National Landmarks at Risk

How Rising Seas, Floods, and Wildfires Are Threatening the United States' Most Cherished Historic Sites

Union of Concerned Scientists

National Landmarks at Risk

How Rising Seas, Floods, and Wildfires Are Threatening the United States' Most Cherished Historic Sites

Debra Holtz
Adam Markham
Kate Cell
Brenda Ekwurzel

May 2014

Union of Concerned Scientists

© 2014 Union of Concerned Scientists
All rights reserved

Debra Holtz is a communications consultant for the Union of Concerned Scientists (UCS). She is also a professional journalist whose work includes the book *Of Unknown Origin* and many articles for publications including the *San Francisco Chronicle*.

Adam Markham is director of the Climate Impacts Initiative at UCS. He has more than 20 years of experience working on conservation and climate change issues in the United States and Europe.

Kate Cell is a senior campaign organizer at UCS. She specializes in involving new expert constituencies such as economists, social scientists, and health professionals in the work of the UCS Climate & Energy Program.

Brenda Ekwurzel is a senior climate scientist with the UCS Climate & Energy Program. She is leading the organization's climate science education work aimed at strengthening support for sound U.S. climate policies.

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

More information about UCS is available on the UCS website (*www.ucsusa.org*).

A fully cited version of this report is available online (in PDF format) at *www.ucsusa.org/LandmarksAtRisk*.

Designed by:
Tyler Kemp-Benedict, Bangkok, Thailand
www.hardworkingtype.com

Cover photo: © William Trinkle Photography

North America's oldest masonry fort, the Castillo de San Marcos in St. Augustine, FL, is threatened by rising seas and storms.

Printed on recycled paper

[CONTENTS]

iv Figures

v About the Project Team

vii Acknowledgments

1 **Introduction**

[SITES]

4 BOSTON HISTORIC DISTRICTS Boston's Historic Districts and Faneuil Hall Are Increasingly Vulnerable to Floods

7 STATUE OF LIBERTY & ELLIS ISLAND Protecting the Statue of Liberty and Ellis Island from Rising Tides

10 HARRIET TUBMAN NATIONAL MONUMENT Monument to Harriet Tubman's Legacy Is Vulnerable to Rising Sea Levels

13 HISTORIC ANNAPOLIS, MD Planning to Prevent Storm Damage in a Historic Colonial Town

16 HISTORIC JAMESTOWN, VA Rising Seas Threaten to Inundate Jamestown Island

18 FORT MONROE NATIONAL MONUMENT Freedom's Fortress Is at Risk from Higher Seas and Heavier Rains

21 NASA'S COASTAL FACILITIES Multiple NASA Sites Face Challenges from Rising Seas

26 CAPE HATTERAS LIGHTHOUSE Saving an Icon: Moving the Cape Hatteras Lighthouse Away from the Shifting Shoreline

28 HISTORIC CHARLESTON, SC Preserving the Past by Planning for Future Floods

30 HISTORIC ST. AUGUSTINE, FL & CASTILLO DE SAN MARCOS Adapting to Climate Change Is Vital to Protecting St. Augustine's Distinctive Heritage

33 PREHISTORIC FLORIDA SHELL STRUCTURES A Race against Time for Florida's Prehistoric Shell Structures

36 MESA VERDE NATIONAL PARK Mesa Verde's Ancient Artifacts and Dwellings Are Increasingly Exposed to Wildfires and Flooding

39 BANDELIER NATIONAL MONUMENT & SANTA CLARA PUEBLO Pueblos Ancient and Modern Face Increased Risks from Fires and Floods

41 GROVELAND, CA Groveland and Other California Gold Rush–Era Towns Are Imperiled by Wildfires

44 CÉSAR CHÁVEZ NATIONAL MONUMENT California Farmworkers Championed by César Chávez Are Now Threatened by Extreme Heat and Drought

47 BERING LAND BRIDGE NATIONAL MONUMENT & SHISHMAREF, CAPE KRUSENSTERN NATIONAL MONUMENT & KIVALINA Native Villages and Ancestral Lands in Alaska Face Rapid Coastal Erosion

50 PU'UHONUA O HŌNAUNAU & KALOKO-HONOKŌHAU NATIONAL HISTORICAL PARKS Sea Level Rise Threatens Hawaiian Cultural Heritage Sites

52 **The Science behind the Changing Risks to Our National Treasures**

57 References

[FIGURES]

1 Figure 1. Map of Case Study Sites

21 Figure 2. NASA Coastal Facilities

52 Figure 3. Shift in Extreme Events

53 Figure 4. Factors That Influence Risk Include Exposure, Vulnerability, and Hazards

54 Figure 5. Storm Surge on a Higher Sea

54 Figure 6. Changes in Wildfire Size and Season

55 Figure 7. Percentage Change in Very Heavy Precipitation

[ABOUT THE PROJECT TEAM]

AUTHORS

Debra Holtz
Adam Markham
Kate Cell
Brenda Ekwurzel

UCS TEAM

Project Manager: Kate Cell
Leadership: Angela Anderson, Nancy Cole, Adam Markham, Suzanne Shaw
Climate Science: Kristina Dahl, Brenda Ekwurzel, Melanie Fitzpatrick
Research: Kathy Pillsbury
Review: Carina Barnett-Loro, Rob Cowin, Lisa Nurnberger, Seth Shulman
Editing: Steven Marcus
Production: Heather Tuttle, Bryan Wadsworth
Design: Tyler Kemp-Benedict
Administrative Support: Andrew Klein

EXTERNAL REVIEWERS

Boston Historic Districts: Benjamin Carp (Tufts University), Nancy Girard (City of Boston), Anthony Janetos (Boston University)
Statue of Liberty & Ellis Island: Bob Kopp (Rutgers University), Jim Miller (Rutgers University)
Harriet Tubman National Monument: Audrey Peterman (Earthwise Productions Inc.), Alan Spears (National Parks Conservation Association)
Historic Annapolis: Jane McWilliams, Sara Phillips (U.S. Naval Academy), Jean Russo (Archives of Maryland Online)
Historic Jamestown: Dorothy Geyer (National Park Service), Molly Mitchell (Virginia Institute of Marine Science)
Fort Monroe National Monument: Ray Gavins (Duke University), Pamela Goddard (National Parks Conservation Association), Adam Goodheart (Washington College), Molly Mitchell (Virginia Institute of Marine Science), Audrey Peterman (Earthwise Productions Inc.), Alan Spears (National Parks Conservation Association)
NASA's Coastal Facilities: Russell DeYoung (NASA), Jonathan McDowell (Harvard University)
Cape Hatteras Lighthouse: Thayer Broili (National Park Service), Orrin Pilkey (Duke University)
Historic Charleston: Rebecca Beavers (National Park Service)
Historic St. Augustine & Castillo de San Marcos: Rebecca Beavers (National Park Service), Len Berry (Florida Atlantic University)
Prehistoric Florida Shell Structures: Len Berry (Florida Atlantic University), Margo Schwadron (National Park Service)
Mesa Verde National Park: Todd Sanford
Bandelier National Monument & Santa Clara Pueblo: Rory Gauthier (National Park Service), Barbara Judy (National Park Service), Lauren Meyer (National Park Service)
Groveland, CA: Todd Sanford
César Chavez National Monument: Erik Loomis (University of Rhode Island), Todd Sanford
Bering Land Bridge: Shelby Anderson (Portland State University), Jeremy Karchut (National Park Service), Tony Weyiouanna (Shishmaref Native Corporation)
Pu'uhonua o Hōnaunau and Kaloko-Honokōhau National Historical Parks: Stanton Enomoto (National Park Service), Adam Johnson (National Park Service)

[ACKNOWLEDGMENTS]

This report was made possible by support from The Barr Foundation, The Energy Foundation, The Grantham Foundation for the Protection of the Environment, the Mertz Gilmore Foundation, and UCS members.

The UCS project team would like to acknowledge the assistance of numerous people in the preparation of this report. We would especially like to thank Marcy Rockman, Climate Change Adaptation Coordinator for Cultural Resources at the National Park Service, who provided invaluable advice, contacts, and guidance throughout. Particular thanks are also due to Shelby Anderson, Amanda Babson, Deborah Bailin, Rebecca Beavers, Karen Brown, Janet Cakir, Lizzy Carlyle, Lisa Craig, Peter DeBrine, Stanton Enomoto, Rory Gauthier, Ray Gavins, Dorothy Geyer, Patrick Gonzalez, Adam Goodheart, Andy Hansen, Cat Hoffman, Adam Johnson, Barbara Judy, Jeremy Karchut, Bob Krumenaker, Craig Lee, Steven Leibo, Ken Lustbader, Lisa Marrack, Lauren Meyer, Giselle Mora-Bourgeios, Shawn Norton, Diane Paviek, Audrey Peterman, Virginia Salazar-Halfmoon, Stephen Saunders, Margo Schwadron, Rhonda Sincavage, Leigh Welling, Jenna Wiser, Peter Wood, and Tony Wood.

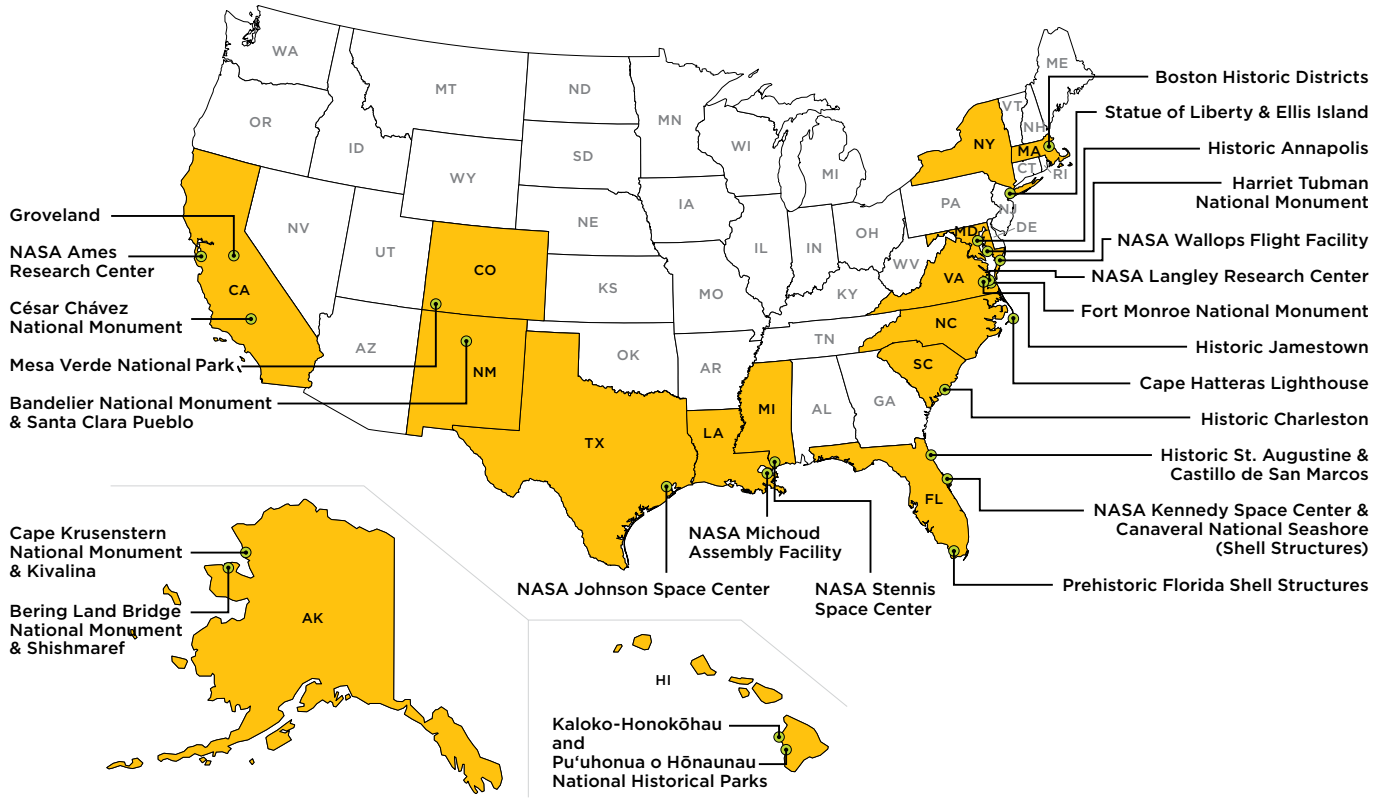
The opinions expressed herein do not necessarily reflect those of the organizations that funded the work or the individuals who reviewed it. The Union of Concerned Scientists bears sole responsibility for the report's content.

(Left:) At Mesa Verde National Park in Colorado, the top of the cliff shows the destruction of a forest fire.

© Kojihirano/Dreamstime.com

Many of the United States' iconic landmarks and heritage sites are at risk as never before. Sea level rise, coastal erosion, increased flooding, heavy rains, and more frequent large wildfires are damaging archaeological resources, historic buildings, and cultural landscapes across the nation.

FIGURE 1. Map of Case Study Sites



(Left:) While NASA undertakes research on other planets (as with the Mars-bound spacecraft being launched in this photograph) and the natural and man-made changes that affect the habitability of our own planet, the agency faces challenges from rising seas and other impacts of climate change.

© NASA/Bill Ingalls

From sea to rising sea, a remarkable number of the places where American history was made are already under threat. The geographic and cultural quilt that tells the American story is fraying at the edges—and even beginning to be pulled apart—by the impacts of climate change.

This report is not a comprehensive analysis of climate change threats to all of the United States' historic places, monuments and memorials, but rather a selection of case studies that vividly illustrate an urgent problem. These examples represent just a few of the many that could have been included, but the places they examine symbolize many of the rich and diverse elements of the American experience. The stories were chosen because the science behind the risks they face is robust, and because together they shine a spotlight on the different kinds of climate impacts already affecting the United States' cultural heritage.

The Range and Scale of Impacts Are Alarming

The range and scale of impacts are alarming. Coastal erosion in Alaska is washing away irreplaceable archaeological sites that chronicle some of the earliest people in the Americas, and also threatening the existence of native villages whose hunter-gatherer traditions originated thousands of years ago. Waves from rising seas batter the walls of ancient Hawaiian sacred sites and jeopardize future operations at Kennedy Space Center, where Apollo and many other pioneering missions were launched. Elsewhere along the Atlantic coast, historic districts, including those of Boston and Annapolis, are experiencing more frequent and severe coastal flooding and storm surges. Meanwhile, worsening wildfires are affecting nineteenth-century California Gold Rush towns and ancient pueblos in New Mexico and Colorado.

The landmarks discussed in this report include historic Jamestown, the U.S. Naval Academy, and Castillo de San Marcos. Ellis Island, where millions of Americans' ancestors entered the country for the first time, was closed to visitors for more than a year after Hurricane Sandy. Affected places include some of the oldest, as well as some of the most recently designated. Consider, for instance, that two of the nation's newest national monuments—sites commemorating Harriett Tubman in Maryland and Fort Monroe in Virginia—already face an imminent threat from sea level rise.

All of the case studies in this report draw on observations of impacts that are either consistent with, or attributable to, human-induced climate change based on multiple lines of scientific evidence. Some of the sites face the risk of severe damage or even eventual loss. Other case studies describe sites which are just now seeing the first signs of damage, or are experiencing disruptions to access and services that are likely to become worse, more frequent, or both. All provide a wake-up call: as the impacts of climate change continue, we must make hard choices now and take urgent steps to protect these sites and reduce the risks.

Just the Tip of the Iceberg

Many of the landmarks covered in this report are sites where innovative, enterprising, and visionary individuals made a difference. Many are places where our ancestors made their homes, and together represent the shared history that makes up the fabric of this nation's heritage. The stories these sites tell symbolize values—such as patriotism, freedom, democracy, respect for ancestors, and admiration for the pioneering and entrepreneurial spirit—that unite all Americans.

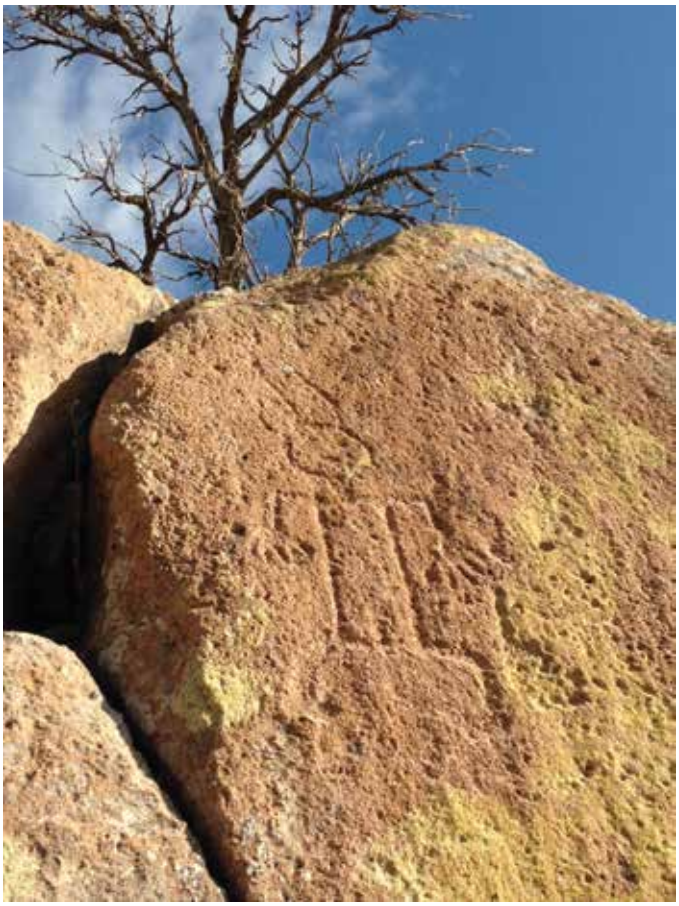
A significant number of the case studies in this report review climate change impacts now being observed in national parks, including Mesa Verde, Bandelier, Cape Hatteras, and the Everglades. The impacts are severe and numerous enough to have led Jon Jarvis, National Park Service (NPS) director, to state, "I believe climate change is fundamentally the greatest threat to the integrity of our national parks that we have ever experienced."

Now, nearly 100 years since the founding of the NPS, the agency finds itself forced to develop new ways to protect the natural and cultural resources in its care from the impacts of a changing climate. A recent NPS analysis shows that 96 percent of its land is in areas of observed global warming over the past century and that at least 85 sites have already recorded changes attributable to climate change. Many more have seen consequences such as increases in winter temperature, decreased snowpack, and shifts in precipitation that are consistent with

This report sounds a wake-up call: as the impacts of climate change continue, we must protect these sites and reduce the risks.

climate change. Another study by NPS scientists has determined that more than 100 national parks are vulnerable to the combined impacts of sea level rise and storm surges.

As this report illustrates, climate change is no longer a distant threat for others to worry about. The consequences are already under way, forcing federal and state agencies, park managers, archaeologists, historic preservationists, engineers, architects, and others to spend time and resources to protect sites today and prepare for expected additional changes tomorrow. Although the report spotlights a sampling of such stories, it bears noting that the United States boasts more than 400 sites in its National Park System and that more than 80,000 sites are listed on the National Register of Historic Places, along with numerous state and local historic parks and buildings. Many of these are already affected too by flooding, coastal erosion, wildfires, and other impacts, and many more will see even greater risks in the coming decades.



© Adam Markham

An example of a petroglyph (or prehistoric rock carving) at Bandelier National Monument.

A Call to Action

Given the scale of the problem and the cultural value of the places at risk, it is not enough merely to plan for change and expect to adapt. We must begin now to prepare our threatened landmarks to face worsening climate impacts; climate resilience must become a national priority and we must allocate the necessary resources. We must also work to minimize the risks by reducing the carbon emissions that cause climate change. The science is clear that by abating our carbon pollution we can slow the pace of change and thereby lower the risks posed by extreme heat, flooding, and rising seas.

The case studies in this report also highlight some of the initiatives that the NPS, the National Aeronautics and Space Administration (NASA), the U.S. Navy, city leaders, and others are pursuing now to reduce the damage and bolster the resilience of these important places. From the installation of breakwaters to protect against coastal erosion on Jamestown Island to the flood-proofing of electrical utilities at the Statue of Liberty, major efforts are now being launched to lessen the impacts of climate change on the United States' national heritage.

More such efforts are needed. If future generations of Americans are to experience the joy and wonder that these extraordinary places engender, we must act now to protect them from the impacts of climate change.

The United States boasts tens of thousands of national parks, landmarks, and historic places—many of them already affected by flooding, coastal erosion, wildfires, and other impacts.

Boston's Historic Districts and Faneuil Hall Are Increasingly Vulnerable to Floods

Founded in 1630 by English Puritans seeking religious freedom, Boston is one of the oldest cities in the United States and the birthplace of the American Revolution. But in the city where the Sons of Liberty plotted independence from Great Britain, some cherished landmarks and historic districts are at risk from rising seas and worsening storm surges.

Faneuil Hall, which is a stop on Boston's Freedom Trail and among the nation's best-preserved historic structures, is one such landmark. Ironically, merchant Peter Faneuil, who built this so-called "Cradle of Liberty" at his own expense, amassed much of his wealth through the slave trade. While the current building dates from 1806, when Charles Bulfinch enlarged Faneuil Hall and moved the cupola, it was first built as a commercial center in 1742 and located on the site of a small cove, which was filled in to accommodate the structure in an area called Dock Square. Over the years, Boston has grown in much this way—through a practice of "wharfing out," or constructing wharves and then filling them in. Consequently, Faneuil Hall is now a little more than a quarter-mile west of the present shoreline.

Directly to the north of Faneuil Hall is the Blackstone Block, a compact district of narrow winding roads and alleys dating from the seventeenth century. The most intact network of early colonial streets in the United States, the district includes the Ebenezer Hancock House and the Union Oyster House, the oldest restaurant in Boston and a favorite of Daniel Webster and John F. Kennedy. Even this far inland, Faneuil Hall and the Blackstone Block are vulnerable, lying within the city's 100-year tidal flood zone. Since official tidal records began in Boston in 1921, extreme high tides—more than three and a half feet above the average high tide—have occurred 20 times, and half of those tides took place within the past 10 years. As a result, several times a year exceptionally high tides already flood parts of the nineteenth-century warehouse neighborhoods around Fort Point Channel and the historic Long and Central wharves.

The public meeting space on the original second floor is what gives Faneuil Hall its fame. Here, Samuel Adams and other Sons of Liberty held public meetings and planned protests against such British colonial policies as the Stamp Act.

In the city where the Sons of Liberty plotted independence from Great Britain, some cherished landmarks and historic districts are at risk from rising seas and worsening storm surges.

It is also the site of the initial meeting about the Tea Act, which prompted the Boston Tea Party. On December 16, 1773, members of the Sons of Liberty disguised themselves as Mohawk Indians, boarded three of the British East India Company's ships, and dumped an estimated 90,000 pounds of tea into Boston Harbor. In response, the British government

© Carlos Alberto Ledesma Castaneda

Faneuil Hall continued to be vital to causes of liberty well into the nineteenth century, as William Lloyd Garrison and Frederick Douglass organized here for the abolition of slavery and Susan B. Anthony advocated women's rights. Now, however, this symbol of liberty and its surrounding neighborhoods are increasingly at risk from rising seas, storm surges, and coastal flooding.

enacted a series of punitive Coercive Acts (called "Intolerable Acts" by the colonists), including an attempt to limit town meetings such as those held in Faneuil Hall.

Two hundred years after the Declaration of Independence, Faneuil Hall was still used as a place for meetings and other events, but its commercial uses had been discontinued. A 1976 renovation restored the building to its central role in Boston life and served as a model for renewal and revitalization in other American cities. Today Faneuil Hall still houses public forums and serves as the anchor of a robust and vital commercial center.

The City of Boston is highly aware of the dangers posed by sea level rise and heavier rains, and is proactive in planning resilience strategies. The Organisation for Economic Co-operation and Development (OECD) ranked Boston the eighth-highest metropolitan area worldwide in expected economic losses, estimated at $237 million per year between now and 2050, due to coastal flooding. In a 2013 report, the Boston Harbor Association noted that if Hurricane Sandy had hit just five or six hours later, at high tide instead of low tide, more than 6 percent of the city would have been under water. A flood of that magnitude would inundate many of Boston's coastal neighborhoods, including 65 percent of the Fort Point Channel and Blackstone Block historic districts. As the sea level continues to rise, the risk of major coastal flooding increases.

During the winters of 2013 and 2014, nor'easters caused storm tides to rise even higher than those from Hurricane Sandy in 2012—one rose a foot higher. Yet so far Boston has been lucky, as these storm surges have all coincided with low tides. If the worst of the storm surges had hit at high tide, major flooding could have occurred, inundating much of the waterfront, past Faneuil Hall up to City Hall, and the part of the North End where Paul Revere began his ride.

Boston officials know that they can't depend on this good fortune to continue indefinitely. Because of sea level rise and other climate threats, including higher temperatures and

increased smog, the city has embarked on major initiatives to address climate change mitigation and adaptation. Boston has improved its emergency warning systems for flooding, high winds, and winter storms. All new municipal construction must include both an evaluation of climate risks through the year 2050 and a description of ways to avoid, minimize, or mitigate those risks. Other measures include deploying "green" infrastructure (which uses vegetation and soil to manage rainfall and reduce urban heat), better enforcement of flood-proofing building standards, and preparedness for addressing a variety of hazards such as floods, hurricanes, and extreme heat before they occur.

From W.D. Cooper's *Boston Tea Party: The History of North America*

A cartoon of the Boston Tea Party from 1789. The City of Boston is protecting its share of national treasures, some of which are located near the waterfront, by improving its emergency warning systems for flooding, requiring all new municipal construction to evaluate climate risks through 2050, and better enforcing flood-proofing building standards, among other measures.

Protecting the Statue of Liberty and Ellis Island from Rising Tides

The Statue of Liberty and Ellis Island, prominently positioned in New York Harbor and serving as a gateway to our nation's largest city, are powerful symbols of freedom and democracy. Each year, millions of tourists visit these monuments to trace their family ancestry or explore the immigration experience so central to the American identity.

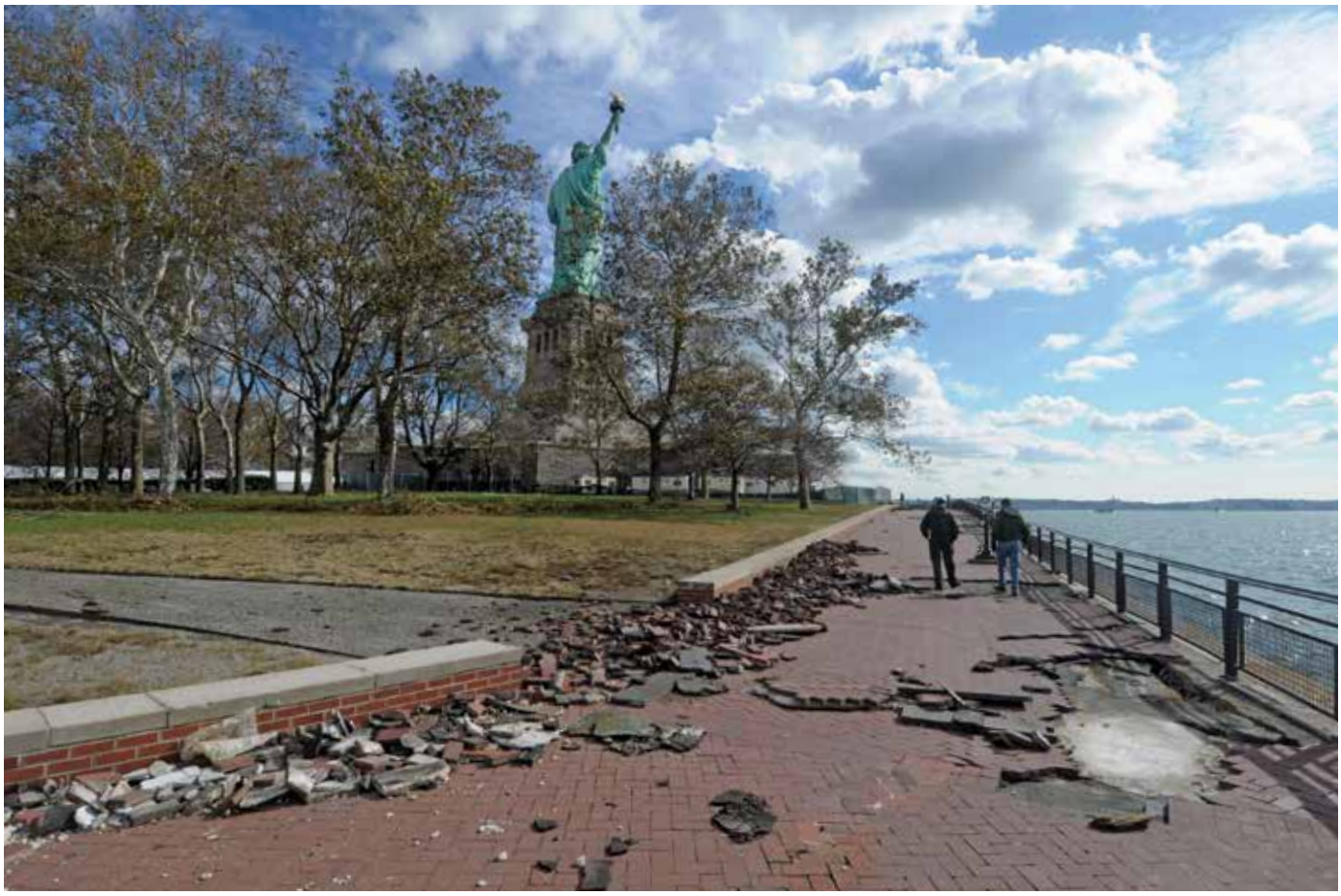
Those visits came to a halt on October 29, 2012, when Hurricane Sandy submerged most of Liberty and Ellis islands, destroying vital operating systems and causing an estimated $77 million in damage. It took many months of recovery efforts before they reopened to the public in 2013. Even then, repairs were still under way to protect Ellis Island from future storms, whose surge of piled-up water will be magnified by rising seas.

Nearly 14 million immigrants entered the United States through New York between 1886 and 1924. The Statue of Liberty with its raised torch, famously called "The Mother of Exiles," welcomed them as they sailed into port. The vast majority of newcomers were processed at nearby Ellis Island, which was the country's largest immigration station. Until 1954, when it officially closed, 12 million immigrants stepped onto American soil for the first time at Ellis Island. For most of these new arrivals, the island marked the beginning of a new life in the United States, one filled with the promise of economic opportunity and freedom from persecution.

But while Liberty Island (upon which the Statue of Liberty stands) and Ellis Island have long represented a safe refuge for generations of immigrants, the islands themselves were not protected from the ravages of Hurricane Sandy. A massive storm unlike any experienced before in New York, together with rising sea levels primarily due to climate change, caused

© Americanspirit/Dreamstime.com

Hurricane Sandy forced the National Park Service to move more than a million treasured artifacts—such as Native American pieces dating back to 783 A.D., personal belongings of immigrants (above), and architectural drawings—off Ellis Island for safekeeping.



© NPS/Daly

Hurricane Sandy's massive storm surge destroyed most of the radio equipment, electrical infrastructure, and security systems of both Liberty and Ellis Islands. Floodwaters inundated three-quarters of Liberty Island—some of the aftermath is pictured, above—and the beloved landmark was closed to the public for more than eight months.

floodwaters to inundate three-quarters of Liberty Island and almost all of Ellis Island.

Liberty Island was closed for more than eight months and Ellis Island partially reopened a full year after the storm, with sections of the historic main building and museum, including most of their exhibits, remaining closed. Statue Cruises, the company that runs ferries to the two islands as well as harbor tours, saw its annual ridership of nearly 4 million drop by more than half, lost 80 percent of its overall revenue, and had to lay off 75 percent of its workforce during the closures.

Hurricane Sandy also marked the end of a 200-year tradition of people living on Liberty Island. The National Park Service (NPS) decided not to rebuild the small brick house located on the lowest part of the island—home to the park's superintendent—because of the danger of placing residents in the path of future flooding.

Previous coastal storms have hit New York with higher winds and more rain than did Hurricane Sandy, but the storm surge it created was unprecedented. Sandy coincided with a higher-than-normal high tide in the Atlantic Ocean and in New York Harbor, given the alignment of the sun and moon at the time. In addition, the storm was 1,000 miles wide, more than three times the size of Hurricane Katrina, which devastated the Gulf of Mexico coast in 2005.

Hurricane Sandy's storm surge rode in on sea levels that had risen by more than a foot and a half since the 1850s, leading to more widespread coastal flooding.

Making matters worse, sea levels in the New York area had risen by more than a foot and a half since measurements began in the 1850s, leading to higher and more widespread

coastal flooding. There is evidence as well that Sandy gained strength from unusually warm upper-ocean temperatures in the North Atlantic; these temperatures are expected to continue rising with global warming.

"Clearly, while Sandy was historic, it was not, in fact, a worst-case scenario for all of New York City. And as the climate changes . . . the risks that New York City faces will only intensify." So concluded *A Stronger, More Resilient New York,* a plan released in June 2013 that recommended investments for protecting the city from the impacts of climate change.

In a preface to the plan, then-Mayor Michael Bloomberg noted that the city had already been preparing when Hurricane Sandy hit, "but the storm set the bar higher," he said. "As the possibility of more severe weather increases with climate change, we must rise to the occasion."

The NPS is also preparing for the possibility that Liberty Island and Ellis Island may again be in harm's way. In working to make these monuments more resilient to future storms, the agency's rebuilding efforts include elevating their electrical systems as much as 20 feet above sea level and designing the heating and air conditioning systems to withstand flooding.

Like New York City, the NPS was already developing nationwide guidelines to identify and manage the risks posed by climate change, particularly regarding its coastal properties. But then Hurricane Sandy struck, making the need to develop and implement a robust adaptation strategy all the more urgent.

"We recognize that these climate change stressors are real," says Shawn Norton, the NPS bureau chief for the Sustainable Operations and Climate Change Group, "and they are going to become more common and intense."

© National Park Service/Sandy Response

The relighting of Liberty's torch after Hurricane Sandy, above, is now a symbol not only of freedom but also of resiliency in the face of rising seas and stronger storms. New York City and the National Park Service are preparing for the possibility that Liberty Island and Ellis Island may again be in harm's way.

Monument to Harriet Tubman's Legacy Is Vulnerable to Rising Sea Levels

By commemorating the life of the legendary abolitionist, renowned for her courage and determination, the Harriet Tubman Underground Railroad National Monument promises to instill in visitors a deeper understanding of the African-American experience of slavery and hard-won freedom.

On March 25, 2013—the centennial of Tubman's death—President Barack Obama designated 25,000 acres on Maryland's Eastern Shore as one of the nation's newest monuments. But this embodiment of Tubman's antislavery legacy may be endangered by sea levels in the Chesapeake Bay, which have risen at almost twice the global rate because of climate change. The site could be largely underwater by 2050.

This imperiled land in Dorchester County is where Tubman was born into slavery in 1822 and toiled under oppressive masters, whose beatings caused her to suffer from chronic seizures throughout her life. She eventually escaped, at age 27, only to return to Maryland numerous times to rescue others and lead them north through thick weeds and marshes to freedom. This delivery of a great many of her people from bondage, via the network of secret routes and safe houses known as the Underground Railroad, earned her the nickname "Moses."

"Harriet Tubman's story is America's story. She risked her life over and over again in the struggle against the evil of slavery. She lived by principles, strong faith in God, her love of family, and a belief in a better life," said Chérie A. Butler, the National Park Service's superintendent of the Tubman monument. "Ms. Tubman's story is a testament that one determined person—no matter [her] station in life—can make a difference."

The new monument fulfills the aspirations of many supporters who spent years pressing for a landmark to honor

© H. Seymour Squyer

Harriet Tubman (above, ca. 1885), the "Moses of her people," led dozens of enslaved people to freedom through lands that now form one of the nation's newest monuments.

© Jay L. Baker

Federal, state, and local officials participate in the groundbreaking for the new Harriet Tubman Underground Railroad National Monument. Left to right: Harriet Tubman Organization President David Pinder, Maryland Department of Natural Resources Secretary John Griffin, National Park Service Director Jonathan Jarvis, Cambridge Mayor Victoria Jackson, Maryland Park Service Superintendent Nita Settina, Governor Martin O'Malley, U.S. Department of the Interior Secretary Ken Salazar, Councilman William Nichols, Maryland Secretary of General Services Alvin Collins.

The visitor center will be built on higher ground, and architecturally elevated, in recognition of the threat posed by rising sea levels.

Tubman's legacy as an abolitionist, nurse, and spy for the Union Army during the Civil War. A 2012 letter to the Department of the Interior requesting the national-monument designation was signed by a bipartisan group of lawmakers that included the state's Republican Representative Andy Harris and Democratic Senators Ben Cardin and Barbara A. Mikulski.

This achievement, however, may not be long-lived. Maryland, with more than 3,000 miles of tidal shoreline and low-lying rural and urban lands, is one of the states most vulnerable to sea level rise. Designating Tubman's birthplace a national monument protects it from development but not from the rising seas off Maryland's coast. Already, the waters of the Chesapeake Bay near the Tubman memorial have risen more than 10 inches over the past 70 years and may rise another 15 inches by 2050.

The Tubman monument is a vast expanse of marshes, fields, and forestlands that today remain much the same as when Tubman was alive. This status could change in the coming decades, as warming oceans increase the likelihood that tropical cyclones that survive the formation process will become Category 3, 4, or 5 storms—with the western North Atlantic (which abuts Maryland, among other states) being hit

especially hard. Powerful storm surges riding on higher sea levels will be able to penetrate farther inland, causing more damage to the shoreline than the region has experienced for thousands of years.

Just weeks before the president announced the monument, Maryland broke ground on the 17-acre Harriet Tubman Underground Railroad State Park, which falls within the boundaries of the national monument and is expected to open in 2015 at a cost of $21 million. Construction is under way on a 15,000-square-foot visitor center, designed with state-of-the-art systems for energy and water efficiency. Moreover, the center will purposely be placed on higher ground, and elevated as well, in recognition of the threat posed by rising sea levels.

But these measures may not be enough. The Tubman monument includes parts of the Blackwater National Wildlife Refuge, where wetlands at sea level are being lost to the rising ocean at the rate of about 300 acres a year. A 2002 study by the U.S. Geological Survey predicted that the refuge could be underwater by 2050—a loss that would deprive nearby communities of the critical protection against storms and sea level rise that the wetlands provide. This area also is home to one of the largest populations of nesting bald eagles on the Atlantic coast, as well as to numerous other bird and mammal species.

Efforts to limit sea level rise by reducing carbon emissions, as well as large-scale projects to restore wetlands, will be necessary to ensure that this landscape remains not only an important national symbol—of our country's checkered history of securing civil rights for all of its people—but also that it remains a vital part of the economy of Maryland's Eastern Shore.

© Steven L. Tahone Nature Photography

The Tubman monument is a vast expanse of marshes, fields, and forestlands known so well by Tubman that she used these natural landmarks as navigational tools on the Underground Railroad's route to freedom. But these marshes are being lost to the rising ocean at an alarming rate and could be underwater by 2050.

Planning to Prevent Storm Damage in a Historic Colonial Town

The next major storm that hits Annapolis, MD, could cause extensive flooding and widespread damage to the city's historic center. Because sea levels continue to rise in Chesapeake Bay, a so-called 100-year storm (a severe event with a 1 percent chance of occurring in any given year) would likely severely damage many historic structures in Annapolis, take years from which to recover, and seriously harm the city's tourism economy.

Laid out in 1695, Annapolis was one of the first planned cities in the United States. Its historic core contains the country's largest concentration of eighteenth-century brick buildings, including the Palladian-style Hammond-Harwood House, widely regarded as one of the finest colonial buildings in America. Settled in the mid-seventeenth century by nonconforming Protestants from Virginia and other religious independents, Annapolis later became the capital of the colony, and the state, of Maryland. The city's eighteenth-century waterfront bustled with ships bringing visitors, immigrants, servants, and slaves to town. Imported goods from Europe, the Caribbean, and other colonies filled dockside warehouses.

All four of Maryland's signers of the Declaration of Independence lived in Annapolis at one time or another, and the city was the first post-Revolutionary War capital of the United States, hosting the Continental Congress in 1783 and 1784. George Washington resigned his commission as commander of the Continental Army here in 1783, and the Treaty of Paris, which formally ended the war, was ratified in the State House in 1784. That building's huge wooden dome—the largest in the nation—became a model in subsequent years for many other American state houses.

Annapolis is also known as the home of the U.S. Naval Academy. Founded as the Naval School in 1845, with an initial enrollment of about 50 students, most of its Beaux Arts–style historic buildings date from the early 1900s, including the chapel with its iconic dome. The body of John Paul Jones, one of the founding officers of the Continental Navy, lies in a crypt under the chapel. The famous flag carrying the words "Don't

© Alexis Bond

This Annapolis statue, commemorating Roots *author Alex Haley and his central character Kunta Kinte, is shown here during Hurricane Isabel in 2003. Isabel's storm surge also caused disastrous flooding in the historic City Dock area, damaging dozens of buildings.*

give up the ship," flown in 1813 by Admiral Oliver Hazard Perry at the Battle of Lake Erie, hangs in Memorial Hall.

Many of the places and structures that provide daily reminders of Annapolis's rich history are today at risk because sea levels along the coast of Maryland are rising. During the last 20 years, sea level along the 620-mile Atlantic coastline north of Cape Hatteras, NC, has risen up to four times faster than the national average. According to scientists at the University of Maryland, Chesapeake Bay's sea level could rise by another one to two and a half feet by the middle of this century. To make matters worse, warmer ocean temperatures are fueling stronger North Atlantic hurricanes. Storm surges associated with hurricanes and other storms have caused the water to ascend three feet or more above mean sea level at least 10 times in Annapolis during the last decade. Resulting damage can be expected to worsen in the future, as rising seas not only raise the frequency of floods from regular high tides but also increase the height of storm surges.

Tropical cyclones and nor'easters can bring powerful winds that push waters up against the head of Chesapeake Bay, potentially causing catastrophic flooding in Annapolis. Hurricane Isabel caused widespread and serious flooding in the city during September 2003, when water levels at the Naval Academy reached about six and a half feet above average, more than two feet over the current 100-year flood level; classrooms, laboratories, athletic facilities, residence halls, and the utility tunnels under the Nimitz Library were inundated, causing more than $120 million in damage. Since Hurricane Isabel, the Naval Academy has developed extensive flood-mitigation plans and implemented many measures to reduce damage and bolster resilience to future floods. Measures have included the installation of door and window dams, temporary flood walls, and check valves on tunnels. Belowground cisterns that capture storm water and slowly release it have been built to mitigate the impacts of flooding.

The storm surge from Isabel caused disastrous flooding in the historic City Dock area too, damaging dozens of buildings. It took a decade before the 1858 Market House was restored, reopening in 2013.

In addition to the threat of major storms, regular nuisance flooding in Annapolis is increasing as a result of sea level rise. Seven of the highest water levels since 1937 have

©Cherie A. Thurlby, U.S. Department of Defense

Although hats were tossed high during this graduation ceremony at the U.S. Naval Academy, the mood during Hurricane Isabel was far from festive. Water levels at the time were more than two feet over the current 100-year flood level, causing more than $120 million in damage to the campus.

©Steven Frame/Dreamstime.com

To help protect historic shops and buildings along the waterfront in downtown Annapolis, the city is developing a Cultural Resource Hazard Mitigation plan, which is likely to become a model for other historic coastal cities facing sea level rise, higher storm surges, and more frequent coastal flooding.

occurred since 2000. Most of the area around City Dock is at just two to four and a half feet above sea level, and minor flooding begins when water levels reach 1.9 feet. At that point, storm drains begin to back up and water discharges from drain inlets.

The city is preparing for the inevitability of another major storm and, by 2050, for at least a doubling of high-tide flooding events. In order to ensure the preservation of the buildings and streetscape within the 100-year floodplain of the city's Historic Landmark District, Annapolis is developing a Cultural Resource Hazard Mitigation plan—beginning with a comprehensive survey of all 140 at-risk buildings in the district—supported in part by the National Trust for Historic Preservation, the Maryland Historical Trust, and Preservation Maryland. Among the many important buildings close to the City Dock that the survey will include are the waterfront Tobacco Warehouse (early nineteenth century); Middleton Tavern (ca. 1750), from which renowned visitors including George Washington and Thomas Jefferson traveled by ferry across the bay; and the Sands House (ca. 1739), one of the city's oldest and lowest-lying buildings. Annapolis's pioneering approach to minimizing damage and disruption from future climate change is likely to become a model for other historic coastal cities.

Many of the places and structures that provide daily reminders of Annapolis's rich history are today at risk because sea levels along the coast of Maryland are rising.

Rising Seas Threaten to Inundate Jamestown Island

© Americanspirit/Dreamstime.com

Jamestown commemorates the first permanent English colony in what is now the United States with the tercentenary monument, the John Smith memorial (both pictured above), archaeological sites, and irreplaceable artifacts. Hurricane Isabel damaged just under a million of Jamestown's artifacts, which had to be hand-dried to prevent mildew and rot.

By the end of this century, the only way to experience "America's birthplace" may be by reading about it in history books or online. That's because rising sea levels and increasingly powerful coastal storm surges could submerge much of Virginia's Jamestown Island—the site of the first permanent English colony in North America—and could carry away much of its buried treasure of centuries-old artifacts.

Virtually all of the land where Pocahontas and Captain John Smith once walked is now less than five feet above water, and this small margin is slipping lower as increasingly severe storm surges and flooding erode the shoreline. To make matters worse, the land is sinking, partly because of groundwater extraction.

Despite efforts to protect Jamestown, scientists and park officials have been sounding ever-louder alarms that saving it may not be possible in an era of climate disruption.

Valued by Americans as the origin of the country's representative democracy, Jamestown is part of the Colonial National Historical Park, which also includes Yorktown—where the last major battle of the American Revolutionary War was fought. Some 3 million visitors a year use the 23-mile scenic Colonial Parkway that connects many of the park's historic sites; according to the National Park Service (NPS), in 2011 these visitors injected an estimated $62.6 million into the local economy.

The waters surrounding Jamestown have been rising at a rate of more than twice the global average, and this local rate is bound to increase with the melting of land-based ice (such as the Greenland and Antarctic ice sheets), as a result of the warming global climate. Projections by the Virginia Institute of Marine Science are that the state's coastal waters could rise as much as two feet by 2050 and up to six feet by the end the century.

Warmer ocean temperatures mean that when North Atlantic storms survive the hurricane-formation process, they often are rendered stronger than at lower temperatures. In 2003, Hurricane Isabel demonstrated the destruction that even a Category 2 hurricane could inflict on this vulnerable area. The national park sustained $20 million in damages when Isabel struck at high tide, producing heavy rainfall and creating one of the highest storm surges on record in the Chesapeake Bay region; thousands of trees were uprooted and lower elevations were flooded. Before Isabel hit, the NPS had already decided to build a new visitor center on a higher elevation, but not soon enough; the existing center and its museum were badly damaged in the storm.

The park's artifacts and archaeological sites are precious and irreplaceable; among other things, they help us better understand the lives of the early settlers and the Native Americans who preceded them. That is why Isabel's damaging of just under a million of Jamestown's artifacts, which had to be evacuated and then hand-dried to prevent mildew and rot, was such a wake-up call. The flooding also submerged the remains of the original furnaces of a 400-year-old glassblowing factory—one of the earliest industrial sites in North America—and almost wrecked a nearby replica, where present-day artisans fashion wine bottles and candleholders using colonial methods.

© Smithsonian Institute

Forensic anthropologist Douglas Owsley (left) and APVA Preservation Virginia/Historic Jamestowne archaeologist Danny Schmidt discussing the double burial of two European males. The site's treasures are so imperiled that archaeologists are rethinking the practice of keeping artifacts still buried in the ground for discovery by future generations.

The NPS is now working to protect Jamestown's resources and ensure that Americans can continue to visit its historic sites. Riprap (a breakwater made from large stones) has been installed around most of Jamestown to prevent future shoreline erosion. The original Jamestown Fort, owned and managed by Preservation Virginia, is being excavated, even though one corner of the fort has already been lost. And the NPS also is monitoring the local rate of sea level rise and planning additional research to determine how Jamestown might further adapt to this and other impacts of climate change.

Freedom's Fortress Is at Risk from Higher Seas and Heavier Rains

Rising seas and heavier rainfall are threatening an iconic place—Fort Monroe, VA—in the centuries-old struggle for liberty and justice in America. This imposing fort, perched on low-lying Old Point Comfort at the mouth of Chesapeake Bay, played a pivotal role in bringing an end to American slavery on the very spot that also had witnessed slavery's beginning. President Obama recognized Fort Monroe's extraordinary history when he designated the site a national monument in 2011. But now the Virginia fort that served as a beacon of freedom to escaping slaves needs protection itself—from rising water levels and increasingly severe flood damage caused by climate change.

On the night of May 23, 1861, just hours after the ratification of Virginia's secession from the Union, three young enslaved people—Sheppard Mallory, Frank Baker, and James Townsend—rowed across the waters of Hampton Roads to Union-held Fort Monroe in search of freedom. The three men had escaped from a work detail that was building Confederate defenses at nearby Sewell's Point. Soon afterward, when a Confederate officer arrived to demand the return of the fugitives, Fort Monroe's newly arrived commander, General Benjamin Franklin Butler, made a decision that would eventually lead to President Abraham Lincoln's Emancipation Proclamation. He refused to return the men, on the basis that they were "contraband of war."

Word of the "contraband" decision spread quickly across the slave states, and soon a flood of escapees began flocking toward Union camps and forts, all seeking liberty. Many volunteered to help the Union cause as soldiers, scouts, and laborers. The courage of these men, women, and children led Congress to pass a series of laws that guaranteed their freedom—and that cleared a path for the president to issue his Emancipation Proclamation.

© Jason Portell

Under this tree, Mary Peake taught children from the "contraband camp." In 1863, people gathered here for the first Southern reading of the Emancipation Proclamation. The Emancipation Oak still stands on the grounds of Hampton University.

As space in and around Fort Monroe began running out, Great Contraband Camp, one of the first self-contained African-American communities in the country, sprang up in the burned-out ruins of Hampton. In 1861, a free black woman, Mary Peake, began teaching classes in the shade of a spreading oak tree, where in 1863 the first Southern reading of the Emancipation Proclamation would be heard. Peake's makeshift schoolroom evolved into Hampton University, one of the nation's first historically black colleges. Today, the Emancipation Oak still stands on the campus, a symbol of the promise of education for all.

© Virginia Tourism

Fort Monroe, VA, at the mouth of Chesapeake Bay, was integral to the end of American slavery. The first African slaves to arrive in English North America made landfall at Old Point Comfort where the fort now sits; 250 years later, "Freedom's Fortress" provided refuge for thousands of escaping slaves during the Civil War.

Fort Monroe was also the setting of an earlier chapter in the history of American slavery. In 1609, soon after the English settlers first arrived at Jamestown, they built a defensive outpost at Old Point Comfort, the site of Fort Monroe, and it was here that in 1619 the first African slaves to arrive in English North America made landfall. Thus across the span of some 250 years, this small spit of land witnessed both the beginning and the end of American slavery.

Fort Monroe is highly vulnerable to sea level rise and coastal flooding. A nearby tide gauge shows that water levels near the fort have risen almost a foot and a half since the 1920s. A study for the Virginia General Assembly projects the state's coastal waters could rise as much as another two feet by 2050 and up to six feet by the end the century. With a higher sea level, coastal storm surges—the potentially destructive increases in sea height that occur during a coastal storm—could inundate areas much farther inland. In addition to the rising sea, since 1950 the area around Fort Monroe has also experienced significantly more heavy-rainfall events than before.

Fort Monroe is highly vulnerable to sea level rise. A nearby tide gauge shows that water levels near the fort have risen almost a foot and a half since the 1920s.

The combination of rising sea levels and heavier precipitation will likely increase the frequency and severity of flooding at Fort Monroe. The tide gauge at Sewells Point measured storm surges of more than four and a half feet during Hurricane Irene in 2011 and over five and a half feet during Hurricane Isabel in 2003. Hurricane Isabel caused more than

$100 million in damage at Fort Monroe, with nearly 200 housing units and administrative buildings damaged by floodwaters and several wooden piers destroyed.

After Isabel, the Army Corps of Engineers built a new seawall, but in so doing it took into account only the historic rates of sea level rise, not the higher rates that Hampton Roads is likely to experience from now on. Already, flooding events triggered by storms and exceptionally high tides regularly inundate basements and cause untreated sewage to flow directly into Chesapeake Bay. One recent study found that among the highest tides recorded at Sewells Point between 1930 and 2010, half of them occurred in the last 13 years of the study period.

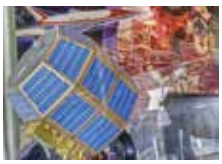
© Peter Stinson

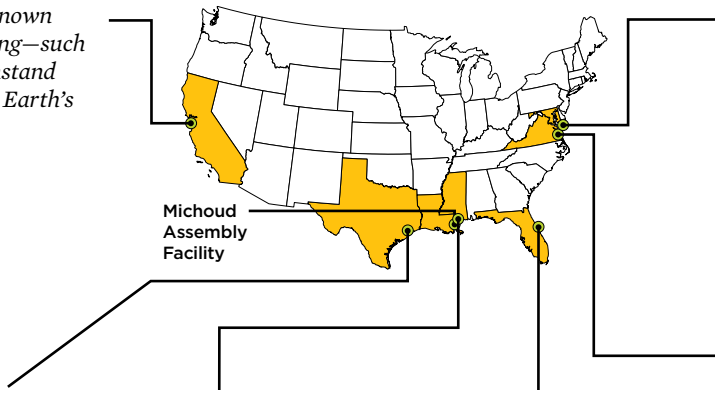
Surrounded by the Atlantic Ocean, Fort Monroe is vulnerable to flooding from rising seas, storm surge, and extreme precipitation. Hurricane Isabel's storm surge of five and a half feet (2003) caused more than $100 million in damage to housing units, administrative buildings, and wooden piers.

Multiple NASA Sites Face Challenges from Rising Seas

FIGURE 2. NASA Coastal Facilities

Ames Research Center, *Moffett Field, near San Francisco, CA. Some of NASA's most vexing challenges have been tackled at this research center known for its innovative problem-solving—such as how to shape vehicles to withstand the extreme heat of reentry into Earth's atmosphere.*





Wallops Flight Facility, *along the Eastern Shore of Virginia. Wallops hosts six launch sites and support facilities; more than 16,000 rockets have been launched from this island since 1945.*

Langley Research Center, *Hampton, VA. Langley boasts a well-earned reputation as a leader in the history of flight technology. This complex houses facilities for simulating flight, including a wind tunnel for testing at supersonic speeds.*

Johnson Space Center, *on Galveston Bay near Houston, TX. This is NASA's command center for human spaceflight operations and is home to the Apollo Mission Control Center, designated a national historic landmark. All U.S. astronauts train at this facility.*

John C. Stennis Space Center, *Hancock County, MS. Launch vehicles used in the Apollo moon landing program and the main engine for the space shuttle were tested here. At a sister site in Louisiana, the Michoud Assembly Facility contains one of the largest production buildings in the country.*

Kennedy Space Center, *Cape Canaveral, FL. Deeply embedded in the American imagination, the Apollo moon missions and many space shuttle missions were launched from this site. The launch pad is very close to the ocean and is vulnerable to the dangers of rapidly rising seas and storm surge.*

For three generations, the National Aeronautics and Space Administration (NASA) has stirred humans to think beyond our home planet and ponder our place in the universe. From the sight of the first people landing on the moon in 1969 to the awe-inspiring beauty of the cosmos beamed back as images from the Hubble Telescope, NASA has inspired us. But with more than two-thirds of its facilities within 16 feet of sea level, and many launch pads and other structures at very low elevations, NASA faces urgent challenges to protect itself from rising seas.

When the Soviet Union launched Sputnik, the first successful artificial satellite, in 1957, Americans were shocked at losing the first phase of the space race to their cold war rival, yet they were also exhilarated by the potential of space exploration. Impelled by this competition, NASA executed a series of manned space missions: Projects Mercury, Gemini, and Apollo. Further propelled by Soviet cosmonaut Yuri Gagarin's first human flight into outer space, President John F. Kennedy vowed in 1962, "We choose to go to the moon in this decade." And indeed, on June 20, 1969, Buzz Aldrin and Neil Armstrong became the first men to land on the moon, thrilling their fellow Americans as they walked on its surface for more than two hours and planted the Stars and Stripes. At the height of the cold war, NASA embodied American courage and innovation and spurred the country to higher scientific achievement.

Since the moon landing, NASA has carried out hundreds of missions, manned and unmanned, including the launch of a prototype space station (Skylab, in 1973). For 30 years, from 1981 to 2011, as the cold war waned and ended, the Space Shuttle Program solidified international cooperation in space. In 1990, NASA launched the Hubble Space Telescope, which takes extremely high-resolution images of deep space—and therefore of the universe's past. The agency has made unmanned explorations of all the planets in our solar system, sampling ice on Mars, confirming temperatures on Venus, and discovering methane lakes on Saturn's moon, Titan, and a possible subsurface ocean on Jupiter's moon, Europa. NASA's Hubble, Chandra, and Fermi observatories have revealed that enormous black holes, present in most galaxies, often emit powerful jets of matter traveling near the speed of light, thereby allowing physicists to test Einstein's theories.

NASA yielded its launch of commercial satellites to the private sector in 1986, but it continues to launch resupply rockets for the International Space Station and other scientific satellites and instruments. Such space tools allow scientists to study the atmosphere and oceans in great detail, provide farmers with weather forecasts that guide them on when to plant and harvest, and help government and industry alike to improve aviation safety and shipping reliability. In October 2012, NASA's space tools enabled predictions that Hurricane Sandy would make landfall in southern New Jersey nearly five days before the storm hit. As devastating as the hurricane was, the accuracy of these predictions meant that officials and citizens could make life-saving decisions about preparedness and evacuation.

In the area of the environment, NASA's Goddard Institute for Space Studies undertakes research on natural and man-made changes that "affect the habitability of our planet," while the agency's Goddard Space Flight Center runs the satellites that study climate. It is ironic that the agency that has done so much to warn us about climate change, and to prepare us for the resulting disruptive weather, itself faces challenges from rising seas and other climate-change impacts.

Wallops Flight Facility

For example, NASA's Wallops Flight Facility, along the Eastern Shore of Virginia, has completed more than 16,000 rocket launches since its establishment in 1945. Billing itself as the "on-ramp to the International Space Station," Wallops hosts six launch sites as well as support facilities and a major Naval Surface Combat Systems Center. According to NASA's own

© Stephen Nakatani

Rockets are still being launched from NASA's Wallops Flight Facility in Virginia (above, 2013), but it's unclear how long this island facility can withstand higher seas, which have risen by more than nine inches in less than 70 years.

climate-adaptation planning documents, Wallops is critical to these missions because it is geographically secluded and adjoins the Atlantic Warning Area, a secure airspace with no commercial traffic. But as of 2013, sea level had risen by more than nine inches since the facility opened. In response, NASA has built seawalls to protect the facility, and in August 2012 the agency completed a dune-building project that added more than 3 million cubic yards of sand. Such precautions, however, were insufficient against Hurricane Sandy, which removed about 700 feet of a protective sand barrier, 20 percent of the beach between Wallops and the sea, and damaged the facility's roofs, siding, and other infrastructure.

Langley Research Center

According to Tom Crouch, an aviation historian at the Smithsonian Institution, "No place has played a larger role in the history of . . . flight technology . . . than Langley Research Center" in nearby Hampton, VA. In this $3.5-billion complex, NASA has specialized facilities for simulating flight, including a wind tunnel for testing in the supersonic speed range and a one-of-a-kind transonic dynamics tunnel that tests aeroelasticity and flutter. However, many of these facilities are already vulnerable to sea level rise and coastal storms. During Hurricane Isabel in 2003, the storm surge was almost five and a half feet above normal high tides. Langley was closed for a week, with much of its eastern area flooded by two feet of water.

© NASA/David C. Bowman

NASA-Langley, with its vacuum spheres (above), holds a venerated position in this country's history of flight, but its reputation is no match for ongoing sea level rise and stronger coastal storms. Hurricane Isabel's (2003) storm surge—almost five and a half feet above normal high tides—closed Langley for a week.

Kennedy Space Center

The Apollo missions that reached the moon, and many missions of the space shuttle, were launched from the Kennedy Space Center at Cape Canaveral, FL. But according to its planning and development office, rising sea levels are the single largest threat to the center's continued operations because they threaten launch facilities and transportation corridors, among other mission-critical infrastructure. Storm surges regularly breach the dunes near the launch pads, and while NASA has undertaken several efforts to protect and restore the dunes, few of these attempts have survived subsequent storms.

© NASA

Members of a hurricane assessment team observe the damage to the roof of the Thermal Protection System (TPS) Facility at Kennedy Space Center after Hurricane Frances (2004). The facility, which created the TPS tiles, blankets, and all the internal thermal control systems for the space shuttles, was almost totally unserviceable after losing approximately 35 percent of its roof.

John C. Stennis Space Center & Michoud Assembly Facility

The John C. Stennis Space Center, in Hancock County, MS, was the test site for launch vehicles used in the Apollo moon landing program, and the main engine for the space shuttle was tested here in 1975. About 50 miles away, in Louisiana, is the Michoud Assembly Facility, which contains one of the largest production buildings in the United States and which supports the next generation of space transportation vehicles. The areas along the coasts of Louisiana and Mississippi near Stennis and Michoud are experiencing sea level rise up to five times the global average because while the seas are rising, the land is also subsiding. Further, because the waters just below and at the surface of the Gulf of Mexico are warmer than they used to be, when hurricanes occur they have a greater chance of becoming stronger—as did Hurricane Katrina.

When Hurricane Katrina hit in 2005, Stennis and Michoud together experienced estimated damages of some $760 million. Most of those costs were incurred at Michoud, where a shuttle-manufacturing plant was severely impacted, though a "ride-out" crew of 37 operated pumps around the clock to protect the factory from catastrophic damage. Following the storm, about 25 percent of Stennis's employees had uninhabitable homes or no homes at all, and the I-10 bridge, which provides main highway access between New Orleans and Stennis, was torn apart.

© NASA

NASA facilities at the John Stennis Space Center (MS) and the Michoud Assembly Facility (LA) are experiencing sea level rise up to five times the global average because while the seas are rising, the land is also subsiding. The above photo shows operators conducting the last space shuttle main-engine test in July 2009.

Ames Research Center

NASA's Ames Research Center (Moffett Field, CA) has long had a reputation for hatching NASA's most innovative small projects. For example, in 1951 director H. Julian Allen solved the vexing problem of how to shape vehicles to withstand the extreme heat of reentry into Earth's atmosphere. He developed the revolutionary "blunt body theory," which allowed astronauts to return safely from Mercury, Gemini, and Apollo missions. But today the center's own safe operation is being threatened as it experiences increasingly intense storms, some of which have flooded underground installations, caused power loss, and closed runways. In 2010, parts of buildings were rendered uninhabitable for weeks by rapidly growing mold. Even modest sea level rise may mean that lighter rainfalls could flood Ames's facilities in the future.

© Photobully/Dreamstime.com

These wind tunnels are used for testing at NASA's Ames Research Center near San Francisco, CA, which has long had a reputation for innovation and creative problem-solving. These qualities are urgently needed to tackle the threats that rising sea levels, storm surges, and extreme rainfall pose to our nation's space program.

According to NASA's planning and development office, rising sea levels are the single largest threat to the Kennedy Space Center's continued operations.

Johnson Space Center

The Johnson Space Center, on Galveston Bay near Houston, is NASA's facility for human spaceflight operations and astronaut training. It is home to the Apollo Mission Control Center, a National Historic Landmark. It also houses the unique collection of returned extraterrestrial samples, including lunar rocks from the Apollo missions. In 2008, when Hurricane Ike crossed the warm waters of the Gulf of Mexico, the storm grew in size, hitting the Texas coast with a 425-mile-wide swath of high winds for up to nine hours. At the Space Center, more than 160 buildings sustained damage from Ike, while the homes of 250 employees were completely destroyed. Such damage may become more common as the climate changes: as sea surface temperatures warm, there is more energy to drive tropical storm winds.

© Christopher Ebdon

"Okay, Houston, we've had a problem here." In the future, the chilling words of Apollo 13 astronaut John Swigert, Jr. to Mission Control may be used to describe impacts of a new threat to the U.S. space program: as sea surface temperatures warm, there is more energy to drive tropical storm winds. Above, the right-hand screen shows a space shuttle mission docking with the International Space Station.

Saving an Icon: Moving the Cape Hatteras Lighthouse Away from the Shifting Shoreline

With its black and white candy-stripe marking, Cape Hatteras Lighthouse on the Outer Banks of North Carolina is one of America's most famous landmarks. More than 200 feet in height, it was the tallest brick building in the world when it was completed in 1870 by the U.S. Army Corps of Engineers. Designed to warn vessels up to 22 miles away of the dangers of nearby Diamond Shoals, in recent years the lighthouse itself was in danger of being lost to the sea.

Coastal erosion and sea level rise prompted the National Park Service (NPS) to take action to save the Cape Hatteras Lighthouse. In 1999, after more than a decade of study and debate, the NPS moved the lighthouse inland. In recent years, sea level has been rising in the Outer Banks two to three times faster than the global average. And since 1970, the number of hurricanes in the North Atlantic that reached Categories 4 and 5 in strength has roughly doubled.

As long ago as 1988, a National Research Council study identified increasing rates of sea level rise as one of the factors imperiling the lighthouse. It was 1,500 feet from the ocean when it was built, but by the end of the twentieth century the distance was only 120 feet. The NPS was faced with several options: It could decide not to take any action and let the sea claim the lighthouse, try to protect the structure with seawalls and groins (walls built perpendicular to the shore), or find a way to move it to a safer place. In the end, after much public discussion, the agency decided to shift the whole building.

The lighthouse's original brick and granite foundation was built on a bed of yellow pine timbers that rested on the compacted sand lying just below the island's water table. The construction engineers of the 1860s did not have pile drivers

Courtesy of the British Museum

This 1585/1586 map, drawn by John White, illustrates the barrier islands known as the Outer Banks. Here, shifting sands and erosion are natural processes. Over the last three decades, however, sea level has been rising in the Outer Banks two to three times faster than the global average.

that could penetrate the hard sand, so they devised this elegant solution as an alternative to supporting the tower on deep vertical pilings. As long as the timbers were under fresh water, they would not rot. But erosion of the surrounding sand and the intrusion of saltwater would threaten the foundation and therefore the entire building.

So the Cape Hatteras Lighthouse, weighing over 4,800 tons, was lifted from its foundation using a complex system of jacks and support beams, and slowly and

© Mdulieu / Dreamstime.com

The Cape Hatteras Lighthouse, a witness to Spanish and pirate ships, Civil War battleships, and German U-boats, was moved inland nearly 3,000 feet to escape relentless sea level rise and coastal erosion—at a cost of approximately $11 million.

painstakingly moved nearly 3,000 feet to the southwest along an improvised steel track. The keepers' quarters and several other historic buildings were also moved.

The situation at Cape Hatteras is not unique. Along its full length, the Outer Banks system of barrier islands is vulnerable to higher seas and strong storms. Barrier islands are constantly changing; they naturally migrate toward the mainland as storms and waves wash sand over them, replenishing the area behind them. But faster sea level rise accelerates the process, and the increased pace of coastal development has brought more people and infrastructure into harm's way.

More than 5 million visitors come to the Outer Banks each year to visit its landmarks and attractions, such as the Cape Hatteras Lighthouse, the Wright Brothers National Memorial, and the "Lost Colony," the first English attempt to settle what is now the United States, on nearby Roanoke Island. Many families return summer after summer, and tourism is a vital economic engine for the eastern part of North Carolina. Many efforts to reduce vulnerability to coastal erosion and storms have been undertaken along the coast, including nourishment of beaches and the rebuilding of dunes, but storms regularly erase these measures. Highway 12, the main route along the Outer Banks, and the Bonner Bridge across the Oregon Inlet are part of the vital but vulnerable infrastructure. Hurricane Irene caused two breaches of Highway 12 in 2011; Hurricane Sandy dumped three to four feet of sand on the roadway in 2012; and in 2013 a nor'easter again buried the highway.

The Cape Hatteras Lighthouse continues to attract more than 3 million visitors every year. But as climate-change impacts continue to become manifest, the hard choices that were made in deciding how to respond to an imminent threat to the lighthouse's future will have to be made again and again for other cherished national heritage sites.

Preserving the Past by Planning for Future Floods

Preserving the past is as much a part of the culture of Charleston as the Spanish moss that drapes from its live oak trees and the ample rain that falls on the South Carolina coast throughout the year. Standing in one of Charleston's quaint streets, one can imagine being there in the nineteenth century well before the Civil War.

The passion for historic preservation in this colonial-era city took firm hold a century ago, driven by a desire to convey Charleston's role in the development of the nation. Pioneering laws passed in 1931 to protect the city's architectural jewels led to the creation of its Old and Historic District—a national landmark that now includes more than 4,800 historic structures—which became a model for cultural stewardship across the country.

But protecting notable buildings from the wrecking ball or the ravages of time may no longer be enough to save some of Charleston's most treasured resources. The city's longtime struggle with flooding is expected to worsen over the coming decades as global warming continues to increase the pace of sea level rise and causes the heaviest rainfall events to dump more water than in decades past.

Established in 1670, Charleston soon became a major port, prosperous trading center, and one of the South's most sophisticated cities. Its architecturally distinct Old Exchange and Provost Dungeon, completed in 1771 as the colony's cultural center, is South Carolina's oldest public building.

Charleston's long military history includes the first naval victory over the British in the War of Independence and the first shots fired by the Confederacy on Union forces at Fort Sumter, thereby sparking the Civil War.

The city is also inextricably tied to the deplorable saga of Southern slavery. The Old Slave Mart Museum, housed in a former slave auction gallery, recalls the harrowing stories of Africans who cultivated plantation crops for long hours under harsh conditions.

© Robin Stevens

As many as 40 percent of enslaved Africans came to the United States through Charleston, many sold at the Old Slave Mart, which is now a museum. Millions of African-Americans today can trace their roots to people who arrived at the Charleston port.

Today, nearly 5 million visitors a year flock to Charleston to savor its Southern hospitality; admire picturesque mansions with high ceilings, ornate plaster, and deep verandas; or tour sprawling eighteenth-century plantations along the nearby Ashley River Road National Scenic Byway.

Charleston also attracts much attention for its modern amenities such as restaurants, galleries, and the annual Spoleto Festival USA, which is internationally recognized as one of the premier performing-arts festivals in the United States. According to the College of Charleston's School of Business, tourism during 2012 pumped more than $3.5 billion into the city's economy.

© Konstantin Lobastov/Dreamstime.com

Sea level around Charleston rose almost twice as fast as the global average during the twentieth century—almost a foot since 1921—and the rate is accelerating. Even today, extreme high tides cause saltwater to back up through the storm drains and spill out onto the roads, snarling traffic and sometimes forcing businesses to close.

But because Charleston is on a harbor off the Atlantic Ocean, is virtually surrounded by water, and lies only a few feet above mean sea level in many places, the city often struggles with flooding—a problem exacerbated by rising sea levels. During simultaneous high tide and heavy rainfall, the stormwater collection system fills with seawater and leaves little room for storm runoff. Even on sunny days, extreme high tides cause saltwater to back up though the storm drains and spill out onto the roads, snarling traffic and sometimes forcing businesses to close. Expensive efforts to build new pumping stations and tunnels are in the works, but the water could still back up whenever the amount of rainfall exceeds the capacity of the new systems.

With air and ocean temperatures on the rise, scientists project that Charleston's flooding problem will only get worse. Already, an increasing percentage of rain comes from extreme storms, which poses increased risk to infrastructure designed for historic, not current, rain patterns.

Routine summer thunderstorms and high tides regularly flood the popular Historic City Market area, sometimes causing residents and tourists alike to wade through thigh-deep water. The frequency of such "nuisance" flooding is also expected to dramatically increase with rising seas. With a sea level rise of four feet—at the high end of the range of what is likely—the market area will become inundated. A sea level rise of only two feet will inundate historic homes south of Colonial Lake Park.

Hurricanes are a major threat to the area during the summer and early fall. And just as warming ocean waters in the North Atlantic can make hurricanes more intense, the seawater is evaporating into warmer air, which holds more water. This can make the heaviest rainfall events even heavier than before. Thus with a changing climate, Charleston residents may face more rainfall in the most intense storms, such as Hurricane Hugo. This Category 4 storm, which struck the South Carolina coast in 1989, killed 26 people, affected 85 percent of the city's properties, and caused more than $6 billion in damage.

Given its growing population and vibrant tourism industry, Charleston will have to be as aggressive in protecting itself from present and future climate change as it has been in preserving the city's cultural past.

Adapting to Climate Change Is Vital to Protecting St. Augustine's Distinctive Heritage

Few cities in the United States boast as many historic distinctions as St. Augustine, FL, but its illustrious past and coastal location come at a price. The low-lying city is prone to flooding, storm surges, and erosion. And its aging infrastructure takes a beating even in light rainstorms, with nuisance flooding regularly closing streets in the historic districts.

St. Augustine is the oldest city in the nation and home to the first port built in America, the country's earliest Catholic parish, and the oldest masonry fort in the continental United States. Many of the city's buildings are listed on the National Register of Historic Places, with some designated as landmarks worthy of special preservation.

© Mike Raker

Sea level rise, worsening storm surges, erosion, and coastal flooding threaten landmarks in the nation's oldest city. Established in 1565 as a Spanish fort, St. Augustine, FL, was the seat of Spanish rule in North America for 200 years.

© William Trinkle Photography

The Castillo de San Marcos is the oldest masonry fort in North America, and the only seventeenth-century fort that survives today.

The ethnic history of St. Augustine goes back a long way as well. The city holds special meaning for people of Hispanic heritage because it was founded as a Spanish military base in 1565 and was the seat of Spanish rule in North America for the next 200 years. In the late seventeenth century, the government of Spain began granting freedom to people escaping slavery in British colonies to the north, which enabled the first free African-American settlement in North America at Fort Mose, just north of St. Augustine. Following the Civil War, formerly enslaved people settled in what later came to be known as the city's Lincolnville Historic District.

Because sea level rise in response to rising temperatures is worsening coastal flooding, storm surges, and erosion, Lincolnville and most of St. Augustine's other historic districts are now particularly vulnerable, as they generally are at lower elevations than other parts of the city. Already, the Atlantic Ocean along Florida's northeastern coast, where St. Augustine is located, has risen by about eight inches since 1930.

> ***"People in St. Augustine don't realize they are vulnerable.…But the increasing pace of sea level rise could overwhelm our ability to stay."***

Sea level rise could significantly compromise the future of St. Augustine's unique cultural heritage. For example, a rise of three feet, which is well within current projections, could permanently inundate portions of the city's historic districts.

Meanwhile, storm surges and flooding could undermine the foundations of many historic buildings unless protections are put in place.

Many of the oldest buildings in St. Augustine are constructed with coquina, an early form of concrete made from shells. A prime example of coquina construction is the Castillo de San Marcos, a waterfront fort dating from the seventeenth century, which is now a national monument. Bordering the 20-acre fort is a nineteenth-century coquina seawall that protects the downtown from flooding, but the ocean waves' pounding of the wall during tropical storms has caused its deterioration and created the need for reinforcement. In 2011, the National Park Service built a "living" seawall. Over time, sediment will build up in front of the wall, and marine life and vegetation will establish themselves there, protecting the historic seawall from erosion and creating a natural habitat.

Heritage tourism, attracting more than 5 million visitors a year, contributes substantially to St. Augustine's economic well-being. To boost tourism yet further, work was recently completed on a $16-million project to maintain St. Augustine Beach by adding sand to the eroded shoreline—part of a 50-year commitment by the Army Corps of Engineers to keep it replenished.

Efforts at coastal adaptation in St. Augustine go back centuries to the time of Spanish rule, but rapidly rising sea levels pose new challenges as the city approaches its 450th anniversary in 2015 and faces an uncertain future. It is possible, for example, that at some point in that future (not too many years from now), parts of St. Augustine could no longer be habitable, and this might come as a rude awakening to many of its residents. "People in St. Augustine don't realize they are vulnerable because the government has taken action to keep flooding out," says Kathryn Frank, professor of urban and regional planning at the University of Florida. "But the increasing pace of sea level rise could likely overwhelm our ability to stay there."

© Karen Peterson

This close-up illustrates the coquina construction used at Castillo de San Marcos. The ocean's constant pounding meant the wall required reinforcement, and the National Park Service has taken steps to create a living seawall to protect the historic coquina wall.

A Race against Time for Florida's Prehistoric Shell Structures

Some of the most remarkable archaeological remains in the world are under severe threat from rising sea levels. The huge prehistoric mounds of oyster and clam shells that dot Florida's Gulf and Atlantic coasts may hold the key to understanding the mysteries of Florida's past—but only if we can protect them from worsening erosion and storm damage.

For 4,000 years, early indigenous Floridians lived among the Ten Thousand Islands, an area of keys and mangroves on the southwestern Gulf Coast, now partly within Everglades National Park. They lived off the rich biological resources in and near these shallow coastal waters, eating a wide variety of foods including meat from turtles, small mammals, and deer,

© Irinnicos

Rising seas and worsening storm surge are endangering the massive prehistoric mounds of oyster shells found in Florida's Ten Thousand Islands (above). Prior to European contact, early indigenous coastal peoples built entire complexes out of discarded shells, thriving in vibrant and well-organized communities.

© John Stockton

Seeking to protect these remarkable archaeological remains, the National Park Service and the University of Central Florida partnered to protect Turtle Mound from erosion by creating "living shorelines" of submerged mats of oysters and newly planted spartina grass and mangroves. This photo was taken from the top of Turtle Mound.

but getting most of their nutrition from fish and shellfish. Over time, they dumped millions of oyster shells in waste piles called middens, which may also have served as a reservoir of potentially useful materials; these indigenous peoples made tools and other objects including hammers, cutting implements, and vessels from conch and whelk shells.

Prehistoric shell middens are common along the U.S. coastline, but Florida's are unique. The state is one of the only places on Earth where coastal hunter-gatherers built such large and complicated shell structures. The shell works, or shell mound complexes, of the Ten Thousand Islands region boast features such as "finger ridges," "plazas," canals, and "water courts." Just a few meters high and often in direct contact with the water at their bases, they were built over many centuries to serve the needs of a growing and well-organized society.

At Dismal Key, for example, low canals run between the finger ridges radiating out to the edge of the site. These canals may have acted as fish traps, water control structures, or channels for canoes to access the community; water courts could have been used to store or even grow fish or shellfish in some form of aquaculture.

The oldest parts of many of these architectural shell complexes are often large ring-shaped shell structures.

Archaeologists are now in a race against time to unlock the secrets of some of the country's earliest inhabitants.

Artifacts found on some these rings, such as drilled sharks' teeth, worked stingray spines, and a limestone pendant suggest they were used for ceremonial purposes or for high-status residences. Clearly these were vibrant and structured communities, and at the time of the first European contact in 1513 there may have been tens of thousands of indigenous Calusa, Timucuan, and other tribes in Florida. But by the mid-1700s they had all but disappeared, victims of disease, warfare, and the slave trade.

Across the Florida peninsula, on the Atlantic coast, lies another massive shell mound. At more than 35 feet tall and covering two acres, Turtle Mound in the northern part of Canaveral National Seashore is thought to be the highest

in North America. The mound dates back at least 1,200 years and is such a remarkable feature of this low-lying coast that it was shown as a navigational aid on the first Spanish maps of the region.

Erosion has recently become a major problem for Turtle Mound. Sea level rise, combined with storm surges and boat wakes, has had particularly severe impacts on the mound. Fears that this archaeological treasure could be irreparably damaged have recently prompted the National Park Service to join with scientists at the University of Central Florida in a project to protect Turtle Mound from erosion. Toward that end, they are creating "living shorelines" consisting of submerged mats of oysters, newly planted spartina grass, and mangroves.

Florida has recorded a sea level rise of eight to nine inches in the last 100 years, and state authorities are projecting an accelerated rise of another 9 to 24 inches by 2060. In the Everglades, this phenomenon is *already* causing problems. Erosion and storm damage, exacerbated by sea level rise, have collapsed the banks of tidal creeks at Sandfly Key, threatening the important shell-work structures there.

The accelerating rate of sea level rise, combined with extreme rainfall events (which are predicted to increase) and their accompanying storm surges, will pose a growing threat to Florida's extraordinary prehistoric shell mound complexes in the coming decades. Archaeologists are now in a race against time to unlock the secrets of some of the country's earliest inhabitants.

© University of South Florida Alliance for Integrated Spatial Technologies

Sea level rise of eight to nine inches in the last 100 years is already causing problems at Sandfly Key in the Everglades. Erosion, pictured above, threatens shell-work structures there.

Mesa Verde's Ancient Artifacts and Dwellings Are Increasingly Exposed to Wildfires and Flooding

Before Mesa Verde National Park was created in 1906, preservationists feared that this rich collection of artifacts and ancient ruins of the Pueblo people's ancestors would fall prey to vandals or thieves—though they did not foresee the impacts of worsening fires. Now, a century later, protecting these ancient ruins means adapting to the hot, dry, and fiery impacts of a changing climate.

The once-nomadic Ancestral Puebloans began settling in the southwest corner of Colorado in the sixth century, a thousand years before Europeans began exploring North America. They built their homes on the high limestone and sandstone plateau of Mesa Verde. By the late eleventh century, they began moving into the sheltered alcoves of the canyon walls beneath overhanging cliffs. They lived in those cliff dwellings less than 100 years before suddenly migrating south into present-day Arizona and New Mexico.

We may never know for sure why its inhabitants abandoned Mesa Verde; archaeologists' theories include depleted resources, crop failures due to drought, and social strife—or some combination of all three. But the handicrafts, mesa-top pueblos, and multi-storied cliff dwellings they left behind give us insights into the lives of these ancient people—the descendants of hunters and gatherers who roamed the plains as long as 10,000 years ago.

Mesa Verde's remarkably well-preserved Native American treasures, representing the cultural heritage of many of today's tribes—including the Hopi, Zuni, and Laguna—make up the largest archaeological preserve in the United States. Protected until now by its designation as both a national park and a World Heritage Site, it is at risk from global warming.

For the past 50 years, the temperatures in the Mesa Verde area have been rising, particularly during the summer, at a much faster rate than they did over the preceding century. In the Southwest overall, it has been warmer since 1950 than any period of comparable length in at least 600 years.

> ***Mesa Verde's treasures—more than 4,500 archaeological sites, including 600 cliff dwellings—are worth protecting from the fiery ravages of a hotter, drier climate.***

Rising temperatures add to the region's natural wildfire risk and increase the likelihood that when fires do occur they will be larger and even more devastating. Because forests across the western mountains are drier more often and for longer periods, more wildfires are ignited and they spread more easily. Also, winter snowpack is tending to melt almost four weeks earlier than in previous decades. As a consequence, the average number of large wildfires of more than 1,000 acres across the western United States has increased from 140 per year in the 1980s to 250 per year between 2000 and 2012. In the Southwest, the area burned in recent decades increased more than 300 percent relative to the 1970s and early 1980s.

Back-to-back fires in the summer of 2000 burned nearly half of Mesa Verde National Park's 52,000 acres. The Bircher Fire forced the evacuation of some 1,000 visitors because of the rapid spread of the flames toward the park entrance.

© Damon Tighe

Designated as both a national park and a World Heritage Site, Mesa Verde represents the cultural heritage of many of today's tribes—including the Hopi, Zuni, and Laguna. The Square Tower House, above, is just one of the intact cliff dwellings in the largest archaeological preserve in the United States.

The fire closed the park for two weeks, but the day it reopened the park had to be evacuated again when the Pony Fire erupted. Both fires caused extensive damage to park infrastructure—including roadway systems, visitor facilities, and watersheds—but spared the famous cliff dwellings.

Firefighters work alongside archaeologists to minimize damage to the ancestral ruins, but some harm is inevitable. Because of Mesa Verde's difficult terrain, fire crews use aerial water drops and fire retardant, called slurry, which stains and damages the sandstone. Red stains are now particularly noticeable along the trail to Spruce Tree House, the third-largest cliff dwelling, which contains 130 rooms and eight kivas (communal spaces once used for spiritual ceremonies). Fire also accelerates spalling, the peeling away of the rock face as the water in the sandstone evaporates, which can destroy ancient rock carvings. For example, a major fire in 1996 destroyed a significant petroglyph.

The most devastating impact of a fire, however, can occur after the flames are extinguished, as it also makes the severely burned landscape susceptible to floods and erosion during winter rains. The reason is that fire turns a healthy soil, which normally allows water to seep in, into a hydrophobic (water-repellent) soil, causing rain to run off the surface and erode structures.

"A fire just brings debris down that can silt in sites or it can undermine walls in the alcove sites and the cliff dwellings," Mesa Verde archaeologist Jane Anderson said after the 2000 fires. "It can change the pattern of the runoff so that the water might cling to the walls of the alcoves, run into the backside of the alcove, stain the walls, and undermine architecture that's in there. There's no vegetation above the alcove site to prevent that water from coming in."

Efforts to protect Mesa Verde from flood damage include reseeding with native grasses to promote vegetation growth, placement of erosion-control features such as log diverters to direct water away from sites, and the application of silicone to the cliff faces to redirect natural drip lines.

Currently, a severe drought is plaguing the Southwest, and climate projections suggest more frequent and severe periods of drought in the region during the coming decades

© Adam Prince

Rising temperatures at Mesa Verde add to the inherent wildfire risk in the region's piñon-juniper forests. Back-to-back fires in the summer of 2000 closed the park, forced the evacuation of roughly 1,000 visitors, and caused extensive damage to the roadways and visitor facilities—but the famous cliff dwellings were spared.

as a result of rising temperatures. Compared with the averages for the twentieth century, precipitation was 4 percent lower, temperatures were 1.3°F higher, and stream flow—the most consistent indicator of drought—declined 16 percent over the first decade of the 2000s.

The high temperatures and dryness of the Colorado Plateau are already having dramatic effects on piñon-juniper forests—the region's dominant wooded ecosystem—which burn easily under these conditions. Sustained heat and drought are weakening piñon pines so much that a combination of drought and bark beetle infestation has caused widespread forest die-off. In 2002 and 2003 alone, heat, drought, and beetles killed 90 percent of the piñon pines in portions of Mesa Verde. This region has lost trees before, but researchers say that more trees died in the recent drought than during previous dry periods because of the higher temperatures caused by climate change.

The vulnerability of Mesa Verde National Park to climate change could have a harmful effect on the region's tourism economy: deterring visitors. In the past, the park has attracted up to a half-million tourists each year, who contribute some $47 million to the local economy. As the first national park designed, in President Theodore Roosevelt's words, to "preserve the works of man," Mesa Verde is home to more than 4,500 archaeological sites, including the 600 cliff dwellings. These cultural artifacts demonstrate the skills of the Ancestral Puebloans at building, making crafts, living off a difficult land, and protecting themselves from the elements by seeking shelter in canyon walls. They are treasures worth protecting.

Pueblos Ancient and Modern Face Increased Risks from Fires and Floods

The ancient rock carvings and cliff dwellings of New Mexico's Bandelier National Monument and nearby Santa Clara Pueblo tell the story of some of the earliest inhabitants of the Americas. This landscape of dramatic mesas and beautiful canyons offers evidence of a human presence dating back more than 10,000 years while also serving as home to modern pueblo communities with an enduring sense of cultural identity.

But protecting this Native American homeland is increasingly difficult as the region experiences a long-term warming trend and as large wildfires and extreme flooding events become more common.

The Southwest has been getting warmer—the period since 1950 has been the warmest time interval of comparable length in at least 600 years—and this trend is increasing the risk of more frequent and larger fires. There has indeed been a dramatic rise in the number of large wildfires since the early 1980s, and research suggests that an increase in average annual temperature of just 1.8°F—only slightly more than the area has warmed in the last century—could multiply the incidence of wildfires in New Mexico by four.

In recent years there have been several major wildfires in and around Bandelier National Monument. In 2000, the Cerro Grande fire raged through the area, destroying 200 buildings in the town of Los Alamos, including several historic structures from the Manhattan Project era. A survey of the fire's impacts on 470 archaeological sites within the boundaries of Los Alamos National Laboratory found that more than 70 percent of these sites had been damaged, including ancestral Pueblo structures and wooden homestead buildings.

In 2011, the Las Conchas Fire, the second-largest wildfire in New Mexico history, burned more than 156,000 acres, including much forest in Bandelier National Monument and more than 16,000 forested acres belonging to the Santa Clara Pueblo. Not long after the fire, disaster struck northern New Mexico again when heavy rains in the Jemez Mountains surged through the scorched canyons. Santa Clara Pueblo, particularly vulnerable to flooding because of its location at the entrance to the Santa Clara Canyon, was under a state of emergency after heavy rains sent tree trunks, boulders, and other debris rushing down the canyons, toppling power lines and washing out roads and bridges.

© Kristen Honig/U.S. Forest Service

Firefighters battled to protect Bandelier from the massive 2011 Las Conchas Fire. The intense heat from fires can cause flaking on ancient rock carvings, ruin pottery shards and ceramic glazes, and change the chemical composition of soil layers (rendering archaeological dating techniques less accurate).

"This is our only homeland; it's the place we've been entrusted with since time immemorial. But never again in our lifetime will we see our traditional and treasured homeland and spiritual sanctuary, the canyon, as we have known it," said Walter Dasheno, then governor of the Santa Clara Pueblo, at a

© William Song

Several large wildfires that raged across northern New Mexico in recent years have left Bandelier National Monument vulnerable. In the fires' wake, heavy rains can cause destructive flash floods, making erosion and extreme rainfall a major threat to the monument's archaeological resources, such as the Talus houses shown above.

U.S. Senate hearing. "It will take generations for our community and lands to recover from the devastation of the fire, and because of climate change it is not clear what the future will look like."

Severe flooding from summer thunderstorms also damaged resources at Bandelier National Monument in 2011 and 2012, washing out its popular Falls Trail and Frijoles Canyon Trail, and again in 2013, when the monument experienced the worst flash flooding in its history. Erosion from floods and extreme rainfall is now a major threat to the monument's archaeological resources.

In the aftermath of large wildfires, heavy southwestern summer rains can cause destructive flash floods. Fires have already denuded landscapes of trees, which might check the water, and the scorched soils, transformed so that they temporarily repel (rather than absorb) water, increase surface runoff for months to several years after the fire. Where trees have died back, whether due to drought, wildfires, or other climate-related impacts (such as beetle attacks on piñon pine forests), the risk is even greater. Extreme precipitation events are expected to worsen throughout the region, even where total annual rainfall decreases.

[GROVELAND, CA]

Groveland and Other California Gold Rush–Era Towns Are Imperiled by Wildfires

©K45025|Dreamstime.com

The town of Groveland, a California Historic Landmark, recalls the days of the Wild West, when stagecoaches rumbled past its adobe and wood-framed buildings and conflicts often ended in gunfights. Today, however, the town is dependent on the tourist trade of the 4 million annual visitors to nearby Yosemite National Park.

© L. C. McClure

Contrary to the glamorous, strike-it-rich-quick popular image, gold miners lived in camps under harsh conditions, often succumbing to poor nutrition and disease. Stealing and gambling were rampant in the lawless frontier.

The Groveland Hotel was built as a trading post in 1849 a year after gold was discovered in California's adjacent Sierra foothills, sparking the largest gold rush in American history. The hotel, still operating, is now usually filled with tourists visiting nearby Yosemite National Park, but in 2013 fire officials and television crews occupied it instead. They were there to battle and broadcast the Rim Fire, a blaze that burned more than 402 square miles of the Central Sierra Mountains—an area more than eight times the size of San Francisco.

California is experiencing a marked increase in giant wildfires. The number of large wildfires now burning each year is double that typical in the 1970s. And of the state's 20 largest wildfires since 1932, 12 have occurred since 2002. The main reason for this growing wildfire risk, not only in California but also across the western United States, is climate change, which drives up temperatures that among other things cause earlier melting of the winter snowpack. As a result, less water is available during the hotter months, forests are drier for longer periods, and they become highly combustible. Average wildfire seasons, which were five months long in the 1970s, now last more than seven months.

The human and economic impacts of these wildfires can be severe. The rapidly growing Rim Fire, for example, overwhelmed the tight-knit Groveland community as some residents lost homes, and businesses were forced to close during the height of the tourist season. The blaze burned for more than two months, smothering Groveland with smoke and closing its Main Street—the most direct and scenic all-weather route to Yosemite for many of the park's annual 4 million visitors.

"We only have four to five months of business a year, basically Memorial Day to Labor Day, and to lose this end of August and Labor Day weekend is just financially devastating for the businesses here in town," Corinna Loh, whose family owns Groveland's Iron Door Saloon and was forced to cut staff, told National Public Radio. Loh lost two homes to the Rim Fire and said the blaze spread faster than any she had ever seen since moving to Groveland as a young child. Mark Morales, a retired fire captain, agreed: "I cannot recall any wildfire in recent history that grew this large as quickly. At the present rate of growth this will challenge record acreage for California fires."

The Rim Fire, which spread fast because of parched vegetation and inaccessible terrain, was the third-largest wildfire in California history, and it cost $127 million to fight. Its long duration bears out observations across the West of an abrupt transition in the mid-1980s from a pattern of infrequent wildfires lasting an average of a week to more frequent and

Visitors spend $200 million annually in Tuolumne County. But the increasing risk of wildfires threatens both the county's gold rush heritage and its current economy.

© Don Barletti/Los Angeles Times

In California and other states across the west, average wildfire seasons, which were five months long in the 1970s, are now more than seven months long. The 2013 Rim Fire (above) spared Groveland's historic landmarks but forced many businesses to close during the height of the tourist season—delivering a devastating economic blow to this small town.

longer-burning fires. Today, the land around Groveland burned by the fire resembles a moonscape, which raises the risk of flash floods when winter storms hit—the scorched soil makes it more likely that the water will run off, rather than seep into the soil, for months or years after the fire.

Extremely dry winter weather, with little precipitation, is putting great pressure on tourism-dependent Tuolumne County, even without fires. Tourism is the county's top private employer, and visitors spend $200 million annually in towns such as Groveland, Jamestown, Chinese Camp, and Columbia, where the State Historic Park brings the Gold Rush back to life with, for example, merchants dressed in 1850s attire and opportunities for visitors to pan for gold.

The original miners—called "forty-niners"—found the gold plentiful and easy to extract by panning the gravel of streams and rivers. With pick, shovel, and pan, they dug among the rocks and clay and used water to sift the nuggets from the dirt.

Word quickly spread and people from across America and around the world arrived in what became known as the Mother Lode, hoping to strike it rich. California's population of non-Native American people exploded from 14,000 in 1848 to nearly 100,000 by the end of 1849 and 250,000 by 1852. The Gold Rush helped spur California's admission to the Union as the thirty-first state in 1850. Eureka, a Greek word meaning "I have found it," has appeared on the state seal ever since and likely refers to the discovery of gold.

Wildfires are expected to burn more land, particularly in mid-elevation sites on the west side of the Sierras, making it more likely that Gold Rush–era communities—as well as the majestic Yosemite Valley—will more frequently be in the path of destruction. In order to protect them, preventive efforts have been proposed, including creating buffers free of flammable vegetation around the towns, removing decaying trees from forests, and allowing some fires to burn to eliminate surplus fuel.

California Farmworkers Championed by César Chávez Are Now Threatened by Extreme Heat and Drought

Before Latino labor leader César Chávez began organizing California farmworkers in the 1960s, migrant grape pickers made as little as a dollar an hour and lived in unheated metal shacks with no indoor plumbing or cooking facilities. Chávez attracted national attention to their plight through fasts, marches, strikes, and a widespread boycott of table grapes. The farmworkers' persistent struggle to improve their lives led to higher wages and safer working conditions.

To honor their leader's legacy, President Barack Obama designated the César E. Chávez National Monument on the land where Chávez lived and ran his United Farm Workers (UFW) union in the rural California town of Keene, southeast of Bakersfield. At a dedication ceremony in 2012, Obama praised Chávez for his "belief in the power of opportunity. He believed that when a worker is treated fairly and humanely by [his or her] employer, that adds meaning to the values this country was founded upon."

In the years since Chávez died (in 1993), California farmworkers have been facing new challenges. Extreme heat and drought are endangering the safety and livelihoods of the men and women who harvest nearly half of U.S.-grown fruits, nuts, and vegetables. The state's unique geography, massive water-resource infrastructure, and Mediterranean climate allowed California to become one of the most productive agricultural regions in the world, but its climate is changing.

Scientific research has shown that periods of extreme heat are increasing in frequency and intensity in California, and especially in the San Joaquin Valley—the heart of the state's agricultural enterprise—where average summertime temperatures have been rapidly rising in recent decades. Hot days are becoming more common, and it is no longer cooling

© Arthur Schatz/Time & Life Pictures/Getty Images

César Chávez talking in a field with grape pickers in support of the United Farm Workers Union, Delano, CA, March 1968.

© Sam Garcia/The City Project

The national monument celebrating the accomplishments of farmworker leader César Chávez and the movement he headed is one of the nation's most recent heritage sites. Shown at the groundbreaking for the historic park—comprised of five sites in California and Arizona—is former Secretary of the Interior Ken Salazar and National Park Service Director Jon Jarvis.

off as much at night. Such changes, which began in the 1980s, appear to have accelerated since 2000.

Climate models show that if our emissions of carbon dioxide and other heat-trapping gases remain high, Bakersfield could have almost 50 days of extreme heat, with temperatures reaching 104°F or more, by 2050—up from four days a year on average between 1961 and 1990.

Extreme heat is already making the lives of California farmworkers harder and more dangerous, leading to increased hospitalizations and deaths. Now it appears that such risks are only going to grow for these workers.

California passed the most stringent heat-safety regulations in the nation in 2005, requiring farmers to provide their employees with adequate water, shade, and rest breaks. However, with field worker deaths continuing in the succeeding years, the UFW claimed the laws are often violated and the state does not provide adequate enforcement.

In one particularly tragic case that raised questions about the effectiveness of the laws, Maria Isabel Vasquez Jimenez, 17 years old and two months pregnant, died from heat exhaustion she suffered while working in a grape vineyard near Stockton on a blisteringly hot day in 2008. By the time she was taken to the hospital, Jimenez's body temperature topped 108 degrees. Her coworkers reported to state officials that the nearest water cooler was a 10-minute walk away, and they were not allowed long enough breaks to get a drink.

High summer temperatures in California also threaten the health of the agricultural industry itself. And when drought conditions prevail, crop yields may fall and quality may be compromised even further.

Recent data indicate that prolonged periods of drought in California—expected with climate change—are on the rise. Californians have spent nearly half of the years since 2000 in dry and critically dry conditions, a marked increase over the previous century.

The state is now in one of its worst droughts since record keeping began, as 2013 had the least amount of rainfall on record. In March 2014, more than 90 percent of California was suffering from at least a "severe drought," 72 percent was experiencing at least an "extreme drought" and 22 percent—including a wide swath of the San Joaquin Valley—was in an "exceptional drought," according to the U.S. Drought Monitor.

Prolonged drought threatens to cripple California's agricultural industry, which currently uses 80 percent of the state's available water resources. In early 2014, federal and state officials notified some farmers that they would not receive any deliveries of irrigation water. As a consequence, some farmers may be forced to leave their fields fallow. That could mean thousands of lost jobs for seasonal farmworkers and higher prices and fewer choices for consumers.

A drought in 2009 caused $340 million in revenue losses in the San Joaquin Valley, when 285,000 acres were left idle and nearly 10,000 jobs were lost. This year, the situation could be even worse. Farm organizations are projecting that up to 800,000 acres of the California farm belt will remain unplanted in 2014, with crops such as tomatoes, broccoli, lettuce, melons, and corn particularly hard hit.

"We're in a dire situation that we've never been in before," said Paul Wenger, president of the California Farm Bureau Federation.

In early 2014, normally the height of the rainy season, the fields were parched around the Chávez National Monument, located at the southern end of California's 450-mile-long Central Valley—the state's top-producing agricultural region. While it is often called "the nation's salad bowl" for the array of fruits and vegetables grown in its fertile soil, this region also is home to some of California's most disadvantaged communities, and poor air quality is a persistent problem.

The monument was created on a property known as Nuestra Señora Reina de la Paz, which includes the UFW headquarters and the Chávez family home—already on the National Register of Historic Places. It was here that César Chávez advocated for the passage of California's Agricultural Labor Relations Act of 1975, the first law in the nation to recognize farmworkers' collective bargaining rights. The union he helped create—the country's first permanent agricultural union—grew into a national voice for the poor and disenfranchised.

To create greater public awareness of Chávez's achievements, the National Park Service (NPS) announced plans in

© Dan Long

Periods of extreme heat are increasing in frequency and intensity in California, and prolonged periods of drought—expected in the state as the climate changes—are on the rise. Hotter conditions are the newest threats to the health and safety of farmworkers who harvest most of the country's vegetables and fruits—seen here cutting and packing celery in Salinas, CA.

October 2013 for a César Chávez National Historic Park, which would contain five sites in California and Arizona (including the national monument) relevant to the leader's life. The proposed park, which must be approved by Congress, is part of an effort by the NPS to tell a more inclusive story of America's heritage.

Yet another way to pay tribute to Chávez would be to protect from environmental harm the farmworkers he championed and the agricultural industry on which they depend. Mechanisms for adapting to a hotter and more drought-prone environment with improved worker protection and water management measures, and policies for reducing the emissions driving these climate impacts, are urgently needed.

Extreme heat and drought are endangering the safety and livelihoods of the men and women who harvest nearly half of U.S.-grown fruits, nuts, and vegetables.

[BERING LAND BRIDGE NATIONAL MONUMENT & SHISHMAREF, CAPE KRUSENSTERN NATIONAL MONUMENT & KIVALINA]

Native Villages and Ancestral Lands in Alaska Face Rapid Coastal Erosion

Arctic warming is reducing winter ice in the Chukchi Sea, causing the thawing of permafrost (subsoil that remains frozen year-round) and threatening not only native Alaskan communities—many of which go back thousands of years—but also some of the oldest archaeological sites in the western hemisphere.

© Sam Garcia/The City Project

The first humans to populate North America may have arrived as long as 15,000 years ago across the Bering Land Bridge from Siberia. Artifacts from as long as 4,000 years ago are at risk in coastal archaeological sites in the Cape Krusenstern National Monument and the Bering Land Bridge National Preserve (above).

Genetic studies have shown that all Native American groups originated from south Siberia. The first humans to populate North America, they arrived perhaps as much as 15,000 years ago, or even earlier, as the ice of the most recent Ice Age retreated. The ancestors of the indigenous people that now inhabit western Alaska today likely migrated later, arriving around 5,000 years ago. These ancient migrants were mobile subsistence hunter-gatherers, and even now, subsistence hunting and gathering is at the core of a lifestyle connecting Alaskan natives directly to the places where their ancestors lived.

Archaeological remains that help us piece together the story of early Americans are scattered across northwestern Alaska's remote and vast terrain. Some of the densest concentrations of artifacts are found in two national parks that face each other across Kotzebue Sound—the Bering Land Bridge National Preserve and the Cape Krusenstern National Monument—both of which were designated for the importance of the cultural heritage they preserve.

Cape Krusenstern protects a series of more than 100 beach ridges, which host archaeological sites that date back 4,200 years and which preserve clues from virtually every phase of Inupiat Eskimo development. At the Bering Land Bridge, fluted stone points more than 12,000 years old, some of the earliest human signs in the Americas, have been found inland at Serpentine Hot Springs. But permafrost degradation due to climate change is damaging some important cultural heritage sites, and coastal erosion is washing away irreplaceable archaeological artifacts at particularly vulnerable coastal locations.

Alaska has warmed more than the lower 48 states in recent decades. Average temperatures across the state have increased by about 3°F over the last 60 years, with winter and spring temperatures warming the most. Over the last three decades, sea ice extent in the Arctic summer has declined more than 10 percent every decade, with new record-low levels of ice occurring on a regular basis. Moreover, permafrost is warming and thawing in many parts of the state.

The combination of the loss of protective seasonal sea ice, the resulting increase in ocean waves near the shore, and the thawing permafrost is leading to severe erosion in coastal areas. In the past, sea ice protected the coastline from erosion during winter storms, but a lengthening ice-free season has hindered this shielding process: given that increasing ocean and air temperatures cause winter sea ice in the Chukchi and Bering seas to form later in the year, more storm damage to the coastline results. Wave heights during extreme events have also increased over the last 20 years.

© Shelby Anderson

As Alaska warms (on average by about 3°F over the last 60 years), protective sea ice is lost, permafrost thaws, and coastal erosion increases. Irreplaceable archaeological artifacts, like this biface spear point from Cape Krusenstern that dates to the Choris period (between 800 and 500 B.C.), are increasingly threatened.

The U.S. Government Accountability Office has concluded that out of more than 200 native Alaskan villages, 85 percent are already being affected by erosion and flooding and that 31 are under imminent threat. Twelve of these communities have decided to completely relocate.

One such community is Kivalina, a small village just north of Cape Krusenstern. Winter storms are removing an average of up to 35 feet of Kivalina's shoreline annually; however, in 2005, the town lost 70 feet from the beach to a single massive storm. The residents of Kivalina hunt walrus, seal, caribou, and fish, and it is the only village in the region that still hunts bowhead whales, at least in principle—no bowheads have been

Climate change is threatening both native Alaskan communities and some of the oldest archaeological sites in the Western Hemisphere.

© Bruce C. Johnson, Jr.

Beach ridges at Cape Krusenstern preserve artifacts from the ancestors of today's Inupiat Eskimo people. But climate change is damaging not only invaluable cultural heritage sites but also the Inupiat's current way of life. Twelve native Alaskan communities have decided to completely relocate to escape coastal erosion and flooding.

taken in more than a decade, and locals blame the changed ice conditions. Cost estimates for moving the community of Kivalina to a new and safer location are about $100 million.

Across the bay, and adjacent to the Bering Land Bridge National Preserve, another Inupiat village, Shishmaref, is also at risk from the rising temperatures. Tony Weyiouanna, president of the board of the Shishmaref Native Corp., told a congressional task force in January 2014 that, "The shortening winter season is impacting our local subsistence culture and our ability to create jobs and investment for our community. It's attacking us from all sides." Echoing a report from the U.S. Army Corps of Engineers, he told a state working group, "The no-action option for Shishmaref is the annihilation of our community."

Sea Level Rise Threatens Hawaiian Cultural Heritage Sites

© National Park Service

The skills associated with building and maintaining fishponds and fish traps, seen here at Kaloko-Honokōhau National Historical Park, were highly developed in Hawaii. The sea around the Big Island is already rising and projected to continue rising—and could increase the risk of damage to the historical parks and their sacred contents.

The west coast of Hawaii's Big Island is rich in cultural and archaeological sites that remain immensely important for Native Hawaiians today. But many of these sites are threatened by coastal flooding linked to rising sea levels. Numerous sacred places and ancient trails, seawalls, and fish traps are vulnerable to wave action and erosion.

For example, important Hawaiian cultural resources at Puʻuhonua o Hōnaunau National Historical Park are at risk. The park lies on the lava flats of the Kona Coast, less than four miles south of Kealakekua Bay, where one of the earliest contacts between Europeans and Native Hawaiians took place and where Captain James Cook was killed in 1779.

A *puʻuhonua* was a wartime place of refuge, where noncombatants and defeated warriors alike could find sanctuary. Hawaiians lived under strict codes and laws, and certain things were sacrosanct. The penalty for breaking *kapu* (sacred laws) would often be death, but the *puʻuhonua* also offered sanctuary to those who had broken sacred laws.

The National Park Service has identified the Great Wall, along with the ʻĀleʻaleʻa Heiau temple site, other structures in the *puʻuhonua*, and two historic sections of trail, as among the park's cultural resources most vulnerable to sea level rise. The ʻĀleʻaleʻa Heiau is a stone platform within the *puʻuhonua* that is thought to have been built as part of the sacred refuge but then became a place where chiefs relaxed and watched hula dancing. These and other irreplaceable cultural resources are located in low-lying areas of the park that have repeatedly been damaged by storm surges and flooding in the past.

The backdrop to Puʻuhonua o Hōnaunau is the Mauna Loa volcano, where the National Oceanic and Atmospheric Administration, together with the Scripps Institution of Oceanography, maintains an observatory that has the world's longest high-quality record of atmospheric CO_2 concentrations. The remote location and clean air make the site ideal for monitoring the state of the atmosphere. The Mauna Loa record—also known as the Keeling curve, after the scientist Charles David Keeling, who began taking the measurements in 1958—is used by climate scientists worldwide. In 2013 the Keeling curve indicated that atmospheric CO_2 concentrations for part of that year topped 400 parts per million—levels that haven't been seen on Earth for more than 3 million years.

Farther north on the Big Island's west coast, at the base of the Hualalai volcano, is Kaloko-Honokōhau National Historical Park, where sea level rise threatens ancient structures that were used for trapping and raising fish. The skills associated with building and maintaining fishponds and fish traps were more developed in Hawaii than in any other part of Polynesia, and the examples at Kaloko-Honokōhau, some of which are being restored for use in present-day traditional aquaculture, are among the most important in the islands.

© Gary and Melissa Annable

The puʻuhonua *in this park is the best-preserved in Hawaii. The refuge is bounded by the ocean on its northern and western sides, but to the east and south it is protected by the Great Wall—a massive structure 12 feet high, 18 feet wide, and close to 1,000 feet long. The wall is more than 400 years old, and one of the masonry techniques used in building its interior section—by laying lava slabs on top of upright stones—has been found nowhere else on the Hawaiian Islands. The National Park Service has identified the Great Wall (above) at Puʻuhonua o Hōnaunau National Historical Park, as well as the temple site and sections of the historic trail, as cultural resources vulnerable to sea level rise; they have been damaged by storm surges and flooding in the past.*

A coastal hazard analysis, carried out for the National Park Service by scientists from Stanford University and the University of Hawaii, identified the Kaloko fishpond, the ʻAiʻōpio fish trap, and the ʻAimakapā fishpond as among the park's historic features most at risk from coastal hazards. The beach in front of the ʻAimakapā fishpond, which was used to raise fish for the royal chiefs and may be more than 600 years old, is currently eroding at a rate of three to four inches per year. Because the beach separates the pond from the ocean, if this rate of change continues, the number of times the beach is overtopped by waves each year will likely increase; the pond could be breached altogether by 2050. Similarly, the walls of the ʻAiʻōpio fish trap could be completely submerged by the end of the century.

Meanwhile, tide gauges show that the sea around the Big Island is already rising and projected to continue rising—the result both of global warming and subsiding land. Higher sea levels could increase the risk of coastal floods' damage to the national historical parks and their sacred contents, as floodwaters would be higher and able to move farther inland, and would worsen erosion of the sand deposits on which the structures are built. Greater damage could also result from the pounding of storms' high waves, which would ride on higher seas. Moreover, a rising ocean could exacerbate the impacts of periodic extreme events such as tsunamis (caused by earthquakes), storm surges, and typhoons.

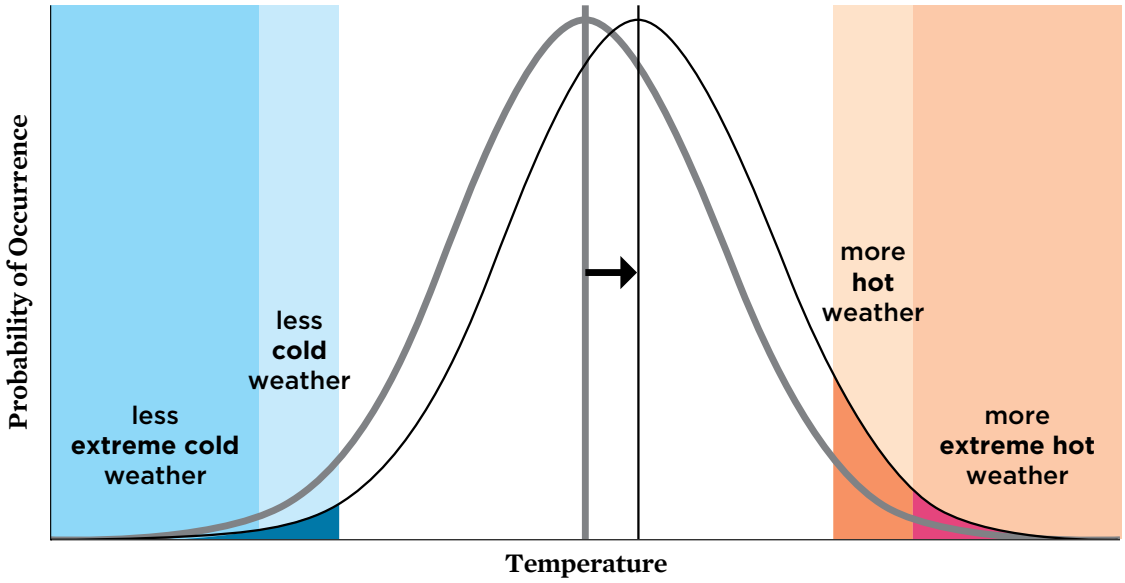
The Science behind the Changing Risks to Our National Treasures

This chapter examines the science on which the growing threats cited in the above stories are based. We discuss the increased chances of extreme weather, rising temperatures, wildfires, coastal flooding, soil erosion, and situations of either too much or too little water.

Shifting Extremes

Earth's global average surface temperature has risen since the late 1800s. Scientists are more certain than ever that since 1950 the warming has been largely due to human activities,

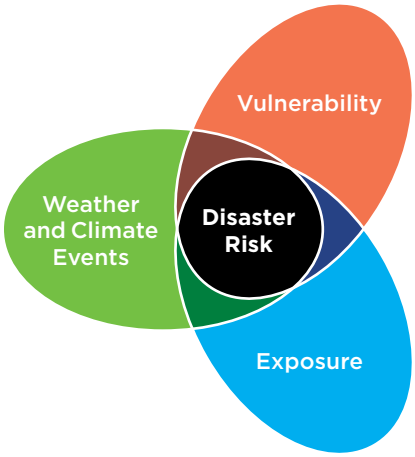
FIGURE 3. Shift in Extreme Events



The figure shows the effects of a simple shift in a region's temperature distribution toward a warmer climate.

ADAPTED FROM IPCC 2012.

FIGURE 4. Factors That Influence Risk Include Exposure, Vulnerability, and Hazards



ADAPTED FROM IPCC 2012.

mostly from the heat-trapping emissions produced by the burning of coal, oil, and gas to provide energy. The global average rate of warming is currently 0.7 degree Fahrenheit (°F) per century. Temperatures in the lower 48 of the United States are rising even faster, at 1.3°F per century. This shift in temperature means that the risk of extreme heat is more likely, and at a level that some places have never before experienced (Figure 3). In other words, the extremes become even more severe, and what used to be extreme becomes commonplace.

Extreme events have the power to transform, sometimes permanently, physical structures, landscapes, and entire ecosystems. And the intensity of such events' effects range from the inconvenient to the deadly. Extreme heat, for example, can mean that outdoor work must be restricted during parts of the day, but in the most severe cases many people may die.

The increased likelihood of extreme events has practical consequences for the sites discussed in this report and the risks they face. Risks change, based on the exposure and vulnerability to hazards, which in turn arise from a combination of natural variability and human-induced climate change (Figure 4). The sites may become at once more exposed and more vulnerable, as a result of choices that have already been made and those yet to be determined. The shifts in extreme events most closely associated with climate change involve high heat, coastal flooding, intense precipitation, and drought.

Coastal Flooding and Erosion

During most of Earth's past, perennial land ice (such as that found in Greenland, Antarctica, and glaciers around the world) did not exist. But perennial land ice has existed for all of human history, and is a key factor in determining sea level. Since the end of the preindustrial period, human-induced climate change has increased temperatures such that nearly all measured glaciers are melting. Shrinking land ice, combined with expanding oceans (as a result of warmer water), increases the rate of sea level rise. Local land subsidence is also a factor. As a result, many coastal areas could progressively become inundated; for example, sea level rise along the U.S. Gulf and East Coasts is among the highest in the world. And note that from this point forward, every additional inch of sea level rise is irreversible for at least several human generations.

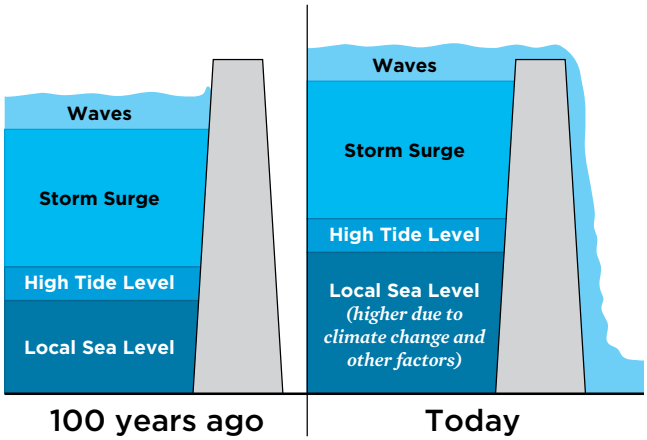
Coastal areas that are not permanently inundated can still experience episodic flooding, resulting from the highest monthly or annual tides, or from strong prevailing winds. Coastal storms can pile water up and create a storm surge capped by waves. Moreover, with each passing decade, these episodic increases in storm surges will occur on top of sea levels that are rising more quickly, primarily because of climate change.

Even if the storm and tidal conditions are entirely of a magnitude that has naturally occurred before, in some cases sea level rise might make all the difference. Consider, for example, a hypothetical storm before industrialization occurred, with the degree of flooding determined by the combined water height of the storm surge, high tide, local sea level, and the effect of wind conditions. In such a storm, the net water level might be just below the height that could overtop the shoreline high point. However, once the climate change–induced increase in local sea level rise is added, that high point could be overtopped (Figure 5, p. 54). Furthermore, when the coastal region is low-sloping, the water can flow inland over great distances.

Coastal erosion can be accelerated as well when storms ride in on ever-higher seas. A severe example of an increase in such erosion is off the coast of Alaska, where the coastline is thick permafrost, comprised of frozen ice and soil. In the past, offshore sea ice prevented winds from making waves during the stormy season. But as climate change melts the offshore sea ice, these coasts are feeling the full brunt of storm waves that in turn rapidly erode the permafrost, which in many places is thawing too.

To assess which possible storm conditions could present a risk to any particular location, scientists and planners look at what is commonly called the 100-year flood. This term means that there is a 1 in 100 chance of such a flood occurring

FIGURE 5. Storm Surge on a Higher Sea



A hypothetical worst-case scenario for a storm surge 100 years ago compared with such an event today. Because the rate of sea level rise has increased as a result of human-induced climate change, this boost in elevation combined with naturally occurring factors can spell trouble during a storm surge. The shoreline protections in place, whether natural or engineered, could be overtopped.

in any given year. Similarly, a five-year flood has a one in five, or 20 percent, chance of occurrence. It is important to remember, however, that this is a probability measure. It does not mean that after a 100-year flood occurs we can expect 99 years until the next one, just as tossing a penny and seeing heads does not affect the likelihood of seeing heads on a subsequent toss.

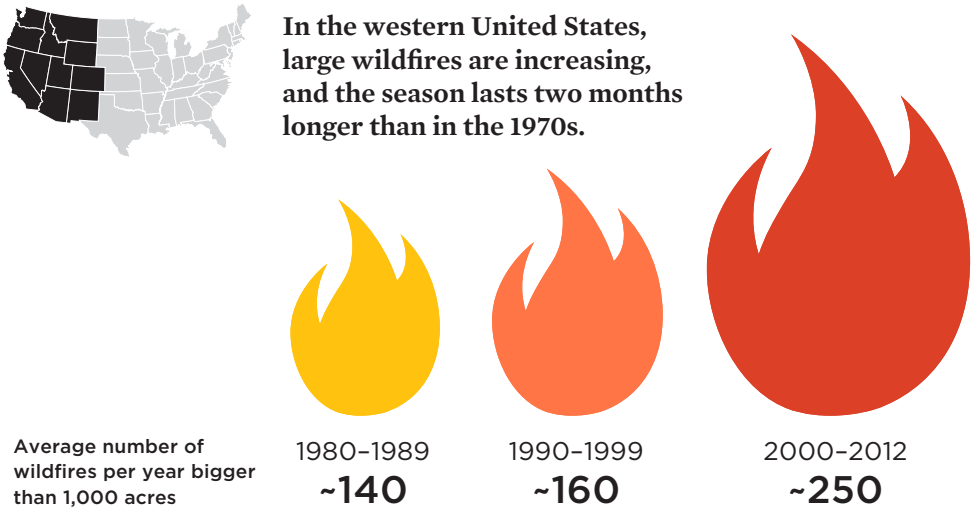
But if another severe flood does happen soon afterward, what constitutes a 100-year flood may need to be reevaluated. With each passing decade, more data are available at each given location, and these data capture the natural and human factors affecting the region. Because scientists have more information to determine the chance of flood heights reaching given elevations, the 100-year flood-level height does tend to change over time. This has already occurred along many parts of the U.S. East Coast, as global sea level rise, together with local factors (such as land-elevation changes and the area's ocean currents), are all taken into account.

Too Little Water or Too Much

Sometimes the water availability in a region departs greatly from the normal conditions that communities expect. Multiple lines of evidence show that climate change is increasing the frequency and severity of some of these extreme departures, regarding cases both of too much and too little water. Too much water over a short period can increase the chances of catastrophic flooding, for example, especially if local infrastructure is designed for a lower sea level or if riverbanks can no longer contain severe flash floods.

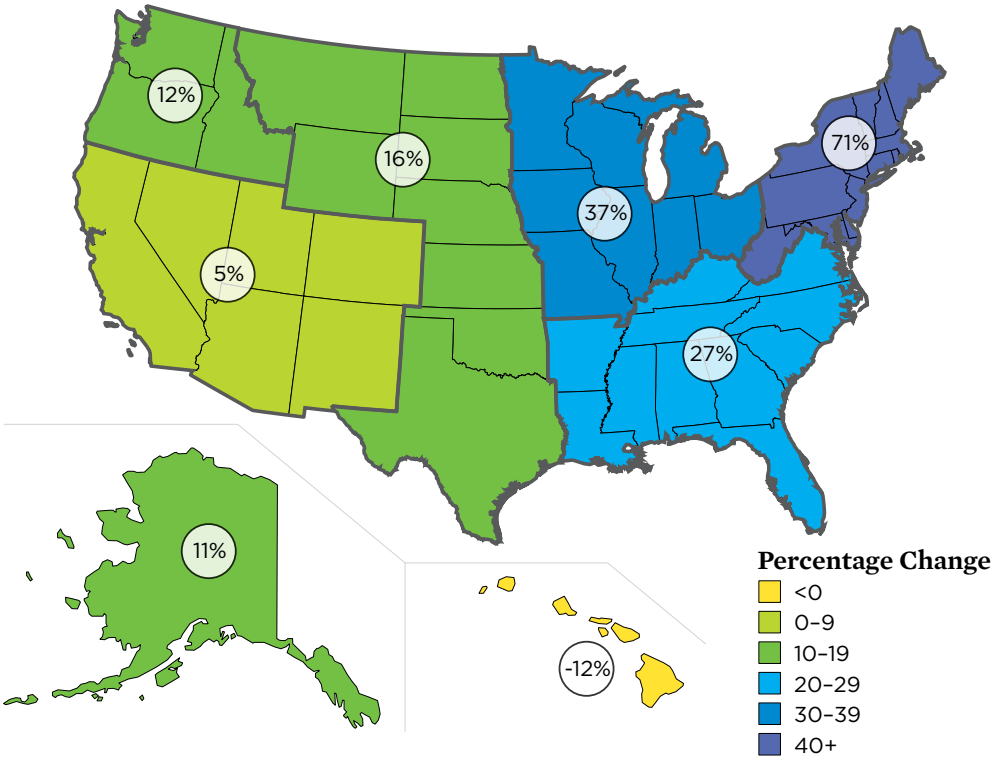
Warmer temperatures increase evaporation rates from surface water bodies. And they also reduce soil moisture, which in turn amplifies the risk of drought. This is especially true

FIGURE 6. Changes in Wildfire Size and Season



SOURCES: USGS 2013; WESTERLING ET AL. 2006.

FIGURE 7. Percentage Change in Very Heavy Precipitation



Percentage change in very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2012 for each region of the United States. The trend toward more very heavy precipitation for the continental United States, and particularly in the Northeast and Midwest, is clear.

SOURCE: MELILLO ET AL. 2014.

for places that already tend to be semi-arid. All else being equal, drier and hotter conditions add to the inherent risk of wildfires.

In the western United States, climate change has increased temperatures. One study reported that by 2002, snowmelt occurred one to four weeks earlier than it did in 1948. In regions where the earlier snowmelt and runoff are followed by a long, hot, and dry summer, the risks of larger wildfires are elevated. In the western United States, the wildfire season—defined as the period from the first outbreak to the final control date of fires larger than 1,000 acres—has increased more than two months during the period from 1970 to 2012 (Figure 6).

Because warmer air can also hold more water vapor, human-induced climate change has raised the overall water vapor content of our atmosphere. When storms occur, more rain or snow may fall compared with similar events decades ago in the same location. Some regions of the United States have shown significant increases in the amount of precipitation falling during the heaviest 1 percent of daily events each year. For example, the Northeast has seen, on average, a 71 percent increase from 1958 to 2012 in the amount falling during the heaviest events; even the arid Southwest registered a 5 percent increase over the same period (Figure 7).

Typically, rain that falls on dry soils seeps in. Once the soil is saturated, additional rain will run off the surface and flow more rapidly downslope, adding to river flood risk. But after wildfires, landscapes are denuded, meaning that there remains little vegetation to take up rainwater. Further, the bare ground receives the full impact of rain, thereby further increasing the erosion potential from runoff.

High heat from wildfires can also increase the rate of runoff by altering the soil so that it repels water. A severe wildfire can vaporize the organic material in a soil and change its very chemistry. Gases from the fire penetrate the soil, and when the gases cool they condense to coat the soil with a wax-like substance that repels water. Together, these impacts can cause a soil to become hydrophobic—literally, "afraid of water." This hydrophobia is at its worst immediately after a wildfire, and recovery can take several years. All in all, the likelihood of a flash flood can increase substantially if heavy rains fall on soils altered by wildfires.

Conclusion

The treasured places cited in this report are all subject to increased risks from climate change, such as extreme storms, hotter temperatures, and more frequent and severe floods, droughts, and wildfires. These impacts, of course, are not limited to the cultural and historical resources selected for this report but also are being felt in most cities and towns across the country. Therefore just as the people responsible for maintaining parks, monuments, and landmarks are planning ahead, so can local communities. Reducing carbon pollution by burning fewer fossil fuels will give us more time to prepare and adapt, while possibly preventing the worst aspects of climate change.

© James Jordan

Moving the Cape Hatteras Lighthouse is an example of an action taken to adapt to change, including climate change. Reducing carbon pollution by burning fewer fossil fuels will give us more time to prepare and adapt, while possibly preventing the worst aspects of climate change.

[REFERENCES]

A fully cited version of this report is available online (in PDF format) at *www.ucsusa.org/LandmarksAtRisk*.

INTRODUCTION

Caffrey, M., and R. Beavers. 2013. Planning for the impact of sea-level rise on U.S. national parks. *Park Science* 30(1):6–13. Online at *www.nature.nps.gov/parkscience/index.cfm?Page=2,* accessed on April 18, 2014.

Gonzalez, P. 2011. Climate change impacts and carbon in U.S. national parks. *Park Science* 28(2):10–15.

National Park Service (NPS). 2010. *National Park Service climate change response strategy*. Fort Collins, CO: Climate Change Response Program of the NPS. Online at *www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf,* accessed on March 23, 2014.

BOSTON HISTORIC DISTRICTS

Archer, R. 2010. *As if an enemy's country: The British occupation of Boston and the origins of revolution.* New York: Oxford University Press.

Boston Harbor Association. 2013. *Preparing for the rising tide*. Online at *www.tbha.org/preparing-rising-tide-report,* accessed on December 12, 2013.

Boston Landmarks Commission. 1983. *Blackstone Block street network: Boston Landmarks Commission study report*.

Carp, B.L. 2010. *Defiance of the patriots: The Boston Tea Party and the making of America*. New Haven, CT: Yale University Press.

City of Boston. 2013. City of Boston hazard mitigation plan, draft 2013, update. Online at *www.cityofboston.gov/environment/mitigationplan.asp,* accessed on December 12, 2013.

City of Boston. 2013. *Climate-ready Boston: Municipal vulnerability to climate change.* Climate Preparedness Task Force. Online at *http://ssuu.com/ees_boston/docs/final_report_29oct13/,* accessed on April 15, 2014.

Federal Emergency Management Agency (FEMA). 2013. Flood insurance rate map: Suffolk County. Online at *http://hazards.fema.gov/femaportal/prelimdownload/searchResult.action* (enter State= Massachusetts and County=Suffolk), accessed on December 12, 2013.

Hallegatte, S., et al. 2013. Future flood losses in major coastal cities. *Nature Climate Change* 3:802–806. Online at *www.nature.com/nclimate/journal/v3/n9/full/nclimate1979.html,* accessed on February 6, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. NOAA/NOS/CO-OPS observed water levels at 8443970, Boston MA. Online at *http://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970,* accessed on February 12, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2013. Extreme water levels. Boston 8443970. Online at *http://tidesandcurrents.noaa.gov/est/northatlantic.html,* accessed on December 12, 2013.

Unger, H.G.. 2011. *American tempest: How the Boston Tea Party sparked a revolution.* Cambridge, MA: Da Capo Press.

STATUE OF LIBERTY & ELLIS ISLAND

Abreu, R. 2014. Personal communication, January 16. Rafael Abreu is director of sales and marketing at Statue Cruises.

Caffrey, M., and R. Beavers. 2013. Planning for the impact of sea-level rise on U.S. National Parks. *Park Science* 30(1):6–13. Online at *www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience30(1)Summer201, 3_6-13_CaffreyBeavers_3647.pdf,* accessed on October 27, 2013.

Chinese, V. 2013. Ellis Island reopens one year after Sandy. *New York Daily News,* October 28. Online at *www.nydailynews.com/new-york/hurricane-sandy/ellis-island-reopens-year-sandy-article-1.1499214,* accessed on October 27, 2013.

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4–5):585–602.

City of New York. 2013. *A stronger, more resilient New York, PlaNYC*. Online at *www.nyc.gov/html/sirr/html/report/report.shtml,* accessed on October 27, 2013.

Eissenberg, M. 2013. Personal communication, December 24. Mike Eissenberg is general engineer at the Denver Service Center of the National Park Service.

Harris, E.A. 2013. A magical island loses the last of its residents. *New York Times,* October 7. Online at *www.nytimes.com/2013/10/08/nyregion/a-magical-isle-loses-the-last-of-its-residents.html,* accessed on October 27, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2013. Updated mean sea level trends: 8518750 The Battery, New York, 1856–2012. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_update.shtml?stnid=8518750,* accessed on October 27, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2012. Observing Hurricane Sandy like a meteorologist. Online at *www.sos.noaa.gov/Education/sandy.html,* accessed on October 27, 2013.

National Park Service (NPS). 2013. Ellis Island: Plan your visit: Visitor alert. Online at *www.nps.gov/elis/planyourvisit/index.htm,* accessed on October 27, 2013.

National Park Service (NPS). 2013. Statue of Liberty National Monument and Ellis Island. Recovery after Hurricane Sandy. Online at *www.nps.gov/stli/after-hurricane-sandy.htm,* accessed on October 27, 2013.

National Park Service (NPS). No date. Ellis Island. Online at *www.nps.gov/elis/index.htm,* accessed on October 27, 2013.

National Park Service (NPS). No date. Statue of Liberty National Monument. Online at *www.nps.gov/stli/index.htm,* accessed on October 27, 2013

Parris, A., et al. 2012. *Global sea level rise scenarios for the United States National Climate Assessment*. NOAA Tech Memo OAR CPO-1. Online at *http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf,* accessed on October 27, 2013.

HARRIET TUBMAN NATIONAL MONUMENT

Boesch, D.F., et al. 2013. *Updating Maryland's sea-level rise projections*. Special report of the scientific and technical working group of the Maryland Commission on Climate Change. Cambridge, MD: University of Maryland Center for Environmental Science.

Boesch, D.F. (editor). 2008. *Global warming and the free state: Comprehensive assessment of climate change impacts in Maryland*. Report of the scientific and technical working group of the Maryland Commission on Climate Change. Cambridge, MD: University of Maryland Center for Environmental Science.

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4–5):585–602.

Dahl, T., and Stedman, S.-M. 2013. *Status and trends of wetlands in the coastal watersheds of the conterminous United States, 2004–2009*. U.S. Fish and Wildlife Service and National Marine Fisheries Service. Online at *www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-In-the-Coastal-Watersheds-of-the-Conterminous-US-2004-to-2009.pdf,* accessed on December 8, 2013.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436:686–688.

Fish and Wildlife Service (FWS). 2010. *Blackwater National Wildlife Refuge: Wildlife and habitat*. Online at *www.fws.gov/blackwater/wildlife.html,* accessed on December 8, 2013.

Fish and Wildlife Service (FWS). 2009. *Blackwater National Wildlife Refuge: Marsh loss and restoration*. Online at *www.fws.gov/northeast/climatechange/pdf/blackwatermarshloss122009.pdf,* accessed on December 8, 2013.

Fritze, J. 2013. Obama establishes Tubman Park on Eastern Shore. *Baltimore Sun,* March 25. Online at *http://articles.baltimoresun.com/2013-03-25/news/bs-md-tubman-20130325_1_tubman-park-harriet-tubman-tubman-site,* accessed on December 8, 2013.

Kowalski, M. No date. Rising seas threaten national landmarks on the Chesapeake Bay. Online at *http://cnsmaryland.org/sealevelrise/?p=131,* accessed on December 8, 2013.

Larsen, C., et al. 2004. *The Blackwater NWR Inundation Model. Rising sea level on a low-lying coast: Land use planning for wetlands,* report 04-1302. U.S. Geological Survey. Laurel, MD: Patuxent Wildlife Research Center. Online at *http://pubs.usgs.gov/of/2004/1302/,* accessed on December 8, 2013.

Larsen, K.C. 2004. *Bound for the promised land: Harriet Tubman: Portrait of an American hero.* New York: Ballentine.

Maryland Department of Natural Resources. No date. Harriet Tubman Underground Railroad State Park. Online at *www.dnr.state.md.us/publiclands/eastern/tubman.asp,* accessed on December 8, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2013. Mean sea level trend: 8571892 Cambridge, Maryland: 1943–2006. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8571892,* accessed on December 8, 2013.

Presidential proclamation: Establishment of the Harriet Tubman Underground Railroad National Monument. 2013. Online at *www.whitehouse.gov/the-press-office/2013/03/25/presidential-proclamation-harriet-tubman-underground-railroad-national-m,* accessed on December 8, 2013.

Tagger, B. 2013. New federal and state parks in Maryland commemorate life and legacy of Harriet Ross Tubman. April 6. Online at *http://march.rutgers.edu/2013/04/new-federal-and-state-parksin-maryland-commemoratelife-and-legacy-of-harriet-ross-tubman,* accessed on December 8, 2013.

HISTORIC ANNAPOLIS, MD

Boesch, D.F., et al. 2013. *Updating Maryland's sea-level rise projections*. Special report of the Scientific and Technical Working Group to the Maryland Climate Change Commission. Cambridge, MD: University of Maryland Center for Environmental Science.

Brown, V.W. 1965. Shipping in the port of Annapolis 1748–1775: Sea power monograph no.1. United States Naval Institute.

City of Annapolis. 2011. *Flood mitigation strategies for the city of Annapolis, MD: City Dock and Eastport area*. Annapolis, MD: Department of Neighborhood and Environmental Programs. Online at *www.annapolis.gov/docs/default-source/dnep-documents-pdfs/03-01-2011-sea-level-study.pdf?sfvrsn=4,* accessed on November 6, 2013.

City of Annapolis. 2011. *Regulatory response to sea level rise and storm surge inundation*. Annapolis, MD: Environmental Resources Management. Online at *http://dnr.maryland.gov/CoastSmart/pdfs/Annapolis_RRSLRnSSI.pdf,* accessed on November 6, 2013.

Guth, P. 2011. Storm surge flooding at the U.S. Naval Academy. Annapolis, MD: U.S. Naval Academy. Online at *www.usna.edu/Users/oceano/pguth/website/storm_surge/flooding.htm,* accessed on November 6, 2013.

Hoyos C.D., et al. 2010. Deconvolution of the factors contributing to the increase in global hurricane intensity. *Science* 312:94–97. Online at *www.sciencemag.org/content/312/5770/94,* accessed on November 6, 2013.

Li, M., et al. 2006. Hurricane-induced storm surges, currents, and destratification. *Geophysical Research Letters* 33(2) L02604.

Maryland Historical Trust. 2013. Certified local government subgrant program. In *Cultural resource hazard mitigation plan for the Annapolis historic district*. Federal grant application from the Maryland Historical Trust/City of Annapolis.

McWilliams, J.W. 2011. *Annapolis, city on the Severn: A history*. Baltimore: Johns Hopkins University Press.

National Oceanic and Atmospheric Administration (NOAA). 2014. Observed water levels at 8575512, Annapolis MD. Online at *http://tidesandcurrents.noaa.gov/waterlevels.html?id=8575512,* accessed on March 27, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2013. Verified hourly heights at 8575512, Annapolis, MD. Hurricane Isabel 2003 on 9/19/2003 at 12:00 GMT. Online at *http://tidesandcurrents.noaa.gov/waterlevels.html?id=8575512&units=standard&bdate=20030917&edate=20030920&timezone=GMT&datum=MLLW&interval=h&action,* accessed on November 6, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2013. Water level report: Monthly max-min report: Severn River, Annapolis, MD 8575512. Online at *http://tidesandcurrents.noaa.gov/reports.html?type=monthlyextremes&bdate=19300101&edate=20131231&units=standard&id=8575512&retrieve=Retrieve,* accessed on November 6, 2013.

Papenfuse, E.C. 1975. *In pursuit of profit: The Annapolis merchants in the era of the American revolution, 1763–1805.* Baltimore: Johns Hopkins University Press.

Sallenger, A.H., Jr., et al. 2012. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change* 2:884–888.

U.S. Army Corps of Engineers (USACE). 2008. *Addendum report: Flood reduction analysis for the United States Naval Academy.*

U.S. Army Corps of Engineers (USACE). 2006. *Final flood damage reduction analysis for the United States Naval Academy.*

U.S. Department of the Interior. 1969. National register of historic places registration form: Annapolis, Maryland. Online at *http://architecturaltrust.org/~architec/wp-content/uploads/2013/06/Report_NR_Annapolis1.pdf,* accessed on November 6, 2013.

U.S. Department of the Interior. 1969. National register of historic places registration form: U.S. Naval Academy.

Wood, P. 2013. New, returning vendors poised to reopen Annapolis Market House. *Baltimore Sun,* June 17. Online at *http://articles.baltimoresun.com/2013-06-17/news/bs-md-ar-market-house-progress-0613-20130613_1_annapolis-market-house-new-vendors-yellowfin-seafood-oyster-bar,* accessed on March 21, 2014.

FORT MONROE NATIONAL MONUMENT

Goodheart, A. 2011. *1861: The Civil War awakening*. New York, NY: Knopf.

Hampton University. 2014. History of Hampton University. Online at *www.hamptonu.edu/about/history.cfm,* accessed on February 1, 2014.

Kunkel, K.E., et al. 2013. Monitoring and understanding trends in extreme storms: State of knowledge. *Bulletin of the American Meteorological Society* 94(4):499–514.

Mitchell, M., et al. 2013. *Recurrent flooding study for tidewater Virginia*. Report submitted by the Virginia Institute of Marine Science to the Virginia General Assembly. Online at *http://leg2.state.va.us/dls/h&sdocs.nsf/4d54200d7e28716385256ec1004f3130/43c5b6688601e52c852579c900531e82?OpenDocument,* accessed on February 1, 2104.

National Oceanic and Atmospheric Administration (NOAA). 2014. Updated mean sea level trends 8638610 Sewells Point, VA. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_update.shtml?stnid=8638610,* accessed on February 1, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. NOAA/NOS/CO-OPS observed water levels at 8638610 Sewells Point, VA for September 18, 2003, and August 27, 2011. Online at *http://tidesandcurrents.noaa.gov/waterlevels.html?id=8638610,* accessed on February 12, 2014.

National Park Service (NPS). 1987. *The architectural heritage of Fort Monroe, volume 1.* Online at *www.nps.gov/history/history/online_books/nnps/fort_monroe.pdf,* accessed on February 1, 2104.

National Park Service (NPS). No date. Fort Monroe national monument. Online at *www.nps.gov/fomr/index.htm,* accessed on February 1, 2014.

National Park Service (NPS). No date. National historic landmarks program: Fort Monroe. Online at *http://tps.cr.nps.gov/nhl/detail.cfm?ResourceId=691&ResourceType=District,* accessed on February 1, 2014.

Rogers, R. 2003. Isabel rewrites Fort Monroe history. *The Daily Press,* September 23. Online at *http://articles.dailypress.com/2003-09-23/news/0309230056_1_unexploded-shells-and-bombs-moat-hurricane-isabel,* accessed on February 1, 2014.

U.S. Army. 2011. Norfolk District has unorthodox "farewell" gift for Fort Monroe. Online at *www.army.mil/article/54063/Norfolk_District_has_unorothodox__quot_farewell_quot__gift_for_Fort_Monroe/,* accessed on February 1, 2014.

U.S. Army Corps of Engineers (USACE). 2013. *Draft environmental assessment: Willoughby spit and vicinity: Coastal storm damage reduction project, Norfolk, Virginia*. Online at *www.nao.usace.army.mil/Portals/31/docs/2WS-LRR-EA.pdf,* accessed on February 1, 2014.

Waterway Surveys & Engineering, Ltd., Virginia Institute of Marine Science, and URS Corporation. 2011. *Hampton beachfront and storm protection management plan*. Online at *http://web.vims.edu/physical/research/shoreline/docs/HamptonBeachfrontPlanFinal110415.pdf,* accessed on February 1, 2014.

Wilder, C.B. 1863. Excerpts from testimony of the Superintendent of Contrabands at Fortress Monroe, Virginia, before the American Freedmen's Inquiry Commission. Online at *www.freedmen.umd.edu/wilder.htm,* accessed on February 1, 2014.

HISTORIC JAMESTOWN, VA

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4–5):585–602.

Eggleston, J., and J. Pope. 2013. *Land subsidence and relative sea-level rise in the southern Chesapeake Bay region,* U.S. Geological Survey circular 1392. Online at *http://dx.doi.org/10.3133/cir1392,* accessed on November 8, 2013.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436:686–688.

Grinsted, A., J.C. Moore, and S. Jevrejeva. 2012. Homogeneous record of Atlantic hurricane surge threat since 1923. *Proceedings of the National Academy of Sciences* 109(48):19601–19605.

Halainen, B. 2004. *Hurricane Isabel: The National Park Service response*. Report of the Hurricane Isabel Review Group. Washington, DC: National Park Service.

Holland, G., and C.L. Bruyère. 2014. Recent intense hurricane response to global climate change. *Climate Dynamics* 42(3-4): 617–627.

Joyce, C. 2013. With rising seas, America's birthplace could disappear. *All Things Considered,* May 14. Online at *www.npr.org/2013/05/14/178809495/with-rising-seas-americas-birthplace-could-disappear,* accessed on November 8, 2013.

Mitchell. M., et al. 2013. *Recurrent flooding study for tidewater Virginia*. Report submitted by the Virginia Institute of Marine Science to the Virginia General Assembly. Online at *http://leg2.state.va.us/dls/h&sdocs.nsf/4d54200d7e28716385256ec1004f3130/43c5b6688601e52c852579c900531e82?OpenDocument,* accessed on February 1, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2013. Updated mean sea level trends 8638610 Sewells Point, VA. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_update.shtml?stnid=8638610,* accessed on November 8, 2013.

National Parks Conservation Association (NCPA). 2007. *Unnatural disaster: Global warming and our national parks*. Online at *www.npca.org/assets/pdf/unnatural_disaster_2.pdf,* accessed on November 8, 2013.

National Park Service (NPS). Historic Jamestowne. No date. Online at *www.nps.gov/jame/index.htm,* accessed on November 8, 2013.

Saunders, S., T. Easley, and T. Spencer. 2010. *Virginia special places in peril: Jamestown, Chincoteague, and Shenandoah threatened by climate disruption*. Louisville, CO, and New York, NY: Rocky Mountain Climate Organization and Natural Resources Defense Council.

NASA'S COASTAL FACILITIES

Boffey, P.M. 1986. Commercial launching by NASA ordered shifted to commercial sector. *New York Times,* August 16. Online at *www.nytimes.com/1986/08/16/us/commercial-launching-by-nasa-ordered-shifted-to-private-sector.html,* accessed on February 12, 2014.

Burroughs, N., and L. Iraci. 2010. *Climate change impacts and adaptation strategies at NASA Ames Research Center: Full report*. NASA Earth Science Division. Online at *http://nex.nasa.gov/nex/static/media/publication/Climate_Change_Impacts_and_Adaptation_Strategies_NASA_Ames.pdf,* accessed on December 8, 2013.

Carr, M.H., et al. 1998. Evidence for a subsurface ocean on Europa. *Nature* 391:363–365. Online at *www.nature.com/nature/journal/v391/n6665/abs/391363a0.html,* accessed on February 16, 2014.

Chaikin, A. 2009. How the spaceship got its shape. *Air and Space Magazine*. Online at *www.airspacemag.com/space/how-the-spaceship-got-its-shape-137293282/?c=y%3Fno-ist,* accessed on February 17, 2014.

Elsner, J.B., J.P. Kossin, and T.H. Jagger. 2008. The increasing intensity of the strongest tropical cyclones. *Nature* 455:92–95. Online at *www.nature.com/nature/journal/v455/n7209/abs/nature07234.html,* accessed on December 8, 2013.

European Space Agency. 2000. Hubble, the black hole finder. Online at *www.spacetelescope.org/news/heic0002/,* accessed on February 16, 2014.

Federal Emergency Management Agency (FEMA). 2009. Hurricane Ike in Texas and Louisiana mitigation assessment team report. Online at *www.fema.gov/media-library-data/20130726-1648-20490-1790/757_ch1_final.pdf,* accessed April 12, 2014.

Halvorson, T. 2005. NASA lauds shuttle fuel tank plant workers. *Florida Today,* September 14. Online at *www.space.com/1549-nasa-lauds-shuttle-fuel-tank-plant-workers.html,* accessed on December 8, 2013.

Kennedy, J.F. Text of President John F. Kennedy's Rice Stadium moon speech. 1962. Online at *http://er.jsc.nasa.gov/seh/ricetalk.htm,* accessed on February 10, 2014.

King, C.T., et al. 2007. *Economic and workforce impacts of Hurricane Katrina, demographic and related changes on NASA's space shuttle program: Findings and recommendations.* Austin, TX: Ray Marshall Center for the Study of Human Resources and IC² Institute, University of Texas. Online at *http://repositories.lib.utexas.edu/bitstream/handle/2152/14469/king-2007-katrina-nasa-final-report.pdf?sequence=3,* accessed on December 8, 2013.

Koumoudis, V., et al. 2009. *Hurricane Ike in Texas and Louisiana: Mitigation assessment team report*. Federal Emergency Management Center (FEMA). Online at *www.fema.gov/media-library-data/20130726-1648-20490-1790/757_ch1_final.pdf,* accessed on December 8, 2013.

Magee, R. 2011. *Case study and lessons learned associated with Hurricane Katrina, August 29, 2005*. Hancock County, MS: John C. Stennis Space Center.

National Aeronautics and Space Administration (NASA). 2014. Goddard Space Flight Center: Present missions. Online at *www.nasa.gov/centers/goddard/missions/index.html#.U1VdiOZdURg,* accessed on April 21, 2014.

National Aeronautics and Space Administration (NASA). 2014. Hubble space telescope. Online at *www.nasa.gov/mission_pages/hubble/main/index.html,* accessed on February 15, 2014.

National Aeronautics and Space Administration (NASA). 2013. Apollo: Humankind's first steps on the lunar surface. Online at *www.nasa.gov/mission_pages/apollo/index.html,* accessed on February 11, 2014.

National Aeronautics and Space Administration (NASA). 2013. Gemini: Stepping stone to the moon. Online at *www.nasa.gov/mission_pages/gemini/index.html,* accessed on February 11, 2014.

National Aeronautics and Space Administration (NASA). 2013. Langley Research Center. Online at *www.nasa.gov/centers/langley/home/index.html,* accessed on December 8, 2013.

National Aeronautics and Space Administration (NASA). 2013. Mercury: America's first astronauts. Online at *www.nasa.gov/mission_pages/mercury/index.html,* accessed on February 11, 2014.

National Aeronautics and Space Administration (NASA). 2013. NASA Wallops recovery continues from Hurricane Sandy. March 5. Online at *www.nasa.gov/mission_pages/hurricanes/features/wallops-sandy.html,* accessed on December 8, 2013.

National Aeronautics and Space Administration (NASA). 2013. Skylab: America's first space station. Online at *www.nasa.gov/mission_pages/skylab/index.html,* accessed on February 15, 2014.

National Aeronautics and Space Administration (NASA). 2013. Space shuttle. Online at *www.nasa.gov/mission_pages/shuttle/main/index.html,* accessed on February 11, 2014.

National Aeronautics and Space Administration (NASA). 2012. *Adapting now to a changing climate: Wallops Flight Facility and the Eastern Shore*. Report NP-2012-10-909-HQ. Climate Adaptation Science Investigator Work Group.

National Aeronautics and Space Administration (NASA). 2012. Record-setting X-ray jet discovered. Online at *www.nasa.gov/mission_pages/chandra/news/xray_jet.html,* accessed on February 15, 2014.

National Aeronautics and Space Administration (NASA). 2011. *Kennedy Space Center: Future development concept 2012–2031*. KSC Center Planning and Development Office.

National Aeronautics and Space Administration (NASA). 2011. *NASA strategic plan*. Office of the Chief Financial Officer. Online at *www.nasa.gov/offices/ocfo/budget/strat_plans.html,* accessed on December 8, 2013.

National Aeronautics and Space Administration (NASA). 2010. *Adapting now to a changing climate: Florida's space coast*. Report NP-2010-11-687-HQ.

National Aeronautics and Space Administration (NASA). 2009. Apollo 11. Online at *www.nasa.gov/mission_pages/apollo/missions/apollo11.html#.Uvu0i_s0-KI,* accessed on February 11, 2014.

National Aeronautics and Space Administration (NASA). 2007. Sputnik: The fiftieth anniversary. Online at *http://history.nasa.gov/sputnik/,* accessed on February 11, 2014.

National Aeronautics and Space Administration (NASA). 2004. Historical backgrounder: NASA Ames Research Center. Online at *history.arc.nasa.gov/backgrounder.htm,* accessed on February 14, 2014.

National Aeronautics and Space Administration (NASA). 2004. Release 04-301: Kennedy Space Center recovers from Hurricane Frances. *NASA News*. Online at *www.nasa.gov/home/hqnews/2004/sep/HQ_04301_FrancesRecovery.html,* accessed on May 4, 2014.

National Aeronautics and Space Administration (NASA). 2002. Science news: Found it! Ice on Mars. Online at *http://science1.nasa.gov/science-news/science-at-nasa/2002/28may_marsice/,* accessed on February 15, 2014.

National Aeronautics and Space Administration (NASA). No date. Earth: Your future, our mission. Online at *www.nasa.gov/topics/earth/index.html#.UwvJTfs0-KI,* accessed on February 12, 2014.

National Aeronautics and Space Administration (NASA). No date. Launch schedule. Online at *www.nasa.gov/missions/schedule/#.UvEirvs0-KI,* accessed on February 10, 2014.

NASA Goddard Institute for Space Studies. 2014. Overview. Online at *www.giss.nasa.gov/,* accessed on February 12, 2014.

NASA Jet Propulsion Laboratory. First space missions: Mariners to Venus. Online at *www.jpl.nasa.gov/jplhistory/mission/venus-t.php,* accessed on February 15, 2014.

NASA John C. Stennis Space Center. No date. Stennis is . . . Online at *www.nasa.gov/centers/stennis/about/stennis/index.html,* accessed on February 14, 2014.

NASA Johnson Space Center. 2008. Hurricane Ike edition. *Roundup,* November. Online at *www.jsc.nasa.gov/roundup/online/2008/1108.pdf,* accessed on December 8, 2013.

NASA Langley Research Center. No date. Delivering for today . . . Preparing for tomorrow. Online at *www.norfolk.gov/DocumentCenter/View/1767,* accessed on December 8, 2013.

NASA Marshall. 2013. NASA Marshall Space Flight Center: Michoud Assembly Facility. Online at *www.nasa.gov/centers/marshall/michoud/#.UquThmRDvy0,* accessed on February 13, 2014.

NASA Office of Inspector General. 2011. *NASA's use of Recovery Act funds to repair hurricane damage at Johnson Space Center*. Report Ig-11-025. Online at *http://oig.nasa.gov/audits/reports/FY11/IG-11-025.pdf,* accessed on December 8, 2013.

NASA Wallops Flight Facility. 2012. Wallops' newest beach. Online at *www.nasa.gov/centers/wallops/news/beach.html,* accessed on December 8, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2013. Mean sea level trend: 8761724 Grand Isle, Louisiana.

National Oceanic and Atmospheric Administration (NOAA). 2013. Mean sea level trend: 8632200 Kiptopeke, Virginia. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8632200,* accessed on December 8, 2013.

National Weather Service (NWS). 2014. Advanced hydrologic prediction service. James River at Sewells Point. Online at *http://water.weather.gov/ahps2/hydrograph.php?wfo=akq&gage=swpv2,* accessed on December 8, 2013.

Overpeck, S. 2009. Hurricane Ike wind analysis for Southeast Texas. NOAA/NWS Houston/Galveston. Online at *www.srh.noaa.gov/hgx/?n=projects_ike08_wind_analysis,* accessed on December 8, 2013.

Roberts, J. 2003. Langley stands up to Isabel. *NASA Researcher News,* October 10. Online at *http://researchernews.larc.nasa.gov/archives/2003/101003/Isabel.html,* accessed on December 8, 2013.

Russo, T.A., A.T. Fisher, and D.M. Winslow. 2013. Regional and local increases in storm intensity in the San Francisco Bay Area, USA, between 1890 and 2010. *Journal of Geophysical Research: Atmospheres* 118(8):3392–3401.

Samenow, J. 2011. The National Hurricane Center's strikingly accurate forecast for Sandy. *Washington Post,* November 1. Online at *www.washingtonpost.com/blogs/capital-weather-gang/post/the-national-hurricane-centers-striking-forecast-for-superstorm-sandy/2012/11/01/e2633b5e-2427-11e2-ac85-e669876c6a24_blog.html,* accessed on December 8, 2013.

Scharroo, R., W.H.F. Smith, and J.L. Lillibridge. 2005. Satellite altimetry and the intensification of Hurricane Katrina. *Eos, Transactions American Geophysical Union* 86(40):366.

Selverston, A. 2011. In bracing Moffett Field for climate impacts, NASA offers brainpower to bay cities. *Millbrae Patch,* February 7. Online at *http://millbrae.patch.com/groups/politics-and-elections/p/in-bracing-moffett-field-for-climate-impacts-nasa-off292e1fc8d1,* accessed on December 8, 2013.

Stefanov, W., and K. Lulla. 2012. Climate change adaptation science activities at NASA Johnson Space Center. Paper for workgroup meeting, July 18-19, Houston, TX. Online at *http://nix.nasa.gov/search.jsp?R=20120015947&qs=N%3D4294950110%2B4294948758,* accessed on December 8, 2013.

Stofan, E.R., et al. 2007. The lakes of Titan. *Nature* 445:61–64. Online at *www.nature.com/nature/journal/v445/n7123/abs/nature05438,* accessed on February 16, 2014.

Turner, C. 2010. Managing effects of climate change at NASA's Wallops Flight Facility. Paper presented at the International Workshop on Environment and Energy: Global Collaboration in Sustainable Environmental and Alternative Energy Strategies, November 2–4, San Diego, CA. Online at *www.c3p.org/Workshop%202010/Thursday%20Nov%204/13-Carolyn_Turner_-_Managing_Effects_of_Climate_Change-WFFTurner.pdf,* accessed on December 8, 2013.

U.S. Government Accountability Office (GAO). 2013. *Climate change: Future federal adaptation efforts could better support local infrastructure decision makers*. Online at *www.gao.gov/assets/660/653741.pdf,* accessed on December 18, 2013.

CAPE HATTERAS LIGHTHOUSE

American Association of State Highway and Transportation Officials. 2013. North Carolina DOT reopens Bonner Bridge, continues push for replacement. December 20. Online at *www.aashtojournal.org/Pages/122013BonnerBridge.aspx,* accessed on April 6, 2014.

Coastal Planning & Engineering of North Carolina, Inc. 2013. *Beach management concept assessment: Town of Kitty Hawk, North Carolina*. Online at *www.townofkittyhawk.org/vertical/sites/%7B991BBDF3-791F-4435-80BA-FEB8F8D09BA4%7D/uploads/WORKING_CPENC_Board_Briefing_Sept_3_20131.pdf,* accessed on October 9, 2013.

Committee on Options for Preserving Cape Hatteras Lighthouse, Board on Environmental Studies and Toxicology, National Research Council. 1988. *Saving Cape Hatteras Lighthouse from the sea: Options and policy implications*. Washington, DC: National Academies Press.

Cui, Y., E. Mahoney, and T. Herbowicz. 2013. Economic benefits to local communities from national park visitation, 2011. Natural resource report NPS/NRSS/ARD/NRR—2013/632. Fort Collins, CO: National Park Service. Online at *www.nature.nps.gov/socialscience/docs/NPSSystemEstimates2011.pdf,* accessed on April 11, 2014.

Drye, W. 2014. Can an iconic lighthouse site be saved from the sea? Preservationists fight eroding shores on the Outer Banks. *National Geographic Daily News,* March 27. Online at *http://news.nationalgeographic.com/news/2014/03/140327-lighthouse-preservation-cape-hatteras-outer-banks/,* accessed on April 6, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Sea level trends. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends.html,* accessed on April 11, 2014.

National Park Service (NPS). No date. Cape Hatteras: The move. Online at *www.nps.gov/caha/historyculture/themovefaqs.htm,* accessed on April 30, 2014.

National Park Service (NPS). No date. Lost to the perils of the sea. Online at *www.nps.gov/caha/historyculture/shipwrecks.htm,* accessed on April 6, 2014.

National Park Service (NPS). No date. Moving the Cape Hatteras Lighthouse. Online at *www.nps.gov/caha/historyculture/movingthelighthouse.htm,* accessed on April 6, 2014.

North Carolina Department of Transportation. No date. Long-term solutions for N.C. 12 breaches. Online at *www.ncdot.gov/projects/bonnerbridgephase2/,* accessed on October 9, 2013.

Nultemeier, B. 2013. Relentless March storm pounds the Outer Banks. *OBXSurfInfo.com,* March 12. Online at *www.obxsurfinfo.com/2013/03/12/relentless-march-storm-pounds-the-outer-banks-photo-gallery/,* accessed on October 9, 2013.

Perry, G. 2013. Reasons to consider storm damage reduction through beach nourishment. Town of Kitty Hawk. Online at *www.townofkittyhawk.org/vertical/sites/%7B991BBDF3-791F-4435-80BA-FEB8F8D09BA4%7D/uploads/Gary_Perry__Presentation_REASONS_TO_CONSIDER_STORM_DAMAGE_REDUCTION_THROUGH_BEACH1.pdf,* accessed on April 6, 2014.

Quinn, D.B. 1985. *Set fair for Roanoke: Voyages and colonies, 1584–1606*. Chapel Hill, NC: UNC Press Books.

Sallenger, A.H., Jr., 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. Online at *www.nature.com/nclimate/journal/v2/n12/full/nclimate1597.html,* accessed on April 11, 2014.

Siceloff, B. 2012. Sandy damage will keep Outer Banks bridge, highway closed for weeks. *NewsObserver.com,* November 1. Online at *www.newsobserver.com/2012/11/01/2452756/sandy-damage-will-keep-outer-banks.html,* accessed on October 9, 2013.

Tabb, K. 2013. Outer Banks moves toward unified shoreline plan. *North Beach Sun,* July 17. Online at *www.northbeachsun.com/outer-banks-moves-toward-unified-shoreline-plan,* accessed on April 6, 2014.

U.S. Army Corps of Engineers (USACE). 2008. Historical vignette 111: Cape Hatteras Lighthouse. Online at *www.usace.army.mil/About/History/HistoricalVignettes/CivilEngineering/111CapeHatterasLighthouse.aspx,* accessed on April 6, 2014.

Webster, P.J., et al. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* 309:1844–1846.

HISTORIC CHARLESTON, SC

Allen, A., et al. 2012. *NOAA's tide gauge network: Tide station operation and sea level analysis*. Silver Spring, MD: National Oceanic and Atmospheric Administration. Online at *www.oco.noaa.gov/resources/Progress_Reports/Allen_TideGauges_FY11_Progress Report.pdf,* accessed on October 14, 2013.

Bender, M.A., et al. 2010. Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. *Science* 327(5964): 454–458.

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4–5):585–602.

City of Charleston. 2013. Market Street drainage improvement project. Online at *www.charleston-sc.gov/index.aspx?NID=591,* accessed on October 14, 2013.

City of Charleston. 2013. The Old Slave Mart Museum. Online at *www.charleston-sc.gov/index.aspx?nid=160,* accessed on October 14, 2013.

City of Charleston. No date. Why does it seem like Charleston always floods when it rains? Online at *www.charleston-sc.gov/index.aspx?NID=588,* accessed on October 14, 2013.

Fung, I., and E. Wolff. 2014. *Climate change evidence and causes: An overview from the Royal Society and the U.S. National Academy of Sciences*. Online at *http://nas-sites.org/americasclimatechoices/events/a-discussion-on-climate-change-evidence-and-causes/,* accessed on October 14, 2013.

International African American Museum. No date. Online at *www.iaamuseum.org,* accessed on December 8, 2013.

Knutson, T.R., et al. 2010. Tropical cyclones and climate change. *Nature Geoscience* 3:157–163.

National Oceanic and Atmospheric Administration (NOAA). 2014. Sea level rise and coastal flooding impacts. Online at *www.csc.noaa.gov/slr/viewer/#,* accessed on April 8, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2013. Mean sea level trend. 8665530 Charleston, South Carolina. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8665530,* accessed on April 18, 2014.

National Park Service (NPS). No date. Charleston & preservation (excerpted from Chase, C.E. 1998. Charleston: Guarding her customs, buildings, and laws. *Preservation Forum,* Fall). Online at *www.nps.gov/nr/travel/charleston/preservation.htm,* accessed on October 14, 2013.

National Parks Conservation Association (NCPA). No date. Fort Sumter National Monument: A resource assessment. Online at *www.npca.org/about-us/center-for-park-research/stateoftheparks/fort_sumter/FOSU-web.pdf,* accessed on October 14, 2013.

Office of Tourism Analysis, College of Charleston. 2012. Estimation of tourism economic impacts in the Charleston area, 2011. Online at *www.charlestonchamber.net/resources/economic-community-data,* accessed on October 14, 2013.

Parris, A., et al. 2012. *Global sea level rise scenarios for the U.S. National Climate Assessment*. NOAA Tech Memo OAR CPO-1. Online at *http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf,* accessed on October 14, 2013.

Pryor, S.C., J.A. Howe, and K.E. Kunkel. 2009. How spatially coherent and statistically robust are temporal changes in extreme precipitation in the contiguous USA? *International Journal of Climatology* 29(1):31–45.

Slade, D. 2013. Charleston plans to complete major projects to address downtown flooding by 2020. *Post and Courier,* June 20. Online at *www.postandcourier.com/article/20130620/PC16/130629921,* accessed on October 15, 2013.

South Carolina Department of Natural Resources. No date. South Carolina climate. Online at *www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php,* accessed on October 14, 2013.

South Carolina Department of Parks, Recreation, & Tourism. 2013. Discover South Carolina: The Old Exchange & Provost Dungeon. Online at *www.discoversouthcarolina.com/products/339.aspx,* accessed on October 14, 2013.

Spoleto Festival USA. 2013. About the Spoleto Festival. Online at *http://spoletousa.org/,* accessed on October 14, 2013.

HISTORIC ST. AUGUSTINE, FL & CASTILLO DE SAN MARCOS

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4–5):585–602.

City of St. Augustine. 2011. St. Augustine seawall flood mitigation project. Online at *www.staugustinegovernment.com/the-city/featured-stories-archive/8_11/documents/seawallpresentation1Aa_001.pdf,* accessed April 4, 2014.

City of St. Augustine. No date. Flood hazard information. Online at *www.staugustinegovernment.com/businesses/flood-hazard-info.cfm,* accessed on November 19, 2013.

City of St. Augustine. No date. Saving the seawall: Public takes advantage of informational meeting. Online at *www.staugustinegovernment.com/the-city/featured-stories-archive/8_11/saveseawall2.cfm,* accessed on April 1, 2014.

Edwards, J. 2011. Barrier to aid sea wall. *St. Augustine Record,* January 31. Online at *http://staugustine.com/news/local-news/2011-01-30/barrier-aid-sea-wall#.U0_iOqJnChM,* accessed on April 17, 2014.

Gardener, S. 2012. Downtown's flooding problem not expected to improve. *The St. Augustine Record,* November 16. Online at *http://staugustine.com/news/local-news/2012-11-15/flooding-problem-most-downtown-st-augustine-not-expected-improve#.UpZguWRDvhU,* accessed April 4, 2014.

Joyner, B.D. 2009. *Hispanic reflections on the American landscape: Identifying and interpreting Hispanic heritage.* Washington, DC: National Park Service. Online at *www.nps.gov/crdi/publications/pubs.htm,* accessed on November 19, 2013.

Korfhage, S. 2012. Renourishment gives St. Augustine Beach a new look. *St. Augustine Record,* September 9. Online at *http://staugustine.com/news/local-news/2012-09-12/renourishment-gives-st-augustine-beach-new-look,* accessed on November 19, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2014. Sea level rise and coastal flooding impacts. Online at *www.csc.noaa.gov/slr/viewer/#,* accessed on April 8, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2013. Mean sea level trend, 8720218 Mayport, Florida. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8720218,* accessed on November 19, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2013. Sea level rise and coastal flooding impacts. Online at *http://csc.noaa.gov/slr/viewer/,* accessed on November 19, 2103.

National Park Service (NPS). No date. American Latino heritage: Castillo de San Marcos National Monument, St. Augustine, Florida. Online at *www.nps.gov/history/nr/travel/american_latino_heritage/Castillo_de_San_Marcos_National_Monument.html,* accessed on November 19, 2013.

National Park Service (NPS). No date. American Latino heritage: Fort Mose site, Florida. Online at *www.nps.gov/history/nr/travel/american_latino_heritage/Fort_Mose.html,* accessed on November 19, 2013.

National Park Service (NPS). No date. St. Augustine: Lincolnville Historic District. Online at *www.nps.gov/NR/travel/geo-flor/28.htm,* accessed on April 4, 2014.

St. Augustine, Ponte Vedra & The Beaches, Florida Visitors and Conventions Bureau. 2004. Tourism and economic impact research.

PREHISTORIC FLORIDA SHELL STRUCTURES

Florida Division of Historical Resources. 1990. Chapter 10: The Caloosahatchee region. In *Florida historical contexts*. Tallahassee, FL: Florida Department of State, Division of Historical Resources. Online at *www.flheritage.com/facts/reports/contexts/,* accessed on February 16, 2014.

Historical Preservation Society of the Upper Keys. No date. *Historic Florida Indians*. Online at *www.keyshistory.org/histindians.html,* accessed on February 19, 2014.

Kunkel, K., et al. 2013. *Regional climate trends and scenarios for the U.S. National Climate Assessment. Part 2. Climate of the Southeast*. NOAA technical report NESDIS 142-2. Online at *www.nesdis.noaa.gov/technical_reports/NOAA_NESDIS_Tech_Report_142-2-Climate_of_the_Southeast_U.S.pdf,* accessed on February 2, 2014.

Lelis, L. 2008. A rare moment to raise history: New boardwalk at Turtle Mound opens windows to past. *Orlando Sentinel,* April 29. Online at *http://articles.orlandosentinel.com/2008-04-29/news/mound29_1_turtle-mound-mound-was-built-new-boardwalk,* accessed on February 19, 2014.

The Mound House. No date. The Caloosahatchee period (ca. 500 B.C.–1750 A.D.). Fort Myers Beach, FL. Online at *www.moundhouse.org/index.php/information/2-000-years-of-history-timeline/the-caloosahatchee-period,* accessed on February 19, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Mean sea level trends: Fernandina Beach, Naples, and Key West, Florida. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends.html,* accessed on February 2, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Sea level rise and coastal flooding impacts. Online at *www.csc.noaa.gov/slr/viewer/#,* accessed on April 8, 2014.

National Park Service (NPS). No date. Everglades: How else is South Florida affected? Online at *www.nps.gov/ever/naturescience/cceffectsnearparkobs.htm,* accessed on February 16, 2014.

Parker, S. 2008. Canaveral National Seashore: Historic resource study. Washington, DC: National Park Service.

Schwadron, M. 2009. *Maritime landscapes of complexity: Prehistoric shell works and the rise of social complexity among coastal foragers in south Florida*. Tallahassee, FL: National Park Service, Southeast Archeological Center.

South Florida Regional Climate Compact Technical Ad Hoc Work Group. 2011. A unified sea level rise projection for Southeast Florida. Online at *www.ces.fau.edu/files/projects/climate_change/SE_Florida_RegionalCompact_SeaLevelRise_April2011.pdf,* accessed on February 2, 2014.

Thompson, V.D., and J.E. Worth. 2011. Dwellers by the sea: Native American adaptations along the southern coasts of eastern North America. *Journal of Archaeological Research* 19:51–101. Online at *www.academia.edu/375732/Dwellers_by_the_Sea_Native_American_Coastal_Adaptations_along_the_Southern_Coasts_of_Eastern_North_America._Journal_of_Archaeological_Research_19_51-101,* accessed on February 16, 2014.

University of Central Florida. 2011. Saving oyster habitat makes "heroes" of UCF biologist and team. Online at *https://today.ucf.edu/saving-oyster-habitat-makes-heroes-of-ucf-biologist-and-team/,* accessed on February 16, 2014.

Breshears, D., et al. 2005. Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Sciences* 102(42):15144–15148.

MESA VERDE NATIONAL PARK

Chief, K., T.P.A. Ferré, and B. Nijssen. 2008. Examination of correlation between air permeability and saturated hydraulic conductivity in unburned and burned desert soils. *Soil Science Society of America Journal* 72:1–9.

Cook, P.S. 2013. *Impacts of visitor spending on the local economy: Mesa Verde National Park, 2012*. Draft, natural resource report NPS/NRSS/EQD/NRR—2013/XXX. Fort Collins, CO: National Park Service. Online at *http://home.nps.gov/meve/parkmgmt/upload/uofi_meve_local_economy_2012.pdf,* accessed on April 16, 2014.

Fleishman, E., et al. 2013. Natural ecosystems. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al. Washington, DC: Island Press, 148–167.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy. 2013. *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment*. A report by the Southwest Climate Alliance. Washington, DC: Island Press. Online at *www.globalchange.gov/what-we-do/assessment/nca-activities/available-technical-inputs,* accessed on November 13, 2013.

Gershunov, A., et al. 2013. Future climate: Projected extremes. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al. Washington, DC: Island Press, 126–147.

Hoerling, M.P., et al. 2013. Present weather and climate: Evolving conditions. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al. Washington, DC: Island Press, 74–100.

Merrill, L. 2001. Controlling erosion after the fire's out: A case study of Mesa Verde National Park. *Erosion Control* 8(1). Online at *www.erosioncontrol.com/EC/Articles/Controlling_Erosion_After_the_Fires_Out_A_Case_Stu_4792.aspx,* accessed on November 18, 2013.

National Oceanic and Atmospheric Administration (NOAA). 2014. Climate at a glance: Time series Colorado, Climate Division 2, 1895–2013. Online at *www.ncdc.noaa.gov/cag/,* accessed on March 25, 2014.

National Park Service (NPS). 2009. Mesa Verde: Fire history. Online at *www.nps.gov/meve/parkmgmt/upload/fire_history_09.pdf,* accessed on November 18, 2013.

National Park Service (NPS). 2007. Archeology and fire. Online at *www.nps.gov/meve/parkmgmt/upload/arch_fire_effects.pdf,* accessed on March 25, 2014.

National Park Service (NPS). No date. Ancestral Puebloans and their world. Online at *www.nps.gov/meve/forteachers/upload/ancestral_puebloans.pdf,* accessed on February 12, 2014.

National Park Service (NPS). No date. Mesa Verde National Park. Online at *www.nps.gov/meve/index.htm,* accessed on November 18, 2013.

Seager, R., et al. 2013. Projections of declining surface water availability for the southwestern United States. *Nature Climate Change* 3:482–486.

Sheffield, J., and E.F. Wood. 2008. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. *Climate Dynamics* 31(1): 79–105.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18(8):1136–1155.

U.S. Geological Survey (USGS). 2013. Federal wildland fire occurrence data. Online at *http://wildfire.cr.usgs.gov/firehistory/data.html,* accessed on November 18, 2013.

Westerling, A.L., et al. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940–943.

BANDELIER NATIONAL MONUMENT & SANTA CLARA PUEBLO

Cayan, D., et al. 2013. Future climate: Projected average. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al., 101–125. A report of the Southwest Climate Alliance. Washington, DC: Island Press.

Climate Central. 2012. The age of western wildfires. Online at *www.climatecentral.org/wgts/wildfires/Wildfires2012.pdf,* accessed on February 13, 2014.

Dasheno, W. 2012. Testimony before the Senate Energy and Natural Resources Committee. Online at *www.energy.senate.gov/public/index.cfm/files/serve?File_id=8936cce7-21d6-4435-a7b5-7cd5801abf82,* accessed on February 11, 2014.

Environmental Protection Agency (EPA). No date. Climate impacts in the Southwest. Online at *www.epa.gov/climatechange/impacts-adaptation/southwest.html,* accessed on February 13, 2014.

Fleishman, E., et al. 2013. Natural ecosystems. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al. Washington, DC: Island Press, 148–167.

Gershunov, A., et al. 2013. Future climate: Projected extremes. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al., 126–147. A report of the Southwest Climate Alliance. Washington, DC: Island Press.

National Park Service (NPS). No date. Bandelier National Monument. Online at *www.nps.gov/band/historyculture/index.htm,* accessed on February 13, 2014.

National Park Service (NPS). No date. The Las Conchas fire. Online at *www.nps.gov/band/naturescience/lasconchas.htm,* accessed on February 15, 2014.

National Weather Service (NWS). 2013. Historical rainfall event, Sandoval County. Online at *www.srh.noaa.gov/abq/?n=2013SeptemberFlooding-SandovalCounty,* accessed on February 13, 2014.

Nisengard, J.E., et al. 2002. *Cerro Grande Fire Assessment Project: An assessment of the impact of the Cerro Grande fire on cultural resources at Los Alamos National Laboratory, New Mexico.* Los Alamos National Laboratory, report LA-UR-02-5713. Online at *http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-02-5713,* accessed on February 13, 2014.

Oster, E.A., S. Ruscavage-Barz, and M.L. Elliott. 2012. Chapter 7: The effects of fire on subsurface archaeological materials. In United States Department of Agriculture Forest Service general technical report RMRS-GTR-42-vol. 3. 2012. Online at *www.fs.fed.us/rm/pubs/rmrs_gtr042_3/rmrs_gtr042_3_143_156.pdf,* accessed on May 4, 2014.

Southwest Fire Consortium. No date. La Conchas fire fact sheet. Online at *http://swfireconsortium.org/wp-content/uploads/2012/11/Las-Conchas-Factsheet_bsw.pdf,* accessed on February 13, 2014.

GROVELAND, CA

Bakken, G.M. 2000. *Law in the western United States*. Norman, OK: University of Oklahoma Press, 209–214.

California Department of Forestry and Fire Protection. 2013. Top 20 largest California wildfires. Online at *www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Acres.pdf,* accessed on February 6, 2014.

California Department of Forestry and Fire Protection. 2010. California's forests and rangelands: 2010 assessment. Online at *http://frap.fire.ca.gov/assessment/2010/document.php,* accessed on February 6, 2014.

California Department of Parks and Recreation. No date. California Admission Day: September 9, 1850. Online at *www.parks.ca.gov/?page_id=23856,* accessed on February 6, 2014.

California Department of Parks and Recreation. No date. Gold Rush overview. Online at *www.parks.ca.gov/?page_id=1081,* accessed on February 6, 2014.

California Governor's Office of Emergency Services. 2013. Governor Brown appeals denial of presidential major disaster declaration for Rim fire. Press release, December 3. Online at *http://caloesnewsroom.wordpress.com/2013/12/03/governor-brown-appeals-denial-of-presidential-major-disaster-declaration-for-rim-fire/,* accessed on February 6, 2014.

Climate Central. 2012. The age of western wildfires. Online at *www.climatecentral.org/news/report-the-age-of-western-wildfires-14873* and at *www.climatecentral.org/wgts/wildfires/Wildfires2012.pdf,* accessed on March 31, 2014.

Columbia County Chamber of Commerce. 2014. Welcome to Columbia, California! Online at *www.visitcolumbiacalifornia.com,* accessed on February 6, 2014.

Desilets, S.L.E., T.P.A. Ferré, and B. Ekwurzel. 2008. Flash flood dynamics and composition in a semiarid mountain watershed. *Water Resources Research* 44, W12436.

Groveland Hotel. 2010. Brief history. Online at *www.groveland.com/about-us/brief-history,* accessed on February 6, 2014.

InciWeb. 2013. Rim fire: Incident updated 10/25/2013. Online at *http://inciweb.nwcg.gov/incident/3660/,* accessed on February 6, 2014.

Morales, M. 2013. Rim fire crosses the 100k acre mark. Online at *www.firefighterblog.com/2013/08/23/rim-fire-crosses-the-100k-acre-mark/,* accessed on March 31, 2014.

National Park Service (NPS). 2013. Rim fire 2013: Burned area emergency response plan. Online at *www.nps.gov/yose/parkmgmt/upload/RIM_BAER_PLAN2013.pdf,* accessed on February 6, 2014.

National Public Radio (NPR). 2013. Iron Door Saloon. Online at *www.npr.org/2013/08/28/216355790/so-far-iron-door-saloon-stays-open-during-rim-fire,* accessed on February 6, 2014.

Office of Environmental Health Hazard Assessment. 2013. Indicators of climate change in California. California Environmental Protection Agency. Online at *www.oehha.ca.gov/multimedia/epic/2013EnvIndicatorReport.html,* accessed on February 6, 2014.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2005. Changes towards earlier streamflow timing across western North America. *Journal of Climate* 18:1136–1155.

Tuolumne County Chamber of Commerce. No date. Welcome to Tuolumne County, California. Online at *www.tcchamber.com,* accessed on February 6, 2014.

U.S. Department of the Interior. 2014. Reclamation announces initial 2014 Central Valley Project water supply allocation, February 21. Sacramento, CA: Bureau of Reclamation Mid-Pacific Region. Online at *www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=46045,* accessed on March 24, 2014.

Valine, K. 2014. It's finally all downhill as Dodge Ridge prepares to open. *Modesto Bee,* February 14. Online at *www.modbee.com/2014/02/10/3181971/its-finally-all-downhill-as-dodge.html,* accessed April 21, 2014.

Westerling, A.L., et al. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313(5789):940–943.

The White House Office of the Press Secretary. 2012. Remarks by the president at the dedication of the César Chávez National Monument, Keene, CA. October 8. Online at *www.whitehouse.gov/the-press-office/2012/10/08/remarks-president-dedication-cesar-chavez-national-monument-keene-ca,* accessed on February 11, 2014.

Wozniacka, G. 2012. California poverty: Three metro areas in Central Valley rank among the poorest in the nation. Associated Press, September 20. Online at *www.huffingtonpost.com/2012/09/20/california-poverty_n_1901642.html,* accessed on March 24, 2014.

CÉSAR CHÁVEZ NATIONAL MONUMENT

Alvord, A. 2014. Water woes: Dramatic increase of droughts in California is a bellwether of future climate impacts. *The Equation,* January 22. Online at *http://blog.ucsusa.org/california-drought-increase-and-future-climate-impacts-385,* accessed on March 12, 2014.

Bardacke, F. 2011. *Trampling out the vintage: César Chavez and the two souls of the United Farm Workers.* New York: Verso.

California Climate Action Team. 2013. *Preparing California for extreme heat: Guidance and recommendations*. Developed by the Heat Adaptation Workgroup, a subcommittee of the Public Health Workgroup. Online at *www.climatechange.ca.gov/climate_action_team/reports/Preparing_California_for_Extreme_Heat.pdf,* accessed on March 13, 2014.

California Department of Food and Agriculture. 2013. California agricultural production statistics: 2012. Online at *www.cdfa.ca.gov/Statistics/,* accessed on March 18, 2014.

California Department of Food and Agriculture. 2013. *Climate change consortium for specialty crops: Impacts and strategies for resilience.* Online at *www.cdfa.ca.gov/environmentalstewardship/pdfs/ccc-report.pdf,* accessed on March 13, 2014.

California Department of Water Resources. 2014. DWR drops state water project allocation to zero, seeks to preserve remaining supplies. Press release, January 31. Online at *www.water.ca.gov/news/newsreleases/2014/013114pressrelease.pdf,* accessed on March 13, 2014.

California Department of Water Resources. 2010. Agricultural water use. Online at *www.water.ca.gov/wateruseefficiency/agricultural/,* accessed on March 17, 2014.

California Farm Water Coalition. 2014. Press release, March 18. Online at *http://new.farmwater.org/new/new-31814-estimate-of-unplanted-acres-jumps-to-800000-consumers-expected-to-feel-impacts/,* accessed on April 11, 2014.

Garcia, M. 2012. *From the jaws of victory: The triumph and tragedy of César Chavez and the farm worker movement*. Berkeley, CA: University of California Press.

Gershunov, A., D. Cayan, and S. Iacobellis. 2009. The great 2006 heat wave over California and Nevada: Signal of an increasing trend. *Journal of Climate* 22:6181–6203. As cited in Garfin, G., et al. 2013. *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment*. Washington, DC: Island Press.

Gershunov, A., and K. Guirguis. 2012. California heat waves in the present and future. *Geophysical Research Letters* 39(18):7-10.

Gorman, S. 2014. Drought forces California farmers to idle cropland. Reuters, February 5. Online at *www.reuters.com/article/2014/02/06/usa-drought-california-idUSL2N0LB00U20140206,* accessed on March 12, 2014.

Guirguis, K., et al. 2013. The impact of recent heat waves on human health in California. *Journal of Applied Meteorology and Climatology* 53:3–19. Online at *http://dx.doi.org/10.1175/JAMC-D-13-0130.1,* accessed on March 12, 2014.

Howitt, R., D. MacEwan, and J. Medellin-Azuara. 2011. Drought, jobs, and controversy: Revisiting 2009. *Agricultural and Resource Economics Update* 14(6):1–4. Online at *http://giannini.ucop.edu/media/are-update/files/issues/V14N6.pdf,* accessed on March 17, 2014.

Khokha, S. 2008. Teen farmworker's heat death sparks outcry. KQED, June 6. Online at *www.npr.org/templates/story/story.php?storyId=91240378,* accessed on March 12, 2014.

National Aeronautics and Space Administration (NASA). 2014. NASA helps growers during California's drought. Press release, February 25. Online at *www.nasa.gov/ames/nasa-helps-growers-during-californias-drought/#.UysWQOddXy1,* accessed on March 12, 2014.

National Drought Mitigation Center. 2014. U.S. drought monitor: California. 2014. Online at *http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA,* accessed on March 18, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Climate at a glance: Time series. California. Precipitation. Climate Division 5: San Joaquin drainage. Online at *www.ncdc.noaa.gov/cag/,* accessed on March 13, 2014.

National Park Service (NPS). 2013. Final César Chávez special resource study. Online at *http://parkplanning.nps.gov/Final_Cesar_Chavez_Study,* accessed on November 4, 2013.

National Park Service (NPS). No date. César E. Chávez National Monument. Online at *www.nps.gov/cech/index.htm,* accessed on November 4, 2013.

Occupational Safety & Health Administration (OSHA). No date. Heat fatalities. Online at *www.osha.gov/SLTC/heatillness/map_text.html,* accessed on March 13, 2014.

Office of Environmental Health Hazard Assessment. 2013. Indicators of climate change in California. California Environmental Protection Agency. Online at *www.oehha.ca.gov/multimedia/epic/2013EnvIndicatorReport.html,* accessed on March 12, 2014.

O'Leary, K. 2009. Fatal sunshine: The plight of California's farm workers. *Time,* August 8. Online at *http://content.time.com/time/nation/article/0,8599,1914961,00.html,* accessed on March 13, 2014.

Rodriguez, R. 2013. Field worker's suspected heat-related death closes South Valley farm. *Fresno Bee,* July 9. Online at *www.fresnobee.com/2013/07/09/3380842/south-valley-farm-shut-down-after.html,* accessed on March 13, 2014.

San Joaquin Valley Air District. No date. Frequently asked questions. Online at *www.valleyair.org/General_info/Frequently_Asked_Questions.htm,* accessed on March 17, 2014.

United Farm Workers (UFW). 2012. Lawsuit says failed enforcement means California's farm workers face daily threat of heat illness and death. Press release, October 18. Online at *www.ufw.org/_board.php?mode=view&b_code=news_press&b_no=12798&page=1&field=&key=&n=877,* accessed on March 14, 2014.

BERING LAND BRIDGE NATIONAL MONUMENT & SHISHMAREF, CAPE KRUSENSTERN NATIONAL MONUMENT & KIVALINA

Alaska Climate Research Center. 2014. Recent temperatures. Online at *http://climate.gi.alaska.edu/,* accessed on February 2, 2014.

Anderson, S., and A.K. Freeburg. 2013. High-resolution chronology for the Cape Krusenstern site complex, northwest Alaska. *Arctic Anthropology* 50(1):49–71. Online at *http://aa.uwpress.org/content/50/1/49.refs,* accessed on February 2, 2014.

Beavers, R. 2013. *NPS cultural resources inventory and vulnerability assessment. Case study: Bering Land Bridge National Preserve, Alaska; and Cape Krusenstern National Monument, Alaska*. Fairbanks, AK: Alaska Climate Research Center. Online at *http://climate.gi.alaska.edu/,* accessed on February 2, 2014.

Bronen, R. 2013. *Climate-induced displacement of Alaska Native communities*. Washington, DC: Brookings Institution. Online at *www.brookings.edu/research/papers/2013/01/30-arctic-alaska-bronen,* accessed on February 2, 2014.

Brubaker, M., et al. 2011. *Climate change in Kivalina, Alaska: Strategies for community health*. Anchorage, AK: Alaska Native Tribal Health Consortium. Online at *www.anthc.org/chs/ces/climate/upload/Climate-Change-in-Kivalina-Alaska-Strategies-for-Community-Health-2.pdf,* accessed on February 23, 2014.

Francis, O.P., G.G. Panteleev, and D.E. Atkinson. 2011. Ocean wave conditions in the Chukchi Sea from satellite and *in situ* observations. *Geophysical Research Letters* 38(24):6-10.

Freeburg, A., and S. Anderson. 2012. *Human-environmental dynamics at Cape Krusenstern. 200 generations: On the beach of their time*. Final report for task agreement J8W07070032. Seattle: University of Washington. Online at *www.cfr.washington.edu/research.cesu/reports/J8W07070032_final_report.pdf,* accessed on April 8, 2014.

Goebel, T., M.R. Waters, and D.H. O'Rourke. 2008. The late Pleistocene dispersal of modern humans in the Americas. *Science* 319(5869): 1497–1502. Online at *http://csfa.tamu.edu/cfsa-publications/Goebel-Waters-Science2008-319-1497.pdf,* accessed on February 2, 2014.

Goebel, T., et al. 2013. Serpentine Hot Springs, Alaska: Results of excavations and implications for the age and significance of northern fluted points. *Journal of Archaeological Science* 40: 4222–4233. Online at *http://csfa.tamu.edu/cfsa-publications/Goebel-etal2013.pdf,* accessed on February 2, 2014.

Markon, C.J., S.F. Trainor, and F.S. Chapin, III. 2012. *The United States National Climate Assessment—Alaska technical regional report,* U.S. Geological Survey circular 1379. Washington, DC: Department of the Interior. Online at *http://pubs.usgs.gov/circ/1379/,* accessed on February 2, 2014.

National Climatic Data Center (NCDC). No date. Climate at a glance: Contiguous U.S. temperature, January–December, 1949–2013. Washington, DC: National Oceanic and Atmospheric Administration. Online at *www.ncdc.noaa.gov/cag/,* accessed on February 2, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Climate at a glance: Time series. Contiguous U.S. temperature, 1949–2013. Online at *www.ncdc.noaa.gov/cag/,* accessed on April 24, 2014.

National Park Service (NPS). 2007. Cape Krusenstern beach ridge complex survey. Archeology program. Online at *www.cr.nps.gov/archeology/sites/npSites/capeKrusenstern.htm,* accessed on February 21, 2014.

National Park Service (NPS). No date. Bering Land Bridge National Preserve. Online at *www.nps.gov/bela/historyculture/index.htm,* accessed on February 23, 2014.

National Snow and Ice Data Center (NSIDC). 2013. A better year for the cryosphere. *Arctic Sea Ice News & Analysis*. October 3. Online at *http://nsidc.org/arcticseaicenews/2013/10/a-better-year-for-the-cryosphere/,* accessed on February 2, 2014.

Reich, D., et al. 2012. Reconstructing Native American population history. *Nature* 488(7411):370–374. Online at *www.nature.com/nature/journal/v488/n7411/full/nature11258.html,* accessed on February 23, 2014.

Shulski, M., and G. Wendler. 2007. *The climate of Alaska*. Fairbanks, AK: University of Alaska Press. As cited in R. Bronen reference above.

U.S. Army Corps of Engineers (USACE). 2006. *Alaska village erosion technical assistance program: An examination of erosion issues in the communities of Bethel, Dillingham, Kaktovik, Kivalina, Newtok, Shishmaref, and Unalakleet*. Online at *http://housemajority.org/coms/cli/AVETA_Report.pdf,* accessed on February 2, 2014.

U.S. Government Accountability Office (GAO). 2009. *Alaska native villages: Limited progress has been made on relocating villages threatened by flooding and erosion*. Report to congressional requesters. Online at *www.gao.gov/assets/300/290468.pdf,* accessed on February 2, 2014.

U.S. Government Accountability Office (GAO). 2003. *Alaska native villages: Most are affected by flooding and erosion but few qualify for federal assistance*. Report to congressional committees. Online at *www.gao.gov/assets/250/240810.pdf,* accessed on February 2, 2014.

Weyiouanna, T. 2014. Statement to Congress's Bicameral Task Force on Climate Change. January 14. Tony Weyiouanna is president of the board of the Shishmaref Native Corp. Online at *http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Tony-Weyiouanna-BTF-Forum-Shishmaref-Alaska-2014-1-14.pdf,* accessed on February 2, 2014.

PUʻUHONUA O HŌNAUNAU AND KALOKO-HONOKŌHAU NATIONAL HISTORICAL PARKS

Asam, S., and E. Rowan. 2012. *Facilities adaptation to climate change impacts in coastal areas: Workshop findings for Puʻuhonua o Hōnaunau National Historical Park*. NPS Sustainable Operations Facilities Management. Workshop held at Puʻuhonua o Hōnaunau National Historical Park, August 21–22, 2012.

Bond, S., and R. Gmirkin. 2003. Restoring a part of Hawaii's past: Kaloko fishpond restoration. *Ecological Restoration* 21(4):285–289.

Caccamise, D.J., et al. 2005. Sea level rise at Honolulu and Hilo, Hawaii: GPS estimates of differential land motion. *Geophysical Research Letters* 32(3).

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4–5):585–602.

Keener, V.W. et al. 2012. *Climate change and Pacific islands: Indicators and impacts*. Report for the 2012 Pacific Islands Regional Climate Assessment. Washington, DC: Island Press.

National Oceanic and Atmospheric Administration (NOAA). 2014. Updated mean sea level trend. 1617760 Hilo, Hawaii. Online at *http://tidesandcurrents.noaa.gov/sltrends/sltrends_update.shtml?stnid=1617760,* accessed on April 8, 2014.

National Park Service (NPS). No date. Puʻuhonua o Hōnaunau National Historical Park. Online at *www.nps.gov/puho/index.htm,* accessed on December 4, 2013.

Pagan, M., et al. 2010. High Earth-system climate sensitivity determined from Pliocene carbon dioxide concentrations. *Nature Geoscience* 3:27–30. Online at *www.nature.com/ngeo/journal/v3/n1/full/ngeo724.html,* accessed on December 4, 2013.

Scripps Institution of Oceanography. No date. The Keeling curve. Online at *http://keelingcurve.ucsd.edu,* accessed on March 11, 2014.

Vitousek, S., et al. 2010. *Puʻukohola Heiau National Historic Site and Kaloko-Honokōhau Historical Park, Big Island of Hawaiʻi: Coastal hazard analysis report,* Natural resource technical report NPS/NRPC/GRD/NRTR-2010/387. Fort Collins, CO: National Park Service.

THE SCIENCE BEHIND THE CHANGING RISKS TO OUR NATIONAL TREASURES

Anderson, B.T., et al. 2010. Observed trends in summertime precipitation over the southwestern United States. *Journal of Climate* 23:1937–1944.

Cayan, D., et al. 2013. Future climate: Projected average. In *Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment,* edited by G. Garfin et al. Washington, DC: Island Press, 101–125.

Chief, K., T.P.A. Ferré, and B. Nijssen. 2008. Examination of correlation between air permeability and saturated hydraulic conductivity in unburned and burned desert soils. *Soil Science Society of America Journal* 72:1–9.

Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32:585–602.

Church, J.A., et al. 2013. Sea level change. In *Climate change 2013: The physical science basis*. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change, edited by T.F. Stocker et al. New York: Cambridge University Press.

Climate Central. 2012. The age of western wildfires. Online at *www.climatecentral.org/wgts/wildfires/Wildfires2012.pdf,* accessed on April 5, 2014.

Cubasch, U., et al. 2013. Introduction. In *Climate change 2013: The physical science basis*. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change, edited by T.F. Stocker et al. New York: Cambridge University Press.

Dai, A. 2011. Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change* 2:45–65.

DeBano, L.F. 2000. The role of fire and soil heating on water repellency in wildland environments: A review. *Journal of Hydrology* 231–232:195–206.

Desilets, S.L.E., T.P.E. Ferré, and B. Ekwurzel. 2008. Flash flood dynamics and composition in a semiarid mountain watershed. *Water Resources Research* 44(12):W12436.

Goelzer, H., P. Huybrechts, S.C.B. Raper, M.-F. Loutre, H. Goosse, and T. Fichefet. 2012. Millennial total sea-level commitments projected with the earth system model of intermediate complexity LOVECLIM. *Environmental Research Letters* 7:045401. Online at *http://iopscience.iop.org/1748-9326/7/4/045401/,* accessed on May 4, 2014.

Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for policymakers. In *Climate change 2013: The physical science basis*. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change, edited by T.F. Stocker et al. New York: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change, edited by C.B. Field et al. Cambridge, UK, and New York, NY: Cambridge University Press. Online at *http://ipcc-wg2.gov/SREX/report/full-report/,* accessed on April 4, 2014.

Ishi, M., et al. 2006. Steric sea level changes estimated from historical ocean subsurface temperature and salinity analyses. *Journal of Oceanography* 62:155–70.

Karl, T.R., et al. 2012. U.S. temperature and drought: Recent anomalies and trends. *Eos, Transactions of the American Geophysical Union* 93(47):473.

Kunkel, K.E., et al. 2013. *Regional climate trends and scenarios for the U.S. national climate assessment. Part 3. Climate of the Midwest U.S*. NOAA technical report NESDIS 142–3. Online at *www.nesdis.noaa.gov/technical_reports/NOAA_NESDIS_Tech_Report_142-3-Climate_of_the_Midwest_U.S.pdf,* accessed on April 29, 2014.

Markon, C.J., S.F. Trainor, and F.S. Chapin, III. 2012. *The United States National Climate Assessment—Alaska technical regional report*. U.S. Geological Survey circular 1379. Online at *http://pubs.usgs.gov/circ/1379/,* accessed on April 4, 2014.

Masson-Delmotte, V., et al. 2013. Information from paleoclimate archives. In *Climate change 2013: The physical science basis*. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change, edited by T.F. Stocker et al. New York: Cambridge University Press.

Melillo, J.M., T. Richmond, and G.W. Yohe (eds.). 2014. *Highlights of climate change impacts in the United States: The third national climate assessment*. United States Global Change Research Program. Online at *http://nca2014.globalchange.gov/highlights,* accessed on May 6, 2014.

Miller, K.G., et al. 2013. A geological perspective on sea-level rise and its impacts along the U.S. mid-Atlantic coast. *Earth's Future* 1(1): 3–18.

National Oceanic and Atmospheric Administration (NOAA). 2014. Climate at a glance: Contiguous U.S. temperature. Online at *www.ncdc.noaa.gov/cag/time-series/us/110/00/tmp/12/12/1895-2013?base_prd=true&firstbaseyear=1901&lastbaseyear=2000&trend=true&trend_base=10&firsttrendyear=1895&lasttrendyear=2013,* accessed on April 5, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Climate at a glance: Global land and ocean temperature anomalies. Online at *www.ncdc.noaa.gov/cag/time-series/global,* accessed April 5, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2014. Climate at a glance: Time series. Global, 1880–2013. Online at *www.ncdc.noaa.gov/cag/time-series/global,* accessed on April 24, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2012. *Global sea level rise scenarios for the United States National Climate Assessment*. NOAA technical report OAR CPO-1. Silver Spring, MD. Online at *http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf,* accessed on April 5, 2014.

Occupational Safety & Health Administration (OSHA). No date. Heat fatalities. Online at *www.osha.gov/SLTC/heatillness/map_text.html,* accessed on March 13, 2014.

Shakesby, R.A., and S.H. Doerr. 2006. Wildfire as a hydrological and geomorphological agent. *Earth-Science Reviews* 74(3–4):269–307.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18:1136–1155.

Trenberth, K.E. 2011. Changes in precipitation with climate change. *Climate Research* 47:123–138.

U.S. Geological Survey (USGS). 2013. Federal wildland fire occurrence data. Online at *http://wildfire.cr.usgs.gov/firehistory/data.html,* accessed on May 4, 2013.

Westerling, A.L., et al. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940–943.

Woods, S.W., A. Birkas, and R. Ahl. 2007. Spatial variability of soil hydrophobicity after wildfires in Montana and Colorado. *Geomorphology* 86(3–4):465-479.

(Right:) Boston's historic Long Wharf, which includes Christopher Columbus Waterfront Park, is at risk from rising seas and storm surge.

©iStockphoto.com/Agnieszka Gaul

National Landmarks at Risk

How Rising Seas, Floods, and Wildfires Are Threatening the United States' Most Cherished Historic Sites

> ***The stories these sites tell symbolize values—such as patriotism, freedom, democracy, respect for ancestors, and admiration for the pioneering and entrepreneurial spirit—that unite all Americans.***

Many of the United States' iconic landmarks and heritage sites are at risk as never before. Sea level rise, coastal erosion, increased flooding, heavy rains, and more frequent large wildfires are damaging archaeological resources, historic buildings and cultural landscapes across the nation. From sea to rising sea, a remarkable number of the places where American history was made are already under threat from the impacts of climate change.

This report offers a selection of case studies that vividly illustrate an urgent problem. These examples represent many of the rich and diverse elements of the American experience. The stories were chosen because the science behind the risks they face is robust, and because together they shine a spotlight on the different kinds of climate impacts already affecting the United States' cultural heritage.

Given the scale of the problem and the cultural value of the places at risk, it is not enough merely to plan for change and expect to adapt. We must begin now to prepare our threatened landmarks to face worsening climate impacts; climate resilience must become a national priority and we must allocate the necessary resources. We must also work to minimize the risks by reducing the carbon emissions that cause climate change.

Union of Concerned Scientists

FIND A FULLY CITED VERSION OF THIS REPORT ONLINE: www.ucsusa.org/landmarksatrisk

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

NATIONAL HEADQUARTERS
Two Brattle Square
Cambridge, MA 02138-3780
Phone: (617) 547-5552
Fax: (617) 864-9405

WASHINGTON, DC, OFFICE
1825 K St. NW, Suite 800
Washington, DC 20006-1232
Phone: (202) 223-6133
Fax: (202) 223-6162

WEST COAST OFFICE
2397 Shattuck Ave., Suite 203
Berkeley, CA 94704-1567
Phone: (510) 843-1872
Fax: (510) 843-3785

MIDWEST OFFICE
One N. LaSalle St., Suite 1904
Chicago, IL 60602-4064
Phone: (312) 578-1750
Fax: (312) 578-1751

WEB: www.ucsusa.org

PRINTED ON RECYCLED PAPER USING VEGETABLE-BASED INKS

© MAY 2014 UNION OF CONCERNED SCIENTISTS