitigation and resilience effectiveness include ocean acidification and warming sea surface temperatures, both of which have associated research and practitioners working on NbS. We also did not examine marine NbS issues. While coral reefs and oyster reefs were commonly referenced coastal solutions, the coastal and marine food web, and especially fisheries aspects, significant drivers of coastal economies and important aspects of coastal cultural heritage, are not addressed. Finally, the Great Lakes region has a significant history and experience with freshwater coastal NbS and thriving coastal economies that are not assessed here, and their knowledge and strategies would undoubtedly enhance national learning. We recommend further research to highlight these topics.

PART II

National findings

Knowledge and Capacity

There is widespread interest in nature-based solutions across the U.S. There is also significant variation in the capacity for understanding, planning, implementing, monitoring, and sustaining natural and nature-based infrastructure.

While we cite a few examples and resources in this section, the majority of them can be found in Part III: Regional Synthesis. *Note that we have included direct quotes from our interviews in italics throughout the report.*

GOVERNANCE

Governance, or the interdependent policies, programs, and regulatory efforts of government and other related actors, was identified as a foundational issue for enhancing NbS effectiveness. Suggestions included examining and streamlining power/decision structures and policies, especially those related to social and economic/funding systems. It includes identifying and addressing underlying systemic and equity issues, and leads to the questions *NbS for whom, at what cost to whom else?*

Governance includes an array of management and decision-making processes. This can include governing with and through networks, in which interdependent 'policy networks,' with sets of formal and informal institutional linkages between governmental and other actors, are structured around shared interests in policy and implementation (Rhodes, 2007). Especially in areas with lack of capacity, governance challenges often preclude the planning and implementation of NbS at scale.

> *We need to look at how we manage ourselves and our systems. We don't talk about the lack of governance within the context of nature-based*

solutions: without proper rules [for how to adapt], even places like Florida have this constant fight, people still want to develop more.

Governance problems often result in **equity** issues. Examining governance requires a contextual and systems perspective, an awareness of how social and economic institutions determine who benefits from what projects. Thinking about governance brings up the questions, *NbS for whom, at what cost to whom else?* For example, in some cases, funding was available at the national level for NbS, but that was perceived as making it more difficult for communities to access funds for other adaptation needs.

The focus on NbS can prevent the funding from the government from reaching the communities in greatest need.

The folks who make the decision related to adaptation are disconnected from the [on the] ground reality.

Practitioners recognize the need for both **incremental and transformative approaches**, and the challenges to incorporating both approaches on the ground. For example, a practitioner could preserve an existing marsh (an incremental step), but without an easement to allow the marsh to migrate inland to a new location as the sea level rises (a potentially transformational solution), the marsh will be submerged in rising seas.

Finally, **institutional path dependence** is a major barrier to implementation everywhere, but especially in rural and under-resourced communities, and communities with limited or no exposure to NbS projects. Research by Matthews et al. (2015) identified three key path dependency challenges for spatial planners: conceptualizing green infrastructure; enshrining green infrastructure within planning tools and processes, and employing green infrastructure in the context of climate change adaptation.

Regulatory Challenges

Multiple and conflicting regulatory policies and frameworks at the local, state, and federal levels related to governance and are a primary impediment to NbS implementation.

Regulatory hurdles are challenging across scales and jurisdictions at municipal, county, state, and federal levels:

There's a lack of understanding, these folks who work in regulatory agencies who deal with all kinds of projects, none are specialized in nature-based solutions, it's whatever comes in the door we have to figure it out to permit. The current [federal] framework does not allow habitat conversions. It's looked at as a permanent fill below the high water mark. We're talking nine months for permits for a few hundred feet of shoreline.

You have multiple regulators: even for just a sea wall, you have county, state, maybe the Army Corps. Often the state and county disagree: what they ask for might be in conflict. The county might ask you to create rip rap, and the state might say no, you can't encroach on the tidal zone. Consistency is really difficult.

Practitioners noted, for example, that in some states, such as Virginia, the regulatory framework moved the burden of proof to gray infrastructure–permit seekers must prove that green will *not* work. Yet in other states, such as Maine, there is no legislative support, and gray infrastructure does not carry a monitoring burden, while green does. Consequently, if an engineer needs to approve an NbS project, they may not be "*willing to risk their stamp*" without political and legal safeguards or reassurances in place.

Virginia is the only state in the nation that has protection for today's tidal wetlands and tomorrow's migration zones. The Code of Virginia **Section 28,2-104.1** declares living shorelines are the default method of shoreline erosion control unless the permittee can prove otherwise. In addition, they created an expedited permit for living shorelines. The statute added to section **28.2-1301** a requirement that the Virginia Marine Resources Commission develop guidelines for tidal wetlands permits that take sea level rise into account–the only state in the country with this authority. The legislature in 2020 also enacted a provision under the **Chesapeake Bay Preservation Act** to develop permitting criteria that take into account "coastal resilience and adaptation to sea-level rise and climate change." As of 2023, the guidelines are being finalized. While these provisions are first in the nation, according to practitioners they are not being systematically enforced or adhered to, with watchdog conservation organizations intervening in permit decisions that have gone towards gray infrastructure.

Multiple practitioners noted that implementation is strongly impacted by **interpretation of existing regulations**, or 'soft law' interpretations, in areas where state governments and legislatures do not directly or politically support NbS. Many noted that existing regulations are generally based on a presumption of historic or static climate conditions, and may not accommodate the necessary retreat of ecosystems as sea levels rise (see also Retreat.)

Regulatory agencies have struggled to adapt regulations to meet local needs, especially at the state and local level. Federal agencies like USACE and NOAA are recognized as leaders in permitting changes, but federal barriers still exist around rules for fish or endangered species habitat, particularly with dredging and the reapplication of dredged material to supplement marsh accretion. The Northeast Regional Ocean Council (NROC) and The Nature Conservancy (TNC) provide leadership and documentation in this space (ie., Davenport et al., 2022; Woods Hole Group, 2017).

Finally, resistance to regulatory change within state agencies was noted by some. One predominant cause, according to practitioners, is a legitimate concern that deregulation could lead to loss of protections for many threatened or endangered species still in need. In other cases, experienced state ecologists and biologists noted their discomfort with the fast pace of climate projects and concern over sacrificing existing habitat for solutions with potentially harmful effects.

Native Nations and Indigenous Leadership

Native nations and Indigenous peoples are often at the front lines of climate impacts and have extensive local knowledge of sustainable practices, but NbS can sometimes co-opt Native practices while simultaneously disempowering Native people and solutions. Collaboration with Native nations helps to support NbS.

Across the U.S., Native nations and as yet federally-unrecognized tribes[1] are often at the forefront of **assisted relocation** and NbS discussions. As we have noted, tensions exist between Western science approaches and Indigenous science. Additional tensions relate to issues of sovereignty in decision processes.

1 The array of federal services and resources reserved for American Indians and Alaska Natives is contingent upon a tribe securing federal recognition

Native nations and Indigenous peoples have been practicing NbS for millenia. Consequently, NbS as interpreted from a Western science perspective may be seen as simultaneously **co-opting** Native practices while **disempowering** Native solutions and people (Funes and Shea, 2022).

> *"It's like suddenly we've discovered this new way of adapting—and we all know who discovers things. It's got the Columbus vibes."*

Indigenous and traditional knowledge are part of nested knowledge systems, in which communities hold knowledge that includes local resource management, governance structures, social norms, spiritual beliefs, and historical and contemporary experiences of colonial dispossession and marginalization (Nalau et al., 2018). In this context, NbS needs a full community engagement approach.

As noted in the Equity and Power section, there can be a bias towards restoration that does not include people and traditional practices:

> *The other thing I hear a lot from tribal leaders, what's the role or place for people? What does it mean for people in communities? Are we abandoning parts of the coast to do ecosystem restoration, will it all be bought by a big green NGO and put in conservatorship?*

Places with examples where Native nations are leaders (see Alaska, Northwest), in NbS and climate adaptation more broadly, are regions where established relationships between Native nations and government and academic institutions have created **institutional memory** for collaborations that respectfully bring together the worldviews and sciences of different knowledge systems, making these collaborations and projects move forward more smoothly. With explicit and institutionalized attention to these relationships, nature-based solutions, retreat, and adaptation projects can better address equity concerns and community needs.

Systems-based Approach

Systems thinking and practice leads to more successful long-term outcomes based on understanding landscape-scale interactions and changing physical and social conditions.

Although systems thinking was rarely explicitly called out by practitioners, those who saw successful implementation and sustainability of projects integrated the social, ecological, and economic aspects of their projects. In particular, the concept of **social-ecological systems (SES)** demonstrates that human systems and ecological systems are inextricably linked (Berkes et al., 2003, Folke et al., 2010, Preiser et al., 2018). The behavior of a system is determined by the nature of interactions, not the character of the components, and so relationships are fundamental (Rogers et al., 2013). SES can also be thought of as **Complex Adaptive Systems** to better characterize interactions in systems. As contexts change, so do systems, because they are a function of their environment; and emergence in the system is nonlinear (Presier et al., 2018).

In other ocean-related sectors, such as fisheries management, **ecosystem-based management** has provided the opportunity to move from a species-based approach to an ecosystem-based approach (McLeod and Leslie, 2009).

VALUATION AND CO-BENEFITS

Our current valuation systems do not properly value the vast varied co-benefits of NbS; economic valuation is set up for more traditional gray infrastructure, and gray to green is not an apples-to-apples comparison.

> *The two most critical elements where progress is needed: capture and evaluate the diversity of benefits provided, from hard economics all the way to equity; and capture them in a way to enable that understanding to be incorporated in decision making.*

Practitioners see the need to explicitly value co-benefits in order to make it easier to justify federal funding. The current funding systems and mechanisms don't work well with NbS (see also Governance).Co-benefits such as improved water quality, recreational opportunities, support of biodiversity, and mental health benefits are documented but difficult to quantify.

Demuzere et al., (2014), demonstrated the challenges with capturing co-benefits, ultimately using multiple scales (city, neighborhood, and site-specific) and discovered that tradeoffs between ecosystem services mean that some benefits could be detrimental to other functions.

A number of interviewees noted that there is a "**double standard**" for cost-benefit analysis that favors gray infrastructure and places the burden of proof on NbS practitioners to prove cost effectiveness for an entirely different solution:

> *There is no easy way to compare [gray and green] options. It takes a long time and is expensive. You can't compare a sea wall to a marsh restoration without doing a preliminary design. The Army Corps has a cost library, with linear foot cost of a sea wall or breakwater, but they don't have similar costs for nature-based solutions, in part because it depends on location. We can't really do an apples to apples comparison between gray and green.*

Ultimately, we still do not have a good way to represent the services and benefits of natural systems. The economic tools available for calculating biodiversity and existence values, recreational benefits, etc., are not viewed with the same confidence as the costs and benefits of constructed infrastructure. The multiple co-benefits of NbS are very difficult to document in dollars and cents.

Benefit Cost Analysis (BCA)

Benefit Cost Analysis (BCA) places emphasis on the dollar value of coastal properties, to the exclusion of nonmonetary benefits and social and environmental co-benefits.

Federal BCAs, which are used by federal agencies to select projects for construction, place a significant emphasis on the dollar value of the properties a proposed project would protect (in the case of flood risk management projects). Environmental and social benefits of nature-based solutions are not included in the evaluation. To finance NbS projects, practitioners must work within a system that requires benefit cost analysis (BCA) and does not properly value co-benefits of a NbS, which range from recreation and public health to maintaining traditional lifeways for indigenous communities. Practitioners recognize that this system of valuation should fundamentally change or transform to better support the intrinsic value of nature, but they also recognize that time is of the essence and they need to work within the system we have now.

The influence of the BCA cannot be overstated:

> *NbS can't be judged by typical project BCAs because parameters governing those BCAs do not recognize or account for NbS performance differences (often in a temporal sense, and always in an operations and maintenance evolution sense given performance variabilities), nor do they allow the capture of "other benefits" that may be valued in non-BCA ways. NbS are often off the table [before planning begins] because the BCA screens them away as a project alternative (option) to explore/pursue (alongside gray or hybrid). Change the BCA and NbS become a viable alternative to assess, design, engineer, build.*

BCAs are the most common tool for capturing the benefits of an infrastructure project, gray or green:

> *Policy-wise, we need to create a level playing field. BCAs are a key part of federal funding, but historically the benefits from ecological approaches are not included, and structural approaches end up looking more cost effective even if they are not in reality.*

Pragmatism is critical for those who work on-the-ground, and there was a notable groundswell of voices seeking better valuation techniques. Financing of NbS projects often plagues practitioners. A funding system that focuses mostly on economic costs and benefits is especially inadequate for meeting the challenge of climate adaptation and nature-based solutions. This is in part due to the long time-frames and co-benefits inherent to adaptation. While many interviewees recognized the need for standardized ways to compare the many co-benefits of natural infrastructure, they simultaneously recognized that dollars do not capture the value of co-benefits.

> *For native peoples, they have counted on this infrastructure for not only their homes and buildings, but also for their ancestors. Self-identity can be tied to the fact that they have been able to practice this same activity as their parents and grandparents. If all of a sudden that tree that has always been referenced as "grandpa" is underwater, and now your grandchildren will not be able to have the same reverence, that's huge. That affects your self identity.*

Outcome-based Standards

Many practitioners desired performance-based standards that could account for context and co-benefits. Standards already exist in international frameworks and documents, and these could be used to build cross-sectoral national or regional standards.

Practitioners at every level (municipal up to federal) desire performance- or outcome-based standards. This is an active area of interest for funders FEMA and NFWF, and convening experts could address this challenge.

> *We did this huge community of practice [on nature-based solutions] and tried to develop a suite of metrics so performance could be measured, to help with design and demonstrate effectiveness. [It] came out loud and clear, from all federal agencies at the table: everybody had different priorities for the same kind of project.*

Various standards exist in a variety of NbS contexts. The International Union for the Conservation of Nature (IUCN) has eight main criteria for a global standard, a "facilitative" framework for designing and verifying NbS to meet project goals. They focus on identifying the societal challenge(s), scale, principles of sustainable development, balancing tradeoffs, managing adaptively, and sustaining outcomes (IUCN, 2020). The USACE Engineering with Nature team created a 1,000+ page document in 2021 that provides international guidelines on nature and nature-based features for flood risk management (Bridges et al., 2021a). A shorter overview document provides guidance on using a systems approach to design in partnership with communities to anticipate, evaluate and manage risk for a NbS project (Bridges et al., 2021b). This guide is specifically for flood risk management, and may not address habitat, social wellbeing, or other goals for U.S.-specific performance-based standards developed with the input of multiple sectors.

The report recommends that monitoring metrics / standards be chosen carefully to capture "the most critical aspects of the project (typically those related to the objectives), and metrics that can inform multiple types of performance should be used when possible" (Bridges et al., 2021b) (see Key Ingredients for Effectiveness).

How do we get guidance and standards that landscape architects, engineering firms, people implementing, can turn to for a level of credibility or liability coverage? Building science has a building code council. I realize this is hugely difficult for something so place-based, but we need something someone can say, 'we can expect these levels [on these variables.]

But there is a reason developing standards is a significant challenge and opportunity: the groups responsible for planning and implementing NbS are accustomed to engineering and architectural standards–and nature often does not fit neatly into guidelines.

Cookbook engineering guidance leads to cookie cutter engineering solutions. Conventional engineering with nature-based solutions can't be replicated in a cookie cutter fashion.

Consequently, standards that are built on outcomes or performance will be more likely to meet the context-specific needs of a region, along with state and local community needs. Outcome-based indicators were explored by Donatti et al. (2020), and they identified 13 distinct outcomes for international NbS projects, including coastally-relevant indicators such as loss of assets during extreme events, reduced negative impacts of climate change on ecological interactions, and reduced negative impacts on water quantity and quality for human use. Building standards around such outcomes leaves space for regional and local contexts in physical, ecological, social, and economic outcomes.

COMMUNICATION AND COLLABORATION

Communication and collaboration are crucial factors in successful NbS projects, but this invisible labor is often uncompensated. Without well-articulated, collaborative framing of goals, benefits, limitations and uncertainty, projects are vulnerable to an array of potential roadblocks.

The need for communication, collaboration, and opportunities to share and listen across regions and sectors was one of the most frequently heard and resonant themes from practitioners. Practitioners noted the need to allocate/compensate time to coordinate with partners across regions, internal departments and sectors; frequently they do not have sufficient time and capacity to coordinate at the level required to build and sustain relationships

of trust and action. This work of collaboration and **relationship building is "invisible labor"**, meaning that the critical work practitioners do to build relationships is not explicitly recognized.

> *Funding relationship building doesn't get a lot of attention, and is hard to report. But it's effective.*

> *I would like to see more shared knowledge: scale it. I make [relationship building a] part of my job, but technically it's not. A lot of experts don't have the time or bandwidth for the constant relationship building. No one is funding me to do it, but I do it anyway. It's a barrier, and I wish there was more I could be doing...There's a lot of pre-work to be (done) before shovels go in the ground.*

Relationships also need to be built **across agencies and sectors**. The wide range of expertise and input needed to implement an NbS often includes engineers, landscape architects, municipal planners, state and federal regulators, and funders. This requires translation between and among professions and areas of expertise.

> *I really think that we need more of our science folks to be able to translate engineering aspects, and regulatory aspects too. That's the coordination piece, this is the problem we see everywhere–people specialized into one group or another. I want to sit with the Army Corps and do beneficial use projects creating habitat for bird islands and [integrate] the benefits to the community. Getting all those folks together, and having the ability to talk to each other, can be very challenging. That's the extension piece: so few people are trained in that.*

> *We need to work on addressing that knowledge gap: take a forester, a geologist, and a materials scientist, and get them to work on this together. There has to be that translation. Each person has their own mental models for how to approach this, let alone how to describe it. Nature-based solutions expose the downside of this kind of siloing.*

In addition, we learned from practitioners that conflicts arise from dramatically different perspectives and opinions about the value of climate adaptation: this occurs among biologists, between planners and civil engineers, and within regulatory agencies, to name a few. This often stems from divergent individual views on the spectrum of the **Resist-Accept-Direct (RAD) framework**, in which decision makers have choices regarding whether to maintain or restore

ecosystems (resisting climate change), allow ecosystems to change (accept it), or actively shape change toward preferred conditions (direct) (Schuurman et al., 2020). This framework is critical for taking a landscape-scale approach to NbS, as well as considering the longer time horizons needed to maintain an NbS, and could support important conversations.

Finally, communication issues on this topic also exist between experts and the public; there needs to be a deliberate plan to enhance flow of information with stakeholders and impacted communities.

> *There is the public education component, but it has to go in both directions. We have to be listening and learning and monitoring and watching, and be able to adapt quickly–because circumstances change very quickly.*

> *People are excited, for good reason, for revived ecosystems. The problem is, when this is done without thinking about the people, how do you expect to have the workforce to properly manage and build [a nature-based solution]? We underestimate the importance of education, and in people understanding the concepts we are explaining.*

In areas where the majority of shoreline is privately owned, the issue of communication is especially critical: practitioners told us that homeowners will usually default to a gray infrastructure solution unless they have either had a bad experience with armoring, or they have been educated on the benefits of NbS. Even where regulations require landowners to use green infrastructure unless there is a proven need otherwise, public knowledge is considered critical for successful implementation of NbS (see also Regulatory Challenges, Social Proof, Messaging and Credibility.)

A useful webinar for understanding practitioner needs is '**Investing in Nature-based Solutions**,' conducted by FEMA and NFWF. The webinar was attended by a cross-section of practitioners at the state and local levels. *'Identifying and bringing together all the right partners'* was the greatest practitioner planning need; adequate funding and local capacity were the two most referenced hurdles for moving NbS projects from planning to implementation (FEMA and NFWF, 2022). Finally, the challenges the practitioner participants anticipated with integrating NbS into their hazard mitigation work were dominated by concerns and gaining local buy-in, particularly of elected officials.

A specific issue that arose in communication was **framing**, or how NbS were portrayed as meeting coastal adaptation needs. As Craig and Dillon (2023) write, *"How an issue is framed determines from the very start what is taken to be the target system…and determines what forms of evidence are deemed relevant and sought out."* If NbS were framed by their advocates as solving coastal climate issues such as storm surge, stakeholders were inevitably disappointed by less than 100% protective abilities. However, if multiple co-benefits were captured during the planning process to meet multiple project goals, with monitoring to identify further benefits, this could work strongly in support of future project implementation (see also Key Ingredients for Effectiveness.)

Messaging and Credibility

It is essential for practitioners to clearly communicate the limitations, uncertainties, and benefits of NbS. There is a disproportionate burden of proof for green versus gray infrastructure, because gray infrastructure is the status quo option for many decision makers.

Advocates for NbS walk a challenging line: they are often asked for proof of effectiveness, but the terms of effectiveness have to be precise enough to not oversell the benefits. Understanding and documenting the limitations (see Effectiveness) of NbS is critical for broader uptake of green infrastructure.

Some municipal and state practitioners with whom we spoke found that much of the reporting and documentation around NbS reads like evangelism:

> *I feel like the dialogue around nature-based solutions, it's almost propaganda, with not enough guidance.*

Communicating about the **limits of nature-based solutions** is particularly critical. In "high energy" environments, especially where there is formation and movement of ice, but also powerful storms (Pacific Northwest, Alaska) and tropical cyclones (Pacific Islands, Southeast and Northeast), provide conditions in which NbS may not provide protective value and may be severely damaged or destroyed as habitat. While marshes, sea grasses, and mangroves can attenuate waves and decrease storm surge (see Ecological Effectiveness), this mitigating effect is dependent on the characteristics of the ecosystem, the geology of the region, and the storm.

Low temperatures can also impact effectiveness: in one example, during a winter storm in the Northeast, a frozen marsh was not able to protect a community because the plants could not provide any wave attenuation (they were frozen under seasonal ice).

The messaging around achievable goals is especially critical in areas where NbS are implemented as pilot projects:

> *If you don't do it right, it won't work, then people say that the nature-based solution didn't work, and they will go back to levees and seawalls. It's a very real risk.*

The quote above illustrates the challenges inherent to NbS: what does it mean to do it right? Right for whom? How is success measured? Communication around risk is critical (see Communication). Research in Mexico that examined two field sites examined the hypothetical versus empirical benefits, and concluded that NbS needed to engage with the tradeoffs of conservation and development. Which is to say–the economic drivers of (coastal) development play a heavy hand in determining the long term benefits of a NbS, and these need to be addressed in the context of each project and landscape.

Social Proof

Despite a plethora of case studies from around the world, what most influences the decision to choose a green solution is local peer acceptance and proof of concept from neighbors and regional projects.

Case studies from around the world don't seem to convince people--what convinces private landowners and public sector decision-makers are pilot projects that are in their own community or a nearby location that they perceive as similar enough to be relevant to their situation. This phenomenon of social proof (Cialdini, 1984) we could call the "neighbor effect" in NbS–practitioners noted that when one private landowner installs natural infrastructure as an early adopter, others will start to inquire and follow suit.

Another way to view social benefits and provide evidence of success is found in the educational value of an NbS, even if its risk mitigation or habitat value are limited. For example, cities in Florida may maintain "hedges" of mangroves, which, due to their lack of width, have limited capacity to reduce flood risk (see Ecological Effectiveness). They may not provide significant wave or storm surge attenuation, but practitioners argued that they serve other important benefits, such as beach stabilization, but perhaps are more important as a demonstration to build public support for natural infrastructure.

There are thousands of global and national examples from which interested parties can learn. That said, these examples, even with similar physical and ecological conditions, are often not enough to convince local leadership. Consequently, **hyper-local pilot projects** are often critical for local traction and uptake.

NBS PLANNING PROCESSES

Where NbS are integrated into key planning documents and processes, investment can more easily flow to NbS projects.

Practitioners told us that planning processes are key, and those that are set up to integrate NbS are more likely to lead to implementation. Typically NbS are not incorporated into the main planning and decision-making frameworks that

drive investments, such as hazard mitigation plans and local comprehensive plans. However, when they are, it can strongly encourage adding NbS to the suite of adaptation options. For example, in Charleston (SC), the 2021 Comprehensive Plan is framed around "water, now and in the future," and mandates attention to adaptive solutions. If overall planning processes and documents are not in place, the governance of an area will often work against NbS implementation instead of for it, which is often the case in under-resourced areas.

Communities often struggle to know where and how to begin–another reason building NbS into planning documents can support the first steps towards implementation.

> *A lot of communities don't even know where to start, and the process is complicated.*

However, some practitioners noted a mismatch between planning processes, especially climate and resilience reporting and initiatives at the state level, and the ability of municipalities to make state funding work for their needs.

RESOURCE

The NFWF National Coastal Resilience Fund (NCRF) provides funding specifically for planning and / or implementation of NbS on the US coasts. A **searchable map** illustrates the location of grant recipients, and they have project fact sheets for each year of the program **available online**.

Human and Ecological Relocation

Relocation of both people and habitat is a critical discussion that needs to be better integrated into NbS understanding, engagement, planning, and implementation. Issues related to "incremental" vs. "transformational" changes need to be addressed in the context of multiple time frames.

At the leading edge of policy and planning are people and places thinking not only about how to assist people to relocate, but how to create space, often in a coast already squeezed by development, for ecosystems to move upland. Some practitioners argued that NbS are not adaptation projects unless they take into account future conditions.

> *We get a lot of the question: is adaptation different from conservation? And there may be ways we have to change [conservation] to be more effective. For coasts, especially salt marsh, we can't focus on places that are strongholds today, we have to think about where [habitat] will be found in the future. And are there things we can do to slow that loss?*

For example, if a current marsh is protected, practitioners stressed that it needs an easement behind it that allows the marsh to migrate to higher ground as seas rise. Many states are just starting to contend with the need to retreat, as research indicates that more than 97% of current vegetated shoreline could disappear by the end of the century without upland wetland refugia and under pessimistic SLR scenarios (Buchanan et al., 2022).

> *I think the predicted losses are on the low side without laws banning shoreline development that are vigorously enforced. As waters rise, I don't see many folks just passively letting the water in–they'll put up a fight and that fight will drown a lot of wetlands in place until they overtop whatever barriers have been erected. Most of our tidal shoreline is privately owned so you're dealing with a very pixelated problem to keep the shoreline open for marsh migration - parcel by parcel decisions on adaptation or armoring. I've been laughed out of a few service club meetings for bringing up the "do nothing" approach to allow wetlands migration.*

> *Most NGOs are not protecting uplands that are migration pathways, they are protecting actual wetland, which will be gone, it has a shelf life. They're buying a product that will expire, not buying the land it needs to move to. Wetlands won't move in if people have built houses on those pathways.*

These discussions among NbS practitioners are often in entirely separate conversations from ongoing discussions around human managed retreat, and further reiterate the need for communication and collaboration across sectors and topics. Currently, human and ecosystem retreat appear to be rarely addressed in the same conversations and policy spaces. On the ground, some practitioners recognize the idea of moving both conversations and planning forward, but with a focus on all of the key ingredients for making these conversations more palatable and realistic:

There has been some work with planning, but it's tricky, finding ways of having managed retreat–or a word other than retreat, because people don't like it. I think it comes to everything: research, education, policy and planning, working hand-in-hand to find solutions.

Green-to-Gray Spectrum

Everyone loses when gray and green infrastructure are presented as competitive alternatives. Instead, experienced practitioners approach project alternatives as a spectrum moving from green to gray, starting on the green end and including combined approaches.

In many cases, green and gray infrastructure are positioned as two separate and opposing options. However, practitioners told us that this may not accommodate the goals set forth by project proponents and communities. Consequently, practitioners noted that a repositioning of green as the baseline, instead of defaulting to gray as the baseline, could support better integration of the two.

Rather than starting at the gray end, start toward the green end, and only go as gray as necessary.

However, integrating gray into green infrastructure could cause maladaptive responses. Taking a systems and landscape scale perspective is necessary to avert problematic interactions between green and gray:

How do we decide where to invest time and energy? How do we protect solutions? If nature-based solutions are happening alongside gray infrastructure, like at Isle de Jean-Charles [Louisiana], it will increase wave action. If we don't treat it all as a big system, it will not succeed. It will not get rid of gray infrastructure, and we may need it to protect the nature-based solution. But we behave as if [green and gray are] in conflict, because different agencies are doing them.

Practitioners noted that starting with green as the baseline and adding in gray infrastructure, with attention to system impacts, may also better integrate community interests.

There shouldn't be an expectation that people want to live behind prison walls. No one wants to live like that.

Both green and gray infrastructure have limits for protecting coastal assets from sea level rise and storm surge. Gray infrastructure seems to be the preferred "safe" option, despite research and experience demonstrating failures of gray infrastructure, even to the point of neither solving the intended short-term problem nor helping people cope with long-term shoreline change on island coasts (Nunn et al., 2021). As of a 2015 analysis, approximately 14% of the continental U.S. coastline had been armored, and hardening correlates with development, with some counties reaching over 50% gray shoreline (Gittman et al., 2015). In multiple conversations with practitioners, they related stories of communities, especially marginalized communities of color, who were offered a NbS, while a wealthier, whiter community already had gray infrastructure. This contrast influenced community preferences (see also Communication, Social Proof).

Something also underappreciated is the risk people are still at when behind flood walls. This is complacent thinking when they think they are protected.

Some practitioners are concerned that they are being directed towards NbS in cases when it is not capable of reducing risk, where instead "*we should support whatever is effective at mitigating hazards.*"

> *The big challenge is what's gonna work, what's going to tangibly reduce risk, at what scale, and do you have the land area sufficient to reduce risk… especially in high energy areas, how much green to gray do you need, and how do you implement multiple lines of defense. When using nature to provide the first line, we need to recognize that isn't all it will take to address the [risk reduction] challenge.*

RESOURCE

The **Green-Gray Community of Practice**, a collaborative effort led by Conservation International across the conservation, construction, engineering and finance sectors, developed the Practical Guide to Implementing Green-Gray Infrastructure. The guide has the goal of shifting engineering and finance structures towards building with nature and taking a green-gray approach. The guide walks through site selection, financing, design, engineering guidance, and policy recommendations.

DEEP CAPACITY NEEDS

Interdisciplinary knowledge is required for NbS: disciplines, such as civil engineering and biology, could each benefit from education about the other, and certifications and trainings for maintenance of NbS have been shown to support project longevity. There are not enough people employed at the national, state, and especially the local level to support NbS needs from planning through implementation and maintenance. There are often community leaders willing and able to take on NbS implementation, but only limited climate services and expert advice to support them.

There are capacity issues at every level — municipalities do not have the training or hours to apply for NbS funding, states often do not have regulators trained in NbS, and federal funding agencies do not have enough people to

meet local and state needs. Lack of capacity was viewed by some practitioners as not coming from a lack of interest or ability; instead, it results from institutional funding priorities.

> *I think the capacity issue is a cop-out–if we wanted to, we should have it, we can. Especially in the US, where there is a lot of funding, if you really want it you can make it happen. The lack of capacity is a lack of political will.*

Multiple municipal-level practitioners expressed that capacity for NbS implementation often exists locally, but is frequently not identified, funded and supported–this is often more about the political will to fund, who is making decisions for whom, and regulatory limits and complexities than it is about capacity per se.

However, this view of capacity was not held by all practitioners. Practitioners across the coasts, from well-resourced to under-resourced areas, even those supported and empowered by local and state governments, were *still* unable to meet the needs of implementing an NbS project in some cases. Sometimes the issue was providing the education and training for multiple municipal and state departments, or simply finding and funding the people with expertise to move NbS projects forward in a timely manner. There is a strong desire in some municipalities to fund and implement NbS, but city budgets and staff are often spread too thin.

> *We have the political will: for our city staff, if we had the time, we would do a whole lot better.*

Lack of capacity in rural, marginalized, and historically disadvantaged communities taps existing capacity and wears down the people who want to support implementation of nature-based solutions projects.

> *We don't have enough people bringing functional knowledge to communities and natural resource management. For example, we have always had a static baseline, the benchmark has always been point in historic time. A new definition for the baseline [because of a changing climate] is a huge fundamental challenge. It takes a lot of meetings, research and planning, it takes so long, and it needs more people. If we can have a 4H [Agriculture] person, why can we not have a resilience climate specialist along the coast? It's needed. We need that capacity, we need to get to a point where baselines and models are functional for decision makers.*

Finally, funding is not enough — integrating science into design, long-term monitoring, and maintenance requires training and interdisciplinary collaboration that is often not available at the project level. However, practitioners generally agreed that there are people, especially at the local level, who can be better champions of a project due to their local relationships and dedication to their community, rather than through credentialed experience as a scientist, engineer, or other NbS-related expertise.

RESOURCE

Nonprofits such as the Anthropocene Alliance are trying to fill the climate services gap in NbS by providing volunteer and paid technical capacity, including grant writing and peer-to-peer learning opportunities, for marginalized communities to receive NFWF NCRF grants. For the 2022-23 grant cycle, 17 Anthropocene Alliance member communities were awarded a NFWF grant for planning or implementation of an NbS project. However, the need greatly exceeds current capacity.

Monitoring and Maintenance

Monitoring, if it occurs at all, is typically conducted by the initial project implementers, while maintenance is an entirely different group of people such as landscapers and grounds crews. Both are necessary for the short and long term success of a project and for scaling NbS regionally.

Monitoring of the effectiveness of NbS as a coastal adaptation practice is ad hoc at best, and in most cases it is absent as a long-term strategy. The need for monitoring to understand the effectiveness of nature-based solutions was noted by multiple practitioners:

> *Clearly there's a need for additional info about their effectiveness and longevity. There are management practices that need to go with them to make sure [NbS] functions over time. There is potential for there to be a deterioration in the effectiveness. If you put a nature-based solution in assuming some standard of effectiveness for a ten year period, and it only lasts for five, that's a problem.*

Is it going to persist? Have you considered climate change, whether temperature changes or sea levels rise, or [increased] development pressure–these are critical for understanding effectiveness.

Yet practitioners cautioned against proposing an ideal monitoring scenario in practice:

There's an expectation and desire for a monitoring investment that will exceed what can be accomplished in reality. You could kill a project by placing too large a monitoring burden on it.

However, all acknowledged that monitoring is a critical need. Some noted that successful monitoring programs were able to identify unexpected outcomes and work to counter potentially maladaptive outcomes, such as spreading mosquito-borne illnesses:

There's a need to watch for unexpected impacts in real time. One of the things we ended up finding was that we had to account for mosquitoes–just a cupful of water will grow mosquitoes. Now we're attending to that.

RESOURCE

The **NFWF Coastal Resilience Open Data Platform** is a website to explore and download ecological and socioeconomic monitoring datasets from the National Fish and Wildlife Foundation's Coastal Resilience program grants. They also have an online **dashboard** that collects and stores annual metrics reported by grantees through a web interface.

As we heard from several practitioners, understanding the social dimensions of an NbS is critical for understanding the value of co-benefits and cultural ecosystem services (see Valuation and Co-benefits). Monitoring for maintenance and for use of the area by people as well as by species is an important concept in "effectiveness."

We need the social science piece for monitoring–how the space is used, how people interact with it, when we're doing projects adjacent to where people live, recreate and work.

Along with monitoring, management and maintenance of NbS are critical factors that are not often funded or implemented. This was a common point of interest and discussion among implementers: education of maintenance and grounds crews needed to happen to support and preserve natural infrastructure.

> *If you don't have education and resources, how do you expect to have the workforce to properly manage and build a nature-based solution?*

In some cases, practitioners noted that the maintenance needed for NbS is significantly lower than that of gray infrastructure. However, in most cases, implementers noted that maintenance was required to support the long term resilience of the project and its ability to meet long term goals such as risk reduction. This necessitates significant education and training where effectively implemented (see Northeast.)

Equity and Power

Equity and institutional power dynamics influence all aspects of NbS implementation. One concern that frequently emerges is that investment in NbS can lead to gentrification in areas currently underserved by natural areas. Other equity issues shared with gray infrastructure include Western science being valued over other knowledges, and economic practices that keep marginalized communities from opportunities for coastal protection.

> *We need to move beyond the idea of starting at plants in the ground, there are systemic issues that have to be addressed first.*

Equity was a broad theme within the comments of practitioners, particularly issues related to decision processes and power dynamics. First, many practitioners noted that systemic issues need to be addressed to make nature-based solutions an effective long term solution. One practitioner provided an example of a community that wanted an NbS, but they were surrounded by commercial-zoned land, and did not have the financial ability nor social capital to invest in a rezoning fight. Another practitioner in a different state related that a wealthy community successfully pushed back on FEMA flood rezoning to keep their properties out of the new flood zone.

At the state level, practitioners noted challenges with financing and of making a benefit-cost analysis work for rural communities:

> *A lot of bigger states with higher populations and tax bases have more Infrastructure dollars than rural states. It's hard for us to make the cost-benefit ratio needed for FEMA funds. Our challenge is getting the attention for climate change issues and resilience, and convincing people that the projects are worth funding in rural states. FEMA BRIC grants fund bigger states with tens of millions in projects, and that's just harder with a smaller capacity.*

Incorporating Indigenous people and practices in NbS projects has been a significant challenge for coastal NbS implementation. In some cases, removing people and traditional practices from the coastal landscape could be harmful to natural infrastructure and endangered species. For example, the cultivation of taro in the Hawai'ian islands has been found to reduce runoff and reef sedimentation while providing habitat for endemic and endangered bird species, but these practices have been discouraged in the face of Western land management practices, according to practitioners.

Sometimes the solution is providing step-by-step support to plan and implement a nature-based solution, but capacity to do this is an important equity issue. We spoke with some practitioners who were specifically doing this kind of needs-driven work, but they were stretched incredibly thin.

> *In terms of capacity and equity, it's the local governments or nonprofits that do this work, but have the least access to the knowledge and resources to design it. That will vary based on what support communities have locally.*

The **gentrification** that can result from green infrastructure investments came up frequently in interviews as well. When green spaces are created in neighborhoods, that can make property values rise and attract wealthier homebuyers. The literature documents this: marginalized communities in some cases prefer to not have green infrastructure projects, in part because of gentrification risks (Hoover et al., 2021).

In North Carolina, Siders and Keenan (2020) investigated a related equity issue: wealth and race influence what solutions are on the table as waters rise and threaten homes. Wealthier, less racially diverse communities receive hard infrastructure solutions and beach nourishment, while low income and

racially diverse communities are bought out. The adaptation decision to armor, nourish, or retreat disproportionately correlates with socioeconomic attributes: buy-outs occur in areas with low home values, low armoring, and high racial diversity, while beach nourishment occurs exclusively in armored areas (Siders and Keenan, 2020).

In Norfolk, Virginia, city planners and USACE proposed to protect neighborhoods on the historically redlined south side of the Elizabeth River with living shorelines and raised homes. On the river's north side, the wealthier neighborhoods downtown would benefit from miles of USACE-designed flood walls, berms and levees (Morrison, 2023). The contrast raised alarms in both neighborhoods, both **questioning their proposed solutions**, which have a $2.6B price tag. The proposal is based on the USACE BCA (see Benefit Cost Analyses,) and while the south side sees that they will not be protected from big storms, the north side is concerned about losing their city's character and waterfront to 12-foot walls. A redesign process more focused on NbS and equity has been proposed.

Planning at the **landscape scale** (see also Effectiveness section) is critical for effective and equitable NbS. Interviewees also noted that it is well known amongst coastal adaptation professionals that hardened shorelines cause negative impacts to surrounding soft shorelines.

> *We have an obligation to not just plan at the parcel by parcel scale, we need to be able to adapt cross-jurisdictionally. This is one of our biggest opportunities and paths forward. Agencies are not set up for this, but it's needed.*

> *We can soften the shoreline in some places, but we have obligations to work cross-jurisdictional and minimize the impacts. Wealthy communities are raising bonds to put up flood walls, and then the less resourced communities have other problems. There's an imperative there.*

There were also significant power dynamics at play among institutions involved in building NbS. Some practitioners who worked directly with communities found that the traditional "experts," such as civil engineers, were opposed to

green infrastructure. In some cases, they have the advantage of automatic credibility in the community, which is frustrating for NbS advocates.

Finally, practitioners pointed out that the process for obtaining funding through federal grant making processes disproportionately favors more affluent communities. Well-funded communities have the capacity to navigate complicated grant applications across federal agencies, administer those grants, and meet their reporting requirements. Practitioners suggested this problem could be addressed incrementally and transformationally. For the former, practitioners who work directly with impacted communities seeking funding noted that there are often community leaders who are more than capable of implementing a project, and that these people are often a huge asset because they have the motivation and social capital to keep a project moving forward. However, these community leaders are often not compensated or funded for this kind of work. For the latter, a restructuring of the methods of funding distribution that does not require individual applications, and instead provides funding based on a needs assessment conducted by federal agencies could be considered.

Observations on Effectiveness

> *There is no such thing as 'best', it's a combination of what people need and want, and what they collectively decide needs to be.*
>
> *Effectiveness is entirely context dependent. It depends on what the intended goals and outcomes are.*

Asking about effectiveness gets a lot of "it depends" responses, given the complex factors that influence project implementation. However, there is still a key foundation from which to examine the effectiveness of NbS and their goals. Based on the literature and the shared experiences from practitioners, we developed a framework for understanding effectiveness in the context of coastal adaptation.

An exhaustive literature review for each pillar of the framework is beyond the scope of this project. Forthcoming research from NOAA's National Centers for Coastal Ocean Science (NCCOS) will use systematic mapping to capture as many resources as possible, and will be a complement to our qualitative synthesis here.

"EFFECTIVENESS" FRAMEWORK: FOUR PILLARS

Characterizing and understanding effectiveness can be done using four simple pillars of effectiveness: physical, ecological, economic and social.

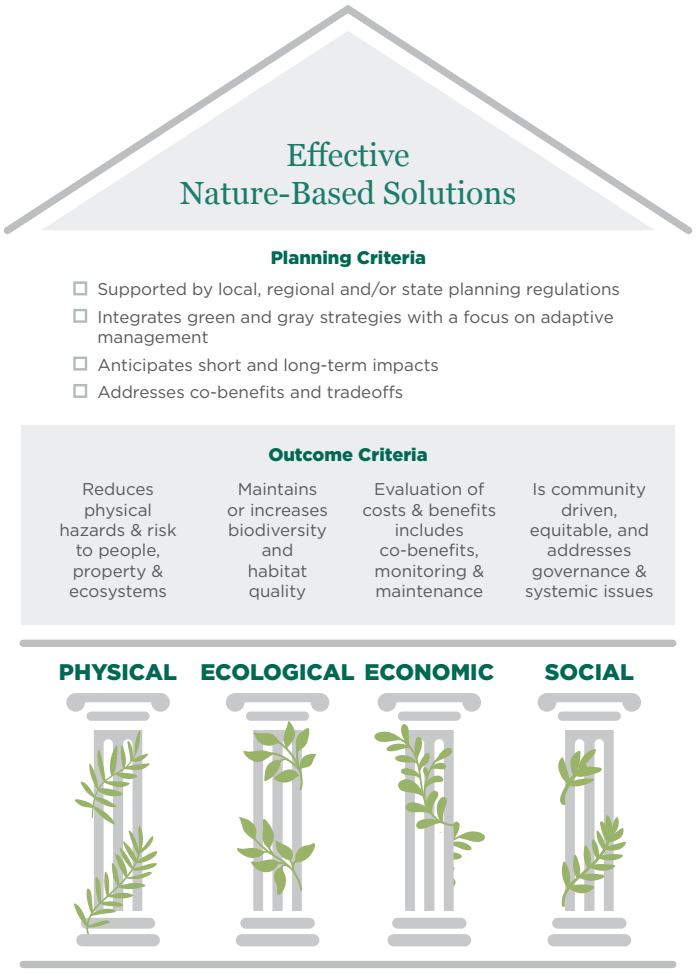
We developed a simple framework to examine effectiveness at the national scale that uses four categories to capture effectiveness: physical, ecological, economic, and social.

This framework acknowledges that *all four* perspectives must be considered for a project to achieve its own effectiveness goals. For example, even if a project can mitigate hazard risk and protect key habitats, if it does not have public support or lacks equity considerations, it will most likely not be able to meet long term potential to protect people and landscapes.

> *We need to look at multiple aspects of effectiveness, not only in the context of climate adaptation. What other services does this infrastructure provide, and how well is it performing those? How durable is it? What other kinds of amenities is it offering? Are there other public benefits?*

Exploring the multiple aspects of effectiveness is critical to avoid serving specific interests over others.

> *I don't think a community thinks that coastal shoreline paths are the same as a 16 foot wall. I don't think many people think we can have mangrove instead of a wall. Many people who live there prefer the nature-based solution and the risk, rather than a 16 foot wall. I think effectiveness is sometimes used to say we can't have nature-based solutions because it's not effective. Sometimes that term is a little bit loaded.*



PHYSICAL

- The ability of an NbS project to mitigate physical risk depends on the functionality and persistence of habitat type and its historic and current degradation, the climate hazards at play, the geology of the region, and specific biological factors.
- The wider the NbS buffer, the more hazards can be mitigated–and most areas do not have the miles of habitat and/or feet of elevation necessary to mitigate storm surge associated with extreme events. There is very little documentation of the real impacts of catastrophic storms on NbS.
- Coastal wetlands do not eliminate risk but do significantly reduce property damage.

The physical structure of a nature-based solution, and the physical hazards that it is intended to mitigate, are critical to understanding its effectiveness in its present and future contexts. Some of the earliest literature on the protective value of natural infrastructure engages an ecosystem services approach to draw out this critical benefit of nature (ie., Barbier et al., 2008, 2011; Borsje et al., 2011). For practitioners, this infrastructural orientation often falls under the purview of engineering performance.

> *Effectiveness may mean engineering performance: will a project hang together, can it be sustained, or do we need to constantly tend it like a flower garden? Managers don't want to show up every week.*

> *People say, 'Put pavers everywhere.' But it's not going to work in Charleston and Miami, where the water is permeating up. Those types of solutions won't be effective, or minimally for a short time frame.*

In support of this context dependency, a National Wildlife Federation and Allied World report (Glick et al., 2020), examined the effectiveness of natural infrastructure for hazard risk reduction by reviewing scientific literature. They found that most existing gray infrastructure was designed for the past climate and likely to fail in increasingly hazardous conditions (ie., Sutton-Grier et al., 2018), and that properties with bulkheads sustained more damage and erosion compared to properties with living shorelines (Gittman et al., 2015, Smith and Scyphers, 2019).

However, practitioners pointed out that, depending on the infrastructure and the hazard, there were critical and often unknown limits to both green and gray infrastructure. Research also indicates the need for more knowledge of physical effectiveness of green and gray solutions during large storm events (Sutton-Grier et al., 2015).

> *Effectiveness during extreme events is questionable, and with more extreme events happening this is worrisome. We also don't know their ability to withstand multiple events.*

Departments of Transportation are often on the leading edge of determining structural effectiveness. A 2018 USDOT white paper provides multiple examples of the effective implementation of NbS to protect roadways, such as Pocket Beach in Yorktown, VA; Holts Landing, DE; and Cape Lookout State Park, OR, to name just a few (Webb and Dix, 2018).

One of the most comprehensive documents used to demonstrate structural effectiveness for hazard mitigation are the USACE Engineering with Nature Atlases. These two atlases provide 118 global examples, 50 of which were developed by ACE across the U.S., where nature has been used as an engineering solution (Bridges et al., 2018, 2021). Each case is discussed using their four criteria: producing efficiencies, using natural processes, broadening benefits, and promoting collaboration.

Living shorelines, or coastal wetlands that have historically been maintained as a dynamic balance between erosion, sediment supply, and accretion, were one of the most commonly discussed nature-based solutions in the scientific literature and in practice (Currin, 2019). The terminology was common enough that living shorelines were sometimes conflated with nature-based solutions, leading to a restricted view of NbS by some adaptation providers.

Marsh vegetation can stabilize shorelines, and the living shorelines term now describes shoreline stabilization efforts that incorporate natural vegetation and habitat (Currin, 2019). Practitioners noted a very wide range of practices involved in living shorelines, and stressed that the goals needed to be considered.

> *What are we really trying to accomplish with a living shoreline? What people think we're trying to accomplish is erosion control. Living shoreline can help decrease the erosion of the shore into the water, which is pollution control, or can help prevent the deterioration of property so land in front of a house doesn't go off into the sea. Those practices, in lieu of a bulkhead, are better solutions for that problem. But when we look at what actually gets installed, the conventional practice is not to use biological material. Convention is a toeline, the toe line is rock foundation, then usually there's some rock fill that goes in behind the toe line, and plants on top of that. A lot of what's getting built under the name of a living shoreline looks a lot like a sea wall, except that it's not concrete.*

Practitioners often raised questions about the effectiveness of a living shoreline in their context. One person in particular noted that placing additional organic debris (such as tree stumps and roots) at the toe of a marsh could impede natural processes that could ultimately protect the marsh and allow it to migrate with sea level rise. Others worried about the impacts of living shorelines on sea grasses in their area. Many practitioners noted that living shoreline approaches varied dramatically by location.

The federal government tends to take a one size fits all approach to thinking about living shorelines, but the physical geographic settings are so wildly different.

Finally, as noted elsewhere in this report, marshes need a place to go as the sea level rises. While maintaining marshes may support short term adaptation, these marshes need an easement behind them to allow them to migrate inland, and depending on the geography this may or may not be possible.

RESOURCE

USACE has cataloged an extensive collection of reports at **Nature-based Solutions Guidance** designed to provide support for practitioners across scales and geographies. Users can scroll through the website and click on reports that provide "technical, policy, and economic guidance," publicly available and accessible with a click from the site. Each report includes a brief summary. This collection is oriented towards flood management and offers easy access to the collected reports, but does not offer a search function for those seeking specific topical guidance.

A recent comprehensive review by Temmerman et al. (2023) found that effectiveness to serve as a coastal buffer depended on functionality (the capacity to reduce waves and storm surge through factors such as the interactions between vegetation properties, such as plant stiffness and height, with hydrodynamic factors, such as wave period and height and currents), and persistence (the ability to resist and recover from storm damage, which depends in turn on the ability to accrete sediment to respond to sea level rise).

The ability of mangroves to attenuate waves and reduce flood risk has been well documented. Practitioners also recognized an additional function: mangroves' ability to trap debris in extreme events. Mangrove parameters (height, species and especially width of forest), geomorphology of the shore, and wave parameters are the dominant characteristics found to influence the protective effect of mangroves (Gijsman et al., 2021). Mangroves can reduce storm surge water levels by slowing the flow of water and reducing surface waves; they can also reduce surface wind waves by more than 75% over one kilometer of mangroves (McIvor et al., 2012).

Coastal wetlands in general have been found to reduce property damage from tropical cyclones, dampening the impacts of strong winds and storm surge. Between 1996 and 2016, U.S counties with more wetlands experienced significantly less property damage from the 88 hurricanes that made landfall in the U.S. (Sun and Carson, 2020).

Throughout the country, areas with salt marsh are being forced to think about how to best protect these marshes, which in turn protect coastal communities. Sediment augmentation, or thin-fill sediment application, uses dredge material to support more rapid accretion processes that, given local circumstances, may be required to keep up with sea level rise. Some successful applications have been documented at small scales (ie., Davis et al., 2022), and new marshes have been successfully developed *as long as there is public support* and attention to livability, biodiversity and flood safety (Baptist et al., 2021).

However, not all projects have been successful. At Sea Beach National Wildlife Refuge in Anaheim Bay, CA, for example, vegetation colonization did not occur at the expected rate, and additional management was required to improve site hydrology (Sloane et al., 2021). Practitioners also noted that augmenting sediment often had a detrimental effect on the marsh, sometimes for multiple years, and this visual change needs to be carefully explained to residents and users. There was also some unease on both the Atlantic and Pacific coasts, with biologists and regulators challenged by their differing perspectives, around potentially damaging a healthy marsh and habitat in the process. In line with the USGS Resist-Accept-Direct framework, different entities fell in different parts of that spectrum when trying to determine whether to permit pilot projects.

Practitioners point out that at least two things must happen to keep salt marshes effective at mitigating risk and providing habitat: current marsh needs to be monitored and potentially supplemented with fill, and land area behind the marsh needs to be acquired to allow the marsh to retreat.

> *There is too much hype on coral and mangroves, they are just not proven during extreme events.*

Many practitioners are concerned about NbS effectiveness in the context of extreme events, which is related to the importance of proper framing and credibility of literature and discussion around NbS, as well as the need to listen to the concerns of those questioning various aspects of an NbS. Testing, monitoring and engagement at the local level are a critical component for

transparent and trust-building interactions among adaptation practitioners and the public.

Laboratory testing of physical effectiveness is helpful in clarifying the utility of alternative options. For example, recent research around coral reefs using a wave tank simulator shows that hybrid reefs, in this case an artificial trapezoidal reef model with coral skeletons, reduces wave height by more than 35% and wave energy by up to 63% under realistic wave conditions; adding the coral skeletons reduced height and energy by over 10% (Ghiasian et al., 2021).

Additional tank models have been used to document and understand wave attenuation in coastal forests such as mangroves. Using a large-scale flume, van Weseenbeck et al. (2022) showed that trees (willows in their experiment) were hardly damaged and strongly reduce wave and run-up heights up to 2.5 meters, and researchers documented for the first time that the most relevant factor for wave attenuation is the *surface area of the tree canopy*, and that flexible leaves limitedly add to effectiveness. This research suggests that coastal forest integration with levees may make hard infrastructure more adaptive.

ECOLOGICAL

- **Ecological effectiveness means increases to habitat quality and quantity, ability to provide ecosystem services, and benefits to ecosystem biodiversity.**
- **Biodiversity is critical to ecosystem function and for providing human health and wellbeing ecosystem services (e.g., recreation).**
- **Considering and planning adaptively for future conditions is critical to preserving associated habitat and biodiversity, and this may come with tradeoffs for current habitat.**
- **Natural systems used to protect infrastructure and habitat can be damaged by storms, and species-specific research and monitoring can support better outcomes.**

Among practitioners, ecological effectiveness of NbS was phrased in terms of biodiversity benefits, increased habitat (quality and quantity,) and ecosystem services, specifically supporting services such as ecosystem functioning and habitat.

Limited scientific literature exists to specifically address the ecological effectiveness of nature-based solutions. However, *decades* of research explores and identifies the ecological benefits of coastal conservation and restoration. Multiple practitioners working in conservation-focused spaces, from NGOs to state departments, remarked that "*we've been doing NbS for decades under a different name: coastal restoration."* However, grant-making conservation organizations noted a key difference between conservation and adaptation projects: adaptation embeds longer timeframes to consider future climate scenarios. Consequently, ecological effectiveness considers the continuity of the system and its ability to support a biodiverse system into the future, which in some cases may mean altering current habitat to meet future conditions.

> *Often we have to break a few eggs to make an omelet: we may have to fill existing wetlands to have wetlands last.*

Practitioners told us that there is no consensus around this tradeoff (losing or altering current habitat to protect future habitat) among biologists and ecologists and within regulatory agencies that influence the implementation of a project. For example, the conditions that enable a salt marsh to persist are not the same that make the development of a new marsh possible (van Wesenbeeck et al., 2008), and there are tradeoffs between biodiversity and flood protection in salt marshes (van Loon-Steensma and Vellinga, 2013), leading to potential conflicting priorities in NbS projects. In addition, coral reef ecosystem service priorities have been documented as both differing and overlapping between scientists, managers, and fishers. Consequently, acknowledging and measuring these priorities could highlight the points of potential agreement between and among groups seeking to protect biological diversity and services (Hicks et al., 2013).

> *The environmental protection community sometimes [advocates that] nothing should change and everything is to be preserved. This is an admirable starting point because of the value of these things, but climate change is already changing many things and future conditions and must be given weight in our projects / possibilities. If we say we can't do a project because it will cause some harm to environmental assets, and yet sea level rise or other physical and environmental factors will make it impossible for those assets to survive and adapt, then we need to enable that (negative) future condition to inform our project alternatives and evaluations. Static / status quo / zero sum approaches — whether from environmental or historic preservation perspective — may end up costing us the very things we want to preserve.*

Research suggests that addressing biodiversity will be critical to the function of the ecosystem services that habitats provide. Existing research at the nexus of biodiversity and NbS has more recently focused on the climate mitigation capacity of forests, particularly the challenges with prioritizing monoculture plantations for storing carbon over intact and diverse ecosystems (Seddon et al., 2019). Taking from biodiversity and ecosystem services research, the identity and richness of species, and the 'niche complementarity', or how ecological differences complement each other, can boost ecosystem function and therefore their services (Balvanera et al., 2006; Cardinale, 2011).

Over 85% of the world's shellfish reefs have been lost in the past two centuries, but significant restoration efforts are occuring, even as the high cost and rate of failure persists (Reeves et al., 2020). Oyster reefs can been effective at wave attenuation (Borsje et al, 2011), but as some are restored or created, research suggests that focusing on positive species interactions (interactions where at least one species benefits and none are harmed) can provide a framework for restoration, and biodiversity enhancement supports a shellfish reef's ability to provide ecosystem services (Reeves et al., 2020).

Ecosystem services research demonstrates that healthy ecosystems provide high quality services, while stressed ecosystems produce degraded services and may harm human well-being (Sandifer and Sutton-Grier, 2014). Importantly, most ecosystem services are supported by biodiversity (Palumbi et al., 2009). Biodiversity in coastal systems helps to provide ecosystems services such as fish habitat and nutrient cycling (MEA, 2005; Mitsch et al., 2015), and a range of cultural services (Rodrigues et al., 2017). Biodiversity may also play a role in the occurrence and transmission of human disease (Sandifer et al., 2015). Healthy and biodiverse ecosystems have been shown to improve physical and mental health, and have potential to provide these services as part of long-term disaster recovery (Sutton-Grier and Sandifer, 2019). These benefits are all still emphasizing the *social* aspects of effectiveness, but demonstrate the clear linkage between these two pillars (ecological and social.)

As mentioned in Standards, the IUCN addresses ecological effectiveness in their third criterion in the NbS global standard. Indicators include: the NbS directly responds to current ecosystem state and drivers of degradation; clear and measurable biodiversity outcomes; monitoring that includes assessment of unintended ecological consequences; and identifying opportunities to enhance system habitat and biodiversity (IUCN, 2020). However, practitioners told us that long term monitoring must be carefully scoped, since monitoring is critically important and that its economic and temporal feasibility can quickly become a burden that kills a project.

Among specific ecosystems studied, sea grasses can protect coastlines, but their composition may be impacted by more severe storms. For example, multiple seagrass beds were monitored following Hurricane Harvey, a Category 4 hurricane that made landfall in Texas and Louisiana in August, 2017. The results suggested that examining species-specific responses to large storms would provide important information to coastal planners and managers (Congdon et al., 2019).

Some research has also been done around comparing natural and hybrid systems. In a unique experiment in New South Wales, Australia, researchers compared natural mangroves with hybrid engineered rock and mangrove habitats and found that, while hybrid solutions could support marine food webs, they could not replicate the biodiversity found in the natural system, underlining the importance of protecting natural habitat (Tachas et al., 2021).

Practitioners told us that funding from conservation or habitat-focused organizations is one of the most important pathways for implementing NbS. These organizations also provide significant documentation and technical guidance on the applications and benefits of NbS projects (ie., Leung et al., 2018; Dumitru and Wendling, 2021; Pathak et al., 2022).

In summary, ecological effectiveness of NbS in the context of protecting coastal habitat and biodiversity is largely under-researched, but conservation NGOs are providing funding for better understanding of ecological effectiveness.

ECONOMIC

- **NbS clearly and irrefutably reduce the damages and costs from sea level rise and catastrophic storms.**
- **Current valuation systems do not name nor value the many co-benefits of NbS that are critical for coastal economies.**
- **Monitoring and maintenance, which require different people and areas of expertise, need to be included in NbS projects from the outset to measure and understand hazard mitigation and co-benefit effectiveness (*see* Monitoring).**
- **This report does not explore the role of insurance and reinsurance in promoting and protecting NbS, but this is an important future research space.**

Practitioners told us that one of the most common questions among decision makers is *what does it cost?*

Overall, a strong economic case can be made in favor of nature-based solutions. Beginning in 2008, Costanza et al. found that wetlands accounted for 60 percent of the relative variation in hurricane damages when comparing areas with wetlands to those without. In a 2017 study by Narayan et al., researchers demonstrated that $625M in direct flood damages were avoided during Hurricane Sandy due to wetlands. The study quantified the risk reduction services of marsh for the county, estimating a 16% average annual flood loss reduction (Narayan et al., 2017). However, compelling cases of nature-based solutions such as this one can be difficult to find due to a lack of published monitoring and evaluation data.

As mentioned in the previous section, Sun and Carson (2020) found that wetlands reduce property damage during storms and that wetland losses increased property damage from Hurricane Irma by $430M. Researchers have modeled reduced property damage from storms due to US wetlands (Rezaie et al., 2020). Research in California demonstrates that dune restoration and beach nourishment would preserve $65M in non-market value through 2100 for just one southern California beach (Sheehan et al., 2022). In international contexts, researchers found that green infrastructure (riparian buffers) were more cost effective than hard infrastructure, noting that the absolute protective value of green infrastructure was lower (Daignealt et al., 2016).

A key concern among practitioners is the ability to integrate co-benefit values into NbS project valuation (see Valuation and Co-benefits). Stroud et al. (2023) examined the climate justice implications of economic valuation using utility weights, or placing monetary value on the important social factors of improved air quality, availability of public transportation, recreational space, rent escalation due to gentrification, and prevented loss of wages due to reduction in mental stress. Integrating these monetized factors into planning could similarly support implementation of NbS for vulnerable communities, although it is difficult to develop weighting systems that meet the needs of multiple projects and individual preferences.

The language of proof of effectiveness across government scales is often economic. For example, on the NOAA Natural Infrastructure website (2023), the leading content highlights three economic values: $23.2 Billion in yearly storm protection services; $7 saved for every $1 spent; and $99,000 worth of yearly services (from a 2.5 acre oyster reef.) Yet on the ground, the economics

of nature-based solutions can be more difficult to prove (see Valuation and Co-benefits.) To receive federal funding for an NbS project, many communities turn to USACE or FEMA. These federal agencies require that a proposed project meets a threshold by which the monetary benefits outweigh the costs: this is the benefit-cost analysis coefficient. However, this currently does not value the many co-benefits of an NbS, and it disadvantages communities with lower property values. It also generally employs a "discount rate" that means benefits to future generations are not properly considered. To help address this problem, USACE economists have been working to modify this one-coefficient CBA to six coefficients that better account for co-benefits (NASEM and USACE, 2022).

For those interested in the complex and institutional challenges to modifying the current federal BCA for USACE, there is a recording of a one-day workshop "**Measuring What Matters: Towards a More Comprehensive and Equitable Evaluation of Benefits**" (NASEM and USACE, 2022). This workshop provided extensive context and strategies for a modified BCA approach.

For this report, we did not explore the insurance and reinsurance aspects of economic effectiveness using nature-based solutions, although we did examine resources more broadly relating to insurance in managing coastal climate risk (see Gray, 2021; NASEM, 2022). In terms of insuring NbS, insurance for reefs, first undertaken by The Nature Conservancy (TNC) in Mexico to repair damage after Hurricane Delta, came to the U.S. in 2022 in Hawai'i, covering damage repair immediately following tropical storm or cyclone damage (TNC, 2022). For the insurance and reinsurance valuation of nature-based solutions in policies, an EU-based study examined merging disaster insurance and nature-based solutions into "insurance value of ecosystems" and "natural insurance value." Researchers found that ecosystem disaster risk reduction, eco-DRR, was gaining importance in the industry, but significant additional data was needed before NbS could be recognized as providing a risk reduction function (Marchal et al., 2019). We recognize this as an important sector for future exploration and research in the context of NbS effectiveness.

RESOURCE

Both the US Environmental Protection Agency (EPA) and NOAA have tools for practitioners seeking to value monetary and non-monetary benefits of nature-based solutions. The EPA **Rapid Benefit Indicators (RBI)** approach can be used to quantify non-monetary benefits from ecological restoration. NOAA's **Digital Coast**, specifically the **Nature-based Solutions: Benefits, Costs, and Economic Assessments**, provides training that includes different processes beyond just BCA to include qualitative analysis.

As discussed previously, practitioners acknowledge that, while the BCA process needs to be fixed, the system of monetizing the value of co-benefits cannot properly account for things like the loss of a subsistence way of life, or the loss of an entire species. Some leading research in applied spaces includes moving beyond monetary value and integrating the wellbeing of humans and all life into qualitative measurement (ie., Allgood et al., 2019).

SOCIAL

- **Governance and regulatory challenges are cited as the most critical gap in NbS implementation.**
- **Where NbS are integrated into local and state planning processes and documents they are much more likely to reach implementation and meet goals.**
- **Research gaps exist in understanding cultural norms around how we think about green and gray infrastructure, compare them, and see them as related assets (or not).**
- **NbS do not exist in isolation and need to be considered in broader social systems and contexts, with more focus on adaptive management that integrates contexts and future, (changing) baselines.**

Practitioners cited social, cultural, institutional, and societal issues and barriers as the most important gap in NbS knowledge. Currently, literature that focuses

on the social aspects of nature-based solutions–the cultural, institutional, political, psychological, communication, and equity and justice factors–is limited compared to the attention and time that practitioners devote to the "people" aspect of projects. Social aspects of nature-based solutions appear to be a critical pivot point for achieving project goals and effectiveness.

> *We need recognition that this is a comprehensive process. Our social systems, our public safety nets, they all have to be holistically included, or nature-based solutions are not more effective than sea walls. This means not just the delivery of an idea through reports, but going to give talks, present infographics, and have extension work done. Federal funding communities are not [supporting these efforts.]*

> *For any resilience or conservation initiative, it is important that efforts center the needs and interests and capacity of the local community, so not be an idea or concept or approach developed from outside and foisted upon or sold to the local area that will actually be impacted. For long term sustainability and access, these are efforts that need to be centered on the needs of local communities, and ideally in decision making, local communities need to have the power, not just a consultation role.*

Without formal integration of NbS processes into planning documents such as comprehensive plans, practitioners told us NbS projects were less likely to be implemented. Yet the state regulatory structure that supports comprehensive and resilience planning is often set up to compel the use of gray infrastructure (Rosenbloom, 2018). Land use laws that integrate NbS and ecosystems options move towards incorporating adaptive governance into the regulation of infrastructure (Rosenbloom, 2018). Such laws remove one of the most significant barriers to landscape scale planning in a changing climate. According to practitioners, states that put the burden of proof back on gray infrastructure, such as in Virginia, eliminate one of the major project implementation hurdles.

Practitioners told us that when neighborhoods and stakeholders learn about green infrastructure, they quickly understand the concept and frequently want it in their communities. However, there are cases where marginalized communities do not want NbS. One concern is fear of gentrification once there are green spaces in the community, and / or the perception that an NbS does not provide the risk reduction of hard infrastructure (especially when wealthier and whiter communities have gray.) These climate and environmental justice issues are poorly documented in the literature specific to NbS, but recent examinations do exist (see Hoover et al., 2021).

There's a social science aspect that I wish I knew better. I wish we could dig that out and understand what the necessary ingredients are in that recipe, to the same level of precision as what is needed from the engineering or siting side.

Throughout our interviews, the themes of systemic power and inequity were broadly visible during NbS planning. In the U.S., there is a wide disparity of wealth and poverty on the coasts, which already manifests in different decisions made in the context of human retreat (see Equity and Power.)

Coastal squeeze, or development pressure on coastal land area from increased human expansion and activities in combination with the effects of sea level rise, receives limited attention in NbS literature. Research shows that coastal green infrastructure (CGI) can be used as a mitigation tactic to slow or repair damages from coastal squeeze, with solutions spanning from 'nature reclamation' to 'engineered ecosystems' to 'de-engineering' (Chávez et al., 2021). Coastal squeeze caused by historical development practices has left limited options for many seaside regions when considering migration pathways, but it has also proven one of the most intractable problems in NbS: the incentives to develop the coast make options other than continued development far more difficult to justify.

Although not specific to NbS, research on cultural heritage policy and solutions under changing climate conditions shows that institutional, technical, financial and social barriers are inhibiting cultural resource adaptation to climate change (Fatoric and Seekamp, 2017). Using a survey of experts, Fatoric and Seekamp (2017) found sixteen distinct barriers; a lack of climate planning processes, institutional guidelines, prioritization processes to carry out adaptation work, and central policies were the predominant barriers. They also found that critical opportunities to overcome those barriers included enhanced collaborative partnerships, development of central policies and clear guidelines, increased climate change research, and strengthened technical capacity. These results were reflected in our qualitative findings among NbS experts as well. Much of the existing NbS social research is international and uses the term ecosystem-based adaptation (EbA), and it is not focused on the coast. Brink et al. (2016) reviewed research on EbA in urban areas, finding that EbA is usually evaluated in bio-geographical terms, and only rarely in economic or social valuations, and few articles considered equity. In contrast, equity came up in nearly all of our interviews as a barrier to implementation of NbS.

Finally, Woroniecki et al. (2020) examined the framing of nature as a benign ally as potentially destructive to equitable outcomes and undermining the

social "emancipatory potential" of NbS. By looking at epistemic (knowledge-related) and power dimensions often hidden in NbS using five case studies that illustrated the frames of nature, they identified separate frames for how we think about 'nature.' These include nature as protection against climate hazards; nature as ecosystem services; nature as the provider of multiple benefits of adaptation; nature as a resource in an intra-state peace process; and nature as source of conflict that highlights injustices. In the first instance, framing nature as protection led to a more top-down process, as decision-makers prioritized ecosystem services (nature) while overlooking vulnerable groups and social aspects of adaptation. With nature as the benefit provider, people experienced different environmental risks based on their relative positions of power, and the embedded assumptions of interventions allowed planners to exercise authority and marginalize potential allies (Woroniecki et al., 2020). Ultimately, the framing of nature as an instrument for use by and separate from society comes from scientific assumptions that marginalize and undermine values and knowledges that do not conform to dominant norms (Woroniecki et al., 2020).

LEADING PRACTICES FOR EFFECTIVE NBS

Limited work has been done to explicitly address our four pillars of effectiveness: physical, ecological, economic, and social. However, discussions around operationalizing ecosystem services has prompted a review of supply and demand of coastal protection from ecosystems (Arkema et al., 2017), and Chausson et al. (2020) created the first systematic map of evidence on the effectiveness of NbS to address climate impacts and "hydrometeorological hazards" on people. They found that most interventions to protect natural ecosystems reported ameliorating adverse climate impacts, while creating new ecosystems (such as afforestation) was associated with tradeoffs. They documented the gaps in social and economic research, particularly in cost-effectiveness comparisons (which, as we have noted, practitioners struggle with for multiple reasons), and few studies considered broader social and ecological outcomes.

Of the four pillars are the foundation of NbS, the following strategies represent the leading practices for NbS from practitioners' perspectives:

- **Community-driven Process**

Communities must drive (or at least actively support) an NbS project. This is not just local "buy-in," but local leadership empowered and funded to act. Local leaders provide direction and support through what can be a long and

challenging planning and permitting processes, provide valuable knowledge exchange throughout the community through its various phases, find local capacity to build the project, and provide the leadership to maintain and sustain the project to meet its goals after implementation. They can also be an important aspect of establishing and maintaining trust.

In order for communities to be engaged at this level, adequate funding is needed for engagement of local partners, with attention to cultural context, equity and justice issues.

> *Having a longer term champion or set of champions, to ensure benefits are realized and translated [to decision makers and the public], is the key to longer term effectiveness.*

- **Clear and Achievable Goals**

It will come as no surprise that practitioners realize that there is a strong relationship between effectiveness of an NbS project and agreeing on a set of clear and achievable goals in the early stages of project development. Multiple goals that could capture the co-benefits of nature-based solutions were seen as a liability by some and as critical to integrate by others, depending on context. Clearly identifying project goals, reaching consensus on definitions of success, and understanding and clearly stating what is possible and what isn't, especially in terms of risk reduction are critical ingredients of success.

Some noted that it is common for NbS solutions to evolve during implementation and stray from the original goals, which may ultimately damage the reputation of NbS as an adaptation strategy. For example, one interviewee noted that mission creep was a problem in a case when growing oysters became the primary goal in the context of building a reef to manage coastal erosion:

> *We can't sacrifice stopping erosion to recruit oysters.*
>
> *Mission creep may also in some cases be about opportunistic funding streams.*

- **Planning at Landscape Scale**

Practitioners struggle to develop NbS on a landscape scale--which is the scale they often feel is needed in order to be "effective" for risk reduction,

habitat creation, and especially equity. Projects are often done piecemeal, when practitioners say these need to be coordinated to have a real impact / be effective. This was especially true for projects that integrated human retreat, such as buy-outs. Without a broader view and plan for the movement of ecosystems and people, these projects could become maladaptive. This planning gap prevents scaling up because practitioners are generally not paid to **build relationships and coordinate** across sectors to expand the scale and build a cohesive management approach.

- **Planning for an Adaptive Baseline**

Finally, a key component to all of these factors is temporal considerations. This captures two critical aspects of time and timing. First, the ability to move through all the phases of an adaptation project — engaging, understanding, planning, implementing, and sustaining (WUCA, 2022) — is a time intensive endeavor. This can make these projects vulnerable to leadership or political changes. Further, monitoring is critical to understand the short and long term viability and success of a nature-based solution to meet its original goals (see also National Findings, Monitoring), and monitoring can be a challenge to maintain, especially as needs and contexts shift.

Second, the challenge shared broadly across adaptation efforts, is integrating the ability to **adapt to current *and future* conditions**. In many places, this can lead to the consideration of tradeoffs between current and future risk mitigation, cost, habitat, and community wellbeing. Practitioners across the country noted that a paucity of data on future conditions, along with governance and decision making systems designed with a historic climate baseline as a basis of future action, were not well suited to making good decisions about NbS. There are multiple opportunities embedded within these challenges (see Recommendations), but our main point here is that these temporal considerations impact effectiveness across the framework.

Finally, even in the early stages of project development, some practitioners need to consider potential assisted relocation or other transformational solutions, given the long time horizons of climate risks.

RESOURCE

NOAA's Digital Coast has a "Green Infrastructure Effectiveness Database," where effectiveness is focused on reducing risk from the impacts of flooding and erosion (biophysical), and economic feasibility (economic) criteria. The database allows the user to search by infrastructure type, hazards, region, state, and source type, and includes peer reviewed, gray literature, books, etc. It does not include webinars or podcasts. We encourage readers to utilize this tool. However, the database is not comprehensive: gray literature, reports, and other items with relevant information about NbS effectiveness may not be included.

- **Explicitly Addressing Tradeoffs and Hybrid Options**

In many cases in the literature and in practice, gray and green infrastructure were pitted against each other in a false dichotomy. Practitioners desired conversations that realistically and honestly addressed the ability of any infrastructure to meet the needs of various planning timelines. Research and international literature also stress the importance of clarifying tradeoffs (IUCN, 2020; Sutton-Grier et al., 2015). Practitioners told us that states that supported starting on the green side of the green-gray infrastructure spectrum, whether by legislative decree or regulatory reframing, facilitated the scaling of NbS.

- **Linking the Four Effectiveness Pillars and Naming / Valuing Co-benefits**

Some limited research addresses the potential for natural infrastructure to enhance coastal resilience, with recommendations that future research focus on the technical and social analysis of coastal protection benefits, including acknowledging the full suite of services provided by NbS, even if they are not assigned monetary value (Sutton-Grier et al., 2015). Whether operationalizing an ecosystem services framework (Arkema et al., 2017) or including co-benefits in the initial project goals and plans for monitoring, addressing all four pillars and their associated co-benefits appears to be one of the most important and effective means by which to implement (and scale) NbS projects.

National Opportunities

This project identified many opportunities to address specific critical issues in NbS implementation that also have more generalizable applications in the context of escalating the pace of adaptation. To take advantage of these opportunities, those in a position to implement NbS will need to integrate scientific and technical knowledge with their experience and understanding of local conditions as well as the values and interests of the broader communities who need to be engaged–not as an afterthought, but from the very initial stages.

The question of where to find reliable information and support for NbS at scale has not yet been addressed. There are many websites offered by federal agencies, NGOs, and university scientific centers. Most of this information is based on specific examples or case studies. Some of it seeks to generalize and draw broader lessons. Practitioners indicate that it can be confusing to navigate all the different sources of information; this has been referred to as the "practitioners' dilemma" (Barsugli et al., 2013); finding which approaches are relevant to their situation (Moss et al., 2019) is similarly challenging.

We envision a national system of climate services that could address these challenges by (1) pointing to authoritative methods and information appropriate to specific applications, (2) providing resources to identify technical assistance, and (3) establishing a focused and accountable organization to coordinate the many different levels and types of climate services providers (US GAO, 2015). We refer to this concept as a sustained assessment, and believe that it could contribute directly to the success of NbS specifically and accelerating adaptation and resilience in the U.S. more broadly. Our report has identified a number of specific areas where climate services could be advanced to support implementation of NbS.

- **Build Relationship Capacity**: In almost every interview, practitioners lamented the persistent siloing of sectors, scales, states, regions, and research as a significant cause of slowing the adaptation process using nature-based solutions. Relationship-building could be moved forward by committing time to this in job descriptions, creating a culture of information sharing, financially rewarding collaborative efforts and relationship-building, and hiring additional staff to cultivate and maintain relationships across departments, levels, sectors, and geographies.

- Engage peer-to-peer learning: state regulators suggested that they would like to learn how other states are integrating NbS into existing regulatory structures; communities who have received a NFWF NCRF grant would like to learn from others and share experiences as they navigate moving their project forward; and in coastal cities, especially those without funded resilience positions that help to coordinate municipal agencies around climate topics, practitioners sought a way to regularly connect across their municipal landscapes to move projects forward more rapidly. We suggest future conversations around the opportunities and requirements to move each of these forward in a useful way.
- Engage internationally: international CoPs, such as the Green-Gray Infrastructure Group, and the Ecosystem-based Adaptation (EbA) Practitioners network, would be both valuable to U.S. practitioners and a model for shared learning.

- **Design Interdisciplinary Training to Build Capacity**: Lack of exposure to and training for NbS planning and implementation significantly hampers implementation. Specific suggestions and existing programs included:

  - Working with state universities and colleges to include NbS design and basic ecological understanding into engineering programs, and include engineering coursework for environmental land management programs;

  - Designing and implementing training and certification programs for landscape architects, landscape maintenance businesses, and municipal and county;

  - Providing training exchanges between engineering and environmental sciences at the state level;

  - Developing and providing training for all engaged professionals, from engineers to architects, in systems thinking and approaches, such as ecosystem-based management, social-ecological systems, or principles and operationalizing complex adaptive systems.

The **Chesapeake Bay Landscape Professional Program** (CBLP) provides a certification to landscape and maintenance professionals to promote sustainable landscape practices. When practitioners discovered that NbS were often not maintained (i.e., were inadvertently mowed down by maintenance crews) because of a lack of knowledge, they developed a regional training program to build that capacity. Since the program began in 2016, CBLP has certified 1,006 professionals at their first level of training (Level 1), and 124 in advanced design and installation (Level 2.)

- **Develop Practices for Centering Equity in NbS**: Funding relationship building, discussed above, will be an integral first step towards equity, moving away from the model in which projects "tack on" representatives from the community, Native nation leadership, or social scientists, but do not include in the formative design phases of projects. Other examples from research and practitioners include:

  - Specifically address tensions between Indigenous leadership and project design and Western science models;
  - Compensate community members for their time and leadership; explicitly build that funding or requirement into projects;
  - Document and address historical contexts of marginalization from the beginning of projects as critical and baseline data;
  - Develop an adaptive national framework with concrete, step-by-step methods for taking a "full community approach" to NbS implementation.

- **Develop Outcome-based Standards that Account for Context**: Standards will quite obviously NOT be one size fits all. Success in this arena will depend on institutions and organizations bringing together multiple sectors, disciplines, and practitioners. It will be critical to include and integrate the experiences of practitioners working in marginalized communities, federal funding agencies, biologists, economists, specialists in ecosystem services, municipal planners, state regulators, coastal and civil engineers, landscape architects, nonprofit organizations, Native nation and Tribal organizations, urban and rural practitioners, current modelers, and multidisciplinary scholars to capture the four pillars of effectiveness.

- **Enable Incremental and Transformative Valuation:** Discussions are already underway to transform BCA calculations towards better incorporation of co-benefits associated with NbS (NASEM, 2022). Yet because many quality of life and biodiversity benefits are difficult to monetize, transformative valuation that is truly triple bottom line (social, environmental, and economic) may be critical to better aligning community adaptation needs with federal and state funding.

- **Monitor NbS in the Context of Natural and Social Systems:** Practitioners cited the need for more and better monitoring of NbS outcomes. The foci for further research and monitoring could include:
  - Detailed understanding of groundwater impacts and implications, especially in places already facing challenges with seawater intrusion (see Southeast.)
  - Better monitoring of hazard events and their impacts. Specifically, the response of coastal vegetation, especially mangroves, to extreme events such as hurricanes or catastrophic flooding would be helpful to municipalities attempting to protect their remaining natural infrastructure.
  - In many places with salt marshes, thin-fill sediment application is proving successful on a small scale, but there is uncertainty at larger scale. Improved monitoring could help answer important questions. The barrier to larger scale adoption is often regulatory, ie., federal permitting for the use of fill on existing marshes. There is interest across the board (engineers to biologists) to "keep it in the system," using dredged material for nearby nature-based accretion, and research in collaboration with all interested parties could support this practice moving forward in a more timely manner.
  - Following connections between coastal habitat and the marine food web: practitioners wanted to understand how NbS solutions are related to the coastal food web, and in turn, understanding the obligate habitat characteristics for nesting birds.
  - Monitoring social impacts of individual projects to better understand and potentially quantify those social impacts was mentioned frequently as a priority by practitioners. Aspects of NbS projects that support well-being of humans, wildlife and ecosystems are critical to monitor.
  - Collect baseline *and emergent* benefits, along with clearly *documenting and having the resources to act on failures*, was seen as critical for implementing across the U.S. Monitoring can assist in moving towards systems-based approaches that could support landscape scale projects.
  - Perhaps most importantly, there are great opportunities to monitor in partnership with ongoing projects and programs, such as the NFWF NCRF, where the need to better monitor and understand

the hydrologic impacts and hazard mitigation benefits of NbS is significant.

- **Support Carbon Sequestration Research:** There is significant ongoing research focused on marshes and seaweeds, but we struggled to find research on carbon sequestration in other NbS contexts, especially dunes and dune vegetation. This research is critical to support the funding of NbS, as investors become increasingly interested in returns from carbon credits (see Male et al., 2022).

- **Pursue Public-Private Partnerships:** These partnerships could support work that otherwise is not funded, keeping NbS on the table in the planning process, which is where they are most often eliminated (NASEM, 2022). These partnerships, however, require dedicated, funded time on the behalf of the organization or institution that employs NbS practitioners, specifically allocating paid time to make these connections. The example below illustrates this need:

  The Army Corps proposed a floodwall, and many didn't like it. One of the large private property owners paid for an engineering firm for an alternative approach. These coastal engineers said, if you did a living breakwater, the cost could be 30% less. We needed that private funding to make [viable] cost estimates.

- **Fund Social Science Research on Social and Economic Aspects of NbS:** There is a dearth of research on social and economic aspects of NbS, especially as they relate to effectiveness. Yet practitioners continually cited these two spaces as the most pressing needs for understanding and lifting barriers. This provides a significant opportunity for investment. Some of the possible topics to be addressed are already included in these recommendations, such as developing new valuation practices and performance-based standards, understanding perceptions of risk in coastal contexts, and tradeoffs between the benefits of NbS versus the possibility of reduced protection in extreme events.

- **Enable State Legislation that Supports NbS:** There is a dramatic difference in implementation in states that support NbS, either through legislation or through streamlined approval of NbS projects, vs. those without explicit support for NbS. As explained in the Virginia example in Regulatory Challenges, supportive regulations are a significant start but are not enough–watchdog groups have needed to intervene to

support the successful enforcement of regulations designed to prioritize NbS. These regulations must have the buy-in of local municipalities and officials, as well as the local capacity to monitor their implementation, all significant but identifiable issues.

- **Focus on Strengthening Adaptive Governance:** Currently, governments and their programs are often far behind the needs of NbS practitioners. Issues detailed in this report, such as developing projects from a landscape scale perspective, valuing co-benefits, and educating practitioners and the public, would all benefit from a more adaptive and innovative approach to governance. We recognize that addressing governance is highly context specific, and that this recognition needs to be part of NbS planning and implementation such that the needs of communities can be best supported by NbS.

- **Focus on Incentives, Especially for Relocation:** Research and our practitioner interviews indicate that incentives to continue developing the coast are overpowering conservation and NbS interests, including the lack of enforcement of regulations designed to decrease the proportion of gray infrastructure projects. Research that could illuminate successful incentive structures to decrease the coastal squeeze could be of benefit to NbS practitioners.

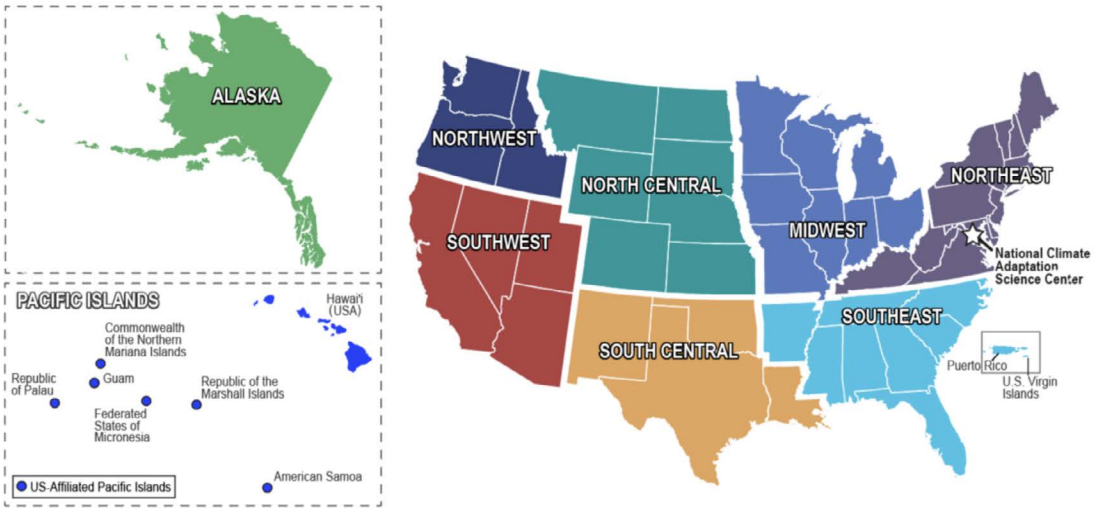
- **In NbS Conversations that Include Relocation, Recognize the Trauma:** As we have noted, it is not only goals and outcomes, but processes that matter. A few practitioners emphasized the need for trauma-informed facilitation of discussions around retreat. Generally speaking, land managers are not equipped or trained to meet the emotions and help manage trauma of people who have to consider moving away from their homes and communities.

PART III

Regional Synthesis

The following synthesis of interviews with regional practitioners and experts suggest topics that warrant follow-up. While there are many commonalities, U.S. coastal regions are not a monolith and have diverse needs, interests, and opinions about NbS. While there may be specific geographic areas in which a national finding does not apply, a number of topics were mentioned in every region, including: social aspects (communication, collaboration, Indigenous leadership, and equity), governance and economic considerations (regulations, monitoring, standards, valuation), the many needs/issues associated with relocation, and capacity and funding constraints. This section is not intended to be a definitive guide to each region; instead, it showcases specific regional NbS directions and examples that may be useful to other national practitioners or stakeholders from other regions.

Each region follows the regional delineation made by the USGS CASCs.



ALASKA

Key Takeaways

- **NbS in Alaska include relocation based on hazards and risks such as severe storms, decreased pack ice, and rapid coastal erosion.**
- **Siloed federal grant making systems burdens already overloaded human capacity in communities.**
- **Alaska needs additional baseline monitoring and assessment, particularly of coastal erosion and harmful algal blooms (HABs), done in partnership with communities.**
- **A full community approach, in which diverse interests come together to share experiences and receive training, has proven effective for designing NbS applications in multiple communities, and is a practice from which other regions could benefit.**
- **The definition of effectiveness or success for adaptation projects should be led and determined by affected communities, especially Alaska Natives.**

Context and Capacity

> *"To be honest, I don't understand why there's such a focus on nature-based solutions. I wish there would be less focus on them. I think that we just need to support what works."*

Alaska, the fastest warming state in the nation, is a predominantly rural state where the cost of coastal adaptation is exceedingly high; even the sheer size and remoteness of the state makes adaptation difficult. With 66,000 miles of Arctic and sub-Arctic shoreline, Alaska faces increased storm surge, flooding and erosion from decreased pack ice (Markon et al., 2018). Coastal adaptation efforts range from relocation of entire communities to funding engagement and planning activities. There is interest in supporting monitoring and assessment of the impacts of climate change on existing coastal resources, particularly when they involve food security, public health, and supporting traditional practices.

In Southeast Alaska, isostatic rebound is keeping pace with rising sea levels, but ocean acidification may decimate an economy heavily reliant on fishing (Markon et al., 2018). Landslides driven by more "atmospheric river" events

have become a significant issue for communities, which are often built on small strips of flat land surrounded by steep fjords and mountains, with few options to move or provide buffer zones. Further north, **sea ice loss** is the main problem causing increased erosion and storm surge risk; while there are mitigation measures, planning, and standard land management strategies to manage these risks, natural infrastructure solutions are limited. Although many communities are experiencing devastating climate-related impacts, planned retreat is going slowly because it is poorly managed and inadequately funded (US GAO 2022).

The nexus of regulatory issues and western science/traditional knowledges represents a long and contentious narrative in Alaska, and continues to impact coastal and Native Alaskan communities. It is important to note that land ownership patterns in Alaska are unique, and coastal livelihoods are affected by fishery, federal, state, and offshore and onshore regulations. For example, practitioners noted that the management of mammals, which have been traditional foods in Alaska for generations, is currently regulated based on Western science, sometimes to the exclusion of traditional knowledge that better supports ecosystem and community health.

NbS projects in Alaska are limited at this point in time, but those that were identified in our research integrated local knowledge and social vulnerability. They include Point Hope **erosion mapping** (Poussard et al., 2023; Bosche, 2023) and an examination of Anchorage green infrastructure (Pallathadka et al., 2021).

In the community of Kluckwan, in southeast Alaska, a recent NbS for disaster risk reduction is engineered log jam structures being built to protect the community from flooding and erosion risks. The jog jams will provide habitat for rearing king salmon while at the same time protect the community (and the new clan house/museum) from increasing flooding events. The Chilkat Indian Village and the **Takshanuk Watershed Council provided the leadership for the project, with support from TNC.**

In Alaska, there is a strong focus on maintaining subsistence lifestyles and preserving the values and identities of Alaska Natives. For example, Nome-

based Alaska Natives have an adaptation plan with seven different initiatives that support traditional lifeways (see Kettle et al., 2017). While there is scant evidence of the ability of specific natural infrastructures such as dune grasses to reduce coastal hazards, there are multiple projects building out community networks to map erosion and inform planning to protect critical natural and cultural resources (ie., Poussard et al., 2023; Buzzard et al., 2019).

Alaskan practitioners recognize that a "**full community approach**" is critical when looking at adaptation planning or relocation efforts. This may include Alaska Natives, village corporations, and regional for-profit corporations, each with attendant diverse priorities.

RESOURCE

The Building Resilience Today trainings brought together diverse interests for a training which "sought to include a range of best practices in education, specifically in climate science and tribal engagement, and build upon the experience and expertise of the partner teams and communities, the facilitating team, and subject matter experts. The overarching goal of Building Resilience Today [was] to introduce planning tools that strengthen community capacity to plan for the future, while maintaining important values grounded in the past" (Chase et al., 2020). Coming together and sharing experiences across sectors in a community has proven "*extremely effective*." This has also been addressed in the the literature with "A Framework for co-production of knowledge in the context of Arctic research *Negeqlikacaarni kangingnaulriani ayuqenrilnguut piyaraitgun kangingnauryararkat*," which argues for systematic change in research practices to better integrate Indigenous People's knowledge systems and science that can lead to more equitable outcomes (Yua et al., 2022).

In interviews, multiple practitioners in Alaska noted that a lack of capacity disadvantaged communities with limited human resources:

> *"[We need] human capacity to navigate these funding systems and access ...these funds. Many [funding sources] require cost sharing, which is out of reach of what small communities can do. This is not just about climate and*

non-climate stressors: there are huge expenses of living in [rural Alaskan] communities. Individuals are doing great work and spread thin, and we need to figure out how to resolve competing priorities. ***The calculus within a cost-benefit analysis does not capture the true costs of the loss of access to subsistence, or subsistence ways of life."***

Baseline assessments and monitoring are a significant need, a need that is shared nationally but particularly acute in Alaska. With an immense coastline, specific needs are to monitor baseline conditions and changes in coastal erosion and harmful algal blooms. This information is important not only to access funds, but to establish the existence of a problem.

Napakiak is a Yup'ik Alaska Native community located on an island in a tidally-influenced estuary along the Kuskokwim River, near the Bering Sea. The community was funded by NFWF in 2023 to restore and protect wetlands. The "project will construct 12 nature-based natural infrastructure house pads from locally-sourced sand and gravel; relocate and decommission 35 threatened structures, and; revegetate the 7.6 acres by planting native grasses and local willow cuttings" (NFWF NRCF, 2023).

RESOURCE

As emphasized throughout this report, planning is critical for NbS. To support adaptation planning in Alaska, Adapt Alaska (**https://adaptalaska.org/**) provides resources for communities seeking to plan an adaptation project, including an index of resources to "**Start the Conversation**," which was a key challenge not just in Alaska, but nationally.

Opportunities

If Alaska Natives are supported to drive the adaptation process in their communities, including understanding what successful adaptation looks like beyond a western science perspective, this could have a significant bearing on

how NbS work is done in the state. Characterizing existing perspectives on NbS and their interconnections with Alaska Native science may illuminate the ways in which existing local practices may be bolstered by NbS-specific funding, and highlight the needs of communities that are already valuing and integrating nature into climate adaptation.

Traditional lifeways for native Alaskans rely on shellfish and ocean resource harvesting, and **harmful algal blooms** (including "red tide") have had deadly consequences in some communities (NOAA, 2021). Alaska does not have statewide shellfish monitoring for toxic algae, yet shellfish harvesting is important for subsistence. The cost of tissue testing is high, but the consequences of eating contaminated food are dire, including illness and death. Subsistence shellfish harvesting provides food security, a key component of social benefit for emerging marine NbS, while supporting ecosystem processes as well as cultural well-being (see Riisager-Simonsen et al., 2022). Funding and monitoring that supports subsistence harvesting would be of significant benefit.

Practitioners noted that the current system of grant making–in which the community must navigate, access, and apply to a wide variety of siloed funding streams–disproportionately disadvantages the communities in Alaska with the greatest needs. According to practitioners, navigating multiple agencies, with multiple grant applications and processes that have not been designed with Alaska in mind makes the process of applying for funding particularly challenging. A Government Office of Accountability report, "Alaska Native Issues: Federal Agencies Could Enhance Support for Native Village Efforts to Address Environmental Threats" (US GAO, 2022) supports the practitioners' comments on this topic.

Alaska shares key perspectives and challenges with other areas that have significant coastal lands owned by Native nations or dispossessed Natives, such as the Pacific Islands, the Pacific Northwest, and the Gulf Coast, especially in addressing retreat. They also share similar hazard risk with the Pacific Northwest. Ongoing conversations between practitioners and researchers in these areas could serve to accelerate applied science and innovative nature-based solutions.

NORTHEAST

Key Takeaways

- **The disparity between rural and urban areas is significant, and rural regions struggle with capacity to support NbS, even as there is growing interest.**
- **Significant areas of the coast are already hardened, and many areas are experiencing even further coastal development 'squeeze', making efforts to evaluate and integrate ecosystem retreat with human retreat critical.**
- **Living shorelines are one of the most common initial pilot projects, but can suffer damages in high energy conditions.**
- **Significant areas of the coast are private, and state regulations, local examples, and experienced coastal engineers all play a critical role in the successful implementation of NbS.**

Context and Capacity

In the Northeast, from Maine to Virginia's southern border, the warm waters from the Gulf Stream support productive marshes, fisheries, and ecosystems, along with coastal economies that depend on the iconic seascape (Dupigny-Giroux et al., 2018). As sea levels rise, "coastal squeeze" threatens shoreline habitats where built and hardened infrastructure offer no option of further retreat for coastal ecosystems without significant land use change.

According to practitioners, there is a strong desire to learn about and implement NbS, and there are active conversations that are bridging siloed stakeholder sectors to move projects forward. This has often begun with discussions around living shorelines and edge modification (ie., Woods Hole Group, 2017), then moved to thin-layer sediment use and marsh augmentation. In some states, regulatory programs require that shoreline solutions use a natural or nature-based solution where possible. There is a wide continuum of practice, in which some states are piloting and learning from small-scale projects, while others are implementing innovative projects funded at a much larger scale. This continuum is often a reflection of funding and capacity; the large metropolitan coastal cities are typically ahead of rural coasts in their experimentation with NbS.

The NE CASC **Sea Level Rise StoryMap** (**https://storymaps.arcgis.com/stories/04f257387c7648aeafec74b34574389c**), focused on sea level rise, documents marshes as critical infrastructure to protect coastal communities, as well as some of the risks of coastal gray infrastructure. The StoryMap references multiple ongoing NE CASC research projects to understand the relationship between coastal armoring and natural systems. NE CASC researchers have provided leadership in examining the effectiveness of runneling in marshes to support short term preservation.

This coast has significant development and shoreline hardening in some areas, such as New York City, as well as extensive rural coasts, such as 'downeast' Maine. There are attendant equity challenges to implementing NbS based on the resources available to private versus public sectors. Some states are already thinking about migration pathways for coastal ecosystems to retreat as sea waters rise; for example, Rhode Island has taken steps to learn what upland areas could be purchased to allow for marshes to move inland. However, most states are just beginning to think about how to protect *future* natural and nature-based infrastructure with rising seas and more damaging storms, and that conversation is not well integrated with ongoing discussions around human relocation.

In 2022, the University of Maine and the Maine **Department of Environmental Protection** (DEP) launched a collaborative research project to collect decision-support information and regulatory examples, interview topic experts and professionals involved in implementing nature-based engineering, and conduct a workshop to solicit further insights and feedback on "resilient infrastructure" for coastal communities. Strategic priorities include creating a centralized forum for guidance and technical assistance; streamlining permitting; developing partnerships and securing funding to adequately monitor living shorelines; linking workforce development with the Maine Climate Corps; adopting regulatory definitions for nature-based engineering approaches that accommodate; and convening and building interagency partnerships in the state (Genoter et al., 2023).

In northern New England, perceptions exist that NbS solutions do not provide risk attenuation for flood and erosion control, but that is changing as states devote more resources to understanding the landscape and specific interventions that work. Ice, in combination with storms, is a significant concern throughout the region, both in the destruction of living shorelines and augmented marshes, as well as the decreased ability of a marsh to attenuate waves when frozen and subsequent failure to provide risk reduction.

Online resources exist to familiarize interested stakeholders with nature-based solutions. The Nature Conservancy's **Piloting Living Shorelines in New England** uses case studies and key takeaways to demonstrate the planning and implementation of NbS projects. These projects include technical details and key lessons learned.

Research in the region is beginning to illuminate the social benefits of NbS, including valuing the non-market benefits and costs of interrelated changes (Stroud et al., 2023). Getting a better understanding around tradeoffs between different solutions was also a consistent refrain:

> *"The best solution isn't going to go all one direction [gray or green], it's the sweet spot in between."*

The Environmental Business Council (EBC) in New England has led the convening of stakeholders, especially private businesses, to understand and implement nature-based solutions. During a December 2022 webinar on getting NbS to scale, leading practitioners from around the country addressed and answered the regional practitioner questions. Many of the participant questions are reflected in other webinars and our interviews, and included: *How do you balance habitat and public access? How long has monitoring been occurring, and are those results available? Do you have enough state regulators to manage this type of work? Where does funding and governance capacity come from?* Projects from around the U.S. addressed included the **Oro Loma Living Laboratory**, the **Living Breakwaters Billion Oyster Project**, and **Mordecai** and **Seven Mile Islands** projects. Takeaways from the seminar included implementer suggestions:

- partner with existing implementers;
- messaging and transparency is really important ("It won't keep the water out");
- local or regional Atlases that characterize the specific physical and biological variables are a huge asset.

There is a growing need for conversations about relocation and retreat of both human and ecological communities, especially in areas with longstanding gray infrastructure:

> *"Historically, building happened in [coastal] areas where it shouldn't have happened. At the end of the day we have to start making hard choices about changing the landscape and moving people into some managed retreat, and [thinking about] where they're moving to. Right now, people are not at that point yet. They think they can build their way out of it, but we need to think about planning. Communities that are frequently flooded that are doing some discussion and planning on that front are not in the mainstream. Most often, we are planning around [maintaining the] status quo."*

Although the hardened shoreline around Manhattan, New York City, NY, may not seem to be a candidate for NbS, the NSF Convergence Accelerator **Urban Shorelines** project is a collaboration of architects, scientists, and engineers developing new bulkheads that are designed to expand engagement with the shoreline; increasing biodiversity and sustainability of marine life; and dissipating wave force and flooding. By terracing hardened shorelines, this innovative collaboration is bringing attention and solutions to existing hard infrastructure.

In many areas in the northeast region, private property owners are the primary audience for implementing NbS. Consequently, private engineering and landscape architecture firms were on the forefront of understanding the uptake of NbS. Exposure to information about nature-based solutions and / or previous experience with gray infrastructure failure were the dominant reasons cited for private landowners seeking NbS for their properties. Exposure to neighbors with an NbS was also a significant factor.

> *It's all about creating the right expectations - the acknowledgement that sometimes these projects look worse before they look better. It's not going to look like a gorgeous ecosystem on day one: it takes three to five years, like growing out your hair.*

Opportunities

Practitioners expressed the need for **research on marsh and coastal habitat migration corridors**. Given this need and the challenges around the topic, opportunities to convene researchers and practitioners focused on managed retreat with state ecologists, regulators, and municipal interests of the region would be a significant step towards meeting the need.

The **Stone Living Lab**, a partnership between Boston Harbor Now, UMass Boston's School for the Environment, the City of Boston, the Massachusetts Department of Conservation and Recreation, the Massachusetts Executive Office of Energy and Environmental Affairs, the National Park Service, and the James M. and Cathleen D. Stone Foundation, engages scientists and the community in research, education, and the promotion of equity. The Lab conducts a range of projects to promote NbS, including baseline assessments to better understand existing conditions in advance of testing nature-based and hybrid approaches, and research to inform how to best develop and implement policies.

Public education was a key opportunity for the region, and could build on past efforts by states (such as Connecticut), nonprofits, and businesses. Research needs in this space include understanding the factors that influence decision making around when and where to implement a nature-based solution:

> *NbS is like lots of snakes. [Coastal property owners] don't want snakes: "Give me bermuda grass down to the shoreline," [they say.] There's lots of marketing to be done. [But we don't know] how property owners make a decision to go one way or another. When is a key decision point?*

Thus social and behavioral research that works to understand **individual property owner decision making**, for both public and private sectors, would provide key insights for practitioners seeking to streamline the process of planning, implementing, and sustaining an NbS.

At **Wetlands Watch** in the Chesapeake Bay, practitioners follow a rigorous process to understand and incentivize behavior change. By identifying that desired behavioral change, then working backwards to systematically identify every barrier that keeps a person from making the decision, they can identify the responses and behaviors where NbS get stuck before, during, and after construction. They then work to remove disincentives and create incentives.

The Northeast region shares many of the social and relocation challenges found in the Southeast. As an area with both extensive shoreline hardening and rural coastal communities, and working waterfronts throughout, there are great opportunities to share lessons along the entire eastern and Gulf coasts of the U.S. In addition, the regulatory hurdles faced by some states in the region have already been surmounted by other state regulators in the region, and regulators *within* the region could greatly benefit from regulator peer-to-peer learning. Finally, some of the practices that are proposed and under construction in the Southwest Region, specifically in the San Francisco Bay Area and other cities with estuaries such as San Diego, may be helpful for Northeast practitioners to at least discuss as they face stark projections on ecosystem losses due to sea level rise in the next 50 to 80 years.

RESOURCE BOX

For the Chesapeake Bay, the Chesapeake Bay Foundation (CBF) has **compiled documentation of NbS case studies** for the area, along with their documented benefits. These include improving water quality, preserving historic neighborhoods, and attracting wildlife (Chesapeake Bay Foundation, 2023).

NORTHWEST

Key Takeaways

- **Native nations provide leadership and experience in NbS, including key collaborations.**
- **Like the Alaskan coast, erosion and significant storms make NbS such as living shorelines less viable for exposed coasts; instead, dynamic revetments (cobble berms that mimic natural cobble) and sandbags with planted vegetation are solutions that offer protection and habitat benefits.**
- **Regional estuaries could benefit from sediment augmentation, and the region could learn from and partner with other regions, such as the Southwest, that are pioneering these solutions.**
- **Urban areas need funded interagency relationship-building to move NbS projects forward, especially in complicated legacy contamination sites that could be transformed to support ecological systems and environmental justice communities.**

Context and Capacity

The Pacific Northwest includes the Oregon and Washington coasts. The coast is predominantly rural, with the Columbia River and the Port of Seattle functioning as major commerce and shipping hubs. This region is known for its natural resources such as timber and hydroelectric power, salmon fisheries, and outdoor recreation opportunities, all of which are threatened by hazards such as ocean acidification, warming waters, decreasing river flows, and harmful algal blooms (Fleishman et al., 2023, May et al., 2018).

Oregon has a legislatively mandated biennial climate assessment which addresses adaptation and tribal resilience, but as yet does not specifically discuss nature-based solutions (Fleishman et al., 2023). A 2022 law, the Kelp Forest and Eelgrass Meadow Conservation Initiative, aims to protect bull kelp and eelgrass and provide marine life refugia (WA DNR, 2022). In addition, existing coastal laws enacted 50 years ago prevent the construction of new hard infrastructure.

Practitioners told us there is strong public as well as municipal interest in NbS, especially in protected estuaries and port areas. On the more exposed areas of

the coast, intensified storms have accelerated coastal erosion (Fleishman et al., 2023), and private landowners, in connection with state and municipal interests, have experimented with nature-based infrastructure, such as sandbags with willow coverage, to protect coastal homes.

> *The coast here is so dynamic, it's really hard to do something you could do on the East coast, we can't do living shorelines.*

Oregon has had some limited success with building vegetated sea walls with sand bag bases, and "dynamic revetments," or cobble berms that imitate natural features. Examples of these projects can be found on the **Oregon Coastal Hazards Ready Library and Mapper**. There are examples of these "natural" walls effectively reducing risk of erosion, as well as examples where conditions have eroded the wall and exposed sand bags. Another solution has been physically moving houses away from cliffs to allow for erosion.

Practitioners in the Northwest recognized that long term partnerships and communication, even between city municipal agencies, is not well supported, and will be critical to the implementation of nature-based solutions.

> *How can we coordinate best with our partners in [our highly urbanized] context? Sometimes it feels like we're working in silos in terms of what our partners are doing.*

Additionally, in the regional urban contexts, existing environmental justice and pollution issues around legacy contamination have delayed NbS implementation and proven costly due to the need for industrial cleanup. This was emphasized by community interest in access to green space, and impatience around the many regulated processes to repurpose a site with legacy contamination:

> *The environmental justice community wanted a park [on a former industrial port site], but it's hard for people to appreciate the complexity. We have to create a clean slate: to have green infrastructure with vegetation, they have to create the appropriate conditions for that to thrive. Is anyone sharing best practices of what is working in these landscapes?*

Thus practitioners sought solutions from similar urban contexts across the U.S. (with significant shoreline hardening and impermeable surfaces, legacy contamination, and environmental justice communities).

Native nations are significant proponents of NbS in the Northwest. Practitioners recognized the need for protecting important cultural sites, along with heritage practices, even as communities are seeing losses.

> *In some cases, the goal is to protect those places. In other cases, we will protect the activity or practice and do it in another place to make sure our future generations have access. Some places we are forced to abandon for whatever reason. But this isn't the first time this has happened: forced migration is a reality for almost all Indigenous people in the U.S.*

On the rural coasts where beach and cliff erosion threatens homes and roads, private landowners who are limited by the 1977 law preventing hardened infrastructure have sought natural and nature-based solutions as discussed in the following section (Observations on Effectiveness).

Oregon Sea Grant and partners hosted a "**Mini-conference and Dune Management Workshop**". Dunes can serve as NbS, since they protect coastal infrastructure and nesting habitat for endangered bird species, while providing co-benefits such as recreation. Issues that complicate the dunes' ability to serve effectively as NbS include recreation that degrades the dunes but is important for the local tourism economy, and non-native grasses that protect the integrity of the dunes but decrease potential bird nesting sites (Oregon Sea Grant, 2022).

The Oregon Department of Land Conservation and Development (DLCD) was funded by NFWF in 2021 to "engage coastal communities in a formal process to identify specific resilience needs and develop a planning framework to push projects forward to advanced stages of coastal resilience activities in Oregon's estuarine areas" with the goal to "leverage existing planning frameworks to accomplish broader resiliency goals and restoration priorities in highly vulnerable estuaries" (NFWF, 2021). DLCD is the state regulatory for nature-based solutions projects, and according to practitioners has been proactive in exploring natural and nature-based infrastructure for the coasts and estuaries.

The NW CASC funded research to model the effects of sea level rise, suspended sediment, and inland habitat migration on estuarine habitat, soil carbon, and the value of stored carbon in the Nisqually River Delta. Researchers determined that, at the current rate, sediment accretion could not keep up with sea level rise, and carbon accumulation would also level out at 100 cm of rise and above. However, with higher sedimentation rates, sea level rise increased carbon accumulation (Moritsch et al., 2022). This paper ultimately supports sediment augmentation for multiple reasons, and highlights that the NW region shares the same problem with most estuaries in the U.S.--sea level rise will destroy the habitat without human intervention. This research supports the need to augment and migrate estuarine habitat in the Northwest, since other areas of the nation (SE, SW) already demonstrated this need and piloted thin-fill sediment augmentation (see Davis et al., 2022).

In 2016, the Oregon Department of Transportation was funded to research green infrastructure techniques to protect the coastal highway. GI was seen as providing an advantage over hard engineering in their natural appearance and potential support for continued coastal processes. Data and modeling were used to understand how impacts varied between sites. This *"highlighted the need for site specific designs that reflect variation in local geography, wave, and beach conditions*," a common refrain in our research. ODOT then worked with permitting agencies to understand what designs would be preferred by managers. Hard infrastructure was preferred in some locations because of a smaller footprint that translated to overall lower impacts on the landscape, or because cobbles from dynamic revetments prevented beach access and recreation. (ODOT, 2016). Ultimately, this research provided valuable insight into the context-driven tradeoffs of NbS.

Finally, some recent research in the Northwest has focused on clam gardens, which are intertidal rock-walled terraces developed by ancient Indigenous people of the region, to alter the slope of soft sediment beaches and expand the optimal intertidal clam habitat (Groesbeck et al., 2014). These gardens dramatically increase the quantity and quality of clam habitat, and could be used for intensive yet sustainable harvest of clams in modern times (Lepofsky et al., 2021).

Opportunities

To build on the CASC research in estuaries and sedimentation (see Moritsch et al., 2022), further research could identify and characterize the processes and actors needed to pursue thin-fill sedimentation or other regionally-appropriate sediment augmentation processes. This could build on existing U.S. and Native nation examples in other regions and integrate lessons learned from those examples into Northwest-specific applications.

Partnerships with existing salmon alliances could be a starting point for addressing the critical gap in knowledge sharing identified by practitioners–connecting stormwater management, water supply and coastal protection objectives. In addition, in cities where there is no department focused on resilience or sea level rise, funding and recognition for communities of practice seeking to address sea level rise could facilitate conversations across departments.

The Northwest region shares many of the biophysical and hazard conditions of Alaska, and the regions could likely share case studies and stories about effective coastal adaptation, although the framing of collaboration as "nature-based solutions" may not be appropriate for Alaska. Strong leadership from Native nations in the region may serve other Native nations and communities with interest in navigating NbS sovereignty and other NbS related topics. Coastal cities, specifically Seattle, would greatly benefit from funding and support to learn from other cities with significant existing hardened coastline and significant port operations, from San Diego (CA) to Mobile (AL) to Portland (ME).

PACIFIC ISLANDS

Key Takeaways

- **Indigenous groups often take an integrated approach to NbS that includes traditional practices and engagement, which may clash with a Western science approach that separates people from the landscape. Native peoples-led framing and approaches could support implementation and sustained projects.**
- **Coastal adaptation is extremely costly, and the islands, especially US-affiliated, are deeply dependent on federal funding to meet adaptation needs, yet struggle to meet the required federal agency BCA ratios.**
- **Despite local interest and support, funding deficits prevent communities from pursuing alternatives to gray infrastructure.**
- **Research that demonstrates and clearly communicates the co-benefits of NbS would support practitioners who work to have local and territorial governments prioritize NbS.**
- **As in Alaska, this region integrates NbS concepts and practices into broader and more comprehensive adaptive planning for sustainability.**
- **As in the Southeast (USVI and Puerto Rico), US territories have limits on international funding, making them especially important to support in this space.**

Context and Capacity

The Pacific Island region is renowned for important terrestrial and marine biodiversity, along with cultural diversity with over 20 Indigenous languages spoken (Kenner et al., 2018). Sea level rise, increasingly powerful tropical cyclones, and development pressure present significant hazards for these varied coasts. The U.S. Pacific Islands region includes the state of Hawai‘ i, as well as the U.S.-Affiliated Pacific Islands (USAPI): the Territories of Guam and American Sāmoa (AS), the Commonwealth of the Northern Mariana Islands (CNMI), the Republic of Palau (RP), the Federated States of Micronesia (FSM), and the Republic of the Marshall Islands (RMI). The economies of many regions depend on tourism, which brings both development pressure and the need for clean water and biodiversity.

The dangers of dependence on the tourism economy became even more evident in the Pacific Islands during the Covid-19 pandemic. As a result, '**Building Bridges, Not Walking On Backs: A Feminist Economic Recovery Plan for Covid-19**' addresses many of the equity and governance issues that are critical to implementing and sustaining NbS in Hawai'i. This state plan calls for a restructuring of Hawaii's economy, moving away a heavy reliance on military, tourism, and luxury development and "ensuring women have access to "green jobs" in renewable energy, energy efficiency, and environmental management and construction jobs (89.9% male workers) through stimulus programs that promote gender and racial equity" (Hawai'i State Commission on the Status of Women, 2020).

The Pacific Islands share many of the challenges of islands in the Southeast region, as well as Alaska: challenges with the high cost of adaptation action, yet limited funding to undertake projects. The Pacific Islands share the common challenges among Native nations, and highlighted by practitioners in Alaska and the Northwest, that NbS may be co-opting Indigenous practices while simultaneously disempowering Native communities. Piecemeal approaches to NbS limit engagement of Native communities from these systems, further exacerbating long standing equity concerns. In some areas, such as the Commonwealth of the Northern Mariana Islands (CNMI), a current economic crisis deeply jeopardizes the ability to move nature-based solutions projects forward.

> *A lot of the institutions set up to advance these [NbS] goals can act as barriers because they are not viewing the people on the ground as being valid experts.*

Funding that built in relationship building, as well as the ability to monitor, was recognized as crucial across the region. But funding was a significant challenge across the affiliated islands:

> *Bringing people together and building the capacity for NbS is a real value add.*
>
> *None of the federal programs comes with long term monitoring, so we had to connect with other projects [to fund our monitoring.]*

We have limited people and funding. People are doing what they can. The most attention, and active management, is in fisheries–trying to preserve habitat to use and enjoy; then shoreline management and development management.

The working paper '**Nature-based Resilience and Adaptation to Climate Change in Hawai'i**' initially intended to address sea level rise impacts, but it became clear that focusing only on the coast did not tackle the critical and interwoven reality that land and sea are inextricably connected. Consequently, this paper provides examples of actions in Hawai'i that employ nature-based "green-blue" strategies to adapt to and mitigate climate change.

Human capacity to support NbS was an issue exacerbated by the global pandemic, the lack of a diversified economy, and the cost of living. Practitioners recognized that it was policy that created this crisis of capacity, and consequently saw these issues as part of the challenge with NbS that are not only inclusive of but driven by Indigenous people.

I think a lot of the questions I have are concerned more with policy than science.

There are a couple of major concerns: one of the largest being water and water access. We have a long history of water divergence for agricultural purposes, and this along with access to abundant clean fresh water, this could be part of NbS systems solutions, navigating different water and its uses.

Land tenure is really important...who is setting the regulations and policies for what is allowed to be restored. Sometimes there are policies, when working in sensitive landscapes, that are made from Western perspective, which says the area needs to be pristine, that's the end goal... Policies don't recognize the need for that active human part of the NbS.

These are all points that are emphasized in the National Findings, but there is significant tension and challenges in the Pacific Islands related to the balance of power across different worldviews.

NbS are integrated into larger initiatives and practices that support sustainability in the region. Guam Green Growth (G3) partnerships developed through the Office of the Governor of Guam, the University of Guam Center for Island Sustainability (CIS), **Global Island Partnership (GLISPA)**, and the **Hawaii Green Growth Local 2030 Islands Hub**, and is a founding member of the Local 2030 Islands Network to advance local and global Sustainable Development Goals. Through the Guam Green Growth Initiative, the creation of the G3 Working Group, and the adoption of the G3 Action Framework, Guam develops tangible solutions to sustainability challenges and contributes to a green economy for the island region. This includes a Conservation Corps that accomplishes numerous NbS projects, including **growing and planting native trees** that can reduce erosion that harms reefs and fisheries, as well as critical outreach to address the root causes of erosion, including OHV (Off Highway Vehicle) use and illegal burning. This work will also be supported by a NFWF NCRF grant to "utilize agroforestry through intercropping fruit trees with ongoing native tree planting to improve biodiversity and habitat for birds in Guam. The project will reduce flow of land based pollutants from significant soil erosion to protect coastal waters and adjacent streams that lead to the Ugum river."

Opportunities

In areas where political transitions and economic crises rattle the social infrastructure that supports the implementation of NbS, practitioners sought ways to quickly and efficiently translate the benefits of NbS to political leadership. Methods of demonstration mentioned included fact sheets and StoryMaps.

> *[If we can] highlight leading practices, or if there are case studies in the Pacific region that resonate with leadership, that gets people's attention. If we can show that planning achieves better outcomes, that helps me do my job.*

Monitoring was a key area ready for development for the region, especially in the affiliated islands. Even rain and stream gauges are inadequate.

More data helps us quantify [NbS] better: if federal funders included small underfunded governments to collect data, we would have a better idea of how to quantify the benefits, and that would help pitch the projects and get more implementation.

As in the Southeast, there was a significant need to understand groundwater aquifers and saltwater intrusion. Water security is a sensitive issue, and research and projects that add understanding of water availability would be a helpful co-benefit.

There are significant opportunities to support traditional and local knowledge and practices on the islands. However, these opportunities need to be driven by Indigenous communities, and assisted by Western scientists, instead of vice versa.

SOUTH CENTRAL

Key Takeaways

- **Sea level rise, subsidence, and increasingly powerful storms are forcing this region to actively address planned relocation at a significant scale, and existing equity issues persist in these actions, especially for Indigenous groups.**
- **The region has the mixed blessing of significant funding from the Deepwater Horizon disaster, but that funding has yet to manifest as an implemented NbS project in Texas.**
- **Well-organized state level planning processes support a landscape level view of adaptation, but communities can feel left out of decision making.**
- **Integrated hybrid strategies preferred: research shows the economic benefits of NbS in the region, but the memory of highly impactful storms such as Katrina deter the use of green infrastructure as a solo strategy.**

Context and Capacity

The South Central region encompasses the Texas and Louisiana coasts. The Texas "coastal bend," where the rate of sea level rise is twice the global average, is the main trade hub for the state and the leading energy producer for the nation (GLO, 2019; Kloesel et al., 2018). Hurricanes Katrina, Harvey, and Ida, which made landfall in this region, were three of the four most costly natural disasters in U.S. history (Shovelin, 2022). In addition to increasingly powerful storms and sea level rise, land subsidence is a significant issue for the region. Conditions in the region have pushed stakeholders to have ongoing conversations about coastal restoration practices, integrating hybrid and gray infrastructure, and assisted relocation / managed retreat (see Rush, 2018).

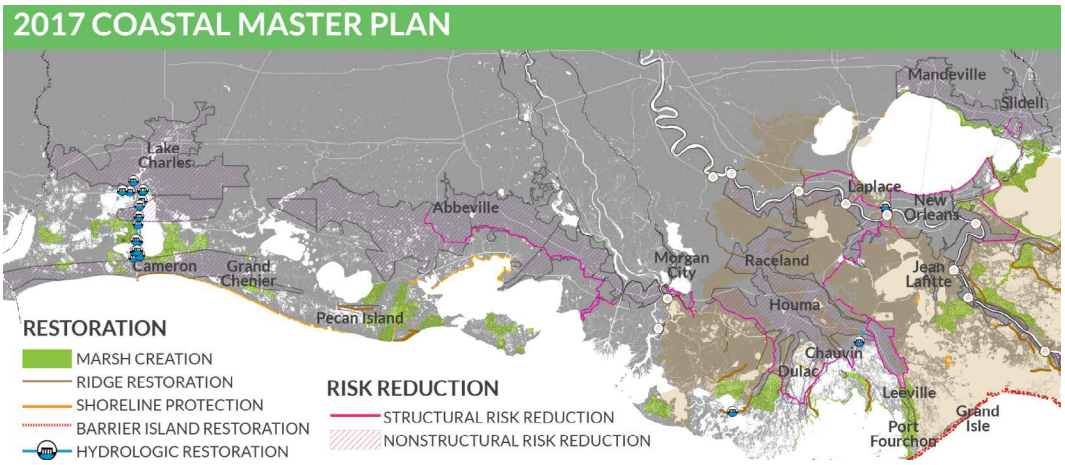
In Louisiana, amid sea level rise and land subsidence, the Mid-Barataria Sediment Diversion Project will reconnect the Mississippi River to the Barataria Basin, potentially restoring thousands of acres of wetlands, but creating economic and equity issues for communities impacted by changing conditions. This reflects larger tensions between the state and communities:

> *A lot of communities feel powerless, but the state has decided engineering is the solution to an already over-engineered situation: [the communities] don't have a lot of power or say about how to protect their own coasts and wetlands.*

According to practitioners, historic land use practices like redlining make NbS a privilege that underserved communities may not be able to access: many communities do not have autonomy over the land around them. It becomes difficult to prioritize wetlands if there is potential commercial value.

> *We need to move beyond the idea of starting at plants in the ground: there are systemic issues that have to be addressed first.*

Both Texas and Louisiana provide leadership and planning efforts that increasingly integrate NbS (GLO, 2019; CPRA, 2017). Louisiana's Coastal Master Plan (2017), being updated for 2023, provides vision and leadership for nature-based solutions such as marsh creation, barrier island restoration, and shoreline protection across the coast (CPRA, 2017).



Proposed coastal restoration and armoring in Louisiana's Coastal Master Plan.

The Texas Coastal Resiliency Master Plan, from the Texas General Land Office, has been leading a stakeholder input process using participatory mapping approaches across Texas — a first for coastal resilience. With the most recent version in 2019 (TX GLO, 2019) and a planned update for 2023, practitioners saw the process of building this document as successfully engaging and understanding decision makers with nature-based approaches.

Unlike other areas, this region has the mixed blessing of funding available from the Deepwater Horizon disaster that could support NbS. However, the limits of human capacity were as deep in this region as others. Practitioners noted that the capacity barriers began at the local level and in specific ways.

> *There's culture in the asks of an RFP put out [by a municipality]: towns get a stamped gray [infrastructure] design if nature-based solutions are not specifically requested. The engineers need the demand.*

Path dependency interacts with capacity in the coastal bend: flood and stormwater management has relied on traditional gray infrastructure. According to practitioners, this manifests as municipal decision makers developing RFPs for infrastructure that do not include natural or nature-based infrastructure. In turn, local engineering and landscape architecture firms do not have or require experience in NbS, and consequently they are not offered. This is a case in which local examples are critical for demonstrating alternative natural or nature-based options.

RESOURCE

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) compiles an up-to-date **database of projects**. Example projects include the Grand Bayou Ridge and Marsh Restoration, in which dredged materials from the Mississippi River will be dewatered and compact to an elevation conducive to emergent marsh in the intertidal zone (Louisiana Coastal Wetlands Conservation and Restoration Task Force, 2022). These projects are not specifically focused on hazard mitigation, although many include that component. They are not yet monitored systematically to understand risk reduction co-benefits, but overlap with the Louisiana Coastal Master Plan.

Community Development Block Grants (CBDG) provide potential avenues to fund significant NbS projects. However, according to practitioners, these funds are not yet being mobilized to support nature-based solutions.

Congdon at el. (2019) illuminated species-specific responses of seagrasses to a major hurricane, in which the late successional species was more sensitive than the pioneer species as measured by greater reductions in cover and blade length and directly related to wind intensity. This work relied on data from the Texas Seagrass Monitoring Program.

Nueces County, Texas, has the potential for strategic regional leadership with the Nueces Delta Shoreline Erosion Protection project, funded through the NFWF Gulf Environmental Benefit Fund (GEBF). This hybrid project, with a breakwater and living shorelines, incorporated planning and initial construction through the Coastal Bend Bays and Estuaries Program.

Multiple challenges exist in implementing NbS at the policy level. For example, the memory of catastrophic storms like Katrina still guides decisions around flooding solutions. Practitioners noted that nature-based solutions are beneficial for more frequent events, but will likely not prevent losses during catastrophic events. In addition, according to multiple practitioners working

directly with communities in this region, nature-based solutions can be perceived as unjust solutions when contrasted with the near-term effectiveness of gray infrastructure.

> The Lowlander Center, frequently cited by practitioners as a highly effective nonprofit organization, supports and honors the residents of coastal and bayou lowlands, including 'Indigenous and all diverse historied groups, by helping them to achieve full engagement for a resilient future.' Projects including filling dredged canals in Louisiana to restore wetlands and culturally-important sites; a toolkit 'Community Field Guide to Engagement, Resilience, and Resettlement: Community regeneration in the face of environmental and developmental pressures' to support communities to control and the planning process and its narratives (Naquin et al., 2019); and the Louisiana Universities Resilient Architecture Collaborative (LURAC), which supports the collaboration of architects from six professional design programs with resilience specialists to develop and implement design solutions at the neighborhood and community scale.

Although throughout this report we caution against taking an "apples to apples" comparison of gray and green infrastructure, practitioners recognize that economic feasibility is a guiding factor for any adaptation project. For that on-the-ground reality, a study by Reguero et al. (2018) compared the cost effectiveness of nature-based and gray infrastructure on Louisiana's Gulf Coast using cost-benefit analysis. They discovered that nature-based adaptation could avert more than $50 billion in project costs, 42 – 57% of the total risk; wetlands and oyster reef restoration were particularly cost-effective (Reguero et al., 2018).

More recently, in a compelling case study comparing a living shoreline with a bulkhead using cost-benefit analysis for the region, researchers with the organization PLACE: SLR, discovered the following:

- "*Over a 60-year time period, implementing a living shoreline is more economically efficient than repeatedly replacing a bulkhead.*
- *Even if the initial cost of a living shoreline is 3.25 times the initial cost of a bulkhead, the living shoreline is still more efficient over a 60-year time period.*

- *Most benefits of implementing a living shoreline come from avoided bulkhead maintenance and repair costs.*
- *The costs of this project were significantly less than other comparable living shoreline projects due to the small size of the living shoreline and the unique multi-organizational partnership involved in its implementation*" (Sicango et al., 2021).

This research is a reflection of engaged and community-engaged efforts: researchers at PLACE:SLR developed this document specifically to support the needs of regional municipalities and proponents of nature-based solutions.

Opportunities

Overall the research opportunities identified by practitioners were focused on the social and cultural aspects of nature-based solutions. Understanding values and beliefs, place attachment, in conjunction with and regime shifts. These were intertwined with a need for convening practical conversations around connection to place and the economics of nature-based solutions and retreat.

> *When natural habitat and community are entwined into who you are as a person, it gets more complicated..it's going to take decades to do strategic relocation. If there's no practical conversation about connection to place and the local economy, it will never happen.*

Research must meet the needs of local stakeholders if it is to be useful in advancing implementation of NbS. This may vary somewhat from urban to rural areas. Multiple organizations exist with expertise to support applied research, including but not limited to the Harte Institute, National Wildlife Federation, and Texas and Louisiana Sea Grant. Practitioners recognized that communities needed a way to more easily fit nature-based solutions into current funding models.

> *"We really need a plug-and-play for nature-based solutions. We have plug-and-play for [gray infrastructure in the current] cost-benefit analyses, but not for hybrid or natural infrastructure."*

In general, practitioners sought a better understanding of how the biophysical and ecological impacts will interact with socio-economic and cultural issues. Practitioners cited the need for research to understand where to invest time and energy into marsh restoration, and how to protect nature-based solutions from storms. They also sought solutions to support a systems view of an integrated gray-green infrastructure. Convening agencies that work separately on gray and green infrastructure would be a starting point.

Questions remain about storm surge on the Gulf coast, particularly the role of barrier islands such as the Chandelier islands and other offshore islands. Again, a systems perspective of combined projects to understand their role in storm surge would support projected investments. In line with that systems perspective, research on larger scale restoration work and the resilience co-benefits would support ongoing work on Master Plans in both states.

Interest in social and cultural research was the most common refrain. Needs included identifying and characterizing ways to support and repair ecosystems in which culture and society are a part of that system, particularly for Indigenous and tribal communities in the Gulf. As in conversations with practitioners in the Pacific Islands region, stakeholders mentioned the ongoing challenge that green solutions often required removing people without recognizing that people can also be a part of the solutions.

Social science research also includes monitoring–documenting how space is used, and how people interact with natural spaces where they live, recreate and work. Finally, enabling collaborations and working groups that address the trauma of grappling with losing homes, livelihoods, and communities could meet the need and build the relationships needed for community engagement with nature-based solutions.

The South Central region shares many of the hazards, social issues, and equity challenges found throughout the Gulf and the Southeast region. One of the interesting similarities it shares is with Alaska, given the high energy environments and need to understand and address retreat, and the inequitable burden on Indigenous and marginalized people, in the present day. Alaskans and Texans also share an economic dependence on resource extraction, as well as a desire for autonomy and independence.

SOUTHEAST

Key Takeaways

- **Coastal squeeze and development are a constant threat not only to existing natural ecosystems on the coast, but to migration corridors for these systems. Continual coastal development is heavily incentivized in the region.**
- **According to practitioners, many in the region are willing to increase their hazard risk exposure to not live behind concrete walls, and there is significant interest in NbS.**
- **Understanding groundwater implications and impacts is a pressing concern when considering potential NbS roles for current and future sea level rise.**
- **This region has regulatory and planning leadership, with Virginia's first-in-the-nation laws requiring the use of coastal NbS unless proven otherwise, and the City of Charleston's Comprehensive Plan that centers water in its structure.**
- **USVI and Puerto Rico have small existing and potential equity-driven projects, but there is concern about their risk mitigation capabilities for severe storms, and practitioners stressed ongoing systemic governance challenges that need to be addressed in NbS planning.**

Context and Capacity

The Southeast region encompasses North Carolina south to Florida, then west to Mississippi. Most of the coastal area is low-lying, with many cities experiencing rapid growth, and rural areas with intransigent poverty (Carter et al., 2018, Hsiang et al., 2017).

According to practitioners, large scale development pressure is a constant threat to natural areas such as mangroves in Florida and salt marsh in the Carolinas. The political interplay between state governments and counties or municipalities has led to some areas being further along in their planning efforts, but there is great interest throughout the region in nature-based solutions. Even in areas with extensive existing armoring and significant gray infrastructure needs, such as Charleston and Miami, there is a desire to improve resilience through the many co-benefits of nature-based solutions, from

improving water quality and fish habitat to the recreational and mental health amenities.

> The Dauphin Island, Alabama, comprehensive planning process created the opportunity for feasibility assessments for natural and nature-based features. These assessments focused on solutions that could strengthen the biological and physical integrity of the island. The comprehensive plan also opened doors for studies around diversifying the economy, and funding to implement projects for health and safety. Practitioners stressed that, even as the planning process took years, it positioned Dauphin Island residents to make informed decisions for NbS implementation.

Building or rebuilding barrier islands is a popular solution for the region. However, practitioners noted the importance of having conversations and setting up governance structures with municipal governments about the specific purpose of building or supplementing barrier islands.

> *We want to build islands to provide wave attenuation benefits. But we're not building a '7 11' on that island: this is habitat.*

Particularly among islands, such as the USVI and Puerto Rico, practitioners recognized governance as a significant barrier to nature-based solutions, particularly in stormwater infrastructure. Coral reef and mangrove projects predominate in the Caribbean, but practitioners noted that the co-benefits are as yet unquantified.

> *I think that, in general, there is a lack of understanding of how systems function during massive storms. The biggest is storm water–we need acknowledgement that it will not perform, and let that water run.*

The nonprofit organization **Un Nuevo Amanecer** was funded by NFWF to develop NbS options for the underserved community of Playa de Ponce in Puerto Rico. The organization received grant writing support from a climate services organization, **Anthropocene Alliance**, and conducted extensive legwork to find experts who could tell them what they needed to consider and model to begin thinking about an NbS. The project was funded to conduct biophysical and social research and planning, including wave and climate modeling, needs assessments, and identifying regulatory frameworks that could impact mangrove reforestation and living shorelines.

Development pressure is the most significant threat to NbS in this region.

> *It's difficult to argue against large scale job creation in the name of long term adaptation. One of the big challenges remains: how do you preserve existing wetlands, and also where they could migrate to. The science, the needs, the risk, these are all relatively straightforward, but they are still hard to do [in practice] because we have larger scale development pressure.*

In the low lying islands and coasts, it is not a foregone conclusion that these areas will be allowed to go underwater with sea level rise.

> *What are the right management tools to be used there, increasing the elevation of the island platform? Digging up sea turtle nests? Increasing dune height? Secondary and tertiary dunes? And what does that mean for building an environment and systems? We need to understand some of that engineering.*

In a rigorous project that involved thin-layer sediment application using dredge sediments in (Spartina Alterniflora) marshes, followed by monitoring over five growing seasons, researchers found accretion on average of six centimeters, potentially increasing the resilience of low-lying marshes (Davis et al., 2022). The careful study of marsh accretion over the past decade in the region has provided encouraging examples to support future projects.

RESOURCE

The Florida Department of Environmental Protection (DEP) maintains a **database of living shorelines projects**. These include information on monitoring, challenges, public feedback, and successes for each project.

Retreat is an active topic of discussion, planning, and implementation throughout the region; however, well-intentioned programs may not be having the desired effect of protecting natural lands. For example, in the Carolinas, for every house purchased in a buy-out program, eight new houses were built in the floodplain (North Carolina Office of Recovery and Resilience, 2022).

Finally, in this low lying region, it may seem impossible that development and coastal squeeze can continue, given the cost to rebuild after increasingly powerful and destructive storms. To learn more about the markets and economic conditions of insurance and reinsurance, the 'How We Survive' podcast by Marketplace provides one of the most concise and understandable explanations we have found in Season 2, Episode 5, '**Risky Business**.' Private insurers and reinsurers have pulled out of coastal Florida, leaving the state as the only insurance provider.

In the city of Charleston, South Carolina, the **2021 comprehensive plan** is framed around water. The four guiding principles for the report are "data smart," "strength in diversity," "community empowered," and "water first: anchored in where water is and where water is going to be." This planning strategy created the basis for slowing development in flood prone areas, and focusing on existing *and future* wetlands.

Opportunities

Practitioners suggested that research taking an integrated approach to land and seascapes and the interacting hazards would support more large-scale adaptation and the needs of local communities. This includes integrating riverine flooding research with the coastal hazards such as sea level rise and storm surge.

> *Sea level projections are great, but [communities] really need to understand how much water is where, when, and how often. This requires not just understanding sea level rise, but high tide, riverine, and precipitation-driven flooding. That's going to require modeling surge, plus understanding the riverine and groundwater [dynamics.]*

One of the key components of this is groundwater understanding and monitoring:

> *We need to understand what sea level rise will do to groundwater, both shallow and deep. Shallow groundwater will be emergent floodwater, and we're not ready for it. If I think of all the risk, from Houston to D.C., sea level rise is going to cause groundwater problems under all those places. We don't understand what sea level rise will do with the shallow and deep aquifers, and what we need to do in response. …. We just need to understand it. [Monitoring agencies] have wells in place, but it's haphazard: we need a more comprehensive approach.*

People are often not willing to let go of homes, whether for humans or endangered or unique species. The Florida Keys are home to unique species, such as the Key deer, Key skinks, and Key Largo woodrat. Practitioners did not see modeled inundation as a realistic estimate of what the space will look like. Consequently, they sought *scenarios that incorporated the social and political realities into the biophysical landscape.*

This relates to an interest in long term sea level rise planning that realistically integrates gray and hybrid infrastructure. This may include understanding the current culture where gray and green infrastructure are often seen and portrayed as competing options. Research around bringing these communities together to think about longer term solutions, possibly through the mechanisms of adaptation pathways to engage with policy making, may serve to move the conversation in this region closer to practitioner needs.

Monitoring natural systems during storm events in real time would be helpful to practitioners in the region. To understand how mangroves behave during hurricane storm surge was "*usually done using watermarks on buildings after the fact."* Practitioners wanted observational data to ground truth the modeling approaches.

Particularly for this region and South Central, an examination of incentives and disincentives that impede NbS implementation, specifically insurance,

reinsurance, and state-owned insurance, would likely shed needed light on this topic. In addition, building relationships with the insurance and reinsurance sectors in the U.S. may be of significant short and long term benefit to researchers, insurers, and people impacted by coastal policies.

The integrated research of freshwater flood plains and saltwater marshes came up again in this region. Understanding and being able to point to simple documentation of growing seasons of marshes, the biologic performance of marshes to support birds and other wildlife–these were all interests of resilience planners in the region.

Finally, understanding and providing standards for valuing nature's ecosystem services and co-benefits came up routinely in conversations. For practitioners rolling up their sleeves to make nature-based solutions happen every day, there is dire need to identify and capture value.

> *We need to capture [the co-benefits] in a way that an accountant can understand them.*

SOUTHWEST (CALIFORNIA)

Key Takeaways

- **California has already undertaken significant coastal NbS projects, and now looks to better integrate long term planning into projects with broader scopes and land areas and with a greater attention to equity, but is severely hampered by state regulations.**
- **Developing and maintaining partnerships was highlighted in this region: cross-agency and sectoral relationships were needed to support the implementation of larger scale projects, and public-private partnerships present significant opportunities.**
- **Outside of the region's significant estuaries and related thin-fill sedimentation and horizontal levee projects, dune restoration and beach nourishment has seen success in both protecting coastal infrastructure and preserving recreation and habitat on exposed coasts.**
- **Key planning documents that integrate adaptation at the intersection of coastal and inland ecosystems provide an excellent opportunity for integrating NbS into regional planning.**
- **Despite relatively strong governance, the region still lacks regulations to support NbS implementation, which complicates and slows NbS permitting. As in the Northeast and elsewhere, existing regulations designed to protect habitat now impede progress.**

Context and Capacity

The Southwest region includes the entire California coast and its approximately 420 public beaches. Ecosystems of chaparral and grasslands in the south slowly transform into more forested areas north and inland, with significant urban areas in the large coastal estuaries and historical wetlands, including San Diego, Los Angeles, the San Francisco Bay area, and Humboldt Bay. The region is already facing significant climate hazards such as increased wildfires and drought, which impact the social and economic priorities of the state, along with the freshwater flow, sedimentation, and resources that feed these estuaries. The increased intensity of downpours, especially from atmospheric rivers, has caused extreme flooding (Gonzalez et al., 2018).

On the coast, 200,000 people live within 3 feet or less elevation above sea level, and the state of California has the second most valuable coastal economy in the country (after Texas), employing over half a million people and generating over $50 billion in economic production in 2019, predominantly from tourism and recreation (Gonzalez et al., 2018, NOAA, 2022). The 1976 California Coastal Act, with clear regulations about development and redevelopment, as well as the Coastal Commission's extensive work on sea level rise, support reduced shoreline hardening, even as temporary emergency sea walls can still be built (Surfrider Foundation, 2021). Without a doubt, the state supports NbS, but does not have legislation that promotes NbS over hard infrastructure.

It took a decade to reach consensus, but the **project to restore Surfers' Point** in Ventura, CA, is an example of multiple groups working together to enable retreat and NbS in one project. The implementation strategy placed a "cobble mattress" at the foundation of the dunes at the back of the beach, which was then layered with imported fill and sand from downcoast beaches (U.S. Climate Resilience Toolkit, 2015). As a result, sediment reserves in the dunes continue to support recreation, inland infrastructure has been protected by the increased elevation of dunes, and these dunes also withstood the flooding from the winter 2023 atmospheric river.

According to practitioners, there is significant interest in coastal nature-based solutions. However, this region, like the Northeast and Southeast, already has significant high dollar investments in privately owned coastal property, making retreat especially difficult for coastal ecosystems.

> *I think the biggest challenge here is the fact that most of the coastline is developed. There are very few opportunities to buy upland areas, because they are already owned. The mansions are already on it. Our coastline is really wealthy. Here there are gazillion dollar homes on the ocean. You're not going to convince these people to give up properties when talking Malibu.*

Planning, especially at the landscape scale, is a strength in this region. In the SF Bay Area, the document that supports this landscape-wide view of NbS is the **SF Bay Shoreline Adaptation Atlas**. The Atlas is accessible and used by a wide range of agencies and practitioners to understand where and how NbS can fit into the landscape.

> *Adaptation Atlas is that comprehensive guide. If you try to get a permit for rip rap, agencies say, did you look in the Atlas? It has provided options for people. One downside: some agencies use it as a stick. If you're trying to get a permit for oyster reefs, in that one spot, the agency might say, 'it didn't say oysters there in the Atlas.' You run the risk: if you put it on a map, it could be interpreted in different ways. It needs to be refined, agencies need to understand the context–it can't be taken as the Bible.*

In the urban estuaries, the region has piloted the concept of **horizontal levees**, which is a wetland gradually rising in height that provides wave attenuation as well as wastewater treatment (Cecchetti et al., 2020). Port of San Diego projects have piloted the use of "ECOncrete," providing intertidal habitat on armored coastlines using concrete with pockets for vegetation growth. Humboldt Bay, which is experiencing the highest rate of SLR in the state, has similar coastal conditions to the Oregon and Washington coasts, and has implemented a NFWF-funded project to support their estuaries in the face of sea level rise.

The **Oro Loma horizontal levee** provides multiple benefits for the adjacent community. Developed by the Hayward Area Shoreline Planning Agency, a coalition of nonprofits, government agencies, and community members, the horizontal levee reduces flood risk from sea level rise, polishes wastewater before it returns to San Francisco Bay from the Oro Loma Sanitary District, and provides habitat on the edge of the Bay, all at a lower cost than gray infrastructure. With a width of 400 feet and length of 200 feet, it provides a gentle slope of 5 feet from the top to the toe of the levee. It was designed to allow research on the effectiveness and optimal operating conditions of the re-imagined levee.

Native nation leadership has fueled conversations and collaborations in northern California, and helped the region think about the co-benefits of traditional knowledge and practices for millennia on this coast.

> *The Swinomish [Nation] has implemented NbS using traditional knowledge and practices, like clam gardens. This is something that has multiple goals: cultural continuity, food sovereignty. Even if this is not feasible here, clamming and clams are very important subsistence food for the Wiyot, past and present, and these solutions may be a less construction-intensive, lower cost way to think about sea level rise.*

> *We're working on a project with Wiyot, a land back project…[they received] California funds to acquire lands, lowland and upland, and a lot of the lands they currently own are at risk of inundation. Can there be a model where a tribe acquires coastal land and leads implementation?*

Wigi or Humboldt Bay is experiencing the fastest rate of relative sea level rise on the U.S. Pacific Coast. The **Wiyot Nation** has provided leadership and collaborated with the Cal Poly Humboldt **Sea Level Rise Institute**. The tribe **received funding** from the California Ocean Protection Council to "begin identifying and prioritizing cultural and natural resources within their ancestral lands and waters that are vulnerable to sea-level rise, enabling the Tribe to collaborate with land management and resource agencies in the development of sea-level rise and climate change adaptation strategies" for Wigi.

Despite state funding mechanisms that strongly support NbS, along with "guidance" and regional goals, the state does not have regulations that support coastal NbS, making the regulatory side challenging. A few agencies have adapted their policies to allow for more NbS; for example, the Bay Conservation and Development Commission (BCDC) has a "fill for habitat" amendment to their Bay Plan, and the state Water Resources Control Board has a new Basin Plan Amendment that supports NbS, but practitioners told us that permitting NbS is still very difficult. Further, federal agencies, such as with USACE, cannot account for future conditions in permitting.

As Southern California faces **losing its beaches to sea level rise**, multiple strategies have been deployed. Beach renourishment, which adds sand to existing beaches, is popular, but fights have ensued over who will pay–municipalities or the state (Connelly and Saavedra, 2022). In Carlsbad and Ventura, dunes with cobble mattresses have been successfully deployed, and an artificial reef and / or groin jetties, in which rock walls are placed in a regular pattern from the sand into the surf, have been proposed for Capistrano Beach. The area has a history of using rock jetties to preserve sand and coastal properties, but current regulations make permitting much more difficult.

Opportunities

The region is asking important questions about the longevity of its wetlands, and partnerships between implementers such as USACE and public utilities and ports would support not only the necessary data, such as modeling sea level rise scenarios, but further build the institutional muscle memory of coastal partnership.

> *I have this subsided piece of land: we want wetlands for endangered species, and flood protection for Silicon Valley. The Army Corps needs to know how much sediment to bring up to water level, before reintroducing the ocean so the wetland doesn't drown. So how do we make this last 100+ years? How much fill do we need, what's the best way to design this, and how best do we create a wetland?*

These are important questions not only for the region, but for the nation, and understanding the modeling, relationships, and processes needed to implement larger marsh accretion projects would potentially accelerate coastal adaptation using NbS.

In the same vein of planning for change, the U.S. Forest Service's coastal refuges have been an important place of conservation for decades. As with other national mission agencies with mandates, the region's federal agencies are seeking ways to better integrate climate change planning into preservation.

Practitioners sought ways to better understand the different levers they could use and adjust in a project, especially considering sedimentation and drawing together the fill from dredging operations and the need for faster accretion in marshes:

> *What are the knobs and dials that we can turn, and what can't we do? With sediment, we have looked at supply and demand analysis for tidal mudflats in the Bay. What is needed, what does this system get out of natural watersheds, what are the manmade sources we can use? We need to bridge the science [with engineering] to develop plans for moving forward.*

Research on larger scale restoration work, and how that might provide resilience benefits, was recommended as a way to integrate science into state level planning.

Equity was a significant concern for the region. The wealth distribution on the coast and inland presents challenges to municipal and state agencies who recognize the discrepancy in services and opportunities for wealthy versus marginalized counties:

> *How can we provide capacity to communities in a way that is ground up and not top down? We don't need a bunch of parachute people telling them their problems and what their solutions are.*

PART IV

Practice-based Learning Opportunities

This section of the report provides an overview of preliminary findings on Question 3, practice-based learning: how could a practice-based learning process advance knowledge and implementation of coastal NbS, and climate risk management more broadly?

SUSTAINED ASSESSMENT OF NBS

Because most of the focus of the project was on NbS itself, here we briefly synthesize what we learned from this project in the context of a **sustained assessment of NbS. In particular, it is clear that there is strong support for a funded Coastal NbS Community of Practice.** Here we consider the potential focus of a CoP, the processes that would be associated with it, and potential expectations for capacity building.

Establishing a Community of Practice

A community of practice, organized by its members and facilitated by a knowledgeable coordinator to support collaborative learning about NbS, could make progress in sharing experience, assessing the state of knowledge (both scientific and practitioner-based), and developing collective understanding of leading practices. Inherent in the definition of a CoP is that the domain and outcomes are driven by the members, which cultivates trust and emergence (Wenger et al., 2002). Given our experience with practitioners and our advisory committee, we share here their collective interests that would be supported by a CoP.

- **CoP Focus**

Our interviewed practitioners, people 'on-the-ground' who are engaged in the 'practice' of NbS, identified specific research and practical questions and needs that require a broader range of expertise and knowledge than is traditionally included in research and assessments. Their questions embody significant social and economic challenges such as community development, disaster

management, infrastructure modernization, public finance, regional planning, social inequality, and public health, drawing on insights from ecology, climate science, social science, Indigenous knowledges, community science, and other fields. Engaging this breadth of experience and perspective will require a clear and specific focus so that individuals from very different backgrounds can relatively quickly develop a shared common understanding of the problem that they are working on and can learn how to communicate effectively.

It is not the purpose of this report to recommend a specific topic but we do feel it could be useful to highlight a number of possible topics that have been highlighted by practitioners and discussed throughout the report that have promise. This list is intended to stimulate additional conversations regarding a path forward.

- Codes, ordinances, standards, and other legal mechanisms that influence and need to be updated to enable NbS to be considered along with other currently more dominant approaches
- Multi-stressor hazards facing communities and how these interact with NbS — is NbS more effective with some than others, and in what contexts?
- NbS as part of a flexible and adaptive set of strategies for transitioning to more resilient and equitable coastal development over long time frames
- Potential role of NbS in affecting the future trajectories of particularly at risk neighborhoods/communities given different timeframes or levels of hazards—relationship to equity and development of historically underserved communities
- How NbS strategies affect financial risks across scales and systems (from individual insurance rates to local property and tax base to state/regional systemic financial risks)
- Institutional factors different communities and governance systems have confronted as impediments to NbS and how they have addressed them at local to federal scales
- Interest in "solution sets" — integrated packages of approaches/ outcomes that serve multiple objectives

A number of the topics above are focused on providing broader context for NbS in the context of the range of coastal adaptation options. Many practitioners are concerned about precluding future NbS options by making

gray infrastructure decisions today. However, practitioners noted that, when a community wants flood protection today, it can be difficult to offer a solution, such as marsh creation, that will take multiple years to provide benefits. Adaptation pathways (designing in future options in the initial project concept) allow for flexible implementation that can address uncertainty about the rate and magnitude of change. However, complete accounting for potential benefits and costs of different measures is often not possible, especially at the time of initial decisions, because subsequent implementation is deliberately left flexible.

- **CoP Process**

Our research indicates there is strong interest in a process that focuses on solutions and takes practitioners seriously, not just to identify information needs but also to contribute their experience and knowledge of "how things work" in practice to identifying solutions and effective methods.

We note the clear message from practitioners that for NbS projects to have legitimacy and to be trusted to meet community-driven goals, the process through which they are developed is extremely important to success. For example, if goals, knowledge, or methods were defined by agencies or imposed by a political process rather than seen as being developed collaboratively through a process that respected the input of stakeholders, the solution was often not perceived as a good fit and not adopted.

Another way of thinking about the importance of a process that builds trust and an environment in which people are supported to share with and learn from others was the need for "social proof." "Evidence" — from regional let alone national or global experience — was often insufficient to convince many local decision-makers or communities to undertake green infrastructure/NbS. It was the 'early adopters' who overcame barriers and provided examples, especially for regions where much of the coast is privately held by individual landowners. However, implicit in spreading the uptake of new solutions is the previously built trusted relationships between 'neighbors.'

Given the focus of the project and the desire to let specific arrangements arise organically in the context of a specific CoP, we did not explore in detail what focal preferences exist. We did identify some specific recommendations and questions:

- Potential participants noted that the CoPs should be supported with dedicated staff — while there is interest in these communities, everyone

is also already overloaded and would have trouble taking primary responsibility for additional work that might come out of the CoP dialogue;

- It is essential to enable the participants to define deliverables and outcomes that would be beneficial to them. Examples of products and results can be helpful in establishing reasonable goals and objectives;
- Communities of practice need to provide resources to facilitate participation by under- resourced communities and individuals;
- Incentives are important – allocating time "on the clock" to participate, including participation as responsibilities in job descriptions, fostering a culture of information sharing (including the sharing of unsuccessful as well as successful strategies), and providing recognition in performance reviews would enable interested individuals to devote time to CoP activities.

- **Capacity Building**

The need for capacity building is one of the strongest messages that comes through the interview and literature review process. Especially at the pilot and community level–a critical scale for demonstrating viability for many counties and states–communities were overwhelmed by the task of implementing and experimenting with NbS. Successful planning and implementation occurred when there was a person who could "hand hold," walking the implementers through the many technical processes. Sometimes this was a person from a nonprofit such as Surfrider or Anthropocene Alliance but it could also be a person with expertise and interest from a state/local/ and federal agency, a private-sector firm, or a small NGO. Another clear signal on capacity building is that even as progress is made in developing new climate services, these tools are most useful when there is a person who can support their use:

> *Not another tool! If you're going to create a tool to help me, there has to be a person–a real live person–on the other end of the phone who can walk me through how to use it. But even then I don't have time to figure out how to use the tool–I need a person to come up with the results and hand it to me.*

It cannot be emphasized enough: more people are needed to help communities–especially historically underfunded and marginalized communities–navigate the current complex and bureaucratic system to

document climate risks and identify, apply for, plan, implement, and sustain NbS.

So how could collaborative learning/sustained assessment build capacity? The idea is not necessarily that it would convene and organize training itself, but that by convening individuals and groups working on a problem it will be possible to identify leading practices by sharing experience and building on the progress and growing expertise in NGOs, professional societies, universities, private-sector organizations, think tanks, and other settings. This progress and emerging collective knowledge provides a foundation for capacity building that can then be supported by organizations with that expertise. The process of distilling this understanding of leading practices through a CoP also holds promise of identifying communication challenges and strategies for more effective training.

Advancing collective knowledge of NbS in collaborative learning builds on the interests of practitioners and academic/professional experts to work together with the expectation of gradual improvement in practice. Some specific areas for capacity building include:

- Incorporating NbS in local (municipal or county level) recovery plans for redevelopment;
- Integrating NbS with other infrastructure options for protection of existing coastal community land use and structure, and transformational approaches such as planned relocation;
- Risk characterization and perception considering sea level rise, various facets of climate change, land use/cover change, contamination of freshwater supplies, environmental legacies, and other issues;
- Risk communication and opportunities for more effective use of remote sensing, in situ observations, and approaches such as crowd sourced data to provide data needed to improve planning and evaluation of benefits and costs;
- Climate services and provision of trusted scientific information and methods to formulate strategies for NbS.

PART V

Next Steps for NbS

Managing the risks associated with climate change in coastal areas is an urgent challenge, with increasing hazards associated with sea level rise, coastal storms, storm surge, and extreme precipitation/flooding. Adaptation efforts need to escalate in number, scale, and pace. Coastal adaptation is currently dominated by coastal protection through gray infrastructure, though there is an appetite for increasing the use of NbS. Given the opportunities to integrate the potential array of ecological, social, and economic co-benefits into coastal infrastructure to mitigate hazard risk, NbS have the potential to serve as the starting point for coastal adaptation and resilience and to work in tandem with gray infrastructure to adapt to current and future coastal conditions.

Implementation of NbS is very location-specific. The effectiveness of NbS in protecting communities, infrastructure, and biodiversity clearly depends on the local physical and social context, including priorities about what and who needs to be protected. Yet, NbS practitioners across regions have remarkably similar frustrations, and agree that an inability to monitor, evaluate, and share practical and credible information about the success of adaptation efforts on the ground is slowing the pace of adaptation Fortunately, practitioners also agree on potential solutions, including the need for coordinated climate services and the need to incorporate on-the-ground experience into an adaptive learning cycle. It is clear that adaptive learning must be the foundation for better integrating NbS into coastal adaptation.

Obtaining relevant information and technical support to facilitate planning and implementation of NbS is a clear challenge. Many organizations seek to help, but climate services in the United States, as organized today, are not keeping pace with escalating climate-related risks. Adaptive learning to build collective knowledge can help create the foundation to support NbS. But it is only part of the solution. A new approach to support a national climate information system needs to include:

- system-wide coordination (organized regionally, sectorally or topically) to enhance sharing of what is learned across applications;
- direct engagement with adaptation practitioners and integration of multiple sources of knowledge;

- credible evaluation of findings across geographies by unbiased reviewers;
- systems to make data and information accessible and usable;
- enhanced communication of results;
- and long-term funding of sustained learning efforts that support the needs of practitioners (Moss and Jacobs, 2021).

Immediate progress towards these goals is possible in the NbS space. Practitioners in this study supported the idea of establishing a Community of Practice to support NbS–and in fact the advisory committee and practitioners consulted for this research provide a potential starting point. It would be very valuable to practitioners to continue a range of pilot CoPs to refine experience with this mechanism and promote accelerated learning, sharing, and implementation of NbS. To be effective, a CoP must provide credible, timely, useful information to participants. This means that it must be managed–a knowledgeable coordinator must spend time and effort to organize, curate, make connections, and facilitate knowledge capture, creation, and sharing. Applying this CoP model in the NbS space would help practitioners in all regions of the country to accelerate adaptation efforts. Regional or topical subgroups would provide a near-term space for practitioners to share knowledge and would accelerate local projects, while building shared knowledge and capacity for the future.

Throughout this document, we have answered three questions: what is the knowledge and capacity for NbS across regions and contexts, what do we know about the "effectiveness" of NbS to meet coastal adaptation needs, and how can practitioners be integrated into a national climate assessment process to advance knowledge and implementation. In addition to the recommendation of a CoP, we present pathways forward to address the specific challenges and opportunities at the national and regional level.

Across regions, these include:

- Building capacity for peer-to-peer (P2P) learning, especially among and between state regulators, and engage and build partnerships with international communities;
- Building capacity with interdisciplinary training, specifically with ecological knowledge for civil engineers, engineering knowledge for ecologists, training and certification for landscape and maintenance professionals, and training in schools, from elementary to university level;

- Center equity in NbS by making them community-driven, compensating people for their time, documenting historical contexts of injustice, addressing tensions between Indigenous and Western science models, and developing frameworks for a "full community approach" to NbS implementation;
- Co-develop (across sectors and levels of governance) outcome-based standards that account for context and build on previous work;
- Make BCA more equitable by accounting for co-benefits and nonmonetary value, and plan for an improved system of valuation;
- Support monitoring for NbS with funding and framing, and examine impacts from catastrophic storms in specific ecosystems and emergent benefits;
- Support carbon sequestration research, especially for unknowns such as sand dune vegetation;
- Pursue public-private partnerships to inject capital into capacity, innovation, and research;
- Fund social science research on the social and economic aspects of NbS, including collaborative research with state regulators to enable rule changes, examining potential standards, and characterizing novel valuation frameworks;
- Enable state legislation that supports NbS, which may range from supporting joint committees in legislature to ask questions about NbS, supporting new legislation with testimony, or funding state capacity to remake rules and regulations to meet NbS needs;
- Focus on strengthening adaptive governance, looking into local planning documents and governance structures to see how NbS can better fit as a part (not whole) of coastal adaptation;
- Focus on incentives, especially for human and habitat relocation, which includes explicitly examining the power structures that drive coastal development;
- And recognize and engage with the trauma of climate adaptation and relocation with the support of trained professionals.

These opportunities apply across government, NGO, philanthropic, and academic sectors, and may apply to specific regional, state, or local needs,

based on that area's timeline in the scope of NbS development.

NbS cannot stand alone in healing our shoreline habitats and communities, nor in buffering people and ecosystems from increasing climate pressures. The idea of using nature to protect people is nothing new. However, NbS in the current moment presents an unique opportunity to work across sectors and scales and build institutional capacity for collaboration, adaptive planning, and social and environmental justice. This report serves as a new national assessment in both content and process, and we look forward to engaging with readers to accelerate coastal adaptation.

APPENDIX I

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APPENDIX II

Coastal NbS Advisory Committee members and affiliations

Dr. Alessandra Jerolleman is an Associate Professor in Jacksonville State University's Emergency Management Department, a researcher at the Lowlander Center, as well as a co-founder of Hazard Resilience. She recently published a book titled: Disaster Recovery through the Lens of Justice. Alessandra is one of the founders of the Natural Hazard Mitigation Association (NHMA). She has worked with the First Peoples' Conservation Council, with Save the Children USA, and with hazard mitigation planning at the local, state, and campus level.

Dr. Arsum Pathak is the Adaptation and Coastal Resilience Specialist at the National Wildlife Federation's South Central Region. Her recent **publication** offers guidance on how to integrate nature-based solutions into community adaptation and resilience planning processes. Through her work, Arsum aims to address the challenges posed by climate change to our social and ecological systems across the Gulf using a science-policy interface.

Dale Morris is Chief Resilience Officer for the City of Charleston, SC. Morris previously served as Director of Strategic Partnerships at the Water Institute of the Gulf in Louisiana. He is co-founder of the Dutch Dialogues, a workshop process that integrates stormwater, groundwater, tidal and surge risks with planning and engineering in targeted cities. He previously served as Senior Economist at the Royal Netherlands Embassy in Washington, DC, and Director of the Dutch Government's water management and adaptation work across the US. Morris started his career in the U.S. Air Force and was Legislative Director to two Members of Congress.

Harriet Festing is Co-Founder and Executive Director of Anthropocene Alliance (A2), a Florida-based nonprofit. A2 is the nation's largest coalition of frontline communities fighting for climate and environmental justice. Her background includes milking cows in rural Dorset, establishing the first network of farmer's markets in England, and place-making advocacy in New York. She worked for the UK government on climate change and sustainable development and undertook ground-breaking research and advocacy on urban flooding.

Jeff Peterson is a Visiting Scholar with the Environmental Law Institute, an affiliate of the **Coastal Floods Resilience Project**, and former Senior Policy Advisor at the United States Environmental Protection Agency (EPA). He is the author of **A New Coast: Strategies for Responding to Devastating Storms and Rising Seas**.

Julie Beagle is the Environmental Planning Section Chief at the US Army Corps San Francisco District. Prior to joining USACE, she worked with the San Francisco Estuary Institute and led the development of the **SF Bay Shoreline Adaptation Atlas**.

Jessica Grannis is the Program Director for Coastal Resilience at the National Fish and Wildlife Foundation (NFWF) where she oversees the National Coastal Resilience Fund. Prior to joining NFWF she served as the Interim Vice President for Coastal Conservation and Coastal Resilience Director at the National Audubon Society, served as the Georgetown Climate Center's Adaptation Program Director and an adjunct professor at Georgetown University Law Center. Prior to her work at Georgetown, she was staff counsel for the California State Coastal Conservancy and the Ocean Protection Council.

Dr. Karen Thorne is a Research Ecologist with the USGCRP. Her research focus includes assessing sea-level rise and storm impacts to nearshore ecosystems, wetland ecology, and wildlife. Her recent publications include sediment augmentation and elevation of tidal marshes and mangroves.

Kim Penn is the acting Manager of the Communities Program, in NOAA's Office for Coastal Management. Kim oversees implementation of the National Coastal Zone Management Program. Previously, at the White House Council on Environmental Quality, Kim led the resilience finance portfolio within the President's Climate Action Plan.

Lisa Auermuller is the Administrative Director of Rutgers' NSF funded Megalopolitan Coastal Transformation Hub (MACH). Prior to this role, Lisa served as the Assistant Manager of the Jacques Cousteau National Estuarine Research Reserve (JC NERR) in Tuckerton, NJ.

Skip Stiles is the Executive Director of Wetlands Watch, a small nonprofit working to conserve wetlands in Virginia. For over two decades prior, Skip held senior staff positions in Congress working on national-level environmental science and policy.

Dr. Todd Bridges is the U.S Army's Senior Research Scientist for Environmental Science. Todd is the National Lead for USACE's Engineering With Nature initiative. Todd also serves as the Program Manager for the USACE Dredging Operations Environmental Research (DOER) program and the Director of the Center for Contaminated Sediments.

APPENDIX III

Semi-structured interview protocol

The following questions provided a guide for the 60+ interviews conducted as part of this project. Because the interviews were 'semi-structured,' these questions acted as a guide, but may have varied significantly depending on the interview.

The confidentiality of the interview participants and their associated organizations is protected as part of an Advarra Internal Review Board (IRB) designation.

Warm-up questions

1. What is your experience with EbA / NbS / GI?
2. What terms are you most often using to describe NbS?

Your region's needs / context

3. What specific or burning questions do you have about NbS in the context of your work or your region?
4. What are the climate adaptation needs for your region, and how are those currently met? How do you see NbS playing a role to adapt?
5. What do you see as the primary challenges for coastal adaptation in your region?
6. What are the questions you hear most frequently from the people interested in NbS {in your region}? In other words, who is asking about NbS, and what information do they need?
7. Do you know of current projects in which NbS is implemented in your region? Which case studies should we know about, and which other people should we reach to to understand the state of knowledge and practice?
8. Do you know anything about the regulatory context that helps / hinders implementation?

Implementation

9. We are studying the "effectiveness" of EbA, but that might mean different things for different people. What components of effectiveness are most important from your perspective?
10. What do you think are the knowledge gaps for EbA implementation?
11. From my literature review and scoping interviews, a few themes have emerged. These include lack of capacity for implementation (from funding to local needs), the framing of EbA (understanding the limits and contexts for implementation), and challenges with institutional power and equity (who has the power to implement NbS). Did any of these particularly resonate with you, and are there other broad themes you have observed in this space?
12. Are there other areas of NbS implementation we haven't covered that are relevant from your perspective?

Your organization

13. Can you tell me a little more about the history of [your organization] and NbS?
14. Is there a catalog or an index of your projects, or case studies? How are these currently shared? Do you have a regular group of partners with whom you share this information, like a community of practice, or are projects usually more one-off?
15. Does [your organization] systematically evaluate projects? How do you monitor and evaluate? Do you use national or regional metrics?
16. Are there challenges or opportunities that you see for NbS specific for this region? How about more broadly, at the national (or even international) level?
17. What else should I know about NbS in the context of your work? What other people, organizations, or institutions have you seen either take the lead on or attempt to learn about NbS?

People

18. Social science interviews can sometimes feel extractive–I'm asking you to share all your knowledge, without any guarantees about what might

be implemented. So I would like to know specifically what outputs or outcomes you would like to see come from this research, knowing the goals of our project?

19. We are building an advisory committee of external partners. We would hope to meet quarterly to discuss knowledge and practices. Do you have any suggestions for people who have a broad perspective on NbS, as well as a deep knowledge of implementation that is transferable across locations? We would be especially interested in folks who perhaps serve as a hub for a network of practitioners, yet maintain and integrate a wide range of perspectives and data. These could be people from the public, private, or NGO sectors.

20. With whom else do you recommend I connect to ask about nature-based solutions?

21. There's a lot of sad news when you work as an expert in this space. How do you personally cope?

22. Final question: is there anything else I should know and didn't think to ask?

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