The time to start is now: How implementing natural infrastructure solutions can improve and protect our coasts

By

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ABSTRACT

Wide beaches, broad dunes, dense mangroves and maritime forests, healthy oyster and coral reefs, and thick salt marshes all can reduce damages associated with sea level rise and coastal storms. Natural defenses work, are cost-effective, and provide a myriad of other benefits. We know enough now to confidently deploy these solutions for some circumstances. Certainly, natural defenses can be used as part of a multiple lines of defense approach – providing protection from more frequent, smaller storm events and lessening the energy punch of large waves and high winds on built, or "gray," infrastructure. However, we lack sufficient modeling, data, and field experience regarding the performance of natural defenses under more severe conditions. Creating risk-reduction engineering design literacy regarding natural defenses will hasten the acceptance and expansion of natural defenses as key components for building coastal community resilience. Development of engineering guidelines that include performance evaluation and monitoring recommendations, followed by extensive outreach and training, is proposed.

Everyone seems to love the seashore. The coastal floodplains of the United States house 16.4 million people (NOAA 2012). More than 5 million people live at an elevation of 4 feet or less above high tide (Strauss *et al.* 2012) and are extremely vulnerable to sea level rise, coastal storms, and hurricane storm surges. We want to live "on the edge"– both literally and figuratively. If populations continue to flock to our shores, combined with the effects of sea level rise and hurricane storm surge, the economic and human toll of coastal flooding will grow. This will be the case — according to Munich Re, the world's largest reinsurance firm (Ceres 2014) — even if hurricanes do not become more frequent or more severe.

Benefits of restoring natural defenses

Especially vulnerable communities are looking for cost-effective solutions to cope with coastal flooding risks in a manner that reflects community values, interests, needs, and resources. Some are looking seriously at managing and restoring their natural defenses – beaches, dunes, shellfish and coral reefs, wetlands, mangroves and maritime forests — as a first line of defense that also provides multiple benefits to the community (Figure 1). Improvement of water quality, capture of fresh water, protection of groundwater, enhanced fisheries, and space for recreation are ecosystem services vitally important to the economic well-being of coastal communities. Of course, by protecting and restoring our coasts' natural defenses, we also enhance the environmental resilience of our coastal and marine ecosystems.

Protection and restoration of natural defenses fit into the three basic strategies employed to address storm flood damages: defend, adapt, and retreat. These strategies are not mutually exclusive in place or time; rather they are mutually supportive. Floodwalls, shoreline stabilization, breakwaters, groins, beach nourishment, and dune creation are defensive approaches. Other natural features also help to defend the coast from waves and reduce the damage caused by storm surges. Every natural defense solution mentioned above can attenuate waves and lessen wave energy to reduce erosion and diminish the power of storm waves (Table 1). For example, oyster reefs, depending on their size and orientation, can attenuate midsize waves (2-5 feet) (USACE 2013; Scyphers *et al.* 2011; Marani *et al.* 2011). Mangrove forests may be the superheroes of natural defenses, as they reduce the damage of tsunamis and typhoons by attenuating waves, reducing wind speed, and catching debris (Cheong *et al.* 2013; Tanaka 2009; Cochard 2008; Algoni 2008;). Natural defenses also enhance the effectiveness of traditional hardened infrastructure by providing an extra line of defense between the sea and the structure. Assuming their incremental risk reduction benefits are quantified, they could even result in less intrusive (lower, smaller) seawalls and other structures.

Customary strategies to adapt and cope with flood waters include drainage improvements, building elevation, and flood warning and evacuation. Communities in the Hampton Roads area of southeast Virginia are now considering the idea of systems of sumps (low spaces that collect water) and wetlands to serve as ways to "live with water," by capturing incursions of beach or back bay waters from king tides, storm water runoff, and coastal storms. Over time, as sea levels rise, these same areas might become systems of canals and wetlands that form the backbone of attractive water-oriented living – much like the canals that exist throughout the Netherlands.

Buyouts and relocation away from flood-prone areas are retreat strategies. Sadly, "retreat" evokes for some a sense of having failed or admitting defeat. For high-risk areas, it is a cost-effective strategy that creates space for new opportunities. For example, vacated land can be used as public space, temporary commercial uses (e.g. seasonal pop-up stores, camping sites), and habitat restoration. If communities install wetlands, dunes or maritime forests, then that habitat also

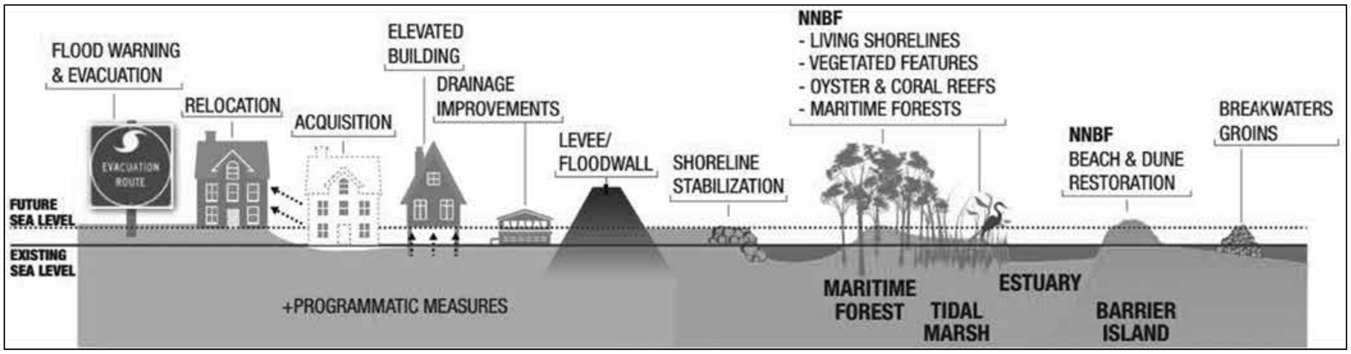

Figure 1: Multiple lines of defense concept as presented by the Corps of Engineers' North Atlantic Comprehensive Coastal Study (2015).

helps defend the coast from the effects of storms.

Natural defenses are cost-effective

Data from the Gulf of Mexico indicate that restoring natural defenses can be far more cost-effective in preventing storm damages than traditional levees (Reguero *et al.* 2014). In some circumstances, restoring natural defenses may be less expensive than hardened shorelines. Ferrario *et al.* (2014) found that the benefits derived from wave height reduction by coral reefs were greater than or equal to the benefits derived from constructed low-crested detached breakwaters — and attained at a much lower median cost. Shell Global Solutions International compared costs for protecting on- or near-shore oil and gas pipelines and found that oyster reef breakwaters cost approximately $1 million per mile, while standard rock breakwaters cost $1.5 million to $3 million per mile (Dow *et al.* 2013). The Chesapeake Bay Foundation (2007) found that installations of shoreline edge wetlands with sills (a.k.a. living shorelines) cost $50-100 per foot less than bulkheads and riprap solutions, costing approximately $500 to $1,200 per foot for sites in the bay.

The return on the investment is actually much higher when other ecosystem services of natural defenses are considered. Grabowski *et al.* (2012) calculated the economic value of oyster reef services (wave attenuation, water quality improvement, etc., but excluding oyster harvesting) as between $13,585 and $244,530 per acre per year. Restoration of oysters and wetlands can help communities meet water quality standards and avoid costly storm water collection and treatment infrastructure. Restored habitat may even increase property values or at least speed property sales — this is the subject of ongoing research by the Environmental Defense Fund (EDF).

Improving engineering confidence in natural defenses

Engineers seek a high level of precision to be confident in and sign off on designs and their expected performance. We lack an understanding of the factors that govern how natural defenses will behave during and after extreme conditions and how effective they are for addressing storm surge. 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. Over the years, we have even gained a greater understanding of the complex coastal processes and how engineering alters those processes — sometimes to the detriment of downcoast properties and activities. Natural systems have not yet been subjected to anything close to the same level of study as engineered solutions.

But that doesn't mean we should not be using natural defenses now. In fact, expert coastal engineers and scientists gathered by EDF in May 2015 concluded there was "sufficient confidence in the ability of natural infrastructure and nature-based measures to reduce impacts of coastal storms and sea level rise to coastal communities such that these approaches should be routinely considered as viable options by decision-makers" (Cunniff and Schwartz 2015).

Given that we know natural defenses can work, are cost-effective, and also provide other benefits, we need to decide where we currently feel comfortable in deploying these solutions and guide their appropriate use. To do this, we must embark on a collaborative engineering design effort to yield engineering guidelines that allow the U.S. Army Corps of Engineers (Corps), the Federal Emergency Management Agency, and state, local and tribal decision-makers to approve and fund projects using natural defenses. We need to define performance success, study installed projects, and scrutinize failures. This means collecting specific information important to engineers on project designs, construction materials, maintenance methods and life-cycle project costs to be able to create risk reduction engineering design literacy for natural defenses.

Concurrent with these efforts, we need to accelerate numerical modeling and lab studies. We need to explore the limits of performance of materials and designs. We need to test new insights with field experience.

To gather enough quality data to facilitate high-volume analyses necessary to draw meaningful conclusions that will guide future projects, we need broad agreement on common metrics and agreements about what, when, where and by whom data collection makes sense. The Living Shorelines Academy (http://www.livingshorelinesacademy.org/) and the Coasts, Oceans, Ports, and Rivers Institute (http://www.mycopri.org/) are preparing to become national repositories for collecting and sharing meaningful data on U.S. living shoreline projects. Deltares and TU Delft are part of the EcoShape Consortium, which has already developed planning guidelines for natural defenses (http://www.ecoshape.nl/en_GB/guidelines.html) and are actively designing a wiki to support collection and sharing of information from projects. We need these kinds of multi-party efforts and cooperation of project implementers, small and large, to reach the full potential of these sites to inform future engineer-

Table 1.

Natural defenses: Summary of risk reduction performance. Factors effecting risk reduction performance include storm intensity, track, forward speed, surrounding local bathymetry and topography.

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’) attenuation (stabilize sediment)	Reduce force & height of medium waves (2’-5’)	Storm surge (low frequency extreme events)
Structural					
Groins	+	-	+		
Breakwaters	+	-	+	+	
Seawalls/revetments/bulkheads	+	+		+	+
Surge barriers	-			+	+
Existing natural					
Wetlands	+		+	~	~
Mangroves/coastal forest	+		+	+	+
Vegetated dunes	+		+	+	+
Nature-based					
Beach nourishment	+	+	+	+	
Vegetated dune creation	+	+	+	+	+
Barrier island restoration	+	+	+	+	+
Small-scale edging and sills (living shorelines)	+	~	+		
Restored oyster/shellfish reefs	+		+	~	
Restored/created coral reefs	+		+	~	
Restored maritime forests (including mangroves)	+	+	+	+	+
Restored wetlands	+	+	+	~	~

ing designs and more rapidly expand acceptance of coastal resilience projects that build in natural defenses.

Engineering guidelines are key

Engineering guidelines are a critical first step toward putting natural defenses on more equal analytical footing with traditional engineered solutions, as it will allow the approaches to be designed to work effectively in concert. It will also allow comparison of the benefits and cost effectiveness of natural defenses and traditional “gray” solutions. Engineering guidelines are a necessary precursor to engineers’ certification of project performance and vitally important for public confidence. Guidelines will therefore also aid the evolution of flood risk reduction policies. Engineering guidelines for natural defenses will also advance the private sector – as they will reduce its risk of failure, grow new practices, aid identification of qualified contractors, and provide a clear means for confirming adequate project execution.

If federal funds for flood risk reduction actions are proposed to be used for restoring or creating natural defenses, federal policies require quantification of the risk reduction benefits. Lacking engineering guidelines for natural defenses, engineers cannot confirm nor endorse a measure’s expected risk reduction performance. Therefore, the Corps, the principal federal agency designing and financing storm damage reduction projects, is, unfortunately, not likely to consider the contribution of natural infrastructure to storm damage reduction. The effect is that many communities, frustrated in their ability to advance ecologically-sensitive approaches, are forced to turn to traditional hardened solutions for their shorelines, and critical coastal habitats are lost.

Once risk reduction benefits can be quantified, then new market-based or private sector funding options can be designed for communities seeking financial support for measures that will enhance their resilience to coastal storms and sea level rise.

Start with beaches, dunes, reefs, and mangroves

Do we have to wait for all this research to be completed to develop engineering guidelines? In September, I put this question to a group of coastal engineers from the Corps, the Netherlands’ Rijkswaterstaat, and leading international engineering firms. They agreed that engineering guidelines for natural defenses could be developed now. And with that additional data and experience, guidance should be regularly updated and refined.

Engineering guidelines already exist for beach nourishment projects and dunes. However, they ought to be updated to incorporate information on planting designs and maintenance practices to encourage beach and dune building. We cannot afford for engineering not to reflect biological factors that improve the structure and function of these features.

The National Academy of Sciences noted that oyster and coral reefs function as submerged breakwaters (NRC 2014). Scientists with The Nature Conservancy have been documenting their performance, and The Nature Conservancy, the EcoShape Consortium and others are testing different designs of oyster substrates in multiple locations in the U.S. and Europe.

The cyclone and tsunami risk reduction performance of mangroves is already fairly well documented (e.g. McIvor *et al.* 2012). Considerable international attention is being given to mangroves owing to increased concern over rapid habitat destruction and the implications associated with the loss of their many ecosystem benefits, including carbon sequestration, fisheries production, and coastal storm and sea level rise risk reduction. Efforts are already underway to quantify ecosystem benefits of mangroves.

Leading engineering institutions like Deltares, TU Delft, the Corps, and Rijkswaterstaat, as well as professional organizations and leaders in the private sector, should work together with others trained in ecosystem restoration and living shoreline design to organize a series of workshops to complete engineering guidelines. With a concerted cooperative and collaborative effort, by 2018 we can complete engineering guidelines for oyster and coral reefs designed primarily for risk reduction; complete methods to quantify tsunami, storm and sea level rise reduction benefits of mangroves by 2019; and complete engineering guidelines to optimize oyster and coral reef designs for risk reduction and other goals by 2020.

We need a clear, prioritized research agenda to inform development of future engineering guidelines. These leading engineering institutions should develop and endorse engineering performance metrics and monitoring protocols for all natural defenses to guide evaluation of projects in a manner that will inform future iterations of engineering guidelines.

CONCLUSION

Natural defenses work for wave attenuation and can complement traditional, hardened engineered solutions. Creation of engineering guidelines will facilitate quantification of the storm damage reduction services of nature defenses and will help decision-makers choose the best combination of methods that reflect community values and enhance coastal community resilience. Therefore, to broaden the number of options available to create more resilient coastal communities, we must hasten efforts to establish engineering guidelines and document their performance.

The seas are rising and times a' wasting. Let's build a commitment to complete engineering guidelines for beach, dune, reefs, and mangroves within the next four years. We can adapt as experience is gained by building and monitoring projects, but the time to start is now.

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