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Review

Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems



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ARTICLE INFO

Keywords:

Ecosystem services

Storm protection

Coastal flooding

Storm surge

Community resilience

ABSTRACT

There is substantial evidence that natural infrastructure (i.e., healthy ecosystems) and combinations of natural and built infrastructure (“hybrid” approaches) enhance coastal resilience by providing important storm and coastal flooding protection, while also providing other benefits. There is growing interest in the U.S., as well as around the world, to use natural infrastructure to help coastal communities become more resilient to extreme events and reduce the risk of coastal flooding. Here we highlight strengths and weaknesses of the coastal protection benefits provided by built infrastructure, natural ecosystems, and the innovative opportunities to combine the two into hybrid approaches for coastal protection. We also examine some case studies where hybrid approaches are being implemented to improve coastal resilience as well as some of the policy challenges that can make implementation of these approaches more difficult. The case studies we examine are largely in the U.S. but also include a couple of international examples as well. Based on this analysis, we conclude that coastal communities and other decision makers need better information in order to incorporate ecosystem protection and restoration into coastal resilience planning efforts. As additional projects are developed, it is important to capitalize on every opportunity to learn more about the cost of natural and hybrid infrastructure projects, the value of the storm and erosion protection benefits provided, and the full suite of co-benefits provided by healthy coastal ecosystems. We highlight top priorities for research, investment in, and application of natural and hybrid approaches. These data are critical to facilitate adoption of these approaches in planning and decision-making at all levels to enhance the resilience of our coasts.

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<http://dx.doi.org/10.1016/j.envsci.2015.04.006>

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1. Introduction

Coastal flooding due to extreme weather events and sea level rise is of growing global concern (IPCC Working Group II, 2014), and increasing coastal resilience to these threats is a priority for many countries and a global need (Barbier, 2014). The United States is no exception. In the U.S., in 2012, there were 11 weather and climate disaster events across the United States, including Hurricane Sandy. Nationally, these disaster events cumulatively caused 377 deaths and over \$110 billion in damages. This makes 2012 the second costliest year on record in the U.S., ranking only behind 2005, which incurred \$160 billion in damages due in part to four devastating coastal hurricanes (National Climatic Data Center (NCDC), 2013). In the wake of these major hurricanes and in the face of increasing chronic risks such as coastal flooding due to sea level rise (Shepard et al., 2012), the resilience of U.S. coastlines has emerged as a major socioeconomic and environmental concern for the federal government. For example, community resilience is specifically called out in the President's Executive Order 13653, "Preparing the United States for the Impacts of Climate Change" (The White House, 2013). In this Executive Order resilience is defined as "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions," and building community resilience is a specific goal of the Executive Order actions. At the U.S. National Oceanic and Atmospheric Administration (NOAA), resilience fundamentally is thought to have at its core three components, or pillars – society, economy, and environment – that must all be healthy and robust for a community to be resilient (NOAA, 2010). Thus, the important role that coastal ecosystems can play in increasing coastal resilience is of growing interest.

Here, based on a synthesis review of existing peer-reviewed literature as well as several published reports, we highlight strengths and weaknesses of the coastal protection benefits provided by built infrastructure, natural ecosystems, and we examine in more depth the innovative opportunities to combine the two into "hybrid" approaches for coastal protection. Specifically, we examine some case studies where

hybrid approaches are being implemented to improve coastal resilience and we explore some of the policy challenges that can make implementation of these approaches more difficult. Notably, this article has a strong U.S. focus because the authors are most familiar with the policy needs and opportunities in the U.S., however, we feature case studies from both the U.S. and from other countries around the world where these approaches are gaining momentum. Much of what we conclude regarding opportunities for increasing coastal resilience using natural or hybrid approaches is relevant for coastal countries around the world.

2. United States policy framework for coastal resilience

In the U.S., as in many countries around the world, the coasts are not only a place where many people want to live (home to nearly four in ten Americans), they are also important economic engines and centers for commerce for the entire country (NOAA, 2014). In 2011, coastal shoreline counties contributed \$6.6 trillion to the U.S. Gross Domestic Product (GDP) – just under half of GDP that year (NOAA, 2012). In the face of climate change, it is critical to the health and prosperity of communities and the economy to think differently about managing and conserving U.S. shorelines. In particular, infrastructure, both healthy coastal ecosystems ("natural") and built ("gray") (Fig. 1) helps protect U.S. coasts from extreme events. To date, built infrastructure, including sea walls, levees, culverts, bulkheads, and other hardened structures, have dominated thinking about coastal protection (Spalding et al., 2014). However, there is an increasing body of evidence (see Section 3) that natural habitats, including wetlands, dunes, barrier islands, sea grasses, coral and oyster reefs, and mangroves reduce the risk of coastal flooding and erosion and provide other social and economic benefits – benefits that meet and cut across the three pillars of resilience. In addition there are also exciting opportunities for designing shorelines that include a combination of natural and built infrastructure (termed "hybrid" infrastructure, Fig. 2, and Section 3). These natural and hybrid approaches may be more



Fig. 1 – Examples of natural (top row) and built (bottom row) infrastructure. Photo Credits: NOAA for all images except Dunes (credit: American Green), Sea Wall (credit: University of Hawaii Sea Grant), and Levee (credit: J. Lehto, NOAA).

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