NATURAL DEFENSES IN ACTION

HARNESSING NATURE TO PROTECT OUR COMMUNITIES

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Dunes, Stone Harbor, NJ. Photo: Stacy Small-Lorenz/NWF

CONTENTS

CONTENTS iii
EXECUTIVE SUMMARY 1
NATURAL DEFENSES IN ACTION 2
Mounting Risks, Increasing Losses 2
Using Nature to Better Protect Communities 3
What Are Natural Defenses? 4
HIGHLIGHTING WHAT WORKS: PROFILES OF RESILIENCE ALLIES 7
Discouraging Risky Development: Preserving Barrier Islands on Alabama's Gulf Coast 8
Keeping Pace with Rising Tides: San Francisco Baylands Restoration 10
Bringing Back the Bayou: Restoring Flows to Protect Coastal Louisiana 12
Leave It to Beavers: Partnering with Ecosystem Engineers in Oregon 14
Making Way for the River: Moving Out of Mississippi River Floodplains 16
Managing Extremes of Wet and Dry: Floodplain Restoration in California's Central Valley 18
Taking a Softer Approach: Creating Living Shorelines in the Mid-Atlantic 20
Breaking the Fire–Flood Cycle: Forest Management to Reduce Floods in Flagstaff, Arizona 22
Dynamic Dunes: Ecological Approaches to Reduce Risk in Cape May County, New Jersey 24
Plant Power: Stabilizing Great Lakes Shorelines with Native Vegetation 26
Linked Futures: Shared Ecosystem and Community Resilience in Coastal Massachusetts 28
Blending Green and Gray: Hybrid Approaches to Protect New York's Jamaica Bay 30
RECOMMENDATIONS TO EXPAND THE USE OF NATURAL DEFENSES 32
Reform Key Policies 32
Target Research 34
Promote Best Practices 34
ACKNOWLEDGMENTS 35
REFERENCES 36

EXECUTIVE SUMMARY

Natural Defenses in Action highlights the important role that natural and nature-based approaches can play in reducing the mounting risks to our communities from weather and climate-related natural hazards. Harnessing nature to protect people and property is not just a good idea—it already is being done across the country.

This report profiles a dozen case studies that highlight best-in-class examples of how natural defenses are being put to use to avoid or reduce risks from flooding, coastal storms, erosion, and wildfire. These examples of what we call "Resilience Allies" demonstrate that ecological approaches to risk reduction can be good for both people and nature.

Parker River National Wildlife Refuge, MA. Photo: Kelly Fike/USFWS

A collaboration among National Wildlife Federation, Allied World Assurance Company, and Association of State Floodplain Managers, this publication builds on our 2014 report *Natural Defenses from Hurricanes and Floods*, which focused on needed policy changes related to natural disasters.

The best protection from natural hazards is to avoid developing in risky places altogether, such as in active floodplains or on geologically dynamic coastal barrier islands. Conserving open space and intact natural ecosystems will be particularly important for maintaining and enhancing the nation's natural defenses.

Where pre-existing developments are already exposed to risks from severe weather, storm surge, flooding, and other hazards, a variety of risk reduction approaches are emerging that make use of natural features, or that emulate them with human-engineered features. Clearly, there are many places where engineered hard structures will continue to be needed to protect people and property, but even there, blending green and gray approaches can be used to create multiple lines of defense.

Deploying natural defenses is good not only for the environment, but also for the economy. Natural and nature-based approaches can be as, or more, cost-effective as traditional man-made structures, and by avoiding or reducing community risks can decrease taxpayer liabilities for disaster response and recovery and result in lower insurance costs to property owners.

Expanding the use of natural defenses across the country will, however, require policy reforms that strengthen incentives for the use of nature-based approaches and that discourage the proliferation of hard structures like seawalls, bulkheads, levees, and dams. It will also require better understanding and research into how nature-based features perform under different conditions, and additional guidance on when and where they are most appropriate, either on their own or in concert with gray infrastructure. And there will be a need to develop and promote best practices for these ecologically promising approaches to disaster risk reduction, through creating and disseminating technical guidance, growing communities of practice, and designing projects that take advantage of emerging principles for climate adaptation and resilience.

As risks from natural hazards mount in the face of rapid climate change, urban population growth, and development pressure, working with, rather than against, the power of nature to protect our communities will only become more imperative.

Hatteras Village, NC. Photo: Cynthia Hunter/FEMA

NATURAL DEFENSES IN ACTION

MOUNTING RISKS, INCREASING LOSSES

From hurricanes and floods to drought and wildfire, extreme weather and climate events impact our communities in many ways. While some effects, like periodically flooded streets, might be considered an inconvenience, other impacts can be devastating, causing loss of life, property, and lasting economic damage. Unfortunately, the frequency and severity of such extreme events is on the rise, and associated costs from natural disasters are spiraling upward.

The National Oceanic and Atmospheric Administration (NOAA) has tracked the rising number of billion-dollar-plus natural disasters over the years. Taking inflation into account, from 1980 to 2015 NOAA recorded a yearly average of 5.2 billion-dollar U.S. weather and climate-related disasters, but between 2011 and 2015 the annual number of such costly disasters more than doubled.[1] In 2015 alone the United States suffered from historic levels of flooding, long-term droughts, and record-breaking wildfires.

The rising frequency, severity, and consequences of these extreme events has multiple causes, some due to patterns of population growth and development, and others rooted in the changing nature of our climate.[2] Coasts and waterways have always been magnets for population centers, providing abundant opportunities for transportation, economic activity, and recreation. Nearly 40 percent of the U.S. population lives in coastal counties, even though those counties constitute just 10 percent of the total land area (excluding Alaska).[3] Similarly, floodplains account for just 7 percent of overall land area, but are home to 15 percent of the nation's urban areas and nearly 10 million households.[4] Continued population growth along our coasts and waterways—and the increasing value of those developments—increases overall risks and costs from floods and coastal storms.

Mississippi River levee break. Photo: Joceyln Augustino/FEMA

A more recent trend has been the dramatic expansion of population into often fire-prone wildland areas, especially in the western United States. The so-called "wildland–urban interface" now contains at least 44 million houses, equivalent to one in every three houses in the country, with the highest concentrations in California, Texas, and Florida.[5] Development in the wildland–urban interface is greatly increasing wildfire risks to people and structures, escalating the costs of major conflagrations, and constraining forest management efforts needed to actually reduce wildfire risks.

Rapid climate change—a phenomenon already underway and accelerating[6,7]—is exacerbating and amplifying the potency of weather and climate-related risks and further compounding problems of development in hazard-prone areas. Warming temperatures and other climatic changes already have led to an increase in the amount of precipitation falling as heavy downpours, increasing risks of localized and regional flooding. Over the past 50 years, for instance, the Northeast has experienced a 71 percent increase in precipitation falling in very heavy events.[8] Rising sea levels, a well-documented symptom of climate change, has been especially acute along parts of the Eastern Seaboard, rising over the past century by more than a foot in places like Philadelphia.[9,10] Coastal cities such as Annapolis, Norfolk, and Miami already are experiencing frequent incidences of "nuisance" flooding, where high tides routinely flood streets and impede normal life.[11] Quite apart from the nuisance factor, elevated sea levels increase the risk of serious coastal flooding by providing an elevated launch pad for storm-driven waves and storm surge, such as occurred during Hurricane Sandy.[12] And as sea levels continue to rise, millions of people in coastal communities will experience increased risk of major flooding, jeopardizing critical infrastructure such as water treatment plants, transportation facilities, and hurricane evacuation routes.[13]

West Alton, MO. Photo: Steve Zumwalt/FEMA

Rim Fire, Stanislaus National Forest, CA. Photo: USFS

Development patterns have contributed to an increase in these risks by putting more and more people in harm's way—often encouraged by outdated public policies and incentives—and by undermining the ability of nature itself to provide protective services. Loss or degradation of natural habitats along our coasts, floodplains, and uplands has diminished the ability of these features to absorb stormwater, buffer wave impacts, and prevent erosion. The unbridled expansion of impervious surfaces is of particular concern, and pavement and other hard surfaces cover more than 43,000 square miles of the United States—an area nearly the size of Ohio.[14] Rain falling on these surfaces cannot be absorbed into the soil, and instead funnels directly into increasingly rain-swollen waterways.

Rapid climate change and sea-level rise are creating new stresses on natural ecosystems, and some habitats, like tidal salt marshes, will need to shift in order to track suitable conditions and remain viable.[15] The pathways for such coastal and inland habitat shifts increasingly are blocked by development and other hard infrastructure, contributing to deterioration of these natural defenses just when they are most needed.

The mounting risks from weather and climate-related disasters are having an enormous cost to both individuals and society as a whole. Total economic losses from Hurricane Sandy alone are estimated to have reached $70 billion, of which about $30 billion were insured losses.[16] The National Flood Insurance Program, which offers federally subsidized flood insurance for homeowners, is now at least $23 billion in the red.[17]

USING NATURE TO BETTER PROTECT COMMUNITIES

Over the past few decades there has been growing appreciation for the value of nature to people, specifically through the provision of "ecosystem services" that promote human well-being and sustain livelihoods.[18] In addition to such important services as clean water and productive soils, there has been increasing attention to the role nature plays, or could play, in moderating extreme weather events and reducing risks from natural hazards.[19,20] Unfortunately, due to historical land use, resource extraction, and development patterns, many of the protective functions that nature provides have been degraded or lost altogether.

In many places, these natural protective features have been replaced by engineered hard structures, such as breakwaters, sea walls, and storm drains. While there are places where such structural approaches are and will continue to be essential for safeguarding property and other human interests, there are other places where a natural approach can be as or more effective.[21] Relying on nature has a number of additional benefits not typically found in engineered structures, including provision of fish and wildlife habitat and enhancement of recreational opportunities.[22] One recent study found that existing coastal habitats reduce by approximately half the proportion of people and property that are most exposed to coastal storms and sea-level rise.[23]

South Cape May Meadows, NJ. Photo: Stacy Small-Lorenz/NWF

Black skimmers. Photo: Heather Paul/Flickr

Regrettably, current approaches for managing risks from weather and climate-related hazards frequently fail to take advantage of the protective functions that natural systems can provide. Instead, public policies and governmental programs at local, state, and federal levels often continue to encourage development in risky areas. At the same time, natural catastrophe policies traditionally have focused on post-disaster response and recovery, rather than emphasizing

pre-disaster preparedness and risk reduction. Even where policies and programs encourage pre-disaster mitigation and pre-positioning of emergency resources, there is still a heavy reliance on structural and mechanical solutions and numerous impediments to employing natural defenses.

This publication is a follow-up to our 2014 report *Natural Defenses from Hurricanes and Floods: Protecting America's Communities and Ecosystems in an Era of Extreme Weather.*[24] That previous report focused on needed policy reforms to address the growing threats of floods and hurricanes across the country. That report laid out five principles for guiding development of public policies capable of safeguarding people and conserving nature in an era of rapid change:

- Better understanding of actual risks can lead to more risk reduction
- Investing in certain risk reductions now can produce large savings over the long term
- Investments in natural infrastructure can maximize resilience
- Actuarially sound insurance provides incentives to reduce risk
- Consideration of social equity is a necessary component of natural catastrophe policy

Shorebirds, San Francisco Bay. Photo: Judy Irving

WHAT ARE NATURAL DEFENSES?

Simply put, the term *natural defenses* refers to the use of natural systems—or engineered systems designed to emulate natural features—that provide protective benefits to people, property, or other valued assets. Natural defenses can be used on their own, or in combination with more traditional engineered structures. Because the science and practice of natural defenses is young and rapidly evolving, questions remain regarding the effectiveness of different approaches in mitigating risks, and therefore when and where various forms of natural defenses may be appropriate, either on their own or in concert with other risk reduction measures.

The U.S. Army Corps of Engineers has characterized the array of coastal risk reduction measures as including natural and nature-based features, non-structural measures, and structural measures.[25] They note that natural features "are created and evolve over time through the actions of physical, biological, geologic, and chemical processes operating in nature," while nature-based features are those that "may mimic characteristics of natural features but are created by human design, engineering, and construction to provide specific services such as coastal risk reduction." Non-structural measures, as defined by the Army Corps, include such things as "modifications in public policy, management practices, regulatory policy, and pricing policy" that can either reduce the probability of exposure to a hazard, or reduce the consequences of exposure. More broadly, non-structural approaches can be viewed as various measures to make existing and future development more resilient to hazards, with techniques including regulations, zoning, buyouts, construction standards, and protection of natural systems like streams, floodplains, and wetlands.[26] For our purposes, we consider non-structural measures that encourage or mandate the use of natural or nature-based approaches for risk reduction—for instance, avoidance of development in hazard-prone and environmentally sensitive areas—as forms of natural defenses.

Boca Chica Key, FL. Photo: NPS

Risks often are evaluated in terms of how likely they are to occur (i.e., probability) and the damages that would result if they did happen (consequences). Natural defenses, depending on the circumstances, can be used either to reduce the likelihood that

an extreme event may affect a community, or to ameliorate its impact if it should occur. Understanding the possible consequences of failures in protective measures (whether structural or nature based) is a key element of preparedness and risk management. As dramatically illustrated by levee failures during Hurricane Katrina, however, communities can be lulled into a false sense of security regarding degree of actual risk.

Avoiding Risk

The best way to reduce risk, of course, is to avoid it altogether. This depends on having an accurate understanding of where natural hazards exist, as well as which areas may be exposed to those hazards in the future. For example, as climate change affects precipitation patterns, the footprint of so-called "100-year floods" (which really means areas with a 1 percent probability of flooding in any given year) will expand dramatically.

Policies or incentives to avoid development of ecologically sensitive and hazard-prone areas are one of the most important and effective means of protecting people and sustaining the protective value of natural habitats. Where development already has occurred in such risky areas, which often are subject to repetitive losses from floods or other hazards, relocating development and restoring the areas to a more natural state (for instance, reconnecting floodplains with their river) can similarly protect people and communities and reestablish natural protective functions.

Reducing Risk

Most natural and nature-based approaches offer opportunities to reduce rather than completely avoid risks, often because they are being applied retroactively in efforts to protect properties already occupying hazard-prone sites. Such risk reduction approaches can range from protecting intact ecosystems on nearby lands and waters to blending green and gray infrastructure approaches.

Protecting Intact Natural Systems

Protecting open space and existing natural habitats are among the most cost-effective ways of reducing risk to communities. Such natural areas can also provide other important services to local communities, from clean water, recreational opportunities, and fish and wildlife habitat. Numerous studies have also found significant positive effects on local property values from adjacency to parks and other protected open space.[27] There are a variety of mechanisms used to protect open spaces and priority habitats from development, ranging from federal and state designations, such as parks, nature reserves, and wildlife refuges, to land acquisition and conservation easements, local zoning (e.g., development restrictions in floodplains, designation of riparian buffers), and policies that restrict federal subsidies that promote developments (e.g., Coastal Barrier Resources System). In the face of climate change–induced habitat shifts, conserving undeveloped open space adjacent to natural ecosystems (for instance, inland from tidal marshes) will become increasingly important in sustaining the protective function of these habitats.[28]

Floodplain buyout property, Crystal City, MO. Photo: Anna Westervelt/FEMA

Cumberland Island, GA. Photo: NPS

Restoring Natural Systems

Because many natural habitats have been lost or degraded, ecological restoration is an important approach for not only rebuilding protective functions, but providing a host of other environmental benefits and enhancements. Restoration efforts can vary greatly, depending on the type of system, degree of remaining system functionality, and complexity and scale of the task. Ecological restoration efforts can range from rehabilitating a small site (a single wetland, for instance) to major regional restoration efforts (e.g., restoring coastal Louisiana marshlands). Although considerable ecological restoration expertise exists for certain system types, there is less experience in designing restoration efforts specifically to provide protective benefits and natural hazard risk reduction.[29] Restoration efforts focused on risk reduction can include practices like prescribed burns to reduce wildfire and associated floods and mudslides, tidal marsh restoration to buffer coastal waves, and restoring hydrological connections between rivers and their floodplains to reduce downstream flood impacts.

Creating Nature-Based Features

Constructing engineered features designed to mimic natural features and functions can also be an effective approach for reducing risks. Nature-based features can include such things as engineered dune complexes to buffer coastal communities, and living shorelines that use mostly native materials (biological and physical) to stabilize shorelines.[30] Engineered reefs, built from or serving as substrate for oysters or corals, are another focus of active experimentation with potential wave attenuation and shoreline protection benefits.[31] Because many traditional ecological restoration efforts require engineering, design, and construction, restoration of purely natural systems and construction of nature-based features are probably best viewed as occurring on a continuum, and any given project may have elements of both.

Oyster reef installation, Mobile Bay, AL. Photo: Craig Guillot

Combining Natural and Manmade Features

Increasingly, practitioners are identifying opportunities to blend green and gray approaches to risk reduction. In some places the protective functions of a structural feature can be augmented with those provided by a natural or nature-based feature—such as dunes, marsh, or natural floodplain—creating "multiple lines of defense."[32] Creating such green–gray hybrids, where ecologically appropriate, can soften the impacts of the structural feature and provide other environmental benefits typically associated with natural infrastructure.[33] Integrating natural, nature-based, non-structural, and structural approaches recognizes that risk reduction needs and opportunities are highly site specific and depend very much on the geophysical and ecological setting as well as the type and sensitivity of the assets to be protected. Given the traditional reliance on structural measures in most heavily populated areas, opportunities to promote and expand the use of natural and nature-based features will often involve incorporating them into such integrated, hybrid risk reduction systems.

Dealing with Residual Risk

No matter what risk avoidance and reduction measures are put into place—whether structural, non-structural, or nature-based—a certain level of risk often remains, particularly in the face of extreme events and major natural catastrophes. For example, properties behind levees or below dams may have flood risks that are not well-recognized by the public.

"Residual risk" traditionally is addressed through the use of insurance, offered through private insurers or through federal or state programs, which serves to spread the financial burden of that risk across a broad population pool. Flood hazard maps generally do not reflect residual risks behind "protective" structures, however, and as a result flood insurance is not required or typically purchased for such properties. A secondary mechanism to address residual risk is through government disaster response and recovery programs, such as those authorized under the Stafford Act and administered by the Federal Emergency Management Agency. Although important, such programs typically do not make people whole after a flood event.

Insurance not only can allow homeowners and communities to recover and rebuild from disasters, but properly priced can provide powerful market signals and incentives for them to take steps to avoid or reduce risks, including through the use of natural defenses. Similarly, disaster response and recovery programs can be used to more proactively reduce risks, including by promoting nature-based measures and encouraging and rewarding more resilient designs during reconstruction, through protecting open space and natural buffers, and through offering voluntary buyouts of properties subject to repetitive losses.[34]

HIGHLIGHTING WHAT WORKS

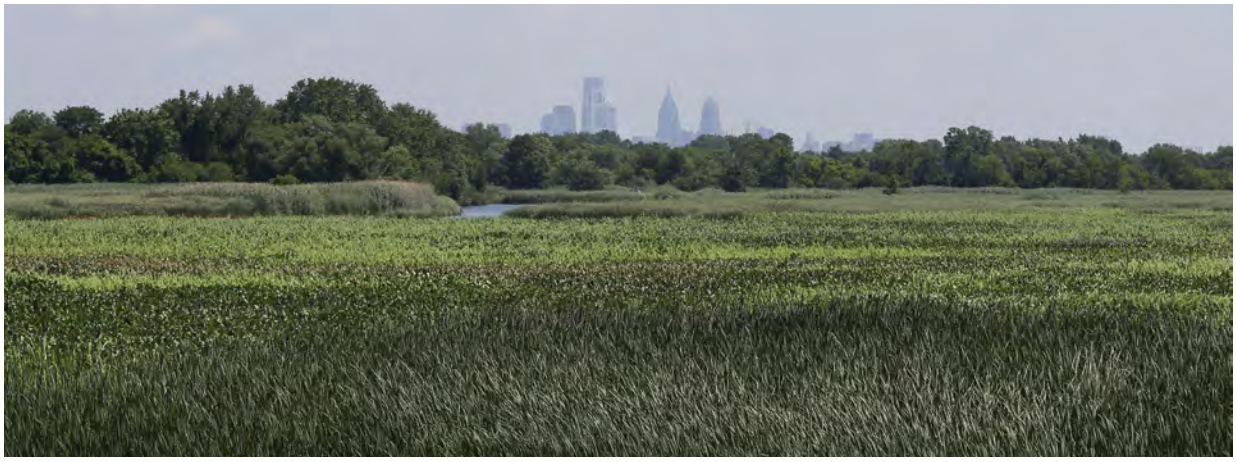
PROFILES OF RESILIENCE ALLIES

Natural defenses not only are a good idea, they already are being put into practice. To promote the broader adoption of natural and nature-based approaches to risk reduction, this report highlights a number of best-in-class examples of how this is being carried out, followed by a set of recommendations for advancing the broader adoption of natural defenses. The pages that follow offer profiles of how nature is being harnessed to protect people and communities across the country. These case studies address different types of hazards—ranging from coastal and inland flooding to wildfires and drought—and employ a range of approaches, from preserving open space, restoring wetlands, and thinning forests, to employing beavers as restoration assistants.

These case studies were drawn from a national solicitation that was carried out in late 2015, and supplemented by background research and interviews with leading practitioners. The case studies focus on projects, communities, or landscapes where natural or nature-based approaches to reducing risk are being developed and implemented. These examples are as varied as the American landscape itself, and reflect the ingenuity and innovation that is underway as people grapple with how to use nature to address the hazards currently facing their communities, as well as prepare for the rapid changes that are yet to come.

Carpenter Fire, Toiyabe National Forest, NV. Photo: USFS

Hurricane Joaquin, Oct. 2015. Photo: NOAA



Heinz National Wildlife Refuge with Philadelphia skyline. Photo: Jim, the Photographer/Flickr

DISCOURAGING RISKY DEVELOPMENT

PRESERVING BARRIER ISLANDS ON ALABAMA'S GULF COAST

I don't understand why people build on sandbars. They are dynamic things. They are not fixed. They will move. They will decay. They will grow. And trying to nail one down by building houses on it, we're fighting Mother Nature.

– John Christy, Alabama State Climatologist[35]

Along our coastal barrier islands an ounce of prevention is worth more than a pound of cure, something nowhere more vividly illustrated than Dauphin Island, Alabama. Avoiding the risks associated with putting houses in harm's way is at the heart of the Coastal Barrier Resources Act (CBRA), a law that has helped to keep environmentally sensitive portions of Dauphin Island intact and free of development and storm-related losses.

Strung along the Atlantic and Gulf coastlines like a strand of jewels, barrier islands buffer many parts of the mainland from the power of the open ocean. In their intact state, these islands serve as one of our most powerful natural defenses. Subject to the constant forces of the wind and waves, though, barrier islands are shape-shifters and in constant flux. Sediment is transported from one location to another, dunes form and shift across the landscape, maritime forests spring up to the rear, and the sheltered bays behind the islands sustain highly productive fish and shellfish habitat.

Monarch butterflies, Dauphin Island. Photo: Barbara Ashe

As climate change results in stronger and more frequent coastal storms, a healthy system of barrier islands can prevent more devastating impacts to cities and towns on the mainland. These sand banks are also highly valued as oceanfront property. From Portland, Maine, to Galveston, Texas, barrier islands have been the sites of increasing concentrations of wealth in the form of beachfront real estate. The permanence of human settlements does not lend itself to the ever-changing nature of barrier islands, however, something repeatedly made clear by the astronomical cost of storm damage to barrier island developments in places such as Atlantic City, New Jersey, and the Outer Banks of North Carolina.

In 1982, President Ronald Reagan signed into law the CBRA to prevent additional risky development on remaining intact and environmentally sensitive portions of our barrier islands. The Act was passed not just to protect against further loss of important natural resources, but to reduce threats to human life, health, and property, as well as to protect U.S. taxpayers from the burden of paying again and again to rebuild in these risky and storm-prone areas. Administered by the U.S. Fish and Wildlife Service, there are now 585 designated units in the system covering about 1.3 million acres. The Act does not bar development outright from designated areas, but rather removes federal incentives for new development, making these areas ineligible for most new federal expenditures and financial assistance, including federal flood insurance. Savings to federal taxpayers from 1983 through 2010 are estimated at about $1.3 billion, with another $200 million in avoided disaster relief estimated through 2050.[36]

Dauphin Island, Alabama, a barrier island located three miles south of Mobile Bay, provides an excellent example of how the Act, in concert with other federal, state and local policies, can be effective in avoiding risks to people and property from hurricanes and coastal storms. When the western spit of Dauphin Island was designated a Coastal Barrier Resources System Unit, state and local level legislation was enacted to align with and codify the goals of the Act. The State of Alabama drew their coastal construction control line to match the boundary of the federal designation. Local officials then zoned the land as conservation and parkland, effectively prohibiting future development. U.S. Fish and Wildlife officials cite such coordination among federal, state, and local regulations as a best practice applied in those areas where the Act has been most effective.[37]

The effectiveness of these measures are highlighted by comparing the island's undeveloped areas—protected under the CBRA—to the highly developed portions of the island, such as the Town of Dauphin Island. Dr. Robert Young, Director of the Program for the Study of Developed Shorelines at Western

Dauphin Island after hurricanes Ivan and Katrina. Photo: Tyrone Turner/Getty

Carolina University, testified before Congress that between 1988 and 2014 the 1,200 residents of Dauphin Island had paid $9.3 million in flood insurance premiums to the federal government, but received $72.2 million in payouts for their damaged homes. In contrast, due to the layering of federal, state, and local regulations, none of the land designated under the CBRA had seen new development or required federal assistance.

As coastal storms continue to wreak havoc on beachfront communities, the CBRA can provide a platform for state and local officials to develop regulations that prevent future development or the rebuilding of repetitive loss properties. In contrast, some state and local officials are moving in exactly the opposite direction, seeking to remove properties from the Coastal Barrier Resources System and promoting additional development in these sensitive and hazardous areas.

Such steps would be counterproductive to efforts needed to enhance community resilience and adapt in the face of climate change. Strong defense of existing units of the Coastal Barrier Resources System is needed to ensure that these geologically dynamic islands remain natural and intact, and continue to buffer the mainland from coastal storms and hurricanes.

At a Glance

- Barrier islands buffer the mainland from the power of the open ocean; development interferes with natural processes like dune formation, reducing the island's protective value.
- Designations under the Coastal Barrier Resources Act (CBRA) remove federal incentives for risky development; complementary state and local regulations can help conserve these dynamic and protective ecosystems.
- From 1988 to 2014, inhabited portions of Dauphin Island received $72.2 million in National Flood Insurance Program payouts; areas protected under CBRA did not require any payouts.

KEEPING PACE WITH RISING TIDES

SAN FRANCISCO BAYLANDS RESTORATION

Look at a map of the Bay today and around most of its shoreline, you'll see a clear boundary between water and land. That's partly mapmakers' convenience and partly a reflection of the way we've reengineered the Bay shore. But 300 years ago, you might have found it hard to tell just where the Bay ended and the land began. The interface between land and water was ever-shifting, pulsing like the heart of California.

– Chris Clarke, San Francisco Bay's Lost World[38]

Clapper rail, Corte Madera, CA. Photo: Len Blumin/Flickr

Tidal marshes and other coastal ecosystems can function as natural infrastructure in the San Francisco Bay region, providing cost-effective protection against extreme floods and sea-level rise, but only if their restoration and protection are made an urgent priority.[39]

Numerous factors put South San Francisco Bay cities at high flood risk, including low elevations, sea-level rise, and historical conversion of tidal wetlands to commercial salt ponds. Sea-level rise, in particular, threatens the long-term survival of the marshes that serve as critical natural buffers. According to the 2015 climate science update to the 1999 Baylands Ecosystem Habitat Goals ("Baylands Goals"), most of San Francisco Bay's protective marshes will be damaged or destroyed by 2100 without immediate intervention.[40]

The Baylands Goals update represents "the most current state of climate science and impacts for San Francisco Bay, and the highest priority adaptation actions to save habitat and protect communities" according to Marilyn Latta of the California Coastal Conservancy. It calls for new adaptation approaches to restoring the bay's tidal marshes to meet an established restoration goal of 100,000 acres. That represents half of the original tidal marshes and would result in a more resilient shoreline. Restoring ecological integrity to significant portions of the baylands by 2030 is anticipated to help them flourish by the time sea-level rise accelerates in the mid-21st century.

It also calls for conservation of transitional zones between the baylands and uplands to allow marshes to migrate landward, where space allows, as sea level continues to rise. This is made especially urgent by the fact that old earthen levees, flood control channels, and other engineered infrastructure that were built right at the edge of the bay will provide inadequate future protection in places like Silicon Valley under projected sea-level rise.

Restoring baylands ecosystems and conserving upland transition zones to allow for inland migration of wetlands is a multi-benefit way to offset rising water levels and storm impacts in the future. However, critical processes like water and sediment flows must be restored to allow these baylands to keep pace with sea-level rise, coastal scientists say. Current sediment supply is not adequate to allow marshes to grow vertically in response to sea-level rise, and scientists are calling for application of clean dredged materials as part of a comprehensive regional sediment management plan.

One promising effort being implemented in the region is the South Bay Salt Pond Restoration Project, a combination of infrastructure modifications and restoration of former salt ponds to tidal marsh, as recommended under the South San Francisco Bay Shoreline Study.[41] The project is the largest tidal wetland restoration effort on the West Coast, and aims to restore 15,100 acres of former commercial salt ponds in South San Francisco Bay to functional tidal marsh when complete, for purposes of flood management for South Bay cities, habitat, and public access. So far, 1,500 acres of functional tidal marsh have been restored.

Another project, the San Francisco Bay Living Shorelines Project, demonstrates how natural features such as submerged aquatic vegetation and native oysters in the subtidal and intertidal zones can reduce wave energy (up to 30–50 percent) and potentially protect adjacent shorelines from erosion and storm impacts.

Coordination of permitting for living shorelines among coastal resource agencies and stakeholder engagement will be two key elements to successful and more widespread adoption of living shorelines efforts in California and beyond, keeping in mind that ecological approaches to shoreline management bring habitat, fisheries, and water quality co-benefits that hard armored shoreline engineering projects do not.

Large-scale tidal marsh restoration, open space planning, and living shorelines pilot projects are showing great promise to provide storm surge reduction benefits and protect adjacent shorelines at a much larger scale throughout the San Francisco Bay region.

Opposite Page : Alameda Creek, San Francisco Bay. Photo: Doc Searls/Flickr

At a Glance

- Sea-level rise makes restoring tidal marshes an urgent priority; regional goals call for 100,000 acres of restored marsh around San Francisco Bay.
- Living shorelines using submerged aquatic vegetation and native oysters can reduce wave energy and protect shorelines from erosion and storm impacts.
- Regional open-space planning provides room for wetlands to migrate inland as sea level rises.
- Outdated hard infrastructure at the edge of the Bay offers inadequate flood protection for future conditions in places like Silicon Valley.
- Coordination of permitting processes among agencies will be key to more widespread adoption of living shorelines approaches.

BRINGING BACK THE BAYOU

RESTORING FLOWS TO PROTECT COASTAL LOUISIANA

The river built the coast; the river is required to sustain it.

– Virginia Burkett, U.S. Geological Survey[42]

The marshes of coastal Louisiana are a national treasure that is fast disappearing. Innovative ecological restoration efforts in places like the Barataria Basin, however, showcase how reconnecting the Mississippi River to its historic delta can both enhance fish and wildlife habitat and rebuild the natural defenses these marshes provide to protect coastal communities.

The Mississippi River delta is home to a rich diversity of habitats, including approximately 40 percent of the coastal wetlands in the continental United States, and serves as the first line of defense against the impacts of storm surge to coastal Louisiana's communities, from the city of New Orleans to the tiniest coastal fishing community. It was a dynamic system. Because the river was free to wander, switching channels and breaching its own natural levee confinement, the delta contained both growing freshwater areas of riverine influence and retreating brackish estuarine areas of Gulf of Mexico marine influence. For thousands of years, sediment flowing into the delta from the great Mississippi River built new land while sustaining existing marshes, swamps, and barrier islands, and keeping the delta in balance.

Construction of levees for flood protection, canals for oil and gas access, and channels around the river's entrance for the transport of goods have had great near-term economic benefits, but came at a grave ecological cost. They also came with long-term economic and social costs, now coming due. These levees and channels cut off the natural flow of freshwater and sediment into the delta, upsetting the freshwater–saltwater balance, and tipping the system toward victory for the erosive forces of the Gulf, resulting in an astonishing rate of land loss.

Jean Lafitte Swamp, LA. Photo: Donna Pomeroy/Flickr

Land loss not offset by inputs of new sediment will increasingly be exacerbated by the effects of climate change—including increasingly severe storms and rising sea levels—and channeling and ditching from oil and gas operations. Because erosion and subsidence are vastly outpacing sediment accretion in the Delta, some of the most ecologically valuable marsh and estuarine ecosystems in the world are drowning, putting many coastal Louisiana communities at increased risk from hurricanes and coastal storms.

The town of Jean Lafitte, located just west of the Mississippi River in the Barataria Basin is a small fishing community, like many other towns in the area. The flood protection benefits from the levees surrounding the New Orleans metropolitan area just to the north do not reach as far as Jean Lafitte. Moreover, the marsh systems and barrier islands, a natural first line of defense from storms for Jean Lafitte and metropolitan New Orleans beyond, are quickly disappearing. Recent strong storms, including Hurricane Rita in 2005 and Hurricane Isaac in 2012, demonstrated how vulnerable towns like Jean Lafitte have become to storm events. Alisha Renfro, a coastal scientist at National Wildlife Federation, says that "rebuilding and enhancing the natural buffer system provides towns like Jean Lafitte, which lack federal 100-year levee systems, the protection they don't currently have from storm surge."

Restoring river flows and sediment into the Barataria Basin is one of the most important components of Louisiana's landmark Coastal Master Plan. Penalties from the Deepwater Horizon oil spill are now providing a major source of financing for coastal Louisiana restoration, including Barataria Basin, through the federal RESTORE Act. Two linked projects that exemplify new approaches to putting sediment from the river back into its delta are the large-scale marsh creation that will lead to a restored Barataria Basin Land-Bridge and the Mid-Barataria Sediment Diversion. These projects are using sand from the Mississippi River's bottom along with silts and clays carried in its streamflow to build new land, nourish existing marsh, and help prevent saltwater from the Gulf of Mexico from penetrating into freshwater marshes and swamps in the mid to upper reaches of the basin. These newly built and restored marshes

Bottom Opposite Page: Sediment transport pipeline. Photo: KDW/NWF

Great egret, Jean Lafitte, LA. Photo: Larry Daugherty/Flickr

will also help reduce storm surge and tidal flooding for the coastal community of Jean Lafitte, as well as for metropolitan New Orleans and nearby Jesuit Bend and Myrtle Grove.[44]

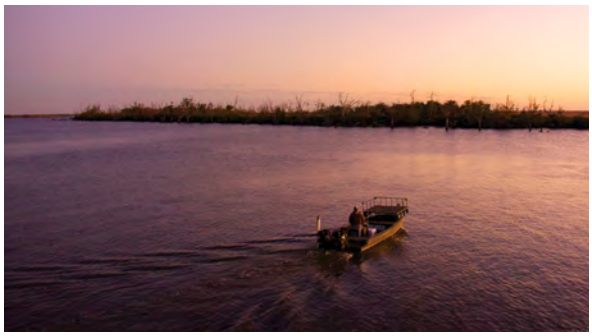
The land-bridge project uses an extensive pipeline system to pump sand and sediment from the Mississippi River. More than 1,000 acres of marsh have been built so far and 1,000 more are currently under construction. Ultimately, the project will create more than 8,000 acres of marsh, forming an intact marsh land bridge that will help separate the Gulf's saltwater from freshwater marshes farther inland.

A related project, the Mid-Barataria Sediment Diversion, will supplement the Barataria Land-Bridge restoration by using a gated structure built through the levee system, which can redirect sediment and freshwater flow into the Barataria Basin and mimic natural fluvial patterns, building a new sub-delta adjacent to the land bridge. The gates can be strategically opened and closed, to account for changes in river levels, thus minimizing effects on river navigation while advancing marsh restoration goals.

Although sediment diversion projects might be difficult to apply elsewhere due to the specific set of conditions needed, the Barataria Basin projects demonstrate how to supplement existing restoration initiatives in a sustainable way. These projects in the Barataria Basin illustrate the kind of forward-thinking and bold vision that is necessary to reverse years of decline in the nation's "vanishing paradise" and to rebuild the protective functions of these ecosystems for coastal Louisiana's culturally rich local communities.

At a Glance

- Louisiana's 2012 Coastal Master Plan is a visionary and large-scale restoration plan that recognizes the role of healthy coastal habitats in protecting people and the economy, while addressing land subsidence and sea-level rise.
- To reverse large-scale land losses, delta restoration efforts seek to build new land, nourish existing marsh, and reestablish the saltwater–freshwater balance needed for coastal habitats to flourish.
- Engineered structures are providing water and sediment flows needed to restore marshland, and to reestablish and sustain the marsh's protective benefits.
- Penalties from the Deepwater Horizon oil spill are now a major source of financing for coastal Louisiana restoration, and the federal RESTORE Act mandates that significant funding be directed to ecosystem protection and restoration.



Barataria Bay. Photo: Kenneth Garcia/Flickr

LEAVE IT TO BEAVERS

PARTNERING WITH ECOSYSTEM ENGINEERS IN OREGON

The beavers have taken back what they'd lost–not only for themselves but for so many other species.

– Kendra Smith, Bonneville Environmental Foundation[45]

In the Columbia River watershed of western Oregon, beavers are proving to be an invaluable partner in taming floods, moderating water shortages, cooling water temperatures, and restoring habitat for fish and wildlife, including coveted salmon. They are a prime example of how re-establishing nature's own engineers can help reduce the need for human engineering.

Beaver. Photo: Bob Armstrong

The Tualatin River basin drains 712 square miles of land, its main river flowing from forested mountains, through agricultural valleys, and finally tumbling past the densely populated communities of Tualatin and West Linn before entering the Willamette River, upstream from its confluence with the Columbia River.[46] Flooding is nothing new to Tualatin Basin communities. Flood risks can be high, especially near the mouth of the Tualatin River—the most urban area. — and Clackamas County has nearly 10,000 individual parcels partially or entirely located within the floodplain.[47]

Under changing climatic conditions, the Pacific Northwest is projected to experience an increase in heavier rainfall events and potential for flooding in the fall and winter, along with enhanced drought conditions and lower streamflows in the summer months—including in western Oregon. Water managers are faced with the problem of both too much and too little water.[48]

A comprehensive survey of the Tualatin Basin revealed that many heavily incised streams no longer had functional connections to their floodplains. Water rushing through the channelized system was causing erosion and sedimentation and failing to recharge groundwater, and floodplains were dominated by invasive reed canary grass. Watershed managers recognized that a basin-wide approach was needed to restore the system to improve water quality and groundwater recharge, and to moderate flood risks.

Kendra Smith, principal author of the 2005 Healthy Streams Plan, realized that native beavers and their preferred food sources were missing from the system. As a result, she worked with city governments to plant native riparian vegetation, end beaver extirpation efforts, and refocus trapping efforts on nutria, an invasive mammal that can cause considerable streamside erosion. By 2014, the number of beavers in the area had almost doubled and their impact was clear: What had once been dense thickets of invasive reed canary grass had transformed into forested, healthy wetlands, improving resilience against drought, enhancing biodiversity, and reducing flood risk to downstream communities.[49]

Beavers don't single-handedly prevent floods, of course. But when active in a watershed they can provide significant flood attenuation benefits. Beaver activity slows water flow and spreads water across the floodplain, helping create vibrant riparian habitats and wetlands. Wetlands in turn can store excess water, increase infiltration, and facilitate groundwater recharge, helping to maintain summer flows. Diminished flow velocities reduce channel incision and erosion. These various hydrologic benefits all help to improve water quality and mitigate against seasonal and climate-driven flood-drought cycles.[50]

Beaver restoration in the Tualatin Basin also helped a wastewater treatment facility avoid building an expensive and energy-intensive wastewater chiller, which otherwise would have been needed to comply with water temperature regulations. Instead, riparian vegetation generated by beaver activity helps keep water cool for salmon and other temperature-sensitive aquatic species. The increased water residence time, combined with shade from streamside trees and shrubs, significantly slows the rate of surface water warming.

Further down the watershed, beaver also helped solve a challenging ecological restoration problem in the Mason Flats area of northeast Portland. At this site, beaver activity naturally improved water infiltration, a problem that would have been difficult and costly to fix mechanically. An adjacent industrial park and airport are now drained more effectively by this restored wetland, reducing flooding hazards and lowering the cost of stormwater infrastructure and maintenance.

Tualatin National Wildlife Refuge. Photo: Darryll DeCoster/Flickr

Regulations protecting riparian zones have been important to the success of restoring beavers. In the Tualatin River Basin, riparian buffers reduced human-animal conflict in suburban and urban areas and ensured that adequate space was available in the floodplain for water storage and infiltration during storms. If development wasn't set back from stream banks, flood damage would occur more often, and the capacity of beavers to restore riparian wetlands would be compromised.

"Beavers were really the limiting factor here," said Smith. In many cases, beaver activity provides similar or better results than human-engineered wetland restoration projects, and practitioners can achieve many of their aims more cost effectively by allowing beavers to perform their natural feats of ecological engineering. Based on such experiences, land and water managers across the West are looking to beavers to help enhance riparian and wetland habitats, and improve flows while offsetting drought and flood extremes.

1996 Tualatin River Flood Peak. Photo: SoulRider.222/Flickr

At a Glance

- Beavers are important ecosystem engineers that can be highly effective at restoring wetlands and riparian forests.
- Beaver-created wetlands can reduce downstream flood risk by slowing and retaining floodwaters, and help recharge groundwater and sustain summer water flows.
- Existing regulations protecting riparian buffers in the Tualatin Basin were key to beaver recovery and wetland regeneration.
- Beaver-created wetlands and riparian forests keep water temperatures cool for salmon, and eliminated the need for a costly chiller for urban wastewater treatment.

MAKING WAY FOR THE RIVER

MOVING OUT OF MISSISSIPPI RIVER FLOODPLAINS

You know, they straightened out the Mississippi River in places, to make room for houses and livable acreage. Occasionally the river floods these places. "Floods" is the word they use, but in fact it is not flooding; it is remembering. Remembering where it used to be. All water has a perfect memory and is forever trying to get back to where it was.

– Toni Morrison, The Site of Memory[51]

At the confluence of the Illinois and Mississippi rivers, 40 miles upstream from St. Louis, sits the city of Grafton, Illinois. Because of its location, Grafton suffers from frequent floods when waters rise in the Mississippi, Illinois, or the even the Missouri River. In its 150-year history the city has flooded, on average, every two years.

This history of repetitive flooding is played out in numerous cities and towns built on the historic floodplains of the Mississippi River and its tributaries. While many of these communities use hard structures, such as floodwalls and levees, in an attempt to control the river and reduce flood risk, history has shown that these structural measures can fail, often with disastrous consequences. In the Great Midwest Flood of 1993, hundreds of levees were breached.[52]

In light of repetitive flooding, and the prospect for even higher flood risks in the future due to a changing climate, communities along the Mississippi are beginning to acknowledge that at times, it is better to move out of harm's way than continue to fight floodwaters. Grafton illustrates how making way for the river can work—and how it could be improved in the future.

In 1993 both the Missouri and Mississippi rivers exceeded the 100-year flood stage, and in sections even surpassed the 500-year flood mark.[53] Grafton was submerged for more than six months and floodwaters were up to 15 feet deep. As the waters receded, town officials, led by Mayor Richard Mosby, began to assess the damage. Two-hundred sixty structures were damaged. One hundred experienced damages over 50 percent of market value and were required to be elevated or were bought out and relocated. In total, 88 properties were bought out using $2.3 million in Federal Emergency Management Agency (FEMA) Hazard Mitigation Grant Program funds and $773,636 in matching funds from the state.[54] In conjunction with buyouts of damaged properties within the floodplain, the town purchased land on top of the bluff and made it available for purchase by those who wished to relocate to higher ground. In total, 70 homes and 18 businesses relocated out of flood-prone areas.

While relocation is often considered a measure of last resort, it has been extremely effective at reducing risk in Grafton. In 2015 the town experienced the fourth highest floodwaters in its history but the relocations, combined with the decision to maintain the riverfront as open space, meant the impact on the town was minimal despite the absence of a levee.

Voluntary, proactive relocations and rezoning of flood-prone areas as open space and parklands not only makes economic sense, it keeps lives and property out of harm's way. It also allows the river to reconnect with its natural floodplains, supporting more productive and diverse ecosystems. On top of that, floodplain wetlands and forests can dissipate and slow floodwaters, increase flood storage capacity, and reduce downstream flood peaks.

Mississippi River, Grafton, IL. Photo: bk1bennett/Flickr

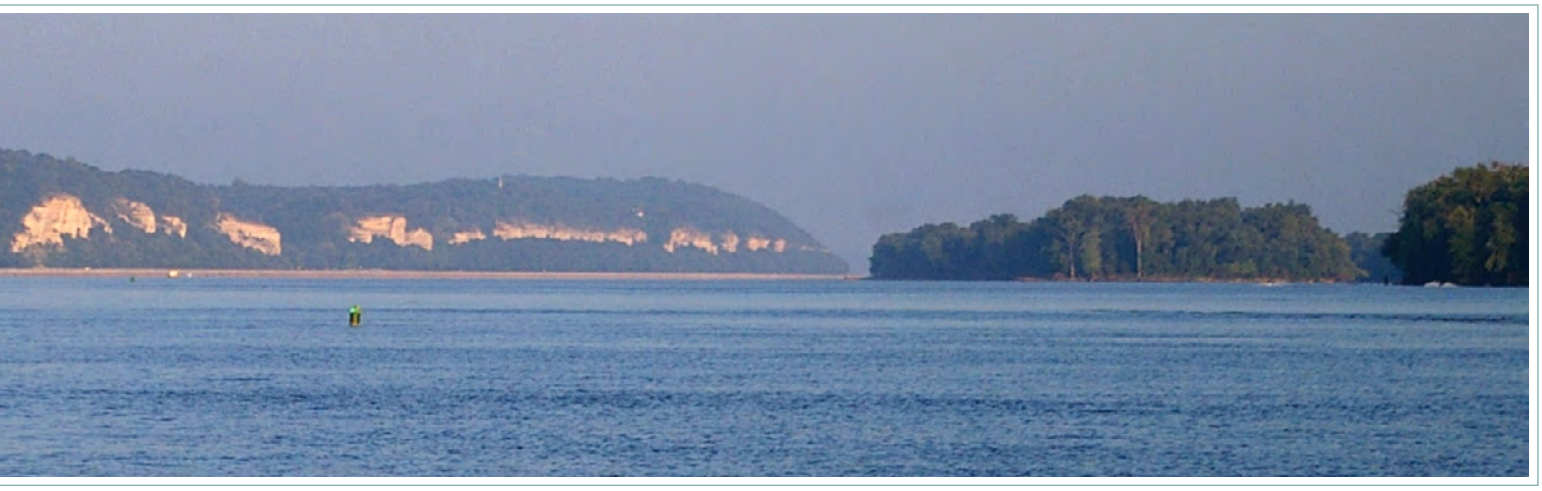
Relocation efforts can also be effective in larger urban areas within the Mississippi River watershed. In 2008, Cedar Rapids, Iowa, experienced a devastating flood that dislocated 18,000 people, damaged more than 7,000 properties, and caused billions of dollars in losses.[55] In response, the city undertook a massive buyout and relocation program, purchasing 1,300 damaged properties. Many of the properties were commercial, and owners used the funds to relocate elsewhere within the city. Cedar Rapids is now moving forward in creating a system of parks and open space along their riverbanks that will be designed to accommodate floods.

Restricting new development in floodplains, and especially the active floodway, is the best way to limit flood losses, but voluntary buyouts and relocation can be an effective means to avoid repeated loss. The process to access FEMA buyout and relocation assistance can be onerous, however. Paul Osman, the State Floodplain Manager for Illinois, says that this process can take up to three years, post-disaster. As midwestern flooding events continue to increase in frequency and magnitude, there will be a need to streamline the process for communities interested in buyouts and relocation to access available public funds. Providing communities with more options for reconnecting rivers to their floodplains, including by moving communities out of harm's way, can have enduring public safety and economic benefits, even as it enhances the river's ecological value.

1993 flood, Grafton, IL. Photo: Liz Roll/FEMA

At a Glance

- Reconnecting the Mississippi River to its floodplains reduces pressure on levees and dams, reduces downstream flood peaks, and creates valuable wildlife habitat.
- In light of increasing flood risks due to climate change, relocation of some flood-prone communities, or portions of communities, can be an economically sound option for risk reduction and avoidance.
- Discouraging building or rebuilding in active floodways can limit flood losses; rezoning floodplains as community open space helps reduce risks from future floods.
- Timely payout of federal funding for voluntary relocation of properties subject to repetitive flooding is essential to help people move out of harm's way.



MANAGING EXTREMES OF WET AND DRY

FLOODPLAIN RESTORATION IN CALIFORNIA'S CENTRAL VALLEY

I know as well as the next person that there is considerable transcendent value in a river running wild and undimmed…but I have also lived beneath such a river when it was running in flood, and gone without showers when it was running dry."

– Joan Didion, Holy Water[56]

The floodplains of California's Central Valley are a place of near-mythical agricultural abundance that have also seen rapid urban population growth in recent years, including the greater Sacramento region. They're also facing growing extremes of flood and drought in the face of climate change and population pressures on California's highly managed water system. In light of such observed and anticipated extremes of wet and dry, ecological floodplain management is a cost-effective strategy that is robust to the uncertainties of future climates.

Sand hill cranes. Photo: Bob Wick/BLM

Several significant projects throughout the Central Valley are striving to manage floodplains in ways that increase a their capacity to take on and dissipate floodwaters in natural areas, resulting in reduced downstream flooding, recharging of dwindling groundwater supplies, and improved habitat for fish, birds, and other wildlife.

Techniques include setting back or breaching levees to reconnect the river channel to the floodplain in undeveloped locations; restoring marginal flood-prone farmland to native riparian vegetation; using floodplain easements and water management infrastructure to reroute floodwaters around dense urban areas; and re-creating more complex floodplain topography in ways that increase the channel roughness to slow and capture floodwaters, while creating or improving fish and wildlife habitat on the floodplain.

A key example is the Cosumnes River, a tributary of the Mokelumne River in the Sacramento–San Joaquin Bay delta, and the only river without a major dam flowing out of the western slope of the Sierra Nevada range. "The Cosumnes is a premier laboratory for levee setbacks and re-engineering," according to Dr. Joshua Viers at University of California Merced. "It's a place that was once perennially wet, but groundwater overdraft from pumping and water diversions, compounded by drought, have left the river dry every summer and fall now."

Accidental and intentional levee breaches, levee removal, and setbacks have reopened hundreds of acres of undeveloped floodplain, allowing natural areas to take on and absorb floodwaters from heavy rains and seasonal snowmelt. Conservation and flood easements purchased by The Nature Conservancy have set the stage for such experiments, with results that have application throughout the Valley and beyond.

Sierra Nevada snowpack is the state's largest natural surface water reservoir, sustaining Central Valley rivers, cities, and farms via a highly engineered water delivery system of dams, levees, and conveyance structures. Climate change–related precipitation shifts, including snowpack decline and more winter precipitation falling as rain, combined with growing urban populations and groundwater depletion, make water management issues in times of floods and droughts some of the most pressing issues facing California.[57]

In addition to dwindling snowpack, groundwater resources are being vastly depleted via pumping for cities and agriculture, causing land subsidence in parts of the San Joaquin Valley so extreme that it puts water conveyance and levee structures at risk and leaves rivers running dry in places.

Ecological floodplain management techniques have the potential for reducing risks of catastrophic flood losses in developed areas while recharging dwindling groundwater resources as insurance against drought and land subsidence. Furthermore, sand and sediment is captured on the floodplain in ways that contribute to land building, rather than sending it out to sea.

Such actions increase the floodplain's capacity to take on floodwaters in places where people and assets will not be harmed, thereby reducing downstream flood risk. Floodwaters are slowed and, where soil conditions permit, filtered as they percolate back into the water table, supporting surface–groundwater exchange and recharging aquifers.

"Allowing the river to reconnect to its floodplains also facilitates the geomorphic evolution of the floodplain, increases topographic complexity, and results in a mosaic of habitats that evolve over time," says Dr. Viers. He points out that soil core samples and radiocarbon dating have also shown that floodplains store carbon for long periods of time, sequestering a potent contributor to climate change.

Cosumnes River Preserve, CA. Photo: Bob Wick/BLM

A related nearby example is the Yolo Bypass, a designated floodway of 60,000 public and private acres between the cities of Davis and Sacramento, created via flood easements that allow the state to flood the land for public safety and ecological benefit. The floodway detours floodwaters around the Sacramento region, flooding roughly six out of ten years. The 16,600-acre Yolo Bypass Wildlife Area managed by California Department of Fish and Wildlife provides essential habitat for fish, waterfowl, shorebirds and wading birds, Neotropical migratory birds, and an array of other wildlife species.

Studies from the Yolo Bypass and Cosumnes River floodplains also show that juvenile salmon grow relatively faster in the relatively warm, shallow, and biologically rich waters of these inundated floodplains, and there is recent evidence that native fish are adapted to find their way out of floodplains as they drain, so as not to be stranded.

A portion of the $7.5 billion in California State water bond funds ("Prop. 1") are to be allocated to riparian and floodplain restoration and management, which could be a significant opportunity to advance ecological floodplain management practices. Debate is heating up, however, regarding allocation of funds for costly dam building versus more ecologically sound "natural infrastructure" floodplain projects.

California is a leading innovator in ecological floodplain management. Projects are underway throughout the Central Valley that demonstrate the feasibility of reconnecting rivers to their floodplains as a low-cost, large-benefit way to capture and store precious western water, while at the same time providing flood risk reduction and wildlife habitat benefits.

At a Glance

- Climate change, groundwater overdraft, and urban expansion into floodplains exacerbate pressures on California's already overtaxed water system.
- Ecological floodplain management, including levee setbacks, is a vital strategy for urban flood protection, groundwater recharge, and fish habitat.
- Reconnecting rivers to floodplains is a cost-effective and ecologically beneficial approach to managing for both flood and drought extremes.
- California's $7.5 billion Water Bond ("Prop. 1") is a significant opportunity for advancing ecological floodplain restoration projects.

Cosumnes River levee breach. Photo: Lorenzo Booth/UC Merced

TAKING A SOFTER APPROACH

CREATING LIVING SHORELINES IN THE MID-ATLANTIC

We're trying to change people's perceptions of what they can do with their shorelines. What's good for the bay doesn't have to be exclusive of what people's goals are [for] their properties.

–Bhaskar Subramanian, Maryland Department of Natural Resources[59]

Over the past decade a quiet revolution has been underway in the Mid-Atlantic region in how property owners and municipalities are protecting their shorelines from erosion. Rather than relying on riprap, bulkheads, and other more traditional hard structures, landowners increasingly are taking greener approaches to shoreline stabilization, known as "living shorelines." These living shorelines seek to re-create or emulate more natural and resilient shoreline conditions.

Eastern Neck National Wildlife Refuge. Photo: Maryland DNR

Estuaries like the Chesapeake and Delaware bays are some of the most productive ecosystems on earth: the mixture of saltwater and freshwater provide unique conditions optimal for many fish and wildlife to spawn, find shelter, and feed. Although they are some of North America's most productive aquatic habitats, they also are quite vulnerable to the combined impacts of climate change, sea-level rise, and long-term land subsidence. In particular, the combination of extreme storm events and exceptionally high relative rates of sea-level rise is having dramatic effects on communities lining these estuaries from erosion and flooding, and leading to accelerated land loss.

The Chesapeake Bay alone has more than 11,000 miles of shoreline, much of it still in natural condition, but with a considerable amount adjacent to low-lying communities and homes. As an alternative to the revetments, riprap, and sea walls that traditionally have been used to slow erosion, an active collaboration among scientists, state and federal agencies, and nonprofit organizations has been developing new and innovative techniques for protecting these shorelines with nature-based approaches. Living shorelines have been defined by Partnership for the Delaware Estuary (PDE) as a "method of shoreline stabilization that protects the coast from erosion while also preserving or enhancing environmental conditions."[60] The concept of living shorelines captures a variety of shoreline stabilization techniques that use site-appropriate, native biological materials, taking ecological dynamics, tides, currents, and wave energy into consideration. Living shorelines projects can use rock sills or shellfish structures to attenuate wave energy, in combination with coir fiber logs, native plants, and other native materials that capture sediment and contribute to marsh accretion and shoreline stabilization.[61]

Not only do living shorelines have greater habitat value for many of the iconic species of the region, like blue crabs and oysters, but once established they can have lower maintenance costs, and can be self-renewing following storms. The PDE and the states of Maryland, Delaware, and New Jersey have been leaders in the promotion, design, and installation of living shorelines.

In 2007 PDE along with the Rutgers Haskin Shellfish Laboratory launched an investigation into some nature-based armoring tactics and their applicability within the Delaware Estuary.

Living shoreline. Photo: Josh Moody/PDE

The group varied the configuration of ribbed mussels, coir-fiber logs, and marsh grasses along the shoreline, and documented the performance of each arrangement. In 2011 they published the results of the study, describing the optimal configuration as the "DELSI Tactic" (DELSI: "Delaware Estuary Living Shoreline Initiative"). This approach has now been used for more than a dozen living shorelines projects in Delaware and New Jersey.

The State of Maryland has also been active in promoting living shorelines for coastal defenses around the Chesapeake. In 2008 the State passed the Living Shorelines Protection Act, which requires all shoreline stabilization efforts to be living shorelines, unless otherwise proven that the area would not be suitable for such a project. By 2013 more than 130 living shoreline projects had been installed in the state. While a great advance over hardened shore protection designs, most of these projects have not adequately taken into account one of the most significant long-term threats to the region's coastlines and the future effectiveness of living shorelines—accelerated sea-level rise. To help address this, National Wildlife Federation is collaborating with the Maryland Department of Natural Resources on design of a living shoreline on Maryland's Eastern Shore that explicitly plans for a projected sea-level rise of 2.1 feet by 2050, and 3.7 feet by 2100. Construction of this "climate-smart" living shoreline is slated to begin in July of 2016, and will stabilize 1,350 linear feet of shoreline around a Dorchester County park.

Although techniques for designing and constructing living shorelines have advanced rapidly, permitting and funding still pose challenges for scaling up these efforts. In most places, hardened shoreline structures are relatively easy to permit, because they are covered by "general permits" issued by the U.S. Army Corps of Engineers under Section 404 of the Clean Water Act. For living shorelines, property owners often must go through a more onerous special permit process, even though the results are more environmentally benign.

Although there has been great success in the Mid-Atlantic region moving from hard infrastructure like riprap and seawalls toward softer stabilization techniques, implementation of living shorelines still faces cultural and technical barriers. As Joshua Moody, Restoration Coordinator at the PDE, put it, for living shorelines to truly take off, the "culture of fear needs to disappear, and become a culture of learning." Fortunately, this region is setting a national example for how natural defenses can be put to work protecting both communities and richly productive ecosystems.

At a Glance

- Living shorelines mimic more complex natural conditions and provide a wildlife-friendly alternative to shoreline armoring.
- Ecosystem engineers, like oysters, can be used as part of living shorelines to reduce wave energy and anchor marsh vegetation.
- Maryland's 2008 Living Shorelines Act has spurred many innovative projects by requiring that, when feasible, living shorelines be used for coastal protection.
- The Mid-Atlantic is experiencing exceptionally high rates of sea-level rise, and living shorelines in the region now are being designed to accommodate rising tides.

Blue crab. Photo: Benjamin Wilson/Flickr

Background: Chesapeake living shoreline. Photo: Stacy Small-Lorenz/NWF

BREAKING THE FIRE–FLOOD CYCLE

FOREST MANAGEMENT TO REDUCE FLOODS IN FLAGSTAFF, ARIZONA

Fires, of course, are a natural part of the forest lifecycle...What is not natural is the frequency and destructiveness of the wildfires in the past decade—fires which move faster, burn hotter, and are proving harder to manage than ever before.

– Richard Schiffman, The Atlantic[63]

Nestled within the 1.5-million-acre Coconino National Forest, Flagstaff, Arizona, is no stranger to having wildfires burn through the mountains surrounding the city. Unfortunately, fire is often just the first threat, as vegetation on the surrounding hillsides is a critical element of natural infrastructure for regulating both the quality and quantity of water flowing to the city. After a severe fire the hillsides, charred and devoid of vegetation and soil cover, can no longer absorb and retain rainfall. A severe rainstorm can send torrents of muddy, sediment-filled water rushing downstream toward the 70,000 residents of the Flagstaff metro region.

This fire-and-flood cycle is a serious risk in much of the Intermountain West. As the population of this region has grown significantly faster than the national average, pushing ever farther into the "wildland–urban interface," there is pressure to suppress most wildfires. While often necessary, suppression is a short-term solution that disrupts natural fire cycles, and can lead to unnaturally high densities of fuel sources. When fire does break out in these fuel-dense forests, it can lead to more severe conflagrations than if smaller, more frequent fires had been allowed to burn. In addition, climate change has led to fire seasons that are 78 days longer, on average, than they were in 1970.[64]

In addition to the threat catastrophic fires pose to people, property, and ecosystems, they are extremely expensive. Fire suppression now consumes more than 50 percent of the U.S. Forest Service's annual budget, compared with just 16 percent in 1995.[65] This figure is growing due to the practice of budgeting for fire on the basis of historical averages, rather than current and future trends, and then "borrowing" from other accounts to pay for growing fire control costs. As a result, in many years there is limited funding and staff capacity to engage in other activities, including proactive forest treatments to reduce the risk of severe fires, and associated impacts such as flooding, erosion, and wildlife habitat changes.

In the summer of 2010 the Schultz Fire quickly burned through 15,000 acres of forest northeast of Flagstaff. Three weeks after the fire, the fourth largest monsoon event on record in Arizona brought torrential rains onto bare mountain slopes. As the water rushed downstream, it caused extensive property damage in Flagstaff neighborhoods and killed a teenage girl. Following this disaster, Northern Arizona University did a full cost-accounting study and conservatively estimated the impacts of the fire and flood at $133–147 million.[66]

The Flagstaff City Stormwater Department reacted by developing flooding projections for a similar fire in the nearby Dry Lake Hills and Rio de Flag watershed. These projections showed that severe flooding would likely inundate downtown Flagstaff, Northern Arizona University, and several other densely populated city neighborhoods. Likewise, fire in nearby Mormon Mountain would wash sediment and ash into Lake Mary, threatening an important part of the city's water supply.

Both city officials and citizens realized that accelerated forest treatments were needed on the Coconino National Forest to reduce these risks. Paul Summerfelt, Flagstaff Watershed Protection Project Manager, feels that "the connection between

Flagstaff below Mt. Elden. Photo: Brady Smith/USFS

fire and water quality and quantity" facilitated citizen support and engagement on the issue. In response, a 2012 ballot measure passed with overwhelming public support, leading to a $10 million bond for forest treatments in the Rio de Flag and Lake Mary watersheds. This project is the only example in the nation of federal forest management being funded through a municipal bond.

Mexican spotted owl. Photo: Chris West

Groundwork for this was laid as a result of nearly two decades of community outreach and education by the Greater Flagstaff Forests Partnership (GFFP), a coalition of scientific, environmental nonprofit, federal, and political representatives. Throughout the late 1990s and 2000s, this coalition advocated for and engaged in numerous forest treatment efforts. By 2012 the partnership had successfully treated more than 70,000 acres of forest, had the mayor participate in a controlled burn, and had been recognized as a leader in innovative and collaborative forest management. Most importantly for this project, their outreach activities resulted in a community with high scientific literacy on the value of forest treatments. As Diane Vosick, a member of the citizens group promoting the watershed protection project, said "It's amazing how much a few engaged citizens can achieve. We were just 12 people and only had $8,000 in funding."

This spirit of outreach and engagement continues as the watershed protection effort brings together a range of partners with a common focus on reducing flood and fire risks to the Flagstaff community. A combination of shared vision and a culture of innovative thinking has resulted in continued progress, including an expedited environmental impact assessment process designed to balance protection of endangered Mexican spotted owl habitat with the need to begin fuel treatments quickly.

The success of this broad-based partnership demonstrates the importance of engaging a range of stakeholders early and often around a common goal, and is a model for a new type of local collaboration in forest planning and management that is taking hold across the West. In this instance, local citizens recognized that reducing unnaturally high fuel loads on surrounding federal forest lands was so important for avoiding potential post-fire floods and for protecting water supplies and infrastructure, that they were willing to invest local tax revenues in those treatments. Developing a robust understanding of the social and economic vulnerability of a community, and continuously communicating with citizens can create new and innovative pathways for project funding and can help ensure long-term success in breaking the fire–flood cycle.

At a Glance

- Proactive forest management can reduce unnaturally high fuel loads and wildfire risks and help protect communities from the flooding that can follow wildfires.
- Innovative project finance models, such as municipal bonds, create new opportunities for funding ecosystem restoration and risk reduction activities.
- Long-term community engagement is a foundation for collaborative forest planning and management and can help expedite regulatory and permitting processes.

DYNAMIC DUNES

ECOLOGICAL APPROACHES TO REDUCE RISK IN CAPE MAY COUNTY, NEW JERSEY

Travelers bold enough to follow now rusting highway signs to Moores Beach and Thompsons Beach are headed for consternation. In two decades, these bayside communities went from shore towns to ghost towns to no towns as the roads leading out to them surrendered to marsh and the houses fell (literally) under the dominion of the tide.

– Pete Dunne, Bayshore Summer[67]

How can a New Jersey barrier island resort town support million-dollar beach homes, endangered beach-nesting birds, and maintain a Triple A S&P bond rating, all while receiving 25 percent discounts on flood insurance?

"We take coastal resilience and the management of our protective natural resources—beaches, dunes, and wetlands very seriously," says Avalon Mayor Marty Pagliughi. "Resilience is our highest priority, and we've understood for a long time the value and protection that these ecosystems bring to our community." As it turns out, investing in natural ecosystems, along with other practical measures like elevating properties above flood level, has made this community a very good investment.

Piping plover. Photo: Matt Poole/USFWS

Entering Avalon's lushly forested beach and dune trail system feels like stepping back in time, when the more famous Wildwoods resort towns to the south were truly "wild woods." However, it's no accident of history that this vegetated dune system is in place, with development setbacks established behind secondary and tertiary dunes.

In the 1940s, bulldozing dunes to make way for development was all the rage, but then the Great March Storm of 1962 walloped the Jersey Shore. Avalon subsequently developed a beach and dune conservation strategy that's grown into a proactive, decades-long effort toward property and environmental protection, serving as a model for other coastal New Jersey communities.

A spring walk along Avalon's sheltering dune trail system, following the sound of pounding surf through dense, wind-sculpted maritime forest, past beach grasses sprouting out of younger dunes and out onto exposed, wind-whipped beaches makes it abundantly clear why wide beaches, dune complexes, and mature dune vegetation offer so much protection to this community during stormy weather, and how a barrier island resort community that swells from a population of 1,300 winter residents to 35,000 in the summer can survive and thrive year-round, alongside biologically rich ecosystems.

Tourists and migratory birds alike flock to Cape May County, at the southern tip of New Jersey, where the Delaware Bay meets the Atlantic Ocean. The region attracts seasonal beachgoers and year-round ecotourists in droves. Cape May's legendary resort towns, from the Victorian-era Cape May City to the rollicking boardwalks of The Wildwoods, are situated on densely developed barrier islands, exposing them to the full brunt of coastal storms, including both hurricanes and frequent nor'easters.

Part of what makes Cape May a world-class destination for human and avian travelers, though, is that 42%, or 76,567 acres, of the county is in protected open space—beaches, dunes, forest, and marsh. There are 81,668 acres of wetlands in total, representing 45% of the county area. On the other hand, all but 11.5% of the developable uplands are built out, and most of the "buildable" open space is currently in agriculture and under intense development pressure.[68]

The South Jersey coastline has always been a dynamic environment, formed of highly mobile sedimentary material—sand and silt—in a setting of high wind and wave energy. Low elevation and flat coastal plain topography put Cape May County at high risk for sea-level rise, storm surge, and back-bay flooding.

Two feet of sea-level rise projected by 2050 makes Cape May's coastal communities and critical facilities even more vulnerable to storm surge, erosion, regular "nuisance flooding" of roads with spring tides after full and new moons, and even permanent inundation in places where the coastline is projected to move significantly landward.[69]

Some communities have already succumbed to the power of wind and waves to re-shape the coastline. Just to the south of Cape May City once stood another resort town, South Cape May, which fell to erosion and storm surge in the mid-20th century.

Bottom Opposite Page: Dunes and beach, Avalon, NJ. Photo: Scott Wahl

In its footprint now stands the biologically-rich South Cape May Meadows, a 200-acre area of constructed dunes and wetlands, where water levels are managed in anticipation of storms and heavy precipitation and for seasonal needs of migratory birds. The project provides measurable flood risk reduction for surrounding communities and eco-tourism revenue.[70]

After Hurricane Sandy, Cape May communities that had participated in U.S. Army Corps of Engineers dune and beach nourishment projects, starting in 1989 with Cape May City, had relatively little storm and flooding damages in places where wider beaches and deeper dune systems provided adequate buffers. However, Sandy brought four-foot waves on top of storm surge to some Delaware Bayshore communities, causing significant damage from reverse winds after the storm made landfall to the north. Damages were especially severe where narrow beaches afforded little buffer for dunes.[71] Coastal storms Joaquin and Jonas subsequently brought even more significant flooding and damages to some Cape May County communities.

In anticipation of sea-level rise and growing coastal storm threats, Cape May municipalities, alongside county, state, federal resource agencies, and the U.S. Army Corps of Engineers, are shoring up with strategically placed natural infrastructure. In collaboration with conservation organizations, they are testing techniques to manage and restore coastal ecosystems in ways that allow dunes and low marshes to gain elevation and potentially keep pace with sea-level rise, making their communities more resilient to coastal storms. Restoration scenarios currently are being developed with many coastal communities at the highest risk for sea-level rise, erosion, and inundation.

Dunes, Stone Harbor, NJ. Photo: Stacy Small-Lorenz/NWF

Restoring and maintaining resilient ecosystems in the surrounding landscape has brought economic benefits to local communities in the form of storm, flood, and erosion protection and—according to Cape May City's Mayor, Ed Mahaney, Jr.—has extended the region's ecotourism season well beyond summer.

At a Glance

- Low elevation combined with a high rate of sea-level rise puts this coastal biodiversity hotspot at great risk of erosion and inundation.
- Restoration and high-quality stewardship of beaches, dunes, and maritime forest provide valuable protection for communities in Cape May County from storm surge, erosion, and long-term inundation.
- Nearly half of Cape May County is protected open space, allowing room for nature to move in response to dynamic coastal processes and sea-level rise.
- Planning is underway for ecological resilience of bayshore communities, where shoreline is migrating inland from erosion and sea-level rise.
- Back-bay flooding and erosion are growing problems for barrier island communities; tidal marsh restoration is a part of the solution.

PLANT POWER

STABILIZING GREAT LAKES SHORELINES WITH NATIVE VEGETATION

Time was beating against the shore. It had rounded stones one wave-tumble every ten seconds for ten thousand years, buried them in ice for a hundred centuries, then rounded them for another ten thousand years. And the work has just begun.

– Jerry Dennis, The Windward Shore[72]

The Great Lakes, their watersheds and connecting waterways are the planet's largest surface freshwater system, holding 20 percent of the world's fresh surface water. Water levels fluctuate dramatically on long- and short-term cycles. Strong winds, high wave energy, sometimes massive storms, and seasonally thick ice make the Great Lakes a great laboratory for vegetated living shoreline projects designed for erosion and sediment control. "Water levels can fluctuate as much as five feet in Lakes Michigan and Huron on decadal cycles, making these very dynamic environments," says Brian Majka of GEI Consultants.

Plants native to Great Lakes shorelines have evolved to thrive in dynamic conditions. In places where high wave energy and ice continually disturb sediments and chew away at lake edges, vegetated living shorelines can often be more naturally durable and resilient than human-engineered hard armoring. Making slopes more gradual and roughening unnaturally straight edges have proven to be successful techniques to facilitate the establishment of native vegetation and create long term stability in these ever-changing conditions.

In the past, industrialization of some Great Lakes shorelines for saw mills and manufacturing resulted in extensively engineered, walled shorelines. There is now a movement afoot to find "softer," greener alternatives to shoreline stabilization rather than walls and bulkheads that create a bathtub effect around developed lake edges. Through extensive trial and error, native vegetation has been established on re-graded, more natural shoreline slopes and is proving to be a resilient alternative to bulkheads and sheet-pile walls for bank stabilization, says Majka.

At Muskegon Lake, a drowned river mouth lake (also known as a lacustrine estuary) connected to Lake Michigan by a

Great Lakes. Photo: Jeff Schmaltz, NASA/GSFC

deep-draft navigation channel, 27 percent of open water and wetlands had been lost to historic industrial filling by the start of the 21st century. The National Oceanic and Atmospheric Administration (NOAA) has partnered with the Great Lakes Commission and local communities to stabilize shorelines and restore wetlands with native habitat at a number of former saw mill and industrial sites. More than 33 acres of wetland and 13,000 linear-feet of hardened shoreline have been restored with native vegetation so far.

Citing a Great Lakes Commission study, NOAA says the $10 million investment in restoration efforts at Muskegon Lake project will generate $66 million in economic benefits, including:[73,74]

- $12 million increase in property values
- $600,000 in new tax revenues annually
- more than $1 million a year in new recreational spending in Muskegon
- 65,000 additional visitors annually
- an additional 55 cents in the local economy for every federal dollar spent

They go on to say, "The project also created jobs in an area with an unemployment rate higher than 12 percent, while creating healthier habitat and more fish."

At a Glance

› Native vegetation is being used to successfully stabilize shorelines and restore industrialized lakefronts to healthy habitat, and can result in tens of millions of dollars of economic benefit.

› Strong winds, high wave energy, fluctuating water levels, and seasonally thick ice present special challenges for living shoreline design in the Great Lakes.

› The federally funded Great Lakes Restoration Initiative has spurred significant investments in habitat restoration using native plants, providing significant erosion and sediment control benefits.

› Shoreline restoration efforts have been aided by strong stakeholder engagement and community involvement in decision-making.

Lake Muskegon shoreline. Photo: GEI Consultants

A primary driver for Great Lakes shoreline restoration has been the remediation of contaminated industrial sites, which has set the stage for subsequent vegetated shoreline restoration efforts. Some living shorelines projects have been motivated by de-listing of toxic sites from the EPA Great Lakes Areas of Concern that spotlights contaminated industrial areas. In places where legacy contaminants have been detected, remediation efforts via the historic Great Lakes Legacy Act have set the stage for restoration with native vegetation for bank stabilization and habitat. Michigan resource agencies have been especially supportive of Great Lakes living shoreline restoration projects that yield multiple resilience, health, habitat, and regulatory benefits.

Through the subsequent Great Lakes Restoration Initiative, Congress has made the largest investment in two decades in the Great Lakes. Federal resources are filtered through federal and state agencies to local groups, with focus areas ranging from toxins to restoring wetlands and other native shoreline habitats.

Much of the decision-making for Great Lakes shoreline restoration has been driven by local stakeholders, says Majka, and communities have being laying the groundwork for many years. "A local, stakeholder-based approach to shoreline restoration is far more successful than communities being told what to do by Federal agencies."

Vegetated bluffs. Photo: GEI Consultants

LINKED FUTURES

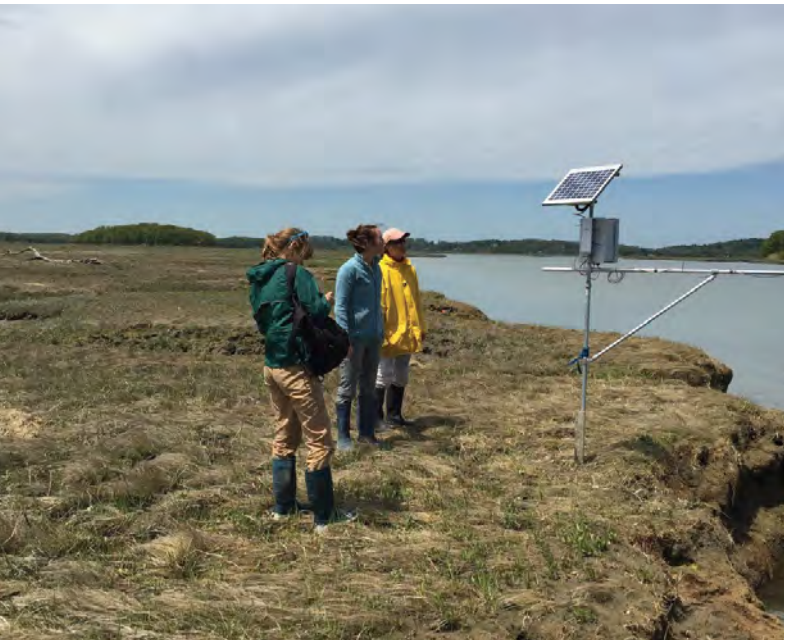
SHARED ECOSYSTEM AND COMMUNITY RESILIENCE IN COASTAL MASSACHUSETTS

To stand at the edge of the sea, to sense the ebb and flow of the tides, to feel the breath of a mist moving over a great salt marsh…is to have knowledge of things that are as nearly eternal as any earthly life can be.

– Rachel Carson, The Edge of the Sea[75]

Ipswich, Rowley, Newbury, Essex. These and other picturesque towns along the Great Marsh in Massachusetts were some of the first colonial settlements in New England. Today, these vibrant coastal communities are at risk from the threats of rising sea levels and increasingly powerful coastal storms.

The Great Marsh—spread along the North Shore of Massachusetts—is the largest salt marsh in New England, spanning more than 20,000 acres of marsh habitat, barrier beaches, and tidal estuaries. This natural ecosystem plays a significant role in buffering nearby communities from the impact of coastal storms and nor'easters. Yet these same storms, in concert with rising sea levels, warmer water temperatures, and an influx of non-native invasive species, are contributing to high rates of marsh loss and coastal erosion, which in turn is degrading the ecosystem's ability to buffer adjacent communities. Along Massachusetts' North Shore, the resilience of the communities is inextricably linked with the resilience of the Great Marsh.



Marsh monitoring. Photo: Chris Hilke/NWF

The Great Marsh Resiliency Partnership is working to strengthen that linkage. With support from the U.S. Department of Interior Hurricane Sandy Coastal Resiliency Program, the project includes a host of partners working together to enhance resilience of the coastal towns and the marsh itself. Key to this work has been engaging the communities in vulnerability assessment workshops designed to identify those assets that are of greatest concern to local citizens and most crucial to protect. The broad-based project partnership, which includes National Wildlife Federation, U.S. Fish and Wildlife Service, several universities, Massachusetts state agencies, and a number of local environmental nonprofits, are working together to reduce those vulnerabilities and protect key assets through implementing nature-based measures designed to work at near-, medium-, and long-term timescales.

Among the most important near-term needs is addressing flooding from both the coast as well as from inland. As climate change increases the severity of heavy precipitation events, sea-level rise, and coastal storms, both inland and coastal flooding risks to these coastal towns are growing. To help mitigate the impacts of inland flooding, the project partnership is inventorying and assessing some 1,500 hydrologic barriers in the region—including dams, bridges, and road crossings of streams and marshes. These barriers are being subjected to risk assessments from both ecological and infrastructure perspectives. High-risk barriers will receive further evaluation, with site-specific upgrades recommended to immediately reduce risks from flooding, as well as to enhance the capacity of nutrients and sediment to flow throughout the marsh.

To address near- to medium-term threats of sea-level rise and coastal storms, project partners are carrying out several ecological restoration efforts to enhance the natural features, and associated resilience benefits, of the Great Marsh. For example, to stabilize existing dune systems, which provide significant community flood protection benefits, native dune flora is being planted, and dunes are being fenced to decrease trampling and other disturbance. Similarly, native vegetation is being restored to hundreds of acres of marsh to help stabilize the ecosystem and bolster its capacity to provide flood protection and attenuate wave energy. These ecological restorations will continue to grow and develop over time, providing the coastal communities with benefits well into the future. As Chris Hilke, NWF's project manager says, "The advantage of well-designed restoration projects is that they become more effective with time, while hard infrastructure degrades over time."

To inform science-based management and restoration in light of future climate projections, the project is developing a hydrodynamic model for the entire marsh system. This

model will help researchers understand sediment and salinity distributions throughout the marsh, and thereby identify sediment deposition patterns into the marsh and tidal creeks, as well as sediment transport and erosional forces on the barrier beaches. Understanding salinity dynamics in the marsh will directly inform invasive species control efforts and other restoration activities. Ultimately this hydrodynamic model will help guide long-term ecosystem management and community resilience in the Great Marsh.

As degradation of estuarine ecosystems in the Great Marsh and many other tidal marshes around the country is poised to accelerate due to climate change and other factors, nearby coastal communities will be left increasingly vulnerable. These communities require operationally feasible adaptation strategies to address both current impacts as well as guidance on interventions that can mitigate future threats. Within the Great Marsh this is being achieved by conducting community-based vulnerability assessments, coupled with the design and implementation of restoration activities specifically intended to reduce those vulnerabilities. By explicitly linking restoration actions to both current risks and future climate impacts, the Great Marsh Resiliency Partnership serves as an illustration for how restoring natural systems can directly contribute to enhancing the resilience of local communities.

Community workshop. Photo: Chris Hilke/NWF

At a Glance

- To reduce community risks from coastal storms and sea-level rise, project partners are working to restore ecosystem structure and function in dunes, salt marsh, and subaquatic vegetation.
- Local citizens are working together to identify community assets most at risk from the impacts of climate change, and to set priorities for enhancing resilience.
- Community adaptation plans are being designed to identify nature-based risk reduction strategies that can be carried out in near- and long-term.

Parker River National Wildlife Refuge. Photo: Matt Poole/USFWS

BLENDING GREEN AND GRAY

HYBRID APPROACHES TO PROTECT NEW YORK'S JAMAICA BAY

We've learned that there is a false dichotomy between green and built infrastructure; the best solutions are often hybrids that complement the geomorphology and land use of a specific neighborhood.

– Daniel Zarrilla,
Director of Resiliency, City of New York[76]

If you've ever flown into New York City by way of JFK Airport, then you know Jamaica Bay. As your plane makes its descent, stretched out below is the Bay, a mosaic of open water, small islands, coastal marshes, and infrastructure. At the back, looking as if it is trying to crowd the green space straight off Long Island and into the water, is the dense development of Brooklyn and Queens. Jamaica Bay is actually New York City's largest open space (even larger than Central Park) and is a mix of federal, state, and city parkland. It is vital stopover habitat for migratory birds among the gray desert of the city, as well as important habitat for many other species. It contains the only National Wildlife Refuge accessible by subway, and city residents are passionate about protecting this cultural and environmental resource.[77]

Osprey nest near JFK Airport. Photo: Don Riepe/ALS

Especially after the devastation brought by Hurricane Sandy. Thirteen feet of storm surge, $19 billion in damage, and tragic loss of life drove home the urgency of building resilience in the face of rising seas and strong coastal storms. The Bay faces many challenges. As the lowest-lying part of New York City, nearby communities experience street flooding at almost every full-moon tide, yet local sea levels are expected to rise a further 11–31 inches by 2050.[78]

A century of development and pollution from runoff has seriously stressed the health of the ecosystem, and about 1,400 acres of tidal salt marsh have been lost since 1924.[79] Furthermore, the communities behind the Bay are not built for current and projected conditions—most homes are freestanding and old, and the population is relatively elderly. Most homes are not elevated above the Federal Emergency Management Agency–recommended levels, and the time and money it would take to elevate them would be many times more than other resiliency options, and probably insufficient in the face of climate change. Frequent and intense storms are expected to become the new normal for coastal New York by 2050, and the many industrial and recreational canals in Jamaica Bay only increase its vulnerability.

At the request of the city, The Nature Conservancy conducted an extensive benefit–cost analysis of four resiliency options for the Howard Beach neighborhood in Jamaica Bay. Two options relied entirely on natural and nature-based features, while the other two incorporated varying levels of traditional hard infrastructure along with green infrastructure. The planners found that the hybrid approaches by far provided the greatest risk reduction and avoided losses from a 100-year storm. The best hybrid option considered had a benefit–cost ratio 8–16 times higher than the green infrastructure–only options, providing an estimated $662,000 in ecosystem services while avoiding $466 million in damages to Howard Beach alone. In addition, hybrid options offered reduced maintenance costs compared with only hard infrastructure and provide other co-benefits that hard infrastructure alone cannot, like providing essential habitat for wildlife.[80]

Marsh restoration, Jamaica Bay, NY. Photo: Don Riepe/ALS

Oystercatchers and Manhattan skyline. Photo: Don Riepe/ALS

New York City has made a significant commitment to climate adaptation, as outlined in its landmark 2013 "PlaNYC," with Jamaica Bay at the epicenter of coastal resiliency efforts.[81] PlaNYC states that relying only on hard engineering solutions, like bulkheads and floodwalls, would actually incur more costs and pose serious threats to the city that would outweigh the protective benefits of those engineering solutions. Taking into account the results of the Conservancy's study, the Jamaica Bay plan includes a mix of stone bulkheads, living shorelines, and restoration and creation of wetlands and reefs.[82]

Many organizations are working to improve the resilience of Jamaica Bay and its communities, including the National Park Service and U.S. Fish and Wildlife Service, city and state agencies, The Nature Conservancy, and others. The American Littoral Society, for instance, has been leading an on-the-ground effort to restore marshes. "Marshes are the lifeblood of the Bay," said their Chapter Director, Don Riepe. Working with EcoWatchers (a coalition of other nonprofits and local government agency representatives) and the U.S. Army Corps of Engineers, they are using dredged materials to rebuild the marshland. The effort is assisted by thousands of community volunteers and participants in the Littoral Society's green-jobs program, which has the side benefit of providing hands-on job opportunities for disadvantaged youths and unemployed citizens. By engaging community members, the project has saved millions of dollars in labor and increased public interest in the success of restoration.[83]

As the Howard Beach experience demonstrates, sometimes a hybrid approach can provide greater resilience and cost-effectiveness than green or gray solutions alone. Furthermore, hybrid solutions can provide multiple co-benefits, including improved water quality, wildlife habitat, recreation, and tourism benefits.

At a Glance

- A combination of green and gray approaches, incorporating both ecosystem features and engineered structures, are being used to protect Jamaica Bay communities from coastal hazards.
- Restoring marshlands in Jamaica Bay provides water quality, habitat, and storm protection benefits.
- Broad partnerships among public and private groups are at the heart of efforts to restore Jamaica Bay's marshes and enhance community resilience.
- Involving youth and community volunteers in marsh restoration has provided on-the-job training, educated the public about ecological principals, and saved thousands of dollars in restoration costs.

Brooklyn and Jamaica Bay. Photo: Joe Mabel

RECOMMENDATIONS TO EXPAND THE USE OF NATURAL DEFENSES

Risks from extreme weather and climate-related events are escalating, and there is an urgent need to dramatically scale up the application of natural defenses to better protect our communities. As the preceding profiles of these resilience allies show, innovative and promising work is underway across the country designed to harness the power of nature to reduce risks from natural hazards such as floods, coastal storms, and hurricanes. For natural and nature-based risk reduction measures to be adopted and applied more broadly, effort is needed in three areas:

- **REFORM KEY POLICIES** to promote and incentivize the use of natural defenses
- **TARGET RESEARCH** to improve effectiveness and advance appropriate applications
- **PROMOTE BEST PRACTICES** to accelerate on-the-ground implementation

We offer suggestions in each of these categories for what will be needed for the nation to dramatically expand the use of—and receive the greatest benefit from—our natural defenses.

REFORM KEY POLICIES

Protect natural systems already providing natural defenses

- Protect and restore healthy rivers, wetlands, and other natural ecosystems, including by adopting policies that promote or require the use of nature-based or non-structural risk reduction measures, where such solutions can provide an appropriate level of protection and benefits.
- Ensure protection of headwaters and wetlands, which are essential for retaining floodwaters, by implementing updated wetland protection rules under the Clean Water Act.
- Adopt policies encouraging new or reconstructed levees to be set back from the water's edge in order to sustain and enhance riparian habitat, reduce erosion and scour, reduce flood levels, and allow natural floodplain ecosystems to better serve their natural functions.
- Support conservation programs that protect and/or acquire environmentally sensitive natural systems and open space.
- Study and propose additional areas for inclusion in the Coastal Barrier Resources System, to ensure that federal subsidies do not provide incentives for new development in these environmentally sensitive and hazard-prone areas.

Adopt flood and natural catastrophe insurance reforms

- Reform the National Flood Insurance Program (NFIP) to reduce subsidies and incentives for developing and re-developing in environmentally sensitive and risky place in coastal areas and floodplains; move the program toward risk-based rates for all properties, with means-tested assistance for those who cannot afford actuarial rates.
- Enhance opportunities in the NFIP Community Rating System to provide credit for natural and nature-based approaches that provide erosion control and flood risk mitigation benefits; develop methods for incorporating natural protective features into flood insurance risk maps.
- Fully fund and implement the National Flood Mapping Program, and finalize updates of Federal Emergency Management Agency (FEMA) 100- and 500-year flood hazard maps, taking into account climate change, sea-level rise, and other watershed and land-use changes.
- Align policies and regulations to ensure that property owners have options to satisfy mortgage requirements for flood insurance through either NFIP or the commercial insurance market.
- Ensure that state windstorm insurance programs send risk-based pricing signals that help guide better coastal land-use planning, incentivize risk mitigation, and don't displace private insurance markets.

High-tide flooding, Queens, NY. Photo: Don Riepe/ALS

Beach grasses, Jamaica Bay, NY. Photo: Don Riepe/ALS

Adopt disaster preparedness and response reforms

- Increase emphasis under the Stafford Act on pre-disaster planning and mitigation and encourage communities to focus more fully on risk reduction, emphasizing nature-based approaches; reduce cost share required for pre-disaster planning and mitigation.
- Better target and increase FEMA hazard mitigation grant funding in ways that encourage meaningful community-wide risk reduction efforts, particularly through application of natural and nature-based approaches; reduce cost share required for voluntary property buyouts under the flood hazard mitigation program.
- Encourage communities to enhance their resilience as part of the disaster recovery process by removing disincentives and funding restrictions for rebuilding to higher and more-resilient standards than existed pre-disaster.
- Discourage building or rebuilding in active floodways, the most dangerous part of the floodplain, and require that any new development does not cause an increase in flood elevations or velocity; end the current regulatory loophole where buildings can be rebuilt in a floodway if the "footprint" does not increase.

Enhance funding for use of natural defenses

- Permanently reauthorize and provide full funding for the Land and Water Conservation Fund, the nation's premiere land acquisition funding program.
- Ensure that robust allocations for enhancing ecosystem resilience and deploying nature-based risk reduction measures are a part of major funding programs, such as disaster recovery and mitigation efforts, regional restoration initiatives, and water resource development programs.
- Establish a dedicated source of funding for wildfire disaster response to ensure that escalating wildfire control and suppression costs do not routinely divert resources from other forest conservation and management activities, particularly those designed to reduce underlying wildfire risks.
- Encourage states, counties, and local communities to adopt innovative financing mechanisms to support nature-based hazard mitigation measures, including use of public bonds, ecosystem service markets, and public–private partnerships.

Reduce regulatory barriers to deploying natural defenses

- Reduce regulatory barriers to well-designed and ecologically appropriate living shorelines through issuance of a new nationwide general permit for living shorelines under Section 404 of the Clean Water Act; increase environmental scrutiny of permits to install hardened shoreline erosion control structures by tightening nationwide permit standards for such structures.
- Improve coordination and alignment among permitting agencies at federal, state, and local levels to increase consistency and predictability in deployment of living shorelines and other nature-based approaches; ensure consideration of system-wide impacts beyond the parcel being permitted.

TARGET RESEARCH

Improve research base on effectiveness of natural defenses

- Accelerate research on the performance and effectiveness of various forms of natural defenses for meeting risk reduction objectives; develop improved specifications on when and where these approaches can be used most reliably.
- Expand social and economic research needed to quantify the benefits of different types of natural defenses (protective benefits as well as co-benefits) and to improve understanding of socioeconomic barriers to and opportunities for deploying natural and nature-based measures.
- Refine criteria for evaluating the success of natural infrastructure projects and continue developing metrics to quantify enhancement in resilience resulting from such projects.
- Advance development of up-to-date digital map products depicting local and regional hazards, such as sea-level rise and flooding, and continue improving public access to such products.

PROMOTE BEST PRACTICES

Promote creation and adoption of best practices

- Develop and disseminate best practices for natural and nature-based approaches that are locally applicable and flexible in implementation; advance development of tools and practices that encourage the synthesis of ecological and engineering expertise.
- Foster communities of practice in the application of natural defenses to spur innovation, collaboration, sharing of best practices; promote practitioner documentation of the full range of lessons learned.
- Develop national and regional best practices for managing and restoring sediment flows, and on ecologically appropriate use of clean dredge materials for the benefit of ecological restoration and coastal defense projects.
- Encourage reestablishment and use of native ecosystem engineers to enhance the restoration and resilience of coastal and inland systems.

Apply climate adaptation and resilience principles in design of natural defenses

- Develop guidance for regional and local planners on incorporating climate change considerations into open space, conservation, and disaster preparedness planning; encourage protection of open spaces needed to allow for climate-related shifts of habitats, such as tidal marshes, that provide natural defenses.
- Ensure the design of nature-based features takes future precipitation patterns, sea-level rise, and other climatic factors into account; encourage designs that are functional across multiple scenarios of future change.

Living shoreline installation, Port Norris, NJ. Photo: PDE/Flickr

Opposite Page: Avocets and other shorebirds, San Francisco Bay. Photo: Don McCullough/Flickr

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REFERENCES

[1] National Oceanic and Atmospheric Administration (NOAA). 2016. Billion-dollar weather and climate disasters: Overview. Asheville, NC: National Centers for Environmental Information, NOAA. https://www.ncdc.noaa.gov/billions/

[2] Herring, S.C., M.P. Hoerling, J.P. Kossin, T.C. Peterson, and P.A. Stott, eds. 2015. Explaining extreme events of 2014 from a climate perspective. *Bulletin of the American Meteorological Society* 96: S1–S172.

[3] National Oceanic and Atmospheric Administration (NOAA) and the U.S. Census Bureau. 2013. *National Coastal Population Report: Population Trends from 1970 to 2020.* Silver Spring, MD: National Ocean Service, NOAA. http://oceanservice.noaa.gov/facts/coastal-population-report.pdf

[4] Wright, J.M. 2008. *Floodplain Management: Principles and Current Practices.* Knoxville: University of Tennessee.

[5] Martinuzzi, S., S.I. Stewart, D.P. Helmers, M.H. Mockrin, R.B. Hammer, and V.C. Radeloff. 2015. The 2010 wildland-urban interface of the conterminous United States. Research Map NRS-8. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

[6] Melillo, J.M., T.C. Richmond, and G.W. Yohe, eds. 2014. *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program. Washington, DC: U.S. Government Printing Office.

[7] National Academy of Sciences. 2014. *Climate Change: Evidence & Causes: An Overview from the Royal Society and the U.S. National Academy of Sciences.* Washington, DC: National Academies Press.

[8] Melillo et al., *Highlights of Climate Change Impacts.*

[9] Sallenger, A.H., K.S. Doran, and P.A. Howd. 2012. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change* 2: 884–888.

[10] Melillo et al., *Highlights of Climate Change Impacts.*

[11] National Oceanic and Atmospheric Administration (NOAA). 2014. *Sea Level Rise and Nuisance Flood Frequency Changes around the United States.* NOAA Technical Report NOS CO-OPS 073. Silver Spring, MD: National Ocean Service, NOAA. http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf

[12] Tebaldi, C., B.H. Strauss, and C.E. Zervas. 2012. Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters* 7: 014032.

[13] DeConto, R.M. and D. Pollard. 2016. Contribution of Antarctica to past and future sea-level rise. *Nature* 531: 591–597.

[14] Frazer, L. 2005. Paving paradise: The peril of impervious surfaces. *Environmental Health Perspectives* 113: A456–A462.

[15] Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment* 7: 73–78.

[16] Allianz Global Corporate & Specialty (AGCS). 2013. *Superstorm Sandy. Lessons Learned: A Risk Management Perspective.* AGCS Risk Bulletin 45. Chicago: AGCS. http://www.agcs.allianz.com/assets/PDFs/risk%20bulletins/Sandy%20risk%20bulletin.pdf

[17] Government Accountability Office (GAO). 2015. *High-Risk Series: An Update.* GAO-15-290. Washington, DC: GAO. http://www.gao.gov/assets/670/668415.pdf

[18] National Ecosystem Services Partnership. 2014. *Federal Resource Management and Ecosystem Services Guidebook.* Durham, NC: National Ecosystem Services Partnership, Duke University. www.nespguidebook.com

[19] Reeve, K.E. and R. Kingston. 2014. *Green Works for Climate Resilience: A Guide to Community Planning for Climate Change.* Washington, DC: National Wildlife Federation. http://www.nwf.org/~/media/PDFs/Global-Warming/Climate-Smart-Conservation/2014/green-works-final-for-web.pdf

[20] Martin, T.G. and J.E.M. Watson. 2016. Intact ecosystems provide best defence against climate change. *Nature Climate Change* 6: 122–124.

[21] Gittman, R.K., F.J. Fodrie, A.M. Popowich, D.A. Keller, J.F. Bruno, C.A. Currin, C.H. Peterson, and M.F. Piehler. 2015. Engineering away our natural defenses: An analysis of shoreline hardening in the US. *Frontiers in Ecology and the Environment* 13: 301–307.

[22] Sutton-Grier, A.E., K. Wowka, and H. Bamford. 2015. Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science & Policy* 51: 137–148.

[23] Arkema, K.K., G. Guannel, G. Verutes, S.A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J.M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3: 913–918.

[24] Glick, P., J. Kostyack, J. Pittman, T. Briceno, and N. Wahlund. 2014. *Natural Defenses from Hurricanes and Floods: Protecting America's Communities and Ecosystems in an Era of Extreme Weather.* Washington, DC: National Wildlife Federation. http://www.nwf.org/~/media/PDFs/Global-Warming/2014/Natural-Defenses-Final-Embargoed-Until-102114-10amET.pdf

[25] U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience.* CWTS 2013-3. Washington, DC: Directorate of Civil Works, U.S. Army Corps of Engineers. http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf

[26] Association of State Floodplain Managers (ASFM). 2007. *National Flood Programs and Policies in Review*—2007. Madison, WI: ASFM.

[27] McConnell, V. and M. Walls. 2005. *The Value of Open Space: Evidence from Studies of Nonmarket Benefits.* RFF Working

Paper. Washington, DC: Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-REPORT-Open%20Spaces.pdf

[28] Stein, B.A., P. Glick, N. Edelson, and A. Staudt, eds. 2014. *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. Washington, DC: National Wildlife Federation. www.nwf.org/climatesmartguide

[29] Hobbs, R.J. and V.A. Cramer. 2008. Restoration ecology: Interventionist approaches for restoring and maintaining ecosystem function in the face of rapid environmental change. *Annual Review of Environment and Resources* 33: 39–61.

[30] NOAA Living Shorelines Group. 2015. *Guidance for Considering the Use of Living Shorelines*. Silver Spring, MD: NOAA. http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf

[31] Scyphers, S.B, S.P. Powers, K.L. Heck, and D. Byron. 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. PLoS ONE 6(8): e22396.

[32] Lopez, J. 2009. The multiple lines of defense strategy to sustain coastal Louisiana. *Journal of Coastal Research, Special Issue* 54: 186–197.

[33] Sutton-Grier et al., Future of our coasts.

[34] Berke, P. and T.J. Campanella. 2006. Planning for postdisaster resiliency. *Annals of the American Academy of Political and Social Science* 604: 192–207.

[35] Cusick, D. 2014. Ala.'s Dauphin Island meets 'Years of Living Dangerously.' ClimateWire, July 18, 2014. http://www.eenews.net/stories/1060003085

[36] U.S. Fish and Wildlife Service. 2002. *The Coastal Barrier Resources Act: Harnessing the Power of Market Forces to Conserve America's Coasts and Save Taxpayers' Money*. Arlington, VA: Division of Federal Program Activities, U.S. Fish and Wildlife Service. http://www.fws.gov/cbra/Docs/TaxpayerSavingsfromCBRA.pdf

[37] Tuggle, B.N. 2004. Statement of Dr. Benjamin N. Tuggle, U.S. Fish and Wildlife Service: Oversight hearing on the John H. Chafee Coastal Barrier Resources System. U.S. House of Representatives, Committee on Resources, Subcommittee on Fisheries Conservation, Wildlife and Oceans. Washington, DC: Government Printing Office.

[38] Clarke, C. 2015. San Francisco Bay's lost world: The saltmarsh. Burbank, CA: KCET, Bay Delta Project. https://www.kcet.org/redefine/san-francisco-bays-lost-world-the-saltmarsh

[39] San Francisco Bay Area Wetlands Ecosystem Goals Project. 2015. *The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015*. Oakland: California State Coastal Conservancy. http://baylandsgoals.org/science-update-2015/

[40] Ibid.

[41] U.S. Army Corps of Engineers. 2015. *South San Francisco Bay Shoreline Phase I Study*. San Francisco: San Francisco District, U.S. Army Corps of Engineers. http://www.spn.usace.army.mil/Portals/68/docs/FOIA%20Hot%20Topic%20Docs/SSF%20Bay%20Shoreline%20Study/Final%20Shoreline%20Main%20Report.pdf

[42] Rosen, J. 2016. Flooding the Mississippi River Delta. *Hakai Magazine*, March 23, 2016. http://bit.ly/1U6d6tm

[43] State of Louisiana. 2012. *Louisiana's Comprehensive Master Plan for a Sustainable Coast*. Baton Rouge: State of Louisiana. http://coastal.la.gov/a-common-vision/2012-coastal-master-plan/

[44] Mississippi River Delta Restoration Coalition. 2014. *Restoring the Mississippi River Delta for People and Wildlife: Recommended Projects and Priorities*. New Orleans: Environmental Defense Fund, National Audubon Society, and National Wildlife Federation. http://www.mississippiriverdelta.org/files/2014/12/Restoring-the-Mississippi-River-Delta-for-People-and-Wildlife.pdf

[45] Smith, K. 2016. Personal communications.

[46] Tualatin River Watershed Council (TRWC). 2015. Tualatin Basin information. Hillsboro, OR: TRWC. http://trwc.org/tualatin-basin-information/

[47] Clackamas County. 2016. County floodplain overview. Beaver City, OR: Clackamas County Planning and Zoning Division. http://www.clackamas.us/planning/flood.html

[48] Tualatin Basin Water Supply. 2016. About the project. Hillsboro, OR: Clean Water Services. http://www.tualatinbasinwatersupply.org/about

[49] Smith, K., personal communications.

[50] Pollock, M.M., G. Lewallen, K. Woodruff, C.E. Jordan, and J.M. Castro, eds. 2015. *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains*. Portland, OR: U.S. Fish and Wildlife Service. http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Beaver.asp

[51] Morrison, T. 1995. The site of memory. p. 83–102. In: W. Zinsser, ed. *Inventing the Truth: The Art and Craft of Memoir*, 2nd ed. Boston and New York: Houghton Mifflin.

[52] Larson, L.W. 1997. The great USA flood of 1993. IAHS Publications-Series of Proceedings and Reports-Intern Assoc. Hydrological Sciences 239: 13-20.

[53] Ibid.

[54] Federal Emergency Management Agency (FEMA). 2003. *The 1993 Great Midwest Flood: Voices 10 Years Later*. Washington, DC: FEMA. http://www.fema.gov/media-library-data/20130726-1515-20490-4930/voices_anthology1.pdf

[55] Carter, N.T. 2009. Federal flood policy challenges: Lessons from the 2008 Midwest flood. Washington, DC: Congressional Research Service. http://www.floods.org/PDF/2008_MidwestFloods/CR_Lessons_Learned_from_the_2008_Midwest_Flood.pdf

[56] Didion, J. 1979. Holy water. p. 59-66. In: *The White Album*. New York: Simon and Schuster.

[57] Hanak, E., J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, and B. Thompson. 2011. *Managing California's Water: From Conflict to Resolution*. San Francisco: Public Policy Institute of California.

[58] Jeffres, C.A., J.J. Opperman, and P.B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. *Environmental Biology of Fishes* 83: 449–458.

[59] Popkin, G. 2016. Reshaping the Chesapeake Bay, one living shoreline at a time. *Washington Post*, March 14, 2016. https://www.washingtonpost.com/national/health-science/reshaping-the-chesapeake-bay-one-living-shoreline-at-a-time/2016/03/14/9c223a4c-c51d-11e5-8965-0607e0e265ce_story.html

[60] Whalen, L., D. Kreeger, D. Bushek, J. Moody, and A. Padelleti. 2011. *Practitioners Guide: Shellfish-Based Living Shorelines for Salt Marsh Erosion Control and Environmental Enhancement in the Mid-Atlantic.* PDE Report 11-04. Wilmington, DE: Partnership for the Delaware Estuary and Rutgers' Haskin Shellfish Research Laboratory. http://delawareestuary.s3.amazonaws.com/pdf/Living%20Shorelines/Final_DELSI%20Practitioners%20Guide_2012.pdf

[61] NOAA Living Shorelines Group, *Guidance.*

[62] Whalen et al., *Practitioners Guide.*

[63] Schiffman, R. 2013. The Southwest's forests may never recover from megafires: "Abnormal" fire risks have become the new normal. *The Atlantic*, July 5, 2013. http://www.theatlantic.com/technology/archive/2013/07/the-southwests-forests-may-never-recover-from-megafires/277545/

[64] U.S. Forest Service. 2015. *The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work.* Washington, DC: U.S. Forest Service, Department of Agriculture. http://www.fs.fed.us/sites/default/files/2015-Rising-Cost-Wildfire-Operations.pdf

[65] Ibid.

[66] Combrink, T., C. Cothran, W. Fox, J. Peterson, and G. Snider. 2013. *A Full Cost Accounting of the 2010 Schultz Fire.* Flagstaff, AZ: Ecological Restoration Institute, Northern Arizona University. http://nau.edu/eri/banner/schulz-fire/

[67] Dunne, P. 2010. *Bayshore Summer: Finding Eden in a Most Unlikely Place.* Boston and New York: Houghton Mifflin Harcourt.

[68] Maser Consulting. 2016. *Cape May County Strategic Recovery Planning Report.* Prepared for Cape May County Board of Chosen Freeholders. Cape May County, New Jersey.

[69] Ibid.

[70] Schuster, E. 2014. *Lower Cape May Meadows Ecological Restoration: Analysis of Economic and Social Benefits.* Chester, NJ: New Jersey Chapter, The Nature Conservancy. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newjersey/cape-may-meadows-economic-report.pdf

[71] Maser Consulting. *Cape May County.*

[72] Dennis, J. 2012. The Windward Shore: A Winter on the Great Lakes. Ann Arbor: University of Michigan Press.

[73] Isley, P., E.S. Isley, and C. Hause. 2011. *Muskegon Lake Area of Concern Habitat Restoration Project: Socio-Economic Assessment.* Allendale, MI: Grand Valley State University. ftp://geoportal.wri.gvsu.edu/awri_website/final%20socio%20economic%202.pdf

[74] National Oceanic and Atmospheric Administration (NOAA). 2012. Habitat restoration in Michigan: A big bang for the buck. Silver Spring, MD: NOAA Fisheries. http://www.habitat.noaa.gov/highlights/michiganhabitatrestoration.html

[75] Carson, R. 1955. *The Edge of the Sea.* New York: Houghton Mifflin.

[76] Freed, A., E. Percifull, C. Kaiser, J. Goldstick, M. Wilson, and E. Maxwell. 2013. *Integrating Natural Infrastructure into Urban Coastal Resilience: Howard Beach, Queens.* New York: The Nature Conservancy. http://www.nature.org/media/newyork/howard-beach-report-12-23-2013.pdf

[77] Sigal, D. 2016. Saving Jamaica Bay: *A Documentary Film.* http://www.savingjamaicabay.com/

[78] New York City Panel on Climate Change. 2013. *Climate Risk Information 2013: Observations, Climate Change Projections, and Maps.* Prepared for use by the City of New York Special Initiative on Rebuilding and Resiliency. NY: City of New York.

[79] U.S. Army Corps of Engineers. 2016. Jamaica Bay Marsh Islands. New York: U.S. Army Corps of Engineers, New York District. http://www.nan.usace.army.mil/Missions/CivilWorks/ProjectsinNewYork/EldersPointJamaicaBaySaltMarshIslands.aspx

[80] Freed et al., *Integrating Natural Infrastructure.*

[81] City of New York. 2013. PlaNYC: *A Stronger, More Resilient New York.* New York: City of New York. http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Lo_res.pdf

[82] Ibid.

[83] Riepe, D. and E. Manclark. 2016. Personal communications.

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