CHAPTER 2

Living Shorelines for People and Nature

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CONTENTS

2.1 INTRODUCTION

Rising seas, expanding coastal development, and increases in the frequency of extreme weather catastrophes are putting shoreline communities around the world at risk from erosion and flooding (Day et al. 2007; Nicholls et al. 1999; US Army Corps of Engineers [USACE] 2015). Spurred by a widened awareness surrounding the loss of coastal habitats and the deficiencies of traditional erosion control structures, much progress has been made to advance the science and implementation of nature-based approaches to coastal protection (Bilkovic et al. 2016; Currin et al. 2008, 2009; Jones et al. 2012; National Oceanographic and Atmospheric Administration [NOAA] 2015; National Research Council [NRC] 2014). Researchers, practitioners, and the private sector have developed a suite of alternative techniques for stabilizing shorelines, such as replanting saltmarsh or restoring oyster reefs (Berman et al. 2005; Currin et al. 2008; Gittman et al. 2016; NOAA 2015; Piazza et al. 2005; Scyphers et al. 2011). Recent studies suggest that the design of living shorelines (e.g., width of marsh, presence of sill) influences various outcomes, including the abundance of ecologically and economically important fish and invertebrates, water quality, and erosion control (Bilkovic and Mitchell 2013; La Peyre et al. 2013; Scyphers et al. 2011; Toft et al. 2013).

In the United States, policy interest in nature-based approaches to coastal protection is also growing. A new memorandum from the Executive Office of the President directs federal agencies to incorporate the value of "green infrastructure" and ecosystem services into planning and decision-making (OMB 2015). Recent state and federal policies highlight living shorelines as the preferred alternative for erosion control, especially along protected coasts (Maryland Living Shoreline Protection Act of 2008; NOAA 2015; NRC 2007; Virginia 2011). A report released by the Obama Administration in August of last year recommends prioritized federal research into ecosystem services and coastal green infrastructure to inform risk reduction, resilience planning, and decision-making (National Science and Technology Council [NSTC] 2015). The hope is that infusing natural features into shoreline stabilization practices will afford protection for communities while maintaining or restoring the multiple benefits of coastal habitats for people and ecosystems now and in the future (Jones et al. 2012).

Despite this technical innovation and political support, several challenges preclude broad uptake of living shorelines into coastal management. One challenge is the lack of tools, guidance, and capacity for identifying appropriate protection measures for a particular setting (e.g., Berman and Rudnicky 2008; NSTC 2015; Restore America's Estuaries [RAE] 2015) and forecasting which ecosystem services are likely to be gained or lost with habitat conversion (Bilkovic et al. 2016; La Peyre et al. 2015). Few designers and engineers are familiar with nature-based techniques for coastal protection, which further hampers implementation (RAE 2015). A second challenge is harnessing the support of coastal communities and key stakeholders for effective project implementation and sustainability (Olsson et al. 2004; Scyphers et al. 2014, 2015). Poor community engagement can lead to a mismatch between project outcomes and community values and expectations (Schultz 2011). These challenges point to the need for science that will help practitioners anticipate trade-offs and potential impacts to target resources, encourage a common language through which multiple agencies and other stakeholders can define goals, and support the development of performance standards that capture social as well as ecological outcomes from living shoreline projects (NSTC 2015; Olander et al. 2015; RAE 2015). Incorporating ecosystem service approaches and tools into living shoreline science and practice provides an opportunity to address these challenges.

Ecosystem services are the benefits that nature provides to people (Daily 1997; Tallis and Polasky 2009). With over a third of the world's population concentrated near the shore (IPCC 2007), humans rely heavily on benefits delivered from coastal and marine ecosystems (Barbier et al. 2011; Tallis et al. 2011). Wetlands, oyster reefs, coral reefs, subtidal vegetation, dunes, and coastal forests provide a suite of ecosystem services. These services include diverse natural resources, protection for public and private property from coastal hazards, coastal and maritime jobs, and opportunities for recreation, tourism, and aesthetic enjoyment (Barbier et al. 2011; Grabowski et al. 2012). Living shorelines have the potential to contribute to the resilience and sustainability of this diversity of important services. Yet, nature-based stabilization projects infrequently define or monitor objectives using an ecosystem services framework that explicitly communicates and quantifies the benefits of coastal restoration to people (Tallis and Polasky 2009; Tallis et al. 2011).

A fundamental assumption of living shoreline projects is that natural features provide a set of benefits that hard infrastructure may not provide (Bilkovic and Mitchell 2013; Chesapeake Bay Foundation 2007; Center for Coastal Resources Management 2006; Davis et al. 2015; Gittman et al. 2016). However, a review of the scientific and gray literature suggests a disconnect between living shorelines, ecosystem services, and human well-being metrics (Figure 2.1). The number of peer-review papers, reports, proposals, and other documents referring to *living shorelines* increases

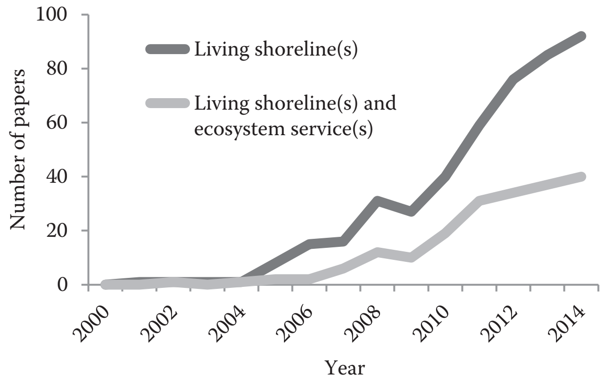


Figure 2.1 Trends in the number of peer-reviewed papers, documents, reports, and other types of gray literature with the phrases "living shoreline(s)" versus "living shoreline(s) and ecosystem service(s)" from 2000 to 2014 based annual searches in Google Scholar.

steadily from 2000 to 2014. However, in each year, only approximately half of these documents also discuss *ecosystem services*. Moreover, of those papers that are about both living shorelines and ecosystems services across all years, just a little more than 50% articulate benefits from living shorelines in terms that directly matter to people (e.g., food from fisheries [e.g., Kalinowski and Baker 2014; La Peyre et al. 2013] or recreational opportunities [e.g., Hoatson 2010; Pendleton 2010]). Even fewer papers (12.5%) actually provide quantitative information using social or economic metrics (e.g., Grabowski et al. 2012; Humphries and La Peyre 2015).

Part of this disconnect likely stems from the breadth of living shoreline definitions. Some definitions describe living shorelines as alternatives to hardening that employ natural habitat elements to protect shorelines from erosion while also providing critical habitat for wildlife and water quality benefits (NOAA 2015; NRC 2007; Virginia 2011), while others refer to specific techniques that baffle wave energy and reduce chronic erosion (Berman et al. 2005). A new NOAA report addresses this issue by clearly describing a continuum of shoreline stabilization strategies as a gradient from natural to built with hybrid structures in the middle and living shorelines falling left of center (NOAA 2015). In general, however, many of the definitions provided by state and federal agencies, nongovernmental organizations (NGOs), and various researchers focus more on ecological and physical outcomes than social or economic ones. Even those definitions that suggest benefits to people, such as "improved water quality" or "shoreline protection," rarely state it explicitly (e.g., improved water quality for waterfront residents or tourists) or define them using social or economic endpoints such as increased visitation to coastal waters with higher water quality (for lakes recreation example, see Keeler et al. 2015).

Endpoints that resonate with people are core elements in ecosystem services science (Tallis et al. 2011) and implementation (Olander et al. 2015) and could provide explicit goals for designing living shoreline projects and monitoring outcomes. An important step to operationalizing the ecosystem service concept is a production function model that relates change in ecosystems to change in the production of services that matter to people. For example, in a living shoreline context, change in ecosystem structure (e.g., oyster restoration; Figure 2.2 (i)) can lead to change in ecosystem function (i.e., reduction in wave height; Figure 2.2 (ii)) and benefits to people (e.g., reduction in erosion of coastal property and associated property damage; Figure 2.2 (iii) and (iv)). Of course, not all assessments of living shoreline projects need to have a quantified benefit for people to be worth implementing. Instead, some projects can remain limited to restoring ecosystem structure and function to provide habitat for species. However, when public or stakeholder participation is involved,

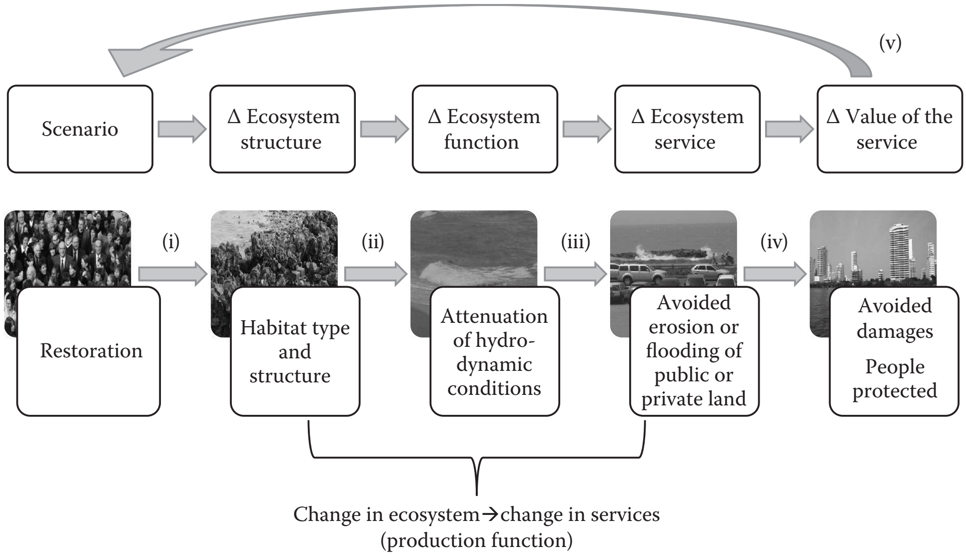


Figure 2.2 General framework for modeling ecosystem services applied to coastal protection provided by living shorelines. The framework links changes in habitat structure (e.g., width and height of oyster reef) as a result of restoration to changes in biophysical conditions (e.g., wave attenuation) to changes in the service provided (e.g., avoided erosion) and ultimately to changes in the value of the service (e.g., avoided damages), which could, in turn, influence the propensity for public and private decision-makers to restore habitat in the future. (Photo credits: Katie Arkema [Natural Capital Project] and Bo Lusk [The Nature Conservancy].)

an important component of the ecosystem services framework is the feedback between change in service value and peoples' decisions (Figure 2.2 (v)). If waterfront communities understand and, ideally, value the suite of benefits of living shorelines, they may be more likely to take actions that further increase the flow of benefits in the future (Scyphers et al. 2015, in review).

Here we argue that drawing upon ecosystem service concepts and tools to inform living shoreline science and implementation has the potential to advance the effectiveness and uptake of nature-based shoreline stabilization techniques. In Section 2.2, we review a suite of benefits provided by natural and enhanced living shorelines, explicitly focusing on endpoints that resonate with people. In Section 2.3, we review emerging research that links geophysical, biological, and climate science with social and economic information to estimate services and understand the factors that are likely to influence their delivery over the short and long term. We also review results from projects that engaged communities to assess how people's perceptions and values are likely to influence the implementation and longevity of living shoreline projects. In Section 2.4, we describe several recent cases that involved heightened calls for ecosystem services information and discuss how a services framework can facilitate better implementation pathways for living shoreline approaches. We end by identifying key ecological and social science research questions and opportunities for advancing ecosystem services science to inform development and implementation of living shorelines.

2.2 ECOSYSTEM SERVICES PROVIDED BY LIVING SHORELINES FOR PEOPLE

People desire numerous services from shoreline ecosystems, including fisheries benefits and wave attenuation. Some of these services are substitutable with built infrastructure. However, hardening a shoreline may be less cost-effective than restoring coastlines, especially after accounting for the influence of armoring and bulkheads on a full suite of ecosystem services (Jones et al. 2012). Several of the subsequent chapters in this book highlight important ecosystem services provided by living shorelines from an ecological perspective. To complement these chapters, we focus this section on the societal relevance of living shorelines. We discuss the evidence for five ecosystem services that living shorelines provide to coastal communities: food and livelihoods from fisheries, protection from coastal hazards for people and property, opportunities for recreation and tourism, carbon storage and sequestration, and human health and well-being. Our goal with this section is to illustrate an ecosystem services approach to framing potential benefits of living shorelines to people.

2.2.1 Habitat to Support Fish, Fisheries, and Livelihoods

People around the world rely on marine and coastal fisheries to provide food resources and support livelihoods. Numerous species of crabs, shrimp, and finfishes that are particularly valued by human communities rely on natural habitats such as saltmarsh, seagrass, and oyster reef for essential habitat and feeding grounds (Beck et al. 2001; Jordan et al. 2012; Peterson et al. 2003). In contrast, some of the most common traditional armoring techniques, such as bulkheads and seawalls, provide a poor habitat alternative and often result in biophysical changes that further degrade natural shorelines (e.g., Bilkovic and Roggero 2008; Bozek and Burdick 2005). A guiding principle that has emerged from recent living shorelines research (e.g., Gittman et al. 2016; Humphries and La Peyre 2015; Scyphers et al. 2011) is the necessity of complex habitat (i.e., high rugosity) for biodiversity and fisheries production. Fisheries benefits are also projected as among the first benefits to appear after implementation (La Peyre et al. 2014) and thus may provide a valuable tool to communicate outcomes from living shorelines to a wide audience of stakeholders and decision-makers. For instance, experimental studies in the Gulf of Mexico found that compared to degraded natural shorelines, oyster reef breakwaters strongly enhanced abundances of blue crabs (*Callinectes sapidus*) and several highly desirable finfish species such as red drum (*Sciaenops ocellatus*) and spotted seatrout (*Cynoscion nebulosus*) (Scyphers et al. 2011, 2015). Conservative assessments of the economic value of enhanced fish production have estimated a hectare of oyster reef to yield approximately $4000 in commercial landings (Grabowski et al. 2012). In addition to being highly valued by recreational and commercial fishing industries, many of these fisheries species are key components of identity and culture in coastal communities (Dyer and Leard 1994).

2.2.2 Coastal Protection for People and Property

Coastal communities persistently face a wide variety of hazards including erosion, ecological degradation, flooding, sea level rise, and storms, and we now know that many traditional shoreline structures can often exacerbate rather than reduce these threats. Oyster and coral reefs, seagrass, mangroves, dunes, and other natural and enhanced coastal and marine ecosystems have the potential to attenuate waves, stabilize shorelines, and buffer storm surge (Ferrario et al. 2014; La Peyre et al. 2015; Scyphers et al. 2011; Shepard et al. 2011), reducing the effects of hazards from which coastal communities suffer (e.g., Barbier et al. 2013; Spalding et al. 2014). Until very recently, little work existed comparing the influence of nature-based options to armored shorelines. However, Gittman et al. (2014) show that natural and enhanced shorelines may be more resilient to storms in some settings. Nearly all of the studies we reference and others have described the nonlinear and inherently context-dependent nature of erosion and storm buffering (e.g., Koch et al. 2009) and highlighted the need for more empirical data across a range of biophysical conditions and settings (NSTC 2015; Pinsky et al. 2013; Sutton-Grier et al. 2015). The context dependency of coastal protection services also extends to humans in the system. A study mapping coastal risk reduction owing to habitats fringing US shorelines (Arkema et al. 2013) (Figure 2.3) suggests that coastal protection

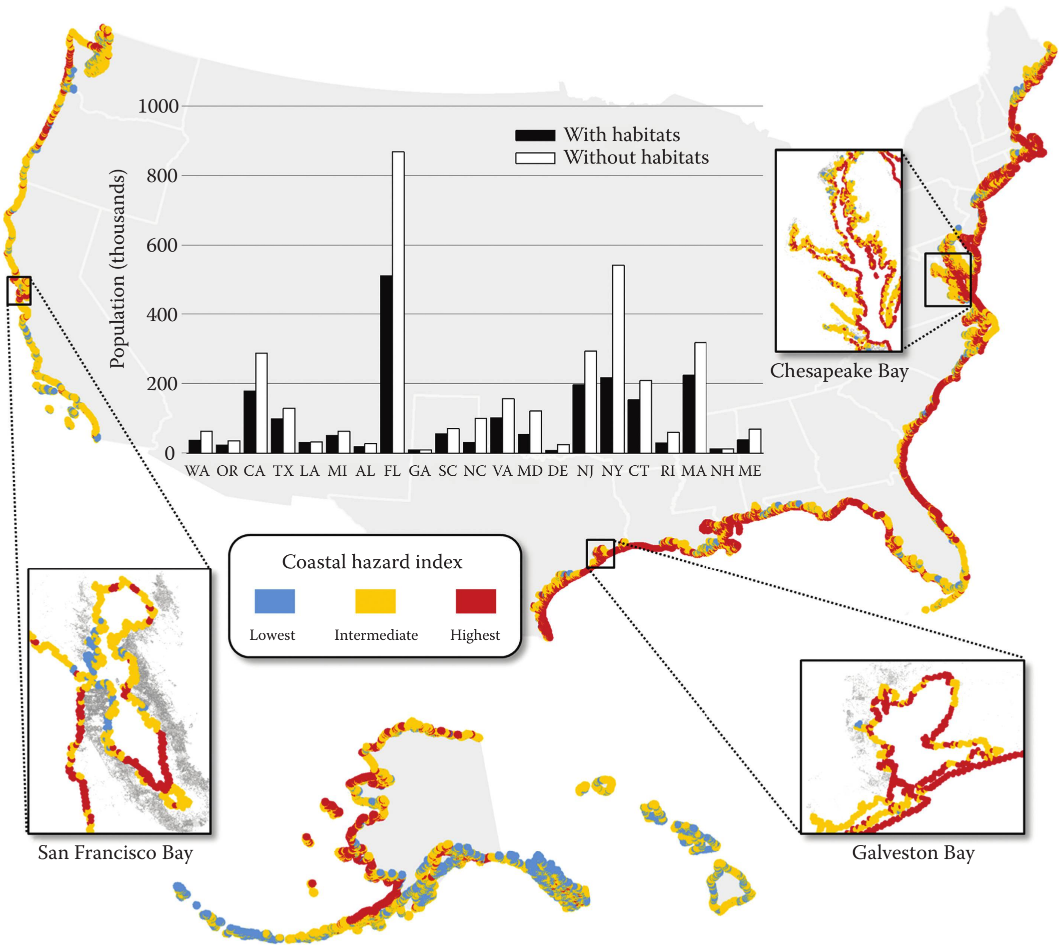


Figure 2.3 Vulnerability of the United States coastline and population to sea level rise in 2100 and storms. (a) Coastal exposure to hazards from the A2 sea level rise scenario and storms. Warmer colors in map and insets indicate regions with the greatest exposure to hazards (index values > 3.36). (b) Black bars show the total population in each coastal state living in areas most exposed to hazards (red in map) with protection provided by habitats, and the increase in vulnerability that would occur if habitats were lost because of climate change or human impacts (white bars). Data depicted in the inset maps are zoomed-in views of the nationwide analysis. This figure first appeared in Nature Climate Change in Arkema et al. (2013).

benefits of living shorelines depend on spatial variation in social and economic factors such as property values and demographics of coastal communities. Taken together, these papers indicate that living shorelines can play an important role in sheltering waterfront residents and communities from coastal hazards, but the ecological, physical, and social context in which these benefits occur needs to be better understood.

2.2.3 Coastal and Marine Recreation and Tourism

Healthy coastal and marine ecosystems provide tourism opportunities and support livelihoods. In the United States alone, ocean-related tourism and recreation generated 9.1 million jobs and $89 billion in economic output in 2010 (Kildow et al. 2014). Fishing, swimming, beach-going, and boating are among the top recreational uses of coastlines for both residents and tourists (Pendleton et al. 2001, 2006). In addition to the commercial values described above, the fisheries enhancement of living shorelines could translate to increased recreational satisfaction among residents and opportunities for visitors (Fedler 1984). Recent studies also suggest that living shorelines play an important role in promoting favorable water quality by filtering out excess nutrients such as nitrogen and phosphorus, as well as stabilizing sediments (Piehler and Smyth 2011). The closure of beaches to swimming as a result of poor water quality is not uncommon can be detrimental for coastal economies (Brown and Clarke 2007; Parsons et al. 2009). Reef-building bivalves such as oysters also contribute to water quality services through filter-feeding and benthic–pelagic coupling; nitrogen removal from one hectare of oyster reef was valued at more than $6700 annually (Grabowski et al. 2012).

2.2.4 Blue Carbon Storage and Sequestration

Globally, terrestrial and ocean ecosystems remove large amounts of carbon dioxide from the atmosphere, helping to regulate the Earth's climate. Seagrasses and mangroves, for example, store and sequester carbon, such that degradation and conversion of these systems globally release 0.15–1.02 Pg (billion tons) of carbon dioxide annually (Pendleton et al. 2012). These emissions are equivalent to 3%–19% of those from deforestation globally and result in economic damages of $US 6–42 billion annually (Pendleton et al. 2012). The degradation of vegetated shoreline can contribute to both the export of stored carbon and diminished sequestration potential (Theuerkauf et al. 2015). By incorporating vegetative elements such as saltmarshes and seagrass in their design, living shorelines have the potential to contribute to the carbon captured by the world's coastal and ocean ecosystems, frequently termed "blue carbon" (Davis et al. 2015). Several studies documenting carbon storage and sequestration rates find that restored seagrass beds and marshes, like their natural counterparts, accumulate carbon through in situ production and in their sediments (Davis et al. 2015; Donato et al. 2011; Mcleod et al. 2011). Rates vary depending on age of the restored plots and density of vegetation. For instance, a recent study of fringing marsh shorelines in coastal North Carolina revealed that older and more mature marshes are much better at storing carbon than younger marsh sites (Davis et al. 2015). Like many of the aforementioned services, restored ecosystems will take time to accumulate carbon at a rate that is comparable to natural systems (Bilkovic and Mitchell 2013; Craft et al. 2003; Davis et al. 2015; Greiner et al. 2013). Unlike other services, however, increases in carbon storage and sequestration resulting from habitat restoration benefit all coastal communities equally, regardless of their location because the atmosphere is well mixed (Mandle et al. 2015).

2.2.5 Human Health and Well-Being

A growing number of studies find that nature positively influences human well-being, including mental health (Bratman et al. 2015; Cracknell et al. 2015; Sandifer et al. 2015). For instance, spending 90 minutes walking in the woods was recently found to lower people's levels of rumination (repetitive thoughts focused on negative aspects of self), which is a known risk factor for mental illness (Bratman et al. 2015). In another study, watching marine life at the National Aquarium in Plymouth, UK, reduced both heart rate and blood pressure. In fact, people were more captivated and their moods more positive with more fish in the tank (Cracknell et al. 2015). Water features appear to be particularly restorative (White et al. 2010) with access to coastal areas reducing stress, increasing physical activity, and resulting in stronger communities (Depledge and Bird 2009). In Britain, the Universities of Exeter and Plymouth are deploying the "Blue Gym" program to examine health benefits from time spent in ocean environments and to create a national network of ocean and coastal activities to promote mental and physical well-being (Depledge and Bird 2009). The aforementioned research suggests the powerful service that coastlines restored with natural materials could provide to waterfront residents and coastal communities. This is likely to be particularly important in urban settings where new studies suggest that city dwellers have a higher risk for anxiety, depression, and other mental illnesses than people living outside urban centers (Lederbogen et al. 2011; Peen et al. 2010).

2.3 ADVANCEMENTS IN ECOSYSTEM SERVICE SCIENCE AND PRACTICE THAT SUPPORT THE DESIGN AND IMPLEMENTATION OF LIVING SHORELINES

Our growing understanding of the ways in which nature benefits people has the potential to inform the science and implementation of living shorelines. Recent research has focused on how change in the structure and function of coastal ecosystems, as a result of restoration, development, and other actions in coastal zones, leads to change in ecosystem services and outcomes for particular groups of people that benefit from those services (Barbier 2013; Olander et al. 2015; Tallis et al. 2011). Quantifying relationships between nature and people is critical for identifying trade-offs among services and effectively engaging stakeholders about their values, beliefs, and expectations for living shoreline projects in the short and long term.

2.3.1 Modeling and Measuring Ecosystem Service Outcomes to Inform Living Shoreline Projects

Advancements in modeling ecosystem services have the potential to provide insights and tools that can be used to forecast outcomes of living shoreline projects in terms that matter to people (Arkema et al. 2015; White et al. 2012). These models take advantage of established approaches in fisheries (Jordan et al. 2012 and references within), coastal engineering (Guannel et al. 2015 and references within), and other disciplines and couple these with new insights about coastal ecosystems and novel data sources (Wood et al. 2013) to model ecosystem function and delivery of services to people. The geographic, ecological, physical, and social context often influence the outcome of management actions, suggesting that the specific location where a living shoreline project takes place matters (Ruckelshaus et al. in press). Working with diverse data sources and across disciplines is integral for predicting where living shoreline approaches are likely to be most effective for achieving multiple goals for nature and people.

Empirical evidence suggests that multiple factors influence the effect of living shorelines on provisioning of services, including the size, shape, and maturity of the project, as well as local environmental conditions. Though the number of field projects that monitor living shorelines and assess ecosystem services over multiple years is growing (Figure 2.1), overall, the empirical data quantifying these relationships are limited. For instance, scientists and practitioners commonly assume that ecosystem service provisioning by living shorelines scales with size (Gedan et al. 2011), yet this relationship has not been verified across multiple living shoreline projects. Another major factor contributing to variability in ecosystem services provided by living shorelines is project age and maturity of nearby habitats (Bilkovic and Mitchell 2013; Gittman et al. in 2016; La Peyre et al. 2014; NOAA 2015). However, in general, very little is known about the rate of provisioning over time as monitoring data rarely extend beyond 1–2 years after construction (if monitoring is even conducted at all). The lack of consistent and long-term monitoring data is a major impediment, making it difficult to test how environmental characteristics, such as salinity, water depth, and wave energy, influence project performance. Adequate funding for pre- and post-project monitoring is essential for elucidating the conditions under which living shorelines are able to achieve desired goals, ultimately leading to the development of well-tested tools and approaches to inform when, where, and how to implement living shoreline projects (Bilkovic et al. 2016; Currin et al. 2009; NRC 2007).

2.3.2 Understanding and Quantifying the Beneficiaries of Living Shoreline Projects

Our Google Scholar search suggests that living shoreline projects that explicitly consider outcomes for people often measure these in economic units (e.g., Grabowski et al. 2012; Humphries and La Peyre 2015). Economic metrics for ecosystem services are compelling for policy- and decision-makers and can serve as a common unit of measurement across several objectives (Arkema et al. 2015; White et al. 2012). Indeed, for a long time, scientists and practitioners assumed that quantifying ecosystem services meant putting a dollar value on nature. However, this assumption is changing. New research into the benefits of nature for human well-being offers insights for living shoreline projects.

Ecosystem services are delivered in a variety of ways with many different values to people, including nutritional benefits from pollinators (Eilers et al. 2011), human health benefits (Myers et al. 2013), and safety from hazards (Arkema et al. 2013; Beck et al. 2013) (Figure 2.3). The magnitude of these values varies tremendously and depends not only on biophysical factors but also on the scarcity of services, their utility to specific communities, and the availability of built and technological substitutes. Recent studies find that quantifying services using a variety of social metrics, such as poverty, literacy, and age can reveal important patterns that strictly economic results may mask (Arkema et al. 2013; Mandle et al. 2015; USACE 2015). For example, Arkema et al. (2013) showed that coastal habitats were important for reducing the number of poor families at high risk in southern Texas and the total value of property at high risk in Florida. Valuing coastal habitats in terms of just the latter economic metric—reduction in total value of property at risk—would have suggested incorrectly that the habitats in Florida were more important than those in Texas for coastal protection services (see p. 32 of NSTC 2015 for more discussion of socioeconomic considerations). Further, quantifying ecosystem services with multiple values tends to be useful for community engagement, as different metrics resonate with different groups of people (Arkema et al. 2015; Barbier 2013).

For living shorelines to continue to grow in popularity as alternatives or complements to traditional engineering approaches (Erdle et al. 2006; NRC 2007), project goals and outcomes must align with stakeholder values. In systems with a high proportion of residential shoreline, understanding how waterfront homeowners make decisions is critical, considering how the management of private yards and shorelines scales up to influence the health and resilience of local ecosystems (Cook et al. 2012). Surveys of homeowner decision-making reveal that biophysical consequences of neighboring armored shorelines, exacerbated by misperceptions of maintenance-related costs, can overshadow aesthetic preferences of natural shorelines and environmental awareness (Figure 2.4) (Scyphers et al. 2015). However, ecosystem service-related social values and economic incentives may provide powerful tools for communicating the benefits of living shorelines and encouraging implementation (Scyphers et al. in review). Along public property and at larger spatial scales, living shorelines planning and implementation hinge on leveraging a broader society informed of the social, ecological, and economic costs; benefits; and trade-offs. Interactive mapping and decision support systems, such as The Nature Conservancy's (TNC) Coastal Resilience decision support tool and the Natural Capital Project's InVEST models, provide unprecedented capabilities to integrate data on both ecosystem services and societal dimensions (Beck et al. 2013).

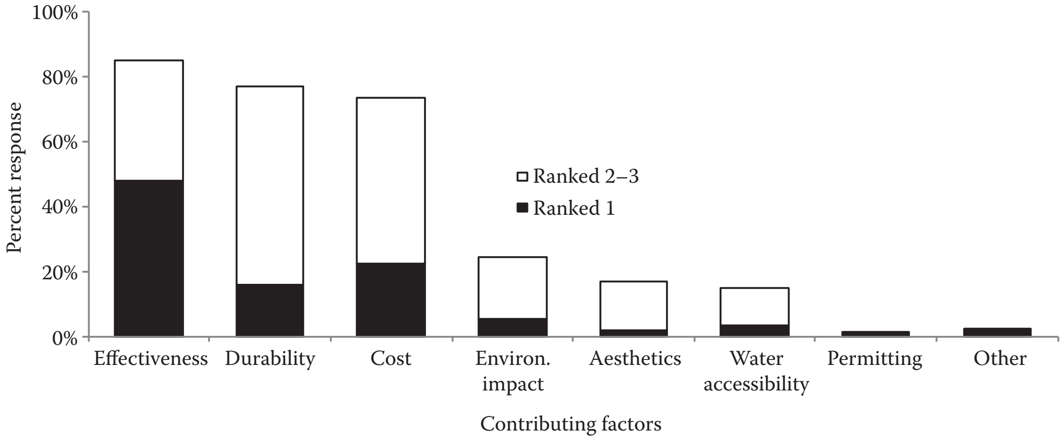


Figure 2.4 Waterfront homeowners are key actors in the decision to implement living shorelines or traditional armoring structures. Scyphers et al. (2015) reported the findings of a survey of waterfront residents in coastal Alabama that showed that economics-centric attributes of effectiveness, durability, and cost far outweighed potential other influences such as concern for environmental impacts, aesthetics, water access, and permitting. Notably, most homeowners perceived armored structures as superior to natural shorelines in terms of the three most influential criteria; however, reported maintenance costs revealed this to be an inaccurate perception as natural shorelines required approximately half the investment of armored structures.

2.3.3 Community Engagement and Capacity Building to Foster Implementation of Living Shorelines

Lack of awareness of nature-based approaches is another limiting factor in the use of living shorelines. Historically, many decision-makers were unfamiliar with options other than seawalls and bulkheads to combat shoreline erosion, and living shorelines were absent from the menu of protection measures offered by contractors and engineering firms. However, community outreach and education efforts, such as those led by NGOs (e.g., TNC, Sea Grant) and federal and state agencies (e.g., NOAA, Maryland Department of Natural Resources, North Carolina Division of Coastal Management), are increasing awareness about the potential for using living shorelines to reduce erosion and restore habitats. Collaborative relationships between conservation NGOs and private engineering forms, such as those recently initiated by TNC and a suite of major engineering firms including CH2M, are increasing the use of nature-based approaches and technologies. Despite these advances, further capacity building and education are necessary to address barriers to living shoreline uptake and implementation (RAE 2015). These can leverage an ecosystem services framework to make clear how living shorelines contribute to a variety of public values beyond those enjoyed exclusively by the landowner.

2.4 LINKING SCIENCE AND PRACTICE

In Sections 2.4.1 through 2.4.3, we describe how ecosystem service concepts and science are being used to inform living shoreline implementation in three case studies. The case studies include ecosystem-based adaptation (EbA) in the Caribbean, Rebuilding after Hurricane Sandy in the northeastern United States, and Restoration of the Gulf of Mexico. While this book focuses on the US context, we have the potential to learn from ecosystem service science and practice occurring around the world; thus, we include an example from the Caribbean. In the case of both EbA and postdisaster restoration, a suite of national and regional policies are calling for management decisions informed by ecosystem service considerations. The following initiatives are examples of how ecosystem services framing, science, and tools can help facilitate implementation pathways for nature-based shoreline stabilization.

2.4.1 Ecosystem-Based Adaptation to Climate Change—Caribbean

Global climate change is one of the most serious threats to sustainable development around the world. This is particularly true for small island developing countries such as those in the Caribbean. To confront this threat, the CARICOM Heads of State commissioned a framework to guide regional climate adaptation (Caribbean Community Climate Change Centre 2009). One component of the overall strategy is EbA, an approach that offers the opportunity to increase resilience to climate change while maintaining benefits from the natural environment that support the region's economy. With so many Caribbean countries heavily reliant on fisheries, tourism, forestry, and agriculture, governments in the region are looking to mainstream EbA into development planning. An ecosystem services framework has the potential to facilitate implementation of living shoreline projects for climate adaptation and economic development.

As an example, Placencia is a small city in southern Belize that specializes in high-end ecotourism resorts where visitors pay more to experience the intact natural environment. Over the last several years, World Wildlife Fund has been engaging stakeholders to identify feasible climate adaptation strategies (e.g., mangrove restoration; Figure 2.5a) on the local scale. For example, despite the threat of storm damage, many stakeholders are opposed to seawalls because of a tourism-driven economy that relies on beautiful beaches and cabanas nestled within mangrove forests to draw visitors. Local residents and resort owners worry about negative effects of seawalls on beaches and would prefer to repair infrastructure after a storm than suffer the irreparable loss of coastal ecosystems to the tourism industry (Nadia Bood, personal communication). Policy-makers and resource managers pursuing integrated management in Belize (Arkema et al. 2015) are asking for evaluations of alternative adaptation options to understand more explicitly these kinds of trade-offs among coastal defense measures, tourism revenue, fisheries, and other services (Figure 2.5b). They foresee using this information to identify where coastal habitat restoration can be most useful for adapting to climate change and anticipating unintended consequences of management decisions.

2.4.2 Rebuilding after Hurricane Sandy—United States

In the northeastern United States, the dense human populations and historical fishing communities highlight the complex trade-offs of how we develop coastlines. In 2012, Hurricane Sandy brought that conversation front and center as many northeast and Atlantic communities suffered from unprecedented flooding and devastation. In the aftermath, several planning initiatives and funding opportunities that emphasized nature-based defenses as central to the rebuilding strategy and future coastal resilience were launched (e.g., Mayor Bloomberg's "A Stronger More Resilient New York," the US federal government's "Hurricane Sandy Rebuilding Strategy," and the National Fish and Wildlife Foundation's "Hurricane Sandy Coastal Resiliency Competitive Grant Program").

As an example of one of the post-Sandy programs, a relatively small number of private organizations and federal agencies launched the "Rebuild by Design" initiative aimed at promoting a paradigm shift in how planners and governments approach disaster preparedness and response. Nature-based approaches to coastal protection and living shorelines in particular have garnered a large role in this initiative with more than half of the 10 finalists incorporating habitats or ecosystem services in their designs. A winning design that focused on Long Island, New York, integrates

(a)

		Adaptation scenarios	
	No action	Integrated	Reactive
NPV of total benefits	$0.790	$1.300	$0.650
NPV lobster fishing	$0.008	$0.009	$0.006
NPV tourism and recreation	$0.782	$1.273	$0.702
NPV carbon storage and sequestration	–	$0.013	–$0.061
NPV of total implementation costs	–$0.005	–$0.015	–$0.191
NPV of erosion damages from sea level rise and storms	–$2.517	–$2.556	–$2.005
Total NPV of all benefits, costs and damages	–$1.731	–$1.275	-$1.550
NPV compared to no action scenario	–	$0.456 billion	$0.181 billion

(b)

Figure 2.5 (a) Mangrove restoration in Placencia, Belize, informed in part by a (b) cost–benefit analysis comparing the net present value (NPV) of Integrated, Reactive, and No Action climate adaptation scenarios. The Integrated scenario that emphasizes nature-based approaches to coastal protection results in more than twice the NPV of the Reactive scenario, owing to higher returns from a suite of ecosystem services provided by storm-buffering mangroves and coral reefs and lower implementation costs. Seawalls were more common in the Reactive scenario and assumed to completely withstand hazards, thus leading to lower damages from storms. Higher damages in the Integrated scenario relative to the No Action scenario are a result of increased coastal development for tourism and corresponding higher property values. (Adapted from Rosenthal, A., K. Arkema, G. Verutes et al. 2013. Identification and Valuation of Adaptation Options in Coastal-Marine Ecosystems: Test Case from Placencia, Belize, Inter-American Development Bank Report. http://community.eldis.org/.59c095ef/Identification%20and%20Valuation%20of%20Adaptation%20Options%20in%20Coastal%20Belize%20FINAL.pdf; and Arkema, K.K., G.M. Verutes, S.A. Wood et al. 2015. Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. *PNAS* 112(24): 7390–7395.)

"eco-edges" of saltmarsh to reduce wave action, improve ecological functioning, and generate new recreational opportunities (Rebuild by Design 2014).

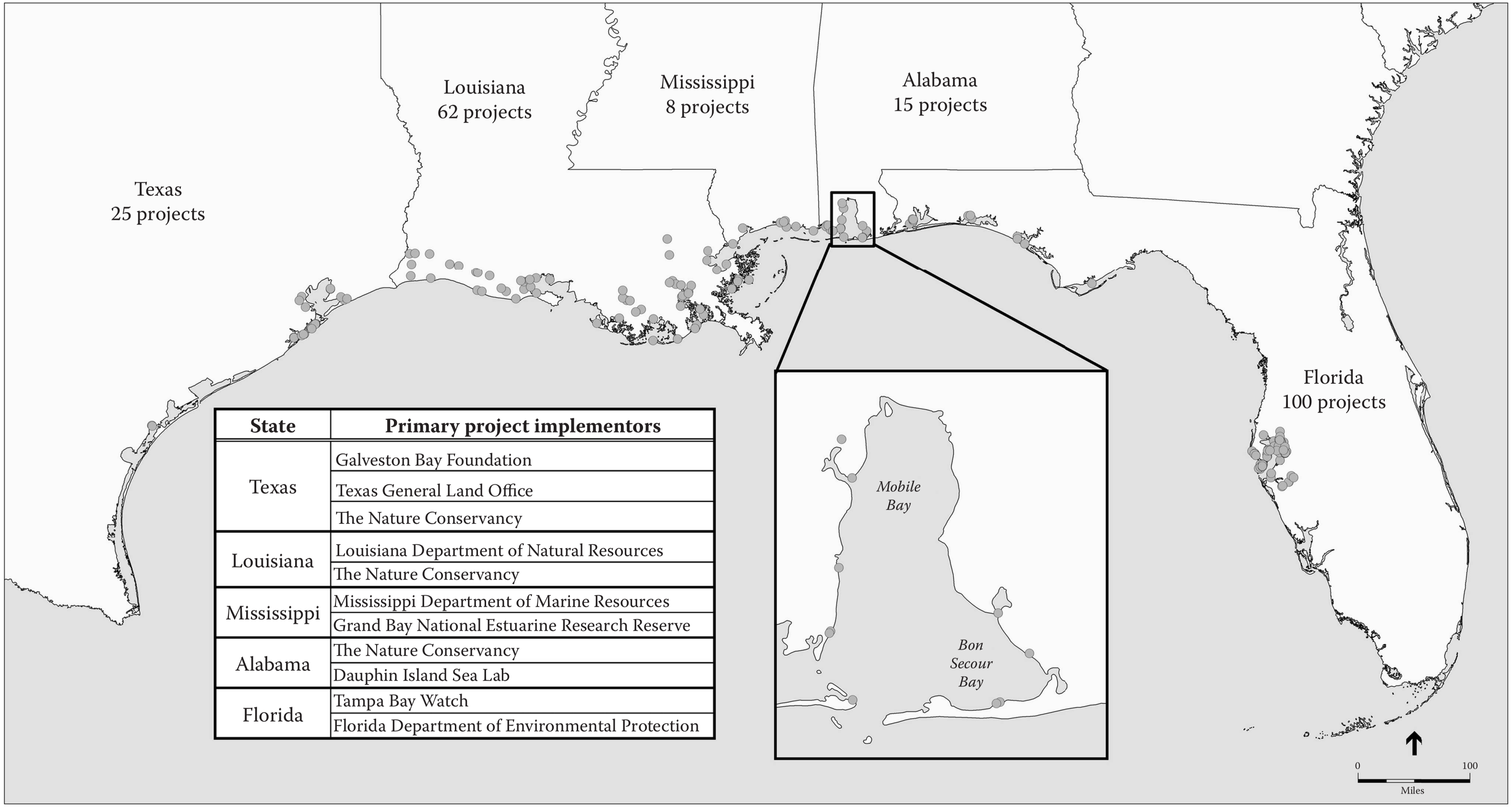
2.4.3 Restoring the Gulf of Mexico—United States

The US Gulf Coast exemplifies a region where the widespread decline of natural shoreline habitats has prompted investments in restoration and living shorelines (e.g., Coastal Protection and Restoration Authority 2012). Vast expanses of saltmarshes, fringing oyster reefs, and sandy shorelines contribute to highly productive commercial and recreational fisheries, as well as vital tourism economies. Historically, shoreline and watershed development, coupled with excessive and destructive harvest of oysters, have been primary drivers in the decline of these habitats. However, this region has also benefited from a long history of coastal restoration. In recent years, multimillion dollar investments in living shorelines were facilitated by the American Recovery and Reinvestment Act, which aimed to restore ecosystems and economies (Edwards et al. 2013). Hurricane Katrina was a particularly powerful focusing event for conversations on the importance of coastal wetlands for storm buffering (Barbier et al. 2013). Now, there is a tremendous need for the ecosystem services and living shoreline research discussed in this chapter and the rest of this book in the Gulf of Mexico where large-scale constructed living shoreline and breakwater projects are being planned across the region in response to the approximate $12.6 billion of restoration funding provided by legal settlements from the Deepwater Horizon Oil Spill (Figure 2.6, Shepard et al. 2015).

In coastal Alabama, Mobile Bay has provided an exemplary system for implementing and evaluating living shorelines (Roland and Douglass 2005; Scyphers et al. 2011, 2015). Importantly, as the science of living shorelines has progressed, implementation has followed suit. For nearly 20 years, living shorelines projects have been implemented at spatial scales ranging from waterfront residential properties to km-long stretches along public properties. Living shoreline initiatives have prospered in coastal Alabama, at least in part, because of strong partnerships among local and national NGOs, state and federal research and regulatory agencies, and local academic institutions working collaboratively. In addition to advancing the science and practice of living shorelines, these partnerships have ensured a broader focus, yielding social and economic benefits for coastal communities through restoration-related jobs and enhanced fisheries-related ecosystem services.

2.5 CONCLUSIONS AND FUTURE DIRECTIONS

Empirical studies of living shorelines have consistently documented enhanced ecological functions compared to armored and degraded shorelines. In this chapter, we extend our understanding of ecological outcomes to incorporate social considerations and metrics using an ecosystem services framework. We discuss the potential for ecosystem service science and practice to inform several challenges facing living shorelines. In particular, framing possible outcomes of living shoreline projects in terms that resonate with people can facilitate stakeholder engagement, enhance project implementation, and influence success. Ecosystem service models that link change in the ecosystem structure and function of natural and enhanced shorelines to services that matter to people have the potential to inform selection of living shoreline sites and provide tools and approaches for engaging community members from the start of a project through to postimplementation monitoring. While empirical evidence and models can help explore potential trade-offs, the reality of on-the-ground engagement is that decisions are rarely the direct result of the science. Rather than suggesting a "best choice" scenario for living shoreline projects, ecosystem service



State	Primary project implementors
Texas	Galveston Bay Foundation
	Texas General Land Office
	The Nature Conservancy
Louisiana	Louisiana Department of Natural Resources
	The Nature Conservancy
Mississippi	Mississippi Department of Marine Resources
	Grand Bay National Estuarine Research Reserve
Alabama	The Nature Conservancy
	Dauphin Island Sea Lab
Florida	Tampa Bay Watch
	Florida Department of Environmental Protection

Figure 2.6 A total of 253 living shoreline projects have been identified in The Nature Conservancy's preliminary Gulf of Mexico Living Shoreline Inventory.

tools and approaches provide visualization and measures through which policy-makers, natural resource managers, and waterfront residents can gain awareness about alternative approaches for shoreline stabilization and revise and refine interventions to meet multiple objectives for a diversity of beneficiaries.

The rapid popularization of living shoreline approaches points to the need for science to keep pace with implementation. This need bridges basic and applied ecology by calling for studies on the relative efficacy of various living shoreline types and technologies for people (i.e., through the provisioning of ecosystem services) and wildlife across varying scales of space and time (NSTC 2015). The following are some potential research questions that remain:

- How does the structural longevity of various living shoreline strategies compare to traditional shoreline armoring structures?
- How do vertical growth rates for living shorelines (e.g., for oyster reefs, marsh, intertidal flats) compare to control sites and to local rates of sea level rise (see Rodriguez et al. 2014 for an assessment of oyster reefs)?
- How can living shoreline projects be optimally designed to attenuate waves and reduce rates of erosion/increase rates of deposition shoreward of the treatments?
- How do the ecosystem services provided by living shorelines composed of multiple habitats compare to single-habitat projects (Guannel et al. 2016)?

Likewise, there is a need for understanding the social dynamics of coastal human communities where living shorelines are typically implemented (e.g., with societal and stakeholder surveys, census data, public/private lands information, etc.) and how human outcomes and decisions relate to the ecological and site-specific characteristics of the projects (RAE 2015). Some potential key research questions are as follows:

- How do the environmental values, beliefs, and social norms of waterfront homeowners and other key decision-makers align with the characteristics of living shorelines and traditional armoring?
- How important are ecosystem services in the shoreline management decisions of waterfront homeowners?
- How does the economic value of natural and restored shorelines compare to armored structures in real estate pricing and property appraisal?
- What is the role of homeowner associations and similar institutions for establishing policies and social norms regarding shoreline management?

In addition to living shoreline research needs, several new frontiers in ecosystem service modeling may soon be useful for living shoreline science and practice. These include quantifying the marginal value of each new unit of area of habitat (Ricketts and Lonsdorf 2013), incorporating interactions between different habitat types in providing services (Guannel et al. 2016), modeling temporal trajectories for habitat restoration (La Peyre et al. 2014), and, last, confronting models with empirical data. For instance, understanding the relative importance of patch size could help prioritize waterfront parcels for maximizing ecological gains, and improved abilities to predict ecosystem service trajectories could benefit both planning for postimplementation monitoring and managing stakeholder expectations.

As the numbers and types of living shoreline projects implemented in the United States and around the world continue to increase, we have an opportunity to compare across projects. This learning, however, will only occur if project funders make project monitoring a priority. A meta-analysis of project performance (based in part on ecosystem service provisioning and beneficiaries) will advance restoration science and living shoreline implementation by documenting the design elements, site characteristics, and environmental factors that lead to the greatest ecological and societal benefits.

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