J. of Marine Env. Eng., Vol. 10, pp. 319–330
Reprints available directly from the publisher
Photocopying permitted by license only

TECHNICAL NOTE

Coastal Resiliency Considerations for America's Four Coasts: Preparing for 2100

RAM MOHAN[1,*] AND THOMAS HERRINGTON[2]

[1] Principal, Anchor QEA, LLC, Horsham, Pennsylvania (Adjunct Professor and Director, Center for Dredging Studies, Texas A&M University), USA. E-mail: rmohan@anchorqea.com; rmohan@tamu.edu; Telephone: 215-756-5030

[2] Associate Director, Urban Coast Institute, Monmouth University, West Long Branch, New Jersey, USA. E-mail: therring@monmouth.edu; Telephone: 732-263-5588

With rising seas come several challenges for our coastlines, including the need to maintain waterways, ports, and harbors; military and infrastructure resiliency; and the protection of valuable coastal ecosystems. This technical note examines coastal resiliency needs and challenges along America's four coasts – Great Lakes, East, Gulf and West coasts, with a review of select case studies. Latest tools for resiliency and adaptation planning are reviewed and presented. Undoubtedly, there is a need for regulation to promote beneficial use of dredged sediments to improve coastal resiliency, including, but not limited to, aligning navigational dredging schedules with coastal protection needs. Permitting of these projects can be challenging as projects are typically reviewed by regulatory agencies as "disposal" or "placement" projects, as opposed to ecosystem restoration projects, which provide a distinct ecological uplift benefit. Quantification of benefits resulting from resiliency projects continues to be an area that needs more analytical tools and project data. The paper concludes with a discussion of future directions, including areas of additional research, and data gaps.

Keywords: Coastal resiliency, coastal protection, ecosystem restoration, natural and nature-based features, engineering with nature, beneficial use

1 INTRODUCTION

The United States' four coasts—east, gulf, west, and Great Lakes—are in a race against time to combat the increasing threat of coastal forces and adapt with the effects of climate change. Each of the coasts have distinct challenges, some overlapping and some quite unique. Proactive analysis, using state-of-the-art engineering tools, to assess effects

---

*Corresponding author e-mail: rmohan@anchorqea.com; rmohan@tamu.edu and a process of adaptive planning to build coastal resiliency over time are long overdue. Inherent in such analysis is also the question of the tradeoff between more robust engineering protection systems versus the softer, adaptive nature-based solutions. Traditionally, owners and engineers are accustomed to designing coastal protection systems for a specific design event (generally related to a certain forcing event, such as flood or storm frequency), which makes tracking the performance of the system over time more quantifiable, as it can be related to the base-design assumption. With nature-based solutions, there is often no specific design event or criteria; consequently, the performance monitoring is essentially a judgement call as to how the functionality of the system is evolving over time and whether it requires specific actions to enhance performance. Funding concerns also play an important role in determining whether to design a system with more certainty upfront, often at a much higher cost, versus a lower-cost adaptive design that requires future investments as part of ongoing maintenance.

Dredging in our ports and waterways provide a continual source of sediments that can be used beneficially as part of coastal resiliency projects to build up degraded habitats (e.g., wetlands) or create new ones (e.g., offshore islands). As our coastal lands continue to flood and submerge from factors such as sea level rise, this dredged material can be one of the tools that is used to offset such effects. Several options exist to use dredged material in a beneficial manner—from the traditional place, dewater, and convert (to wetlands or islands) approach to the more precise method of thin-layer placement over existing marsh to provide elevation enhancement. It is imperative that these options are considered as part of a holistic coastal systems plan along various coasts to combat the climate change effects the future is going to bring.

2 COASTAL RESILIENCY CONSIDERATIONS

Figure 1 presents the common challenges associated with quantifying sea-level rise risks and its effects on coastal resources.

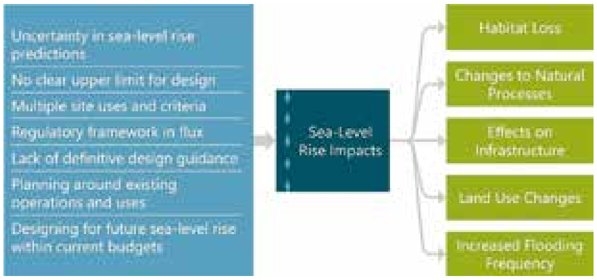

FIGURE 1
Challenges of quantifying sea-level rise risks.

Figure 2 illustrates various coastal features and their interconnectivity as part of the coastal system. From an examination of this figure, these natural features not only provide an ecological value, but they also provide buffering during storm events, thereby acting as a key link in coastal flood risk management. Rising sea levels and other climatic and geomorphological effects have transformed the effectiveness of these coastal systems over the last decade and rendered them somewhat less effective. Incorporation of proactive restoration plans for such features as part of coastal flood risk management plans would facilitate beneficial use of sediments from coastal dredging projects while providing quantifiable flood risk management and economic value.

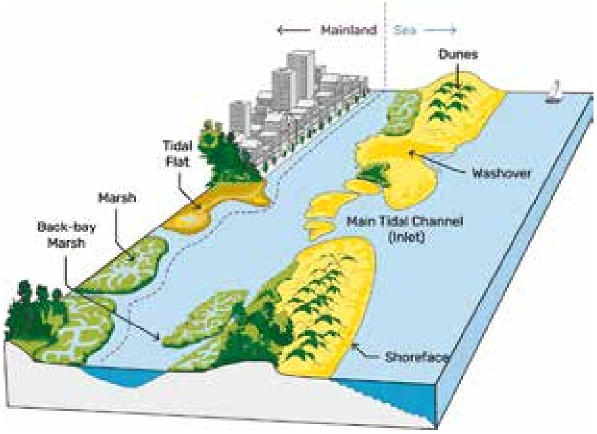

FIGURE 2
Key components of coastal systems (Graphics credit: Bridges et al., 2021, in press).

The U.S. Army Engineer Research and Development Center (ERDC), along with key international agencies and partners, is in the process of finalizing the *International Guidelines on Natural and Nature-Based Features for Flood Risk Management* (Bridges et al., 2021, in press), which provides specific guidance on how nature-based solutions can be used for both coastal and fluvial flood risk management. The guidelines provide a framework for planning, design, community and stakeholder engagement, tools and techniques, performance measures, implementation considerations, adaptive management, and case studies of select projects. The document also provides specific discussion (chapter by chapter) of various coastal and fluvial systems, including beaches, dunes, wetlands, islands, reefs, plant systems (emergent and submerged vegetation), and fluvial geomorphological features. Essentially, the guidelines' framework (see Figure 3) breaks down the planning, design, and implementation process into 11 steps, covering five functional components—scoping, planning, decision-making, implementation, and operations—and illustrating how to incorporate nature-based solutions in coastal design.

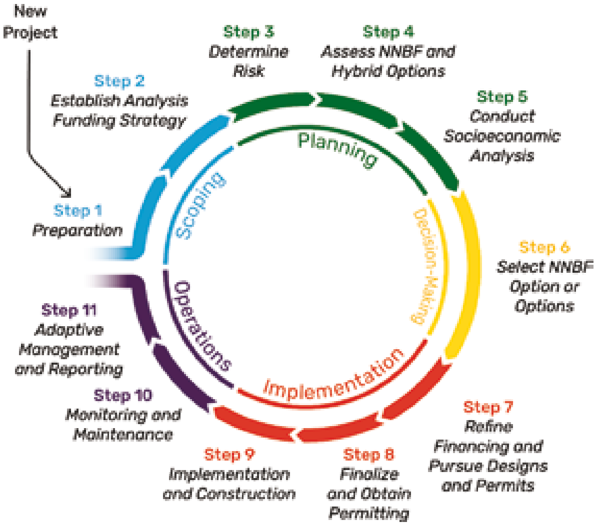

FIGURE 3
Framework for incorporation of natural and nature-based features (NNBF) in coastal projects (Graphics credit: Bridges et al., 2021, in press).

3 RESILIENCY PLANNING PROCESS

The process of developing the adaptation plan is as important as the plan itself. Generally, the planning process includes several key steps including engaging stakeholders, organizing community resources, and assessing risks or benefits. Hazard mitigation (or adaptation) planning is the outcome of the process and assists with prioritizing projects and developing long-range budgets. The resiliency planning process starts with a vulnerability assessment of the assets of interest and includes the following fundamental steps: mapping and categorizing assets; estimating which assets fall within potential inundation zones; assessing damage thresholds for continued functionality of assets; and finally, quantifying impacts, such as downtime effects, costs to repair, etc. Figure 4 illustrates these steps via a schematic of a typical vulnerability assessment process for a coastal town.

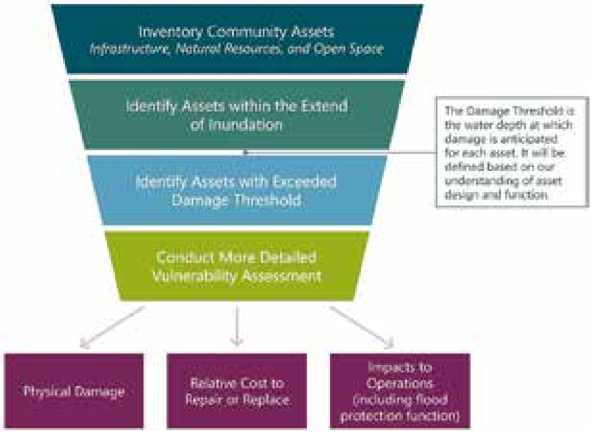

FIGURE 4
Example vulnerability assessment framework.

There are four important steps for efficient adaptation planning: 1) estimate or anticipate the impact; 2) measure the ability to absorb or withstand the event; 3) evaluate mode(s) of recovery; and 4) adapt. The first two steps can be evaluated using site-specific coastal process modeling. Predicting water levels can be challenging, especially with uncertainties related to future climatic trends (which has significant inherent uncertainties and, therefore may require a bounded analysis), design criteria (i.e., varying levels of protection), and regulatory framework. Step 3 can be a combination of effects-based modeling to test various "what-if" scenarios to assess the most efficient solutions. A multi-use criteria analysis (see Figure 5) is often used, where the benefits of specific coastal resources are weighted based on the user's threshold for sustained damages (or associated risks), resulting in a hierarchical ranking of the most valuable resources that require protection. Once the suite of adaptation or mitigation measures are developed, the last step (adaptation) can be accomplished, either naturally or via specific intervention techniques and tools.

FIGURE 5
Example multi-use criteria analysis framework.

4 SPECIFIC ISSUES ALONG OUR FOUR COASTS

The Great Lakes, east, gulf, and west coasts have challenging, intersecting, and distinct coastal resiliency issues. A knowledge of the local geography, coastal processes, and natural systems are critical to developing the most efficient adaptation plans.

4.1 Great Lakes Coast

The Great Lakes coast is unique in that it is a mix of fluvial systems and sand-engine fed by eroding bluffs with natural wetland habitats situated mostly along the larger lakes and harbors. The primary issue facing the Great Lakes is the interruption in sand supply in the littoral zone due to the continued hardening of the shorelines by ongoing development. Historically, the sediment supply from bluff erosion provided continuous source of sand for downstream beaches (see Figure 6, which shows the conceptual sediment transport model). Armoring, bulkheading, or other means of shoreline stabilization cuts this sand supply, essentially requiring an alternate means of sediment supply to maintain the littoral transport. Wetland systems along the Great Lakes have their own challenges; for example, the Detroit River has lost 97% of its wetlands due to development in the last century. Similar issues exist elsewhere in the system.

To offset for such loss in sediment supply, one can creatively think in terms of augmenting or reintroducing the lost sand back into the system. This can be achieved via strategically placed confined placement sites (formerly called confined disposal facilities) with weirs or berms that are designed to erode over time or "leak" sediments back into the littoral system. This is analogous to the innovative concept of "sand engine" that the Dutch have been experimenting with since 2011 in The Hague, the Netherlands and showing promising results through monitoring (Deltares, 2021). The sand engine placed millions of cubic yards of sand off the coast of the Netherlands with the intent of letting natural wave forces redistribute them to downstream beaches over time. Another concept that is

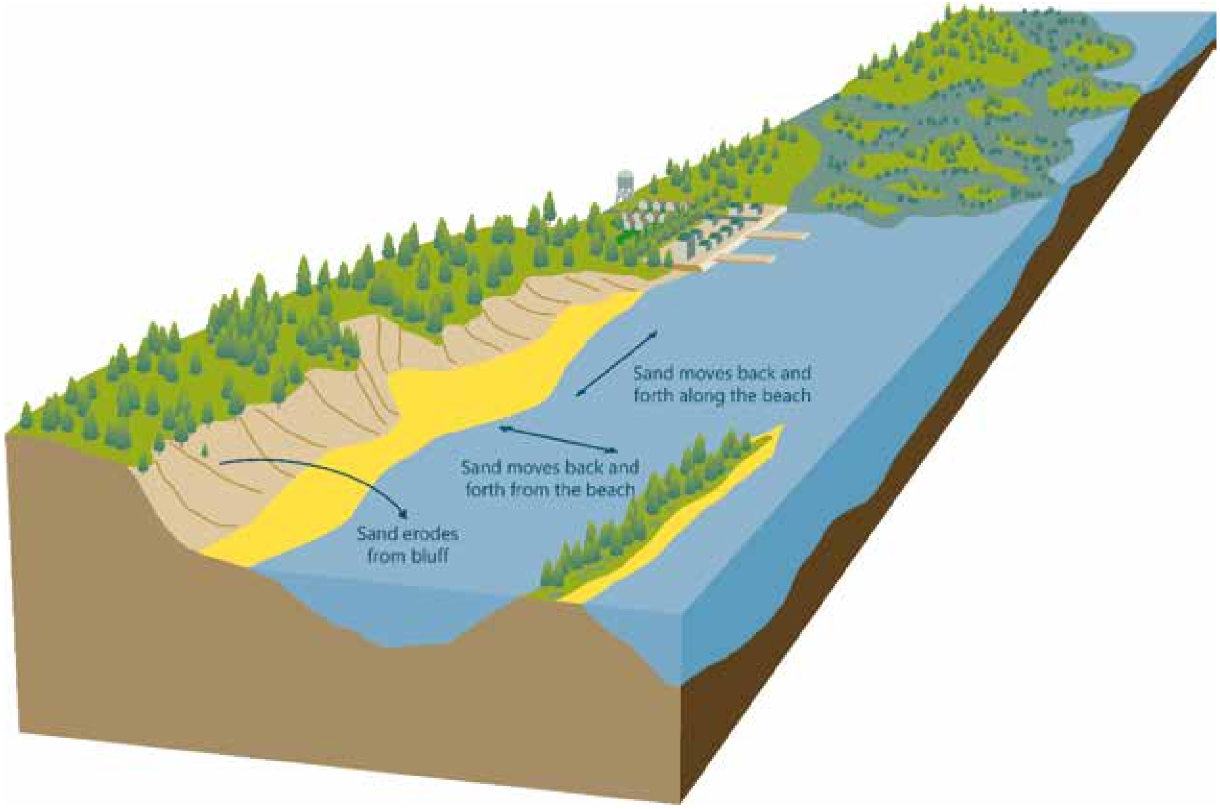

FIGURE 6
Generalized conceptual site model for sediment transport along the Great Lakes.

being studied by the Great Lakes Healthy Port Futures Consortium (GLHPFC) is the "Drumlin" beach concept that is currently piloted in Port Bay, New York (Healthy Port Futures, n.d.-a). This pilot-scale project placed compacted sand in the form of coastal drumlin with noticeable elevation features under the premise that over time the feature will erode, thereby forming a continuous source of sand for downdrift areas well into the future; monitoring is ongoing at this site.

A third concept being planned by the State of Illinois and GLHPFC is the placement of offshore reefs along Illinois State Beach Park (see Figure 7). This design features offshore reefs as a submerged "ridge" field to dissipate energy over a wider distance offshore compared to traditional nearshore protection. The obvious tradeoff is the balance between an immediate shoreline beach nourishment versus gradual, long-term buildup of the beach using the concept of offshore berms or reefs. Over time, the reefs are expected to evolve its geometry, resulting from wave forces; however, its effectiveness is expected to last over the long term based on modeling evaluations performed by Anchor QEA and GLHPFC. Numerical modeling of the reefs has shown greater than 50% wave height reduction under normal conditions.

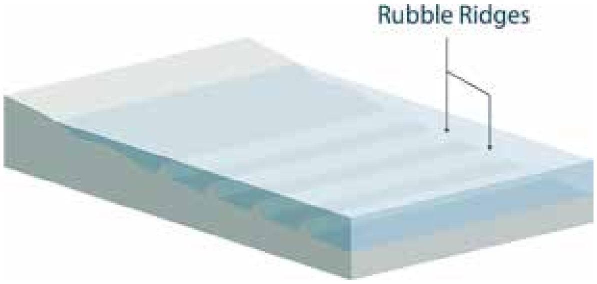

FIGURE 7
Conceptual plan for Illinois Beach State Park nearshore reef (Photo credit: Healthy Port Futures, n.d.-b).

4.2 East Coast

Due to the heavily developed, urban nature of most east coast shorelines, the economic impacts from sea-level rise and coastal flooding are estimated to be tremendous. Wetland loss is a major contributing factor to decreased coastal resilience and is another ongoing challenge. Degradation of coastal wetlands along the east coast are a function of two processes: increased ponding or pools within the marsh interior (from processes such as land subsidence); and edge erosion from ongoing wave erosion, resulting in wetland retreat. If there is a back corridor available for the coastal marsh to migrate, edge erosion is not necessarily of concern. However, in cases where there are no such back corridors, it becomes essential to consider restoring the marsh edge loss. Johnson and Ortiz (2021) present an in-depth analysis of these processes via their study of historic wetland loss along two North Carolina Coastal marshes, which sheds additional insights into the underlying causes and potential mitigation methods. One way to combat coastal wetland erosion is through living shorelines, which protect a marsh edge from eroding, followed by thin-layer placement of sediments (often dredged material) over the marsh interior for elevation enhancement and/or marsh nourishment. The forthcoming ERDC *Thin Layer Placement Guidance* (Candice et al, 2021, in press) is a good source of best practices to use for such projects; it generally recommends placement of compatible sediments on the marsh surface in a layer not to exceed 12 inches so that the marsh vegetation will naturally restore over two to three growing seasons, building resiliency along the way. Incremental benefit of living shorelines and thin-layer placement projects can be modeled using traditional hydrodynamic models as was done during the design and planning phase of the ongoing National Fish and Wildlife Foundation grant-funded Shooting Island Restoration project in New Jersey, which was also sponsored by the City of Ocean City, New Jersey. This three-phase project provides coastal resiliency to back-bay residents using living shorelines (rock sills and oyster castles) for the first phase (see Figure 8), followed by placement of restoration backfill behind the sills (planned for 2022) for the second phase, and thin-layer placement to restore interior ponds and pools (possible future project) for the third phase.

FIGURE 8
Shooting Island, New Jersey living shoreline sills (Photo credit: Anchor QEA and ACT Engineers).

4.3 Gulf Coast

The gulf coast has similar issues as the east coast in terms of coastal resiliency, but perhaps augmented more by the increased frequency and exposure to annual hurricanes, which inflict significant damage along that coast. Since the Deep-Water Horizon oil spill and following the availability of RESTORE funding, the Gulf Coast has led the United States, in terms of ecosystem restoration projects. Ramseur (2020) presents a good summary of the State of Mississippi's estuarine habitat and coastal projects and outlines goals, lessons learned, and future directions. Ramseur discusses the three major state projects—Deer Island, Round Island, and Hancock County Marsh Living Shoreline (see Figure 9)—where some innovative coastal restoration strategies have been deployed. The Mississippi Department of Environmental Quality's Hancock County Marsh Living Shoreline is the longest living shoreline in North America and involved over 6 miles of sill placement (designed to be barely above mean high water with water circulation gap widths and transmissible core for sediment filtration) along with 46 acres of underwater reef habitats and another 46 acres of intertidal marsh creation. The project's performance is being assessed by the National Oceanic and Atmospheric Administration. The monitoring shows significant coastal sediment accretion behind the structure as well as benthic recolonization of the structure itself.

FIGURE 9
Hancock County Marsh living shoreline project, Mississippi living shoreline sills (Photo credit: Ramseur, 2020).

Another example of infrastructure-based resiliency along the gulf coast is the "Resilient" terminal design at the Mississippi State Port Authority at Gulfport, Mississippi (see Figure 10). The project involved hurricane forecast modeling to determine the optimal level of shore protection elevation for the project and an adaptable design of landward port structures that can accommodate the effects of hurricane-related forces and flooding. This resulted in a cost-effective design of a futuristic terminal that is efficient, yet resilient.

FIGURE 10
Port of Gulfport resilient terminal (Photo credit: Anchor QEA).

The 84-acre expansion and increased height supports deep draft navigation and used dredged material beneficially for developing a hurricane-resilient terminal and restoring a historic marsh on Deer Island. Design elevations were chosen to withstand a 100-year storm surge/flood elevation but be operationally ready shortly following a 500-year event (via enhanced structural retrofits). Analyses were completed using ADCIRC and CMS-Wave models for hurricane surge conditions.

4.4 West Coast

The west coast presents a mix of challenges, with greater range of topographic conditions and shore forms, and a diversity of substrates and geology, ranging from sands, to gravels, and cobbles, and exposed bedrock. A variety of resiliency tools have been used along the west coast, often combining habitat restoration and recreation goals with infrastructure and property protection measures. Nature-based solutions have been used often in the Pacific Northwest; a good example is Seahurst Park in Washington state (see Figure 11), which used a layered gradation of gravel and sand/gravel beaches to transform a formerly armored and eroded shoreline to a new salmon- and recreation-friendly beach that protects relocated utility infrastructure and park property as well as restores the natural bluff to beach sediment supply. The project was given numerous awards for innovative shoreline design, including a Best Restored Beach Award from the American Shore and Beach Preservation Association.

FIGURE 11
Seahurst Park living shoreline (Photo credit: Anchor QEA).

Another example of a resilient terminal is the Port of Long Beach's Terminal Fill project in California. The project used dredged material from navigation channels to create new land for a 300-acre container terminal, including 120 acres of slip fill using 3 million cubic yards of dredged material. Dredged material was bottom placed (via split hull barge, see Figure 12), then hydraulically pumped over the dike to +10-foot final elevation. Surcharge was trucked in for final site contouring.

FIGURE 12
Port of Long Beach Terminal (Photo credit: Anchor QEA).

5 FUTURE DIRECTIONS

As NNBF for shoreline stabilization grow in acceptance as cost-effective options to hard structures to protect communities, properties, infrastructure, and ecosystems from growing climate-change-driven threats, there is a need to turn attention to improved management of the natural resources that are the building blocks of natural coastal resilience projects. Presently, many different authorities and agencies manage and regulate materials and land use of natural resources (e.g., U.S. Army Corps of Engineers [USACE], U.S. Environmental Protection Agency, port authorities, Fish and Wildlife Service, National Oceanic and Atmospheric Administration, and state and local agencies). Often beneficial use of dredge material is hindered by misalignment of dredging windows and material placement opportunities, and sediments are disposed of in the least costly manner, typically at offshore disposal sites that remove the material from the coastal system. There is a need to develop policies and commitments to better align dredging cycles and coastal ecosystem resilience projects.

Beneficial use of dredge material also requires an alignment with the land management goals of resource agencies that may be willing to accept material to increase ecosystem resilience. For instance, most of the United States' tidal marsh lands are conserved and managed for specific endangered species, migratory flyways, essential fish habitat, rookeries, etc. A broad range of design variables need to be considered to match project design to land management objectives, including sediment grain size, placement technique, site elevation requirements, dewatering, and site subsidence, among others. In many instances, available dredge material or volumes will not match specific project requirements. Regional coordination with land use managers is required to identify a number of potential resilience projects of differing design specifications to insure maximum use of available material in the system (Herrington and Fouad, 2019). In spring 2019, the USACE, The Wetlands Institute, and the New Jersey Department of Environmental Protection launched the Seven Mile Island Innovation Laboratory (SMIIL)[1] as

---

[1] https://www.nap.usace.army.mil/Portals/39/docs/Civil/Coastal/SMIIL%20Factsheet_2019-12.pdf?ver=2019-12-18-121511-927

an initiative to advance and improve dredging and marsh restoration techniques. Based on an international concept pioneered by a Dutch organization that uses a "Living Lab for Mud," the SMIIL will enhance the science and engineering that supports dredging and placement practices for resilience, Regional Sediment Management, and Engineering with Nature principles and practices through sustained monitoring and modeling of hydrodynamics, sediment transport, and restoration techniques. Similar living laboratories are needed around the country to better understand restoration techniques in all coastal environments.

For most of the 20th century, natural floodplain processes were viewed as destructive to communities and commerce, requiring floodplain management through control structures, floodwalls, and levees. In coastal waters, port and harbor operations required deeper draft channels and continual maintenance dredging. Recognition of the importance of the sediments delivered to the coast in sustaining the coastal beaches, barrier islands, and marshes has led to calls for the removal of structures, beaching of levees, and the deposition of dredged sediments within the active coastal system. Many inoperable dams presently block sediments from reaching shorelines, exacerbating coastal erosion and land subsidence. In 2020, 69 dams were removed in 23 states in an effort to restore fish and wildlife habitat, improve ecosystem health, and reintroduce downstream sediment supply. Presently, USACE is finalizing a plan to breach a portion of a levee that holds back the Mississippi River 30 kilometers south of New Orleans to create a diversion in the river. A 3.5-kilometer-long canal will carry sand and fine silt from the river into the bay, helping to rebuild vast wetlands eroded by sinking land and rising seas. Over 5 decades, researchers forecast that the project could move enough sediment to create at least 54 square kilometers of new wetlands. Although costly, more projects to restore natural sediment delivery to the coast are needed to maintain coastlines, wetlands, and tidal marshes against increasing sea levels and coastal storms.

Coastal resilience is often approached from the perspective of adapting the built environment to withstand and rapidly recover from a variety of natural coastal hazards that are driven by episodic events (i.e., storm surge, inundation, and erosion) and long-term coastal changes (sea level rise). The anthropogenic view is based on widespread public perception that coastal change is primarily a hazard to property and infrastructure and that both hard and soft structural defenses are required to mitigate coastal hazards (Cooper & Jackson, 2019). In fact, most state coastal zone management plans prioritize the use of hard coastal structures for shoreline stabilization and erosion control. There is a growing body of evidence, however, that indicates coastal ecosystems can, and often do, provide coastal protection and resilience to coastal communities (Shepard et al., 2011; Gittman et al., 2014; Narayan et al., 2017; Reguero et al., 2018) and that nature-based solutions, such as living shorelines, enhance the resilience of natural ecosystems and coastal communities (Smith et al., 2016). Continued documentation of the protective capacity and ecosystem benefits of NNBF solutions for shoreline stabilization is required to build the knowledge base required to assess the cost and benefits of natural solutions against traditional hard structures and engineered systems. Sustained funding to support post-construction monitoring, storm impacts, and adaptive management requirements is needed to advance our understanding on the use of NNBF for improve coastal resilience.

6 CONCLUSIONS

Resiliency, if tied to beneficial use of dredged material from navigation projects, can be a "win-win" for all, by providing suitable material for restoration projects, which in turn, improve coastal flood risk benefits. A commitment to innovation is probably a precursor, as is evident from the case studies highlighted in this paper. Also, some states have mandated a beneficial use requirement for dredging state water bottoms; for example, in Mississippi, the owner of a non-federal dredging project has to first demonstrate that all possible avenues for beneficial use have been explored before an upland placement can be permitted (for projects exceeding 2,500 cubic yards in clean dredge volume). Stakeholder and interagency collaboration can foster broader, grander, and more cost-effective projects (good examples are the Beneficial Use Group (BUG) in Texas, and the BU Working Group in Maryland). However, there has to be an ecological benefit for coastal projects; they cannot be "forced" but have to fit in a systemic context. Finally, more information should be collected on the ecological and economic (resiliency) benefits of these projects over the long-term and that information should be published so that practitioners can learn from past projects.

7 ACKNOWLEDGMENTS

The authors wish to acknowledge Matt Henderson, Renee Robertson, Wendell Mears, Travis Merritts, Peter Hummel, Walter Dinicola, and Steve Cappellino, for their review and constructive comments of this manuscript.

REFERENCES

Bridges, T. S., King, J. K., Simm, J. D., Beck, M. W., Collins, G., Lodder, Q., & Mohan, R. (Eds.). (2021, in press). *International Guidelines on Natural and Nature-Based Features for Flood Risk Management*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Candice, P., Welp, T., & Mohan R. (2021, in press). *Thin Layer Placement Guidance*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Cooper J. A. G., & Jackson D. W. T. (2019). Coasts in Peril? A Shoreline Health Perspective. *Front. Earth Sci.*, 7: 260. doi:10.3389/feart.2019.00260

Deltares. (n.d.). Retrieved May 20, 2021, https://www.deltares.nl/en/projects/sand-engine/

Gittman, R. K., Popowich, A. M., Bruno, J. F., & Peterson, C. H. (2014). Mashes with and without sills protect estuarine shorelines from erosion better than bulkheads during a Category 1 hurricane. *Ocean & Coastal Management*, 102, 94–102. doi:10.1016/j.ocecoaman.2014.09.016

Healthy Port Futures. (n.d.-a). Port Bay. Retrieved June 1, 2021, from http://healthyportfutures.com/port-bay/

Healthy Port Futures. (n.d.-b). Illinois Beach State Park. Retrieved June 1, 2021, from http://healthyportfutures.com/illinois-beach-state-park/

Herrington, T. O., & Fouad, G. (2019). *Framework for a Coastal Ecological Adaptation Prioritization Support Tool: Methodology*. Prepared for the New Jersey Department of Environmental Protection. West Long Branch, NJ: Urban Coast Institute, Monmouth University. 92 pp. https://library.monmouth.edu/wp-content/uploads/sites/28/2020/07/Coastal-Ecological-Adaptation-Framework-Methodology.pdf

Johnson, F. M., & Ortiz, A. C. (2021). Quantifying interior coastal marsh degradation at two North Carolina Marshes. *Shore & Beach*, Vol. 89, No. 1.

Narayan, S., Beck, M. W., Wilson, P., Thomas, C. J., Guerrero, A., Shepard, C. C., Reguero, B. G., Franco, G., Ingram, J. C., & Trespalacios, D. (2017). The value of coastal wetlands for flood damage reduction in the Northeastern USA. *Scientific Reports*, 7: 9463 doi:10.1038/s41598-017-09269-z

Ramseur, G. S. (2020). Field of dreams: Restoring estuarine habitat and structure in Mississippi after the Deepwater Horizon oil spill. *Shore & Beach*, Vol. 88, No. 1.

Reguero B. G., Beck, M. W., Bresch, D. N., Calil, J., & Meliane, I. (2018). Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States. *PLoS ONE*, 13(4): e0192132. doi.org/10.1371/journal.pone.0192132

Shepard C. C., Crain C. M., and Beck M. W. (2011). The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. *PLoS ONE* 6(11): e27374. doi:10.1371/journal.pone.0027374

Smith, C. S., Puckett, B., Gittman, R. K., & Peterson, C. H. (2018). Living shorelines enhanced the resilience of salt marshes to Hurricane Matthew (2016). *Ecological Applications,* 28(4), 2018, pp. 871–877.