RESTORING NATURAL DEFENSES TO HELP COMMUNITIES IN COASTAL FLOODPLAINS ADAPT TO CLIMATE CHANGE

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Oyster and coral reefs, dunes and mangroves act as speed bumps and shock absorbers to reduce the impacts of rising seas and coastal storms. These natural defenses are cost effective and provide myriad benefits to coastal communities. Natural defenses can complement traditional approaches to floodplain management, such as building and zoning codes and hardened engineered solutions, to create multiple lines of defense against storms. E*xpanding engineering design literacy for natural defenses will hasten their acceptance as key features for building coastal community resilience.*

Introduction

Millions of people live "on the edge"– literally and figuratively. In the United States, more than five million people live less than 4 feet above high tide (Strauss et al. 2012). That means far too many homes and livelihoods are extremely vulnerable to sea level rise, coastal storms and hurricane storm surges. Recently we've learned that sea level rise may be occurring at faster rates and to a greater extent than previously predicted. Melting of the Antarctic ice sheet alone may add one meter to sea level by 2100 (DeConto and Pollard 2016). If populations continue to flock to the coasts, the economic and human toll of coastal flooding will increase even if hurricanes do not become more frequent or more severe (Ceres 2014). How we choose to adapt to these impacts of climate change will be a critical element in defining our future.

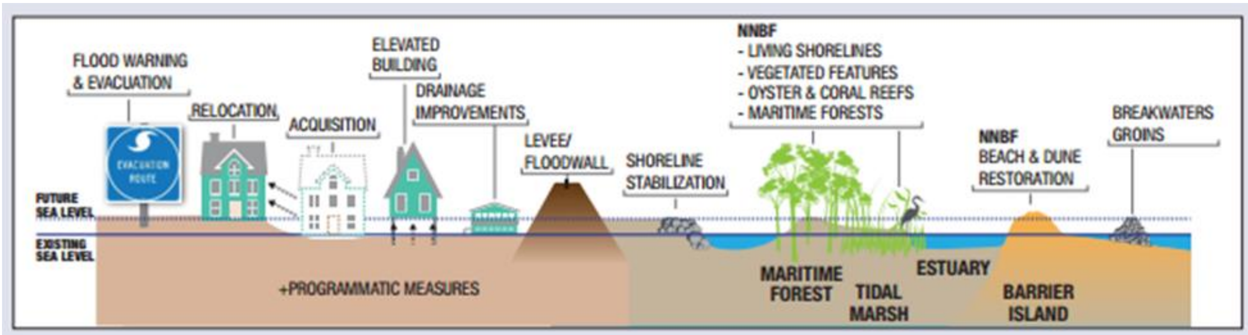
Building resilience to the shocks (e.g., hurricanes) and stresses (e.g., sea level rise) that our coastlines will face in a climate changing environment is a complex task. Vulnerable individuals and communities need ways to adapt to these growing risks while maintaining the qualities that attracted them to the shore – jobs, esthetics, and recreation – in a cost-effective manner aligned with their values and interests.

As sea levels rise, nature holds the key to building coastal resiliency. Types of natural defenses include wetlands, mangroves, cypress and maritime forests, coral and shellfish reefs, beaches, dunes and barrier islands.

The Role of Natural Defenses in Coastal Community Landscapes

Every floodplain manager knows traditional engineered structures do not provide perfect solutions and can actually create false perceptions of safety. They do not always perform as expected. Take for example Hurricane Katrina's impact on New Orleans' levees in 2005 and the tsunami that overtopped Miyako's seawall in 2011. We need to revisit our historical approach to shore protection, which is often based on using a single feature to meet a requisite standard (e.g., protection from a 500-year storm).

Figure 1: Schematic of the multiple lines of defense concept as presented by the Corps of Engineers' North Atlantic Comprehensive Coastal Study (2015). The Corps uses "Natural and Nature Based Features" (or "NNBF") to capture the concept of using natural or restored habitats and processes to enhance protection from coastal storms.



If we desire to create resilient communities, we must intentionally create system redundancy. Using natural features can serve as a first line of defense, adding a valuable layer of protection to minimize the negative consequences of floods (**Figure 1, above**). Adding multiple natural features, such as oyster reefs and wetlands, provides more diverse risk reduction services. As flood-prone buildings are elevated or relocated to safer ground, restoring natural infrastructure in the space made available can enhance the flood risk reduction value of that open space.

Natural defenses also can enhance the effectiveness of traditional hardened infrastructure by providing a buffer between the sea and development, lessening the energy punch of large waves and high winds on built infrastructure. If the incremental risk reduction benefits of natural defenses are quantified, then the use of natural defenses could even result in less intrusive (i.e., lower, smaller) seawalls or other shoreline stabilization structures.

Additionally, there is little doubt that natural defenses can help communities lessen erosion and flooding from more common events such as king tides and smaller storms. But under the right conditions, natural defense solutions can also be a key defense from coastal storms. Constructed dune fields, for example, protect one side of the Port of Rotterdam, Europe's largest port. That's all the more significant when one considers that the requisite standard for these dunes is to protect the port against a 1 in 10,000-year storm event.

The significant advantages of natural defense solutions over traditional hardened measures, like seawalls and revetment, are the additional ecosystem services they provide. Daily, these ecosystems deliver benefits vital to the economic well-being of coastal communities, including water quality improvement, fresh water capture, groundwater protection, fisheries enhancement, birding hotspots and recreational space. These same services are often compromised and even lost when communities choose poorly planned and designed traditional hardened coastal protection measures (Sutton-Grier et al., 2015).

Protecting and restoring our coasts' natural defenses also enhances the environmental resilience of our coastal and marine ecosystems. Emerging practices accounting for these ecosystem services demonstrate a high return on investment associated with natural defenses. For example, Grabowski et al. (2012) found that the value of oyster reefs' ecosystem services (i.e., wave attenuation, water quality improvement, etc., but excluding oyster harvesting) ranged between $13,585 and $244,530 per acre per year.

Natural Defenses Work and are Cost-Effective

We know where and how we can confidently deploy natural defense solutions. Protecting and restoring salt marshes, coral and oyster reefs, mangrove and wetland and coastal forests and dunes can help reduce the damage caused by storms to human infrastructure. Each feature can attenuate waves to reduce their erosive power (see Table 1). For example, oyster reefs, depending on their size and orientation, can attenuate midsize waves of 2-5 feet in height (USACE, 2013; Scyphers et al. 2011; Marani et al. 2011). Mangrove forests can reduce the damage caused by tsunamis and typhoons by attenuating waves, reducing wind speed and catching debris (Cheong et al. 2013; Tanaka 2009; Cochard 2008; Algoni 2008; McIvor et al. 2002).

The situation is more complicated with salt marshes. Gedan et al. (2011) found even small, narrow wetlands provided wave attenuation, but also noted that salt marshes were most effective in attenuating wind waves during low energy events. Multiple factors affect our ability to forecast their capacity to predictably attenuate large waves and reduce the impacts of storm surge. When wetlands are waterlogged, as when storm surges or king tides occur, they may not provide the same wave attenuation benefits – they may even increase wave energy (Resio and Westerink 2008). But there's also evidence that salt marsh grasses' expansive root systems increase soil integrity and resistance to wave-driven erosion. Möller et al. (2014) found that wetland vegetation is responsible for up to 60% of the wave attenuation during storms events; even when waves were large enough to break salt marsh vegetation stems, the plants protected the soil from eroding during major storm events.

A growing body of evidence demonstrates that restoring natural defenses can be far more cost-effective in preventing storm damage than hardened shorelines (Reguero et al. 2015). Ferrario et al. (2014) found that coral reefs reduced wave heights as much or more that constructed low-crested detached breakwaters and did so at a lower median cost. Oyster reef breakwaters cost approximately $1 million per mile, while standard rock breakwaters cost $1.5 to $3.0 million per mile (Dow et al. 2013). The *Chesapeake Bay Foundation* (2007) found that installations of shoreline edge wetlands with sills cost $50-100 per foot less than bulkheads and riprap solutions, which cost approximately $500 to $1,200 per foot for sites in the bay. There is also evidence that unlike traditionally engineered coastal infrastructure, with the right conditions, many natural defenses can grow and keep pace with sea level rise. (Spalding et al., 2014a, Spalding et al., 2014b, Rodriguez et al., 2014).

Creating a New Archetype for Coastal Floodplain Design

Despite this growing body of research, communities still often gravitate toward hard engineered solutions. Decades, even centuries, of experience designing seawalls and erosion control structures ensure reproducible results and confidence. We have learned what materials, designs and siting work best from an engineering perspective. Engineers consider a set of design principles when designing infrastructure and necessarily seek a high level of precision to be confident in and sign off on designs and their expected performance (Slinger 2016).

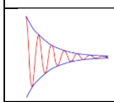
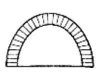
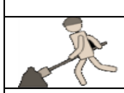
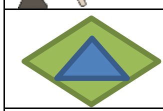
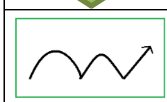
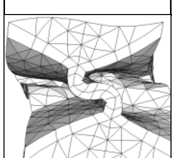
The U.S. Army Corps of Engineers' Coastal Engineering Manual (2002) reflects the vast experience and presents tools and procedures to plan, design, construct, and maintain storm damage reduction projects. Methods to guide engineers in the evaluation and/or design of natural or nature-based features are a necessary precursor to engineers' certification of project performance and vitally important for public confidence. To facilitate broader acceptance of natural defenses, advocates need to think about them as engineers would: What do I need to know to site them properly, what forces will they withstand, will they behave as expected, can they adapt to sea level rise? **Figure 2 (below)** identifies the key engineering design considerations for natural defenses.

Developing similar engineering guidelines for the variety of natural defenses is an important first step toward putting natural defenses on more equal analytical footing with traditional engineered solutions. The result would give communities additional options – options that can address other community goals than solely risk reduction. Engineering guidelines will provide confidence that the solution sets they choose will perform as expected.

Improving engineering confidence in performance of natural defenses does not mean natural defenses provide perfect safety under all conditions. It means engineers will understand the conditions affecting their performance and the anticipated boundaries of performance. Like engineered structures, the performance of natural defenses will depend on how well they are maintained and they will not always perform as expected. For any shore "protection" project, local governments and the public need to recognize and plan for the risks that will remain.

Natural systems have not yet been subjected to anything close to the same level of study as engineered solutions. We lack a deep understanding of the factors that govern how natural defenses will behave during and recover from extreme conditions, including storm surge. To address these needs, we need to gather data on factors affecting natural defenses' ability to control or withstand variability (e.g., wave conditions), structural integrity

Figure 2: Design considerations for natural defenses (modified from Slinger, 2016).

	**Requisite standard**: Can the natural defense withstand all conditions apart from those exceeding the design criteria? When used as part of a Multiple Lines of Defense Strategy (MLOD), does it help a gray /engineered solution meet or exceed design criteria; does it enhance the resilience of the community?
	**Control of environmental variability** (to ensure access, connection or supply): Can the natural defense reduce wave height? Does it decrease flood height or duration? How much?
$	**Reasonable cost**: Can the natural defense be created, restored and maintained at a reasonable cost (e.g., life cycle costs) When used as part of an MLOD, how does the natural defense affect total project life cycle costs?
	**Structural integrity** (stability & strength): Will the natural defense remain in position to perform its functions? As part of an MLOD strategy, does it affect the integrity of gray/engineered solutions?
✓	**Reliability**: Can we expect the natural defense to not need many repairs; can it be maintained? As part of an MLOD strategy, can it increase the reliability of a gray/engineered solution?
	**Implementability**: Can the natural defense be reasonably constructed or restored? Is there local capability?
	**Adaptability**: Can potential future changes in conditions be taken into account in the design phase or after it is built? Can the natural defense grow to respond to sea level rise? What are the conditions necessary to ensure the natural defense does grow/adapt?
	**Resilience**: Can the natural defense withstand a second shock of similar magnitude to the first and still retain its structural integrity to meet functional requirements? How long until it regains its structural integrity and functions? As part of an MLOD strategy, does it add to the resilience of a gray/engineered structure?
	**Appropriate boundary conditions and loads**: Can the natural defense be designed to meet the hydraulic boundary conditions it will experience while also meeting the requisite standard at a reasonable cost?

(e.g., strength and stability), reliability (e.g., how easily maintained), and resilience (e.g., ability to withstand a second shock, within its design standard, and still function).

Nonetheless, we can start using use natural defenses as part of our coastal adaptation and shoreline defense strategies now. Expert coastal engineers and scientists gathered by Environmental Defense Fund in May 2015 concluded there was sufficient confidence in the ability of natural defense measures to reduce impacts of coastal storms and sea level rise to coastal communities, and that these approaches should be routinely considered as viable options by decision makers (Cunniff and Schwartz 2015).

By starting with where we are confident in performance (**Table 1, pg. 6**), we can gather more data to help address performance under more extreme conditions and explore design and materials options. We need to define performance success and scrutinize failures. We can verify modeling results and test new insights with field experience. To guide where and how we can confidently deploy natural defenses, we need a collaborative engineering design effort that creates a new broader risk reduction engineering design literacy that includes natural defenses. This will in turn allow federal, state, tribal and local decision makers to explore, approve and fund projects using natural defenses.

We also need to systematically gather data on constructed projects. O'Donnell (2016) notes the importance of developing better online resources to keep property owners, coastal consultants and regulators up-to-date with rapidly evolving information on design, costs, performance and maintenance of natural defenses. Deltares and TU Delft, as part of the EcoShape Consortium, are actively designing a wiki to support such data collection and sharing of information from projects employing natural defenses and other "*Building with Nature*" projects.

Begin with Dunes, Reefs and Mangroves

Working in concert with ecologists and practitioners of ecosystem-based disaster risk reduction, leading engineering institutions like Deltares, TU Delft, the Corps of Engineers and Rijkswaterstaat, as well as non-governmental organizations, professional associations and private sector leaders, should join together to hold workshops that accelerate completion of engineering guidelines and train engineers to launch a new era of coastal design.

Engineering guidelines already exist for dunes but they need updating. Incorporating new information (e.g., planting designs, regionally appropriate species mixes and maintenance practices) to encourage natural beach and dune building processes, would improve their chances of keeping pace with sea level rise. We cannot afford for engineering to ignore biological factors that improve the structure, function and longevity of these features.

Table 1: Natural Defenses: Summary of risk reduction performance. Factors effecting risk reduction performance include storm intensity, track, forward speed, surrounding local bathymetry, topography and condition of the natural defense (after Cunniff, S. and A. Schwartz, 2015).

Key
- = Low confidence, feature not likely to address
+ = High confidence, data available
~ = Limited confidence refinement needed
Blank = no confidence or no data

Strategy			Risk Reduction Performance				
			Reduce coastal erosion/ Shoreline Stabilization	Nuisance floods (high tides with sea level rise)	Short wave (<2′) attenu-ation (Stabilize Sediment)	Reduce force & height of med. waves (2- 5′)	Storm Surge (low frequency extreme events)
Strategy	Structural	Groins	+	-	+		
	Structural	Breakwaters	+	-	+	+	
	Structural	Seawall/ Revetments/Bulkheads	+	+		+	+
	Structural	Surge Barriers	-			+	+
	Existing	Wetlands	+		+	~	~
	Existing	Mangroves/coastal forest	+		+	+	+
	Existing	Vegetated Dunes	+		+	+	+
	Nature-based	Beach Nourishment	+[1]	+	+	+	
	Nature-based	Vegetated Dune creation	+	+	+	+	+
	Nature-based	Barrier Island Restoration	+	+	+	+	+
	Nature-based	Small scale edging and sills (living shorelines)	+	~	+		
	Nature-based	Restored Oyster/Shell-fish Reefs	+		+	~	
	Nature-based	Restored/Created Coral Reefs	+		+	~	
	Nature-based	Restored Maritime Forests (including Mangroves)	+	+	+	+	+
	Nature-based	Restored Wetlands	+	+	+	~	~

[1] Beach nourishment increases beach width to temporarily stave off the effects of erosion; erosion will continue.

Likewise, guidelines need to reflect biological and physical considerations that dictate where each type of natural feature can be placed (e.g., tidal, salinity, wave exposure, temperature limits, etc.) and reflect design considerations for optimizing or balancing other ecosystem benefits of natural features.

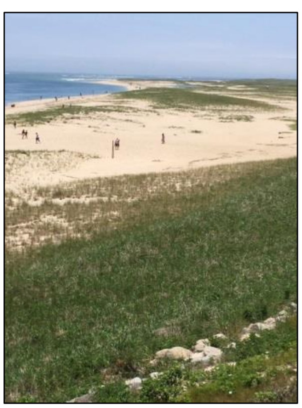
Oyster and coral reefs are nature's speed bumps and function essentially as submerged breakwaters (NRC 2014). Scientists with *The Nature Conservancy* and others have been documenting their risk reduction performance and other ecosystem benefits (World Business Council for Sustainable Development 2015). The EcoShape Consortium, TNC and others are testing designs and materials for oyster substrates in multiple locations across the globe. The good news is that documentation on how oyster reefs can meet engineering design principles will soon be possible, if it isn't already.

Mangroves' cyclone and tsunami risk reduction effectiveness as "shock absorbers" is already fairly well documented, but primarily with anecdotal observations and models. Given worldwide concern over the extent and acceleration of mangrove loss, efforts are already underway to quantify their ecosystem benefits and incentivize their protection and restoration. Data to support engineering design principles could be available as soon as the next two years.

Therefore, with a concerted cooperative and collaborative effort, new engineering guidelines could be completed by 2019 for vegetated dunes, oyster and coral reefs and mangroves. Ideally, these guidelines will reflect how to optimize designs for risk reduction, habitat value and other ecosystem services.

Conclusion

Natural defenses are attractive for coastal communities adapting to climate change because they are cost-effective solutions that provide multiple benefits, contributing to community and ecological resilience.



Natural defenses work by attenuating waves, reducing erosion, and, under the right circumstances, can be self-repairing and even grow. Natural defenses can complement traditional approaches to floodplain management, such as building and zoning codes and hardened engineered solutions, to create multiple lines of defense against storms.

By respecting and meeting engineering design principle needs, we can expand consideration of natural defense measures' contributions to storm damage reduction. With engineering guidelines in place, decision makers will have more options and the ability to choose the best combination of methods that reflect community values and enhance coastal community resilience.

Communities are already struggling with the impacts of storms and sea level rise and are seeking more complete solutions. We must hasten efforts to establish engineering guidelines for natural defenses and document their performance. We can start now, and with concerted effort, complete engineering guidelines for beach, dune, reefs and mangroves in the next three years. And as experience is gained from building and monitoring these projects, we can update the guidelines to better protect our coasts.

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