8 Coastal Effects

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8 Coastal Effects

Natural "green barriers" help protect this Florida coastline and infrastructure from severe storms and floods.

Key Message 1

Coastal Economies and Property Are Already at Risk

America's trillion-dollar coastal property market and public infrastructure are threatened by the ongoing increase in the frequency, depth, and extent of tidal flooding due to sea level rise, with cascading impacts to the larger economy. Higher storm surges due to sea level rise and the increased probability of heavy precipitation events exacerbate the risk. Under a higher scenario (RCP8.5), many coastal communities will be transformed by the latter part of this century, and even under lower scenarios (RCP4.5 or RCP2.6), many individuals and communities will suffer financial impacts as chronic high tide flooding leads to higher costs and lower property values. Actions to plan for and adapt to more frequent, widespread, and severe coastal flooding would decrease direct losses and cascading economic impacts.

Key Message 2

Coastal Environments Are Already at Risk

Fisheries, tourism, human health, and public safety depend on healthy coastal ecosystems that are being transformed, degraded, or lost due in part to climate change impacts, particularly sea level rise and higher numbers of extreme weather events. Restoring and conserving coastal ecosystems and adopting natural and nature-based infrastructure solutions can enhance community and ecosystem resilience to climate change, help to ensure their health and vitality, and decrease both direct and indirect impacts of climate change.

Key Message 3

Social Challenges Intensified

As the pace and extent of coastal flooding and erosion accelerate, climate change impacts along our coasts are exacerbating preexisting social inequities, as communities face difficult questions about determining who will pay for current impacts and future adaptation and mitigation strategies and if, how, or when to relocate. In response to actual or projected climate change losses and damages, coastal communities will be among the first in the Nation to test existing climate-relevant legal frameworks and policies against these impacts and, thus, will establish precedents that will affect both coastal and non-coastal regions.

Executive Summary

The Coasts chapter of the Third National Climate Assessment, published in 2014, focused on coastal lifelines at risk, economic disruption, uneven social vulnerability, and vulnerable ecosystems. This Coastal Effects chapter of the Fourth National Climate Assessment updates those themes, with a focus on integrating the socioeconomic and environmental impacts and consequences of a changing climate. Specifically, the chapter builds on the threat of rising sea levels exacerbating tidal and storm surge flooding, the state of coastal ecosystems, and the treatment of social vulnerability by introducing the implications for social equity.

U.S. coasts are dynamic environments and economically vibrant places to live and work. As of 2013, coastal shoreline counties were home to 133.2 million people, or 42% of the population.[1] The coasts are economic engines that support jobs in defense, fishing, transportation, and tourism industries; contribute substantially to the U.S. gross domestic product;[1] and serve as hubs of commerce, with seaports connecting the country with global trading partners.[2] Coasts are home to diverse ecosystems such as beaches, intertidal zones, reefs, seagrasses, salt marshes, estuaries, and deltas[3,4,5] that support a range of important services including fisheries, recreation, and coastal storm protection. U.S. coasts span three oceans, as well as the Gulf of Mexico, the Great Lakes, and Pacific and Caribbean islands.

The social, economic, and environmental systems along the coasts are being affected by climate change. Threats from sea level rise (SLR) are exacerbated by dynamic processes such as high tide and storm surge flooding (Ch. 19: Southeast, KM 2),[6,7,8] erosion (Ch. 26: Alaska, KM 2),[9] waves and their effects,[10,11,12,13] saltwater intrusion into coastal aquifers and elevated groundwater tables (Ch. 27: Hawai‘i & Pacific Islands, KM 1; Ch. 3: Water, KM 1),[14,15,16,17] local rainfall (Ch. 3: Water, KM 1),[18] river runoff (Ch. 3: Water, KM 1),[19,20] increasing water and surface air temperatures (Ch. 9: Oceans, KM 3),[21,22] and ocean acidification (see Ch. 2: Climate, KM 3 and Ch. 9: Oceans, KM 1, 2, and 3 for more information on ocean acidification, hypoxia, and ocean warming).[23,24]

Although storms, floods, and erosion have always been hazards, in combination with rising sea levels they now threaten approximately $1 trillion in national wealth held in coastal real estate[25] and the continued viability of coastal communities that depend on coastal water, land, and other resources for economic health and cultural integrity (Ch. 15: Tribes, KM 1 and 2).

Impacts of the 2017 Hurricane Season

Quintana Perez dumps water from a cooler into floodwaters in the aftermath of Hurricane Irma in Immokalee, Florida. *From Figure 8.6 (Photo credit: AP Photo/Gerald Herbert).*

State of the Coasts

U.S. coasts are dynamic environments and economically vibrant places to live and work. As of 2013, coastal shoreline counties were home to 133.2 million people, or 42% of the population.[1] The coasts are economic engines that support jobs in defense, fishing, transportation, and tourism industries; contribute substantially to the U.S. gross domestic product (GDP; Table 8.1);[1,26] and serve as hubs of commerce, with seaports connecting the country with global trade partners.[2] Coasts are home to diverse ecosystems such as beaches, intertidal zones, reefs, seagrasses, salt marshes, estuaries, and deltas[3,4,5] that support a range of important services including fisheries, recreation, and coastal storm protection. U.S. coasts span three oceans as well as the Gulf of Mexico, the Great Lakes, and Pacific and Caribbean islands.

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Collectively, these threats present significant direct costs related to infrastructure.[27,28] The more than 60,000 miles of U.S. roads and bridges in coastal floodplains are already demonstrably vulnerable to extreme storms and hurricanes that cost billions in repairs.[29] The national average increase in the Special Flood Hazard Area by the year 2100 may approach 40% for riverine and coastal areas if shoreline recession is assumed, and 45% for riverine and coastal areas if fixed coastlines are assumed.[30] Additionally, indirect economic costs (such as lost business) and adverse sociopsychological impacts have the potential to negatively affect citizens and their communities.[31,32,33] People exposed to weather- or climate-related disasters have been shown to experience mental health impacts including depression, post-traumatic stress disorder, and anxiety, all of which often occur simultaneously;

Economic Importance of U.S. Coastal Areas

Region	Employment		GDP		Population		% Land Area
	Millions	% of US	$Trillions	% of US	Millions	% of US	
United States	134.0		$16.7		316.5		
All Coastal States	109.2	81.5%	$13.9	83.7%	257.9	81.5%	57.0%
Coastal Zone Counties	56.2	42.0%	$8.0	48.0%	133.2	42.1%	19.6%
Shore-Adjacent Counties	50.2	37.5%	$7.2	43.2%	118.4	37.4%	18.1%

Table 8.1: The coast is a critical component of the U.S. economy. This table shows U.S. employment, GDP, population, and land area compared to coastal areas as of 2013. “Coastal zone counties” comprise shore-adjacent counties plus non-shore-adjacent counties. For more complete definitions, see: http://www.oceaneconomics.org/Market/coastal/coastal_geographies.aspx. Source: Kildow et al. 2016[1]

furthermore, among those most likely to suffer these impacts are some of society's most vulnerable populations, including children, the elderly, those with preexisting mental illness, the economically disadvantaged, and the homeless (Ch. 14: Human Health, KM 1 and 2).[34]

Although storms, floods, and erosion have always been hazards, in combination with rising sea levels they now threaten approximately $1 trillion in national wealth held in coastal real estate (Figure 8.1)[25] and the continued viability of coastal communities that depend on coastal water, land, and other resources for economic health and cultural integrity (Ch. 15: Tribes, KM 1 and 2). The effects of the coastal risks posed by a changing climate already are and will continue to be experienced in both intersecting and distinct ways, and coastal areas are already beginning to take actions to address and ameliorate these risks (Figure 8.2).

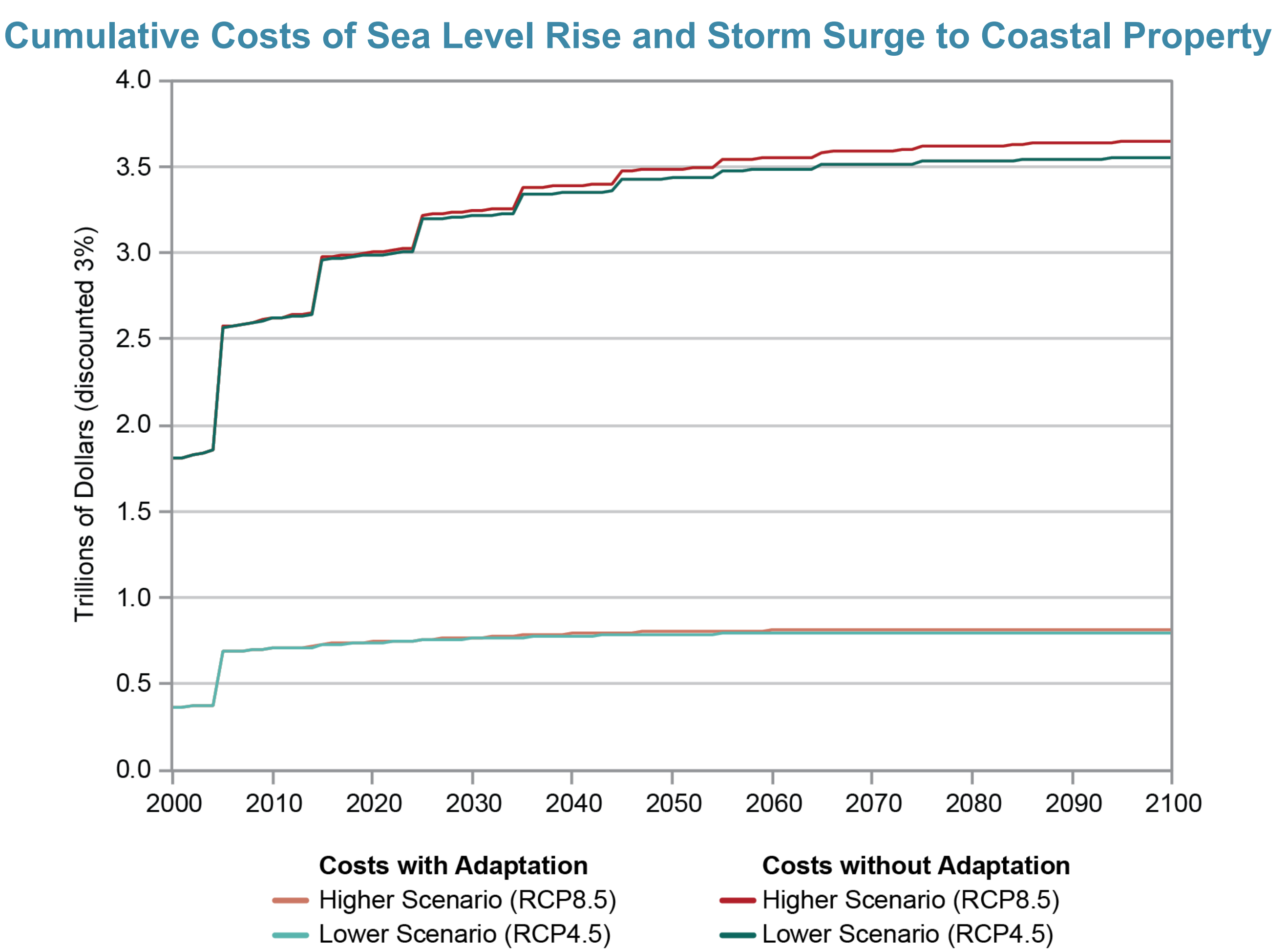

Figure 8.1: This figure shows that cumulative damages (in 2015 dollars) to coastal property across the contiguous United States would be significantly reduced if protective adaptation measures were implemented, compared to a scenario where no adaptation occurs. Without adaptation, cumulative damages under the higher scenario (RCP8.5) are estimated at $3.6 trillion through 2100 (discounted at 3%), compared to $820 billion in the scenario where cost-effective adaptation measures are implemented. Under the lower scenario (RCP4.5), costs without adaptation are reduced by $92 billion relative to RCP8.5 and are $800 billion with adaptation. Note: The stepwise nature of the graph is due to the fact that the analysis evaluates storm surge risks every 10 years, beginning in 2005. Source: adapted from EPA 2017.[35]

Regional Coastal Impacts and Adaptation Efforts

	Impact	Adaptation Efforts
Northeast 	Recurrent coastal flooding	The cities of Binghamton, New York, and Boston, Massachusetts, promote the use of green infrastructure to build resilience, particularly in response to flooding risk.
Southeast 	Sea level rise	Charleston, South Carolina, has developed a Sea Level Rise Strategy that plans for 50 years out based on moderate sea level rise scenarios, reinvests in infrastructure, develops a response plan, and increases readiness. As of 2016, the City of Charleston has spent or set aside $235 million to complete ongoing drainage improvement projects to prevent current and future flooding.
Midwest 	Multiple stressors	The Great Lakes Climate Action Network (GLCAN) is a regional, member-driven peer network of local government staff who work together to identify and act on the unique climate adaptation challenges of the Great Lakes region. GLCAN is working with the Huron River Watershed Council and five Great Lakes cities (Ann Arbor, Dearborn, Bloomington, Indianapolis, and Cleveland) to develop a publicly available universal vulnerability assessment template that mainstreams the adaptation planning process and results in the integration of climate-smart and equity-focused information into all types of city planning.
Northwest 	Aquatic species vulnerabilities	In the Yakima Basin, irrigators, conservation groups, and state and federal agencies worked together to replenish the diminished tributary flows to bolster the salmon runs and riparian habitat during the 2015 drought.
Southwest 	Storm surge	In 2016, residents of the nine counties of the San Francisco Bay voted in favor of Measure AA, which provides funding for wetlands restoration to naturally reduce risks of flooding and inundation due to sea level rise and storm surge.
Southern Great Plains 	Critical infrastructure damage	The Texas Coastal Resiliency Master Plan promotes coastal resilience, defined as the ability of coastal resources and coastal infrastructure to withstand natural or human-induced disturbances and quickly rebound from coastal hazards. This definition encompasses the two dimensions of resilience: 1) taking actions to eliminate or reduce significant adverse impacts from natural and human-induced disturbances, and 2) responding effectively in instances when such adverse impacts cannot be avoided. The Plan will be updated regularly to assess changing coastal conditions and needs and to determine the most suitable way to implement the appropriate coastal protection solutions.
Alaska 	Recurrent coastal flooding	The people of Shaktoolik developed and undertook an initiative to build a community-driven, mile-long and seven-foot-high berm made out of driftwood and gravel to protect itself from flooding and erosion during storm episodes.
Hawai'i and U.S.-Affiliated Pacific Islands 	Multiple stressors	Adaptation options in Hawai'i and the U.S.-Affiliated Pacific Islands are unique to their island context and more limited than in continental settings. Current adaptation examples include policy initiatives and adaptation programs, such as the accreditation of the Secretariat of the Pacific Regional Environment Programme to the Green Climate Fund; the passage of the Hawai'i Climate Adaptation Initiative Act; and the creation of separate climate change commissions for the City and County of Honolulu.
U.S. Caribbean 	Coastal erosion	In Puerto Rico, the U.S. Fish and Wildlife Service and Puerto Rico Department of Natural and Environmental Resources have funded wetlands and dune restoration projects at various sites along the coast of Puerto Rico as non-structural solutions to coastal flooding and beach erosion.

Figure 8.2: The figure shows selected coastal effects of climate change in several coastal regions of the United States. See the online version of this figure at http://nca2018.globalchange.gov/chapter/8#fig-8-2 for additional examples. Source: NCA4 Regional Chapters.

Key Message 1

Coastal Economies and Property Are Already at Risk

America's trillion-dollar coastal property market and public infrastructure are threatened by the ongoing increase in the frequency, depth, and extent of tidal flooding due to sea level rise, with cascading impacts to the larger economy. Higher storm surges due to sea level rise and the increased probability of heavy precipitation events exacerbate the risk. Under a higher scenario (RCP8.5), many coastal communities will be transformed by the latter part of this century, and even under lower scenarios (RCP4.5 or RCP2.6), many individuals and communities will suffer financial impacts as chronic high tide flooding leads to higher costs and lower property values. Actions to plan for and adapt to more frequent, widespread, and severe coastal flooding would decrease direct losses and cascading economic impacts.

Due to sea level rise (SLR), coastal storms and high tides have amplified coastal flooding and erosion impacts, and this trend will continue into the future, with some regions more vulnerable than others (Ch. 2: Climate, KM 9).[6,7,8,9,36,37,38] High tide flooding is already forcing some East Coast cities to install costly pump stations to frequently clear floodwaters from the streets (such as Miami Beach, as shown in Figure 8.3) (see also Ch. 19: Southeast, KM 2) and to mobilize emergency responders to routinely close flooded streets. Along with increases in tidally driven flooding, storm surges are higher due to SLR.[36,39,40] Warmer air temperatures have increased the probability of heavy precipitation events,[41,42,43] permafrost thawing, and earlier season sea ice loss, leading to increased erosion over significant miles of coastline (Ch. 26: Alaska, KM 2). The severity of compound events—the coupling of surge, discharge from rivers, and heavy precipitation—has increased in many coastal cities (Ch. 19: Southeast, KM 2; Ch. 3: Water, KM 2).[18,19] In addition, modeling suggests that tropical cyclone intensity will increase,[40,44,45] which would lead to greater damage upon landfall. Collectively, these factors already threaten coastal economies, public safety, and well-being, and continued growth and development along the coast increase the risk to more people and infrastructure.

Even under a very low scenario (RCP2.6) (see the Scenario Products section of App. 3 for more on scenarios), projections indicate that the frequency, depth, and extent of both high tide and more severe, damaging coastal flooding will increase rapidly in the coming decades.[7,8,36,46,47,48] With rapid ice loss from Greenland and Antarctica under the higher scenario (RCP8.5), an Extreme scenario of global sea level rising upwards of 8 feet by 2100 is a possibility.[36,37,49,50,51,52] Under this rise, the average daily high tide would exceed the current 100-year (1% annual chance) coastal water level event in most U.S. coastal locations.[8,39,53] Because these low-probability, high-consequence risks cannot be ruled out, a robust risk management approach to future planning would involve their consideration.

Coastal property owners are likely to bear costs from SLR and storm surge, including those associated with property abandonment; residual storm damages; protective adaptation measures, such as property elevation; beach nourishment; and shoreline armoring.[35] The potential for future losses is great, with continued and often expensive development at the coasts increasing exposure (Ch. 5: Land Changes, KM 2).[54,55] Shoreline counties hold 49.4 million housing units, while homes

Flooding Impacts in Miami Beach

Figure 8.3: Tidewater is pumped back into a canal near the Venetian Causeway entrance from Purdy Avenue, where the seawall is also being raised, during a seasonal king tide in Miami Beach, Florida, in 2016. Photo credit: Max Reed/The New York Times/Redux.

and businesses worth at least $1.4 trillion sit within about 1/8th mile of the coast.[56] Flooding from rising sea levels and storms is likely to destroy, or make unsuitable for use, billions of dollars of property by the middle of this century, with the Atlantic and Gulf coasts facing greater-than-average risk compared to other regions of the country.[57,58,59] Recent economic analysis finds that under a higher scenario (RCP8.5), it is likely (a 66% probability, which corresponds to the Intermediate-Low to Intermediate sea level rise scenarios) that between $66 billion and $106 billion worth of real estate will be below sea level by 2050; and $238 billion to $507 billion, by 2100.[60]

These market impacts have the potential to influence property developers, lenders, servicers, mortgage insurers, and the mortgage-backed securities industry.[58,61] Coastal property and infrastructure losses cascade into threats to personal wealth and could affect the economic stability of local governments, businesses, and the broader economy.[62] Some coastal property owners are dependent on recouping losses from private or public insurance policies, and there are few private flood insurance policies currently available.[63,64] Mortgage holders located within the federally designated Special Flood Hazard Area defined by the Federal Emergency Management Agency are required to purchase flood insurance, which is almost always obtained through the National Flood Insurance Program (NFIP). Losses generated by the NFIP create substantial financial exposure for the Federal Government and U.S. taxpayers.[65,66] There are already indications in places like Atlantic City, New Jersey, and Norfolk, Virginia,[58,67] that homes subject to recurring flooding may become unsellable. The impacts of Hurricanes Harvey, Irma, and Maria in 2017 will only exacerbate the NFIP losses. (For more information on the 2017 Atlantic hurricane season, see Ch. 2: Climate, Box 2.5.) Additionally, diminished real estate values are likely to result in lower tax revenues and reduced community services (Ch. 28: Adaptation, KM 5).[68,69]

In addition to private property risks, coastal infrastructure, such as roads, bridges, tunnels, and pipelines, provides important lifelines between coastal and inland communities, meaning that damage to this infrastructure results in cascading costs and national impacts (Ch. 12: Transportation, KM 1 and 2).[70] Oil and gas from critical energy infrastructure along the coast is distributed to the entire nation.[71,72] Similarly, the entire country depends on coastal seaports for access to goods and services, as they handle 99% of overseas trade (Ch. 12: Transportation, KM 1). Incorporating adaptation into infrastructure upgrades will be expensive. For instance, the estimated cost to elevate and retrofit the major commercial ports of California (such as San Diego, Los Angeles/Long Beach, San Francisco) to adapt to 6 feet of SLR is $9–$12 billion.[73] Investing in these interconnected lifelines would support community stability and the Nation's economy (Ch. 3: Water, KM 2; Ch. 11: Urban, KM 3; Ch. 17: Complex Systems, KM 1 and 3).[70]

Key Message 2

Coastal Environments Are Already at Risk

Fisheries, tourism, human health, and public safety depend on healthy coastal ecosystems that are being transformed, degraded, or lost due in part to climate change impacts, particularly sea level rise and higher numbers of extreme weather events. Restoring and conserving coastal ecosystems and adopting natural and nature-based infrastructure solutions can enhance community and ecosystem resilience to climate change, help to ensure their health and vitality, and decrease both direct and indirect impacts of climate change.

Coastal ecosystems such as estuaries, deltas, marshes, mangroves, seagrasses, beaches, and reefs provide valuable benefits to the economy and society.[35] They support fisheries, reduce shoreline erosion from waves, improve water quality, and create valuable recreation opportunities.[74] Between 2004 and 2009, it was estimated that U.S. coastal wetland environments have been lost at an average rate of about 80,160 acres per year, with 71% of coastal wetland loss occurring in the Gulf of Mexico.[75] At this rate, by 2100 the United States will have lost an additional 16% of coastal wetlands.[75] Sea level rise in the Atlantic is contributing to the declining health and integrity of Atlantic marshes. Marsh degradation is expected to occur faster in the Atlantic than in the Pacific due to the higher SLR expected along the U.S. Atlantic coast.[76,77]

Coastal wetlands generate climate mitigation benefits by serving as natural sinks for atmospheric carbon dioxide.[78,79,80] As these ecosystems are degraded or lost, their carbon uptake potential will be diminished and their stored carbon potentially released. In addition, wetlands are a first line of natural defense against erosion, waves, flooding, and storm surge.[81]

Natural and nature-based infrastructure provides alternatives to traditional hard structure approaches such as seawalls, levees, and dikes and can improve the resilience of coastal communities and the integrity of coastal ecosystems.[81,82,83] This approach includes a range of efforts, such as the protection or restoration of natural habitats to mitigate waves and erosion (Figure 8.4) (see also Ch 19: Southeast, KM 3)[84,85,86,87,88,89] and hybrid approaches that combine built and natural features, such as some living shorelines options.[83,90] These types of approaches are being considered in the Superstorm Sandy Rebuild by Design challenge, the Changing Course competition

focused on the Lower Mississippi River delta, and in experimental studies and the development of guidance conducted within estuaries.[91] Studies suggest that healthy coastal ecosystems provide important cost savings in terms of flood damages avoided,[92,93,94] but more research would be useful to increase the level of confidence.

Natural and Nature-Based Infrastructure Habitats

Figure 8.4: Natural and nature-based infrastructure habitats include seagrass meadows (not shown), (a) coastal wetlands, (b) barrier islands, (c) beaches, (d) corals, (e) oyster reefs, and (f) dunes. Each of these habitats provides storm and erosion risk reduction by causing waves to break or slow as they roll over the ecosystem. Waves slow down, for example, as they flow across the rough surfaces and crests of reef ecosystems; likewise, water decelerates as it pushes through the vegetation of wetland ecosystems. This slowing decreases wave height and energy as the wave proceeds through or across each ecosystem, reducing the amount of erosion that the wave would otherwise cause. Photo credits: (a) Gretchen L. Grammer, NOAA National Ocean Service; (b) Erik Zobrist, NOAA Restoration Center; (c) NOAA; (d) LCDR Eric Johnson, NOAA Corps.; (e) Jonathan Wilker, Purdue University; (f) Ann Tihansky, USGS.

Key Message 3

Social Challenges Intensified

As the pace and extent of coastal flooding and erosion accelerate, climate change impacts along our coasts are exacerbating preexisting social inequities, as communities face difficult questions about determining who will pay for current impacts and future adaptation and mitigation strategies and if, how, or when to relocate. In response to actual or projected climate change losses and damages, coastal communities will be among the first in the Nation to test existing climate-relevant legal frameworks and policies against these impacts and, thus, will establish precedents that will affect both coastal and non-coastal regions.

Flooding and erosion impact many populations along the coast. However, for socially and economically marginalized and low-income groups, climate change and current and future SLR could exacerbate many long-standing inequities that precede any climate-related impacts (Figure 8.5) (see also Ch. 11: Urban, KM 1; Ch. 18: Northeast, KM 3).[95,96] Underrepresented and underserved communities facing additional threats from climate change span a variety of regions and contexts, ranging from the elderly in Florida[97] to rural and subsistence-based fishing communities in Alaska (Ch. 26: Alaska, KM 4).[98] The 2017 hurricane season provided grim imagery of the impacts to these socially and economically vulnerable coastal residents, and the long-term impacts on these communities are as yet unclear (Figure 8.6) (see also Ch. 2: Climate, Box 2.5). Given limited resources, the core of this challenge rests on questions about who is most vulnerable to the impacts, who should pay for losses incurred,

Societal Options for Resource Allocation in a Changing Climate

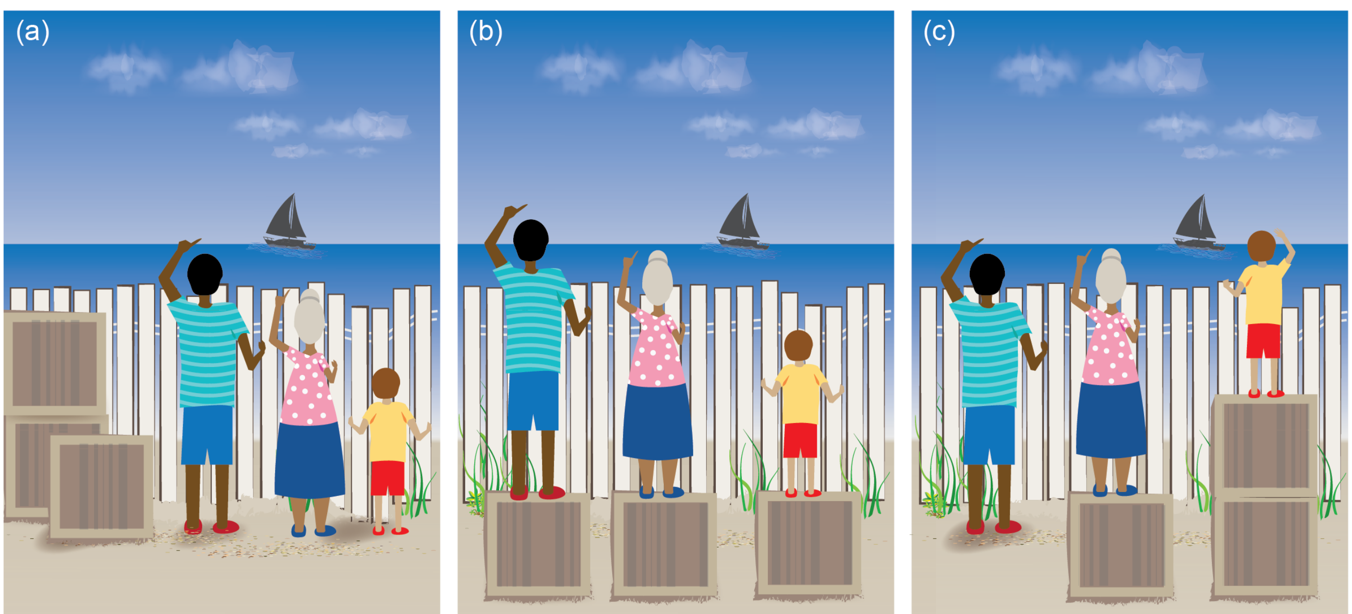

Figure 8.5: Society has limited resources to help individuals and communities adapt to climate change. Panel (a) illustrates that there are finite resources available and that individuals and communities are starting from different levels of readiness to adapt. Panel (b) illustrates the option for society to choose an equal allocation of resources where everyone gets the same amount of help, or as illustrated in panel (c), society can choose to distribute resources equitably to give people what they need to reach the same level of adaptation. Source: adapted with permission from Craig Froehle.

who should pay for protecting coastal communities in the future, and how governments and communities set protocols and policies for keeping people safe. These types of questions bring to light the divergent views of various stakeholders regarding the role of individuals, businesses, and governments in assuming the risks and benefits of living and working near the coast (Ch. 14: Human Health, KM 2 and 3).[99]

Adaptation strategies, including the decision to retreat from, accommodate, or protect against a particular impact, are dependent on several factors. Economically, a property owner's access to capital or insurance to fund these strategies contributes to adaptation choices, making poverty a driver of vulnerability in the face of climate-based impacts.[100] Some property owners can afford to modify their homes to withstand current and projected flooding and erosion impacts. Others who cannot afford to do so are becoming financially tied to houses that are at greater risk of annual flooding.[67] Additionally, communities are composed of renters and other individuals who do not own property, making it more difficult for them to contribute their voices to conversations about preserving neighborhoods. Culturally, coastal communities have ties to their specific land and to each other, as is the case from the bayous of Louisiana, to the beaches of New Jersey, to the sea islands of South Carolina and Georgia. These ties can impede people's ability and willingness to move away from impacted areas. For Indigenous villages to most effectively respond to critical climate impacts, decision-makers should consider identifying a suitable place to relocate that does not infringe on the needs and territories of other populations, is large enough for the entirety of the village, and is suitable for building and accessing infrastructure (Ch. 15: Tribes, KM 3).[101]

Impacts of the 2017 Hurricane Season

Figure 8.6: Quintana Perez dumps water from a cooler into floodwaters in the aftermath of Hurricane Irma in Immokalee, Florida. Photo credit: AP Photo/Gerald Herbert.

Climate change impacts are expected to drive human migration from coastal locations, but exactly how remains uncertain.[102,103,104] As demonstrated by the migration of affected individuals in the wake of Hurricane Katrina, impacts from storms can disperse refugees from coastal areas to all 50 states, with economic and social costs felt across the country.[105] Sea level rise might reshape the U.S. population distribution, with 13.1 million people potentially at risk of needing to migrate due to a SLR of 6 feet (about 2 feet less than the Extreme scenario) by the year 2100.[102] The Biloxi-Chitimacha-Choctaw tribe on Isle de Jean Charles in Louisiana was awarded $48 million from the U.S. Department of Housing and Urban Development to implement a resettlement plan.[106,107] The tribe is one of the few communities to qualify for federal funding to move en masse. (Ch. 15: Tribes, KM 3; Ch. 19: Southeast, KM 1).

Coastal Adaptation

Coasts will confront a more diverse and, to a great extent, unique range of climate stressors and impacts compared with the rest of the country. Rising sea levels will force many more coastal communities to grapple with chronic high tide flooding, higher storm surges, and associated emergency response costs over the next few decades.[6,7,36,75] The growing concentration of people and economic activity in coastal areas will introduce a greater degree of risk, including impacts that will ripple far beyond coastal communities themselves.[70,108]

Understanding these realities, coastal cities such as Boston, New York City, Miami, San Francisco, New Orleans, and Los Angeles are beginning to make investments to adapt to SLR (see the Case Study: "Key Messages in Action") (see also Ch. 19: Southeast, KM 1). From these efforts, and others like them, examples of successful adaptation planning are being collected to provide guidance to other communities facing similar challenges (Figure 8.2) (see also Ch. 28: Adaptation).[109,110,111]

However, while many current plans call for risk identification, monitoring, research, and additional planning, there is still little focus on the major investments or immediate implementation actions and cost-dependent tradeoffs required to successfully adapt.[110] The financial resources currently being devoted to adapt to or mitigate coastal climate change impacts are insufficient to meet the projected challenges ahead.[112,113,114] Additionally, with the limited and often expensive adaptation opportunities currently under consideration, including elevating properties or constructing seawalls, climate-driven impacts may lead to a great deal of unplanned and undesired community change that is likely to disproportionately impact communities that are already marginalized. Resilience planning that considers cultural heritage and incorporates community-driven values, experiences, concerns, needs, and traditional knowledge promotes social inclusivity and equity in adaptation decisions (Ch. 15: Tribes, KM 3).[115,116]

Case Study: Key Messages in Action—Norfolk, Virginia

Low-lying Norfolk—Virginia's second-largest city—is enduring serious physical, financial, and social impacts as the frequency of high tide flooding accelerates due to rising local sea level.[6] High tide flooding threatens access routes, historical neighborhoods, personal and commercial property integrity and value, and national security, given that Norfolk houses the world's largest naval base. The city has begun to invest in mitigation and adaptation actions,[117] but recent estimates indicate it will cost hundreds of millions of dollars to improve storm water pipes, flood walls, tide gates, and pumping stations.[118] Natural and nature-based infrastructure projects such as the Colley Bay living shoreline have improved water quality, mitigated erosion, and restored habitats.[119] Additional planned projects include constructing berms, reclaiming filled waterways and wetlands, and raising roads and structures. City officials have identified the neighborhoods of The Hague and Pretty Lake as top priorities for flood mitigation, but in other areas of the city where containment will be more difficult, residents face the possibility of abandoning their homes (Figure 8.7).[118,120]

Vision 2100: Designing the Coastal Community of the Future

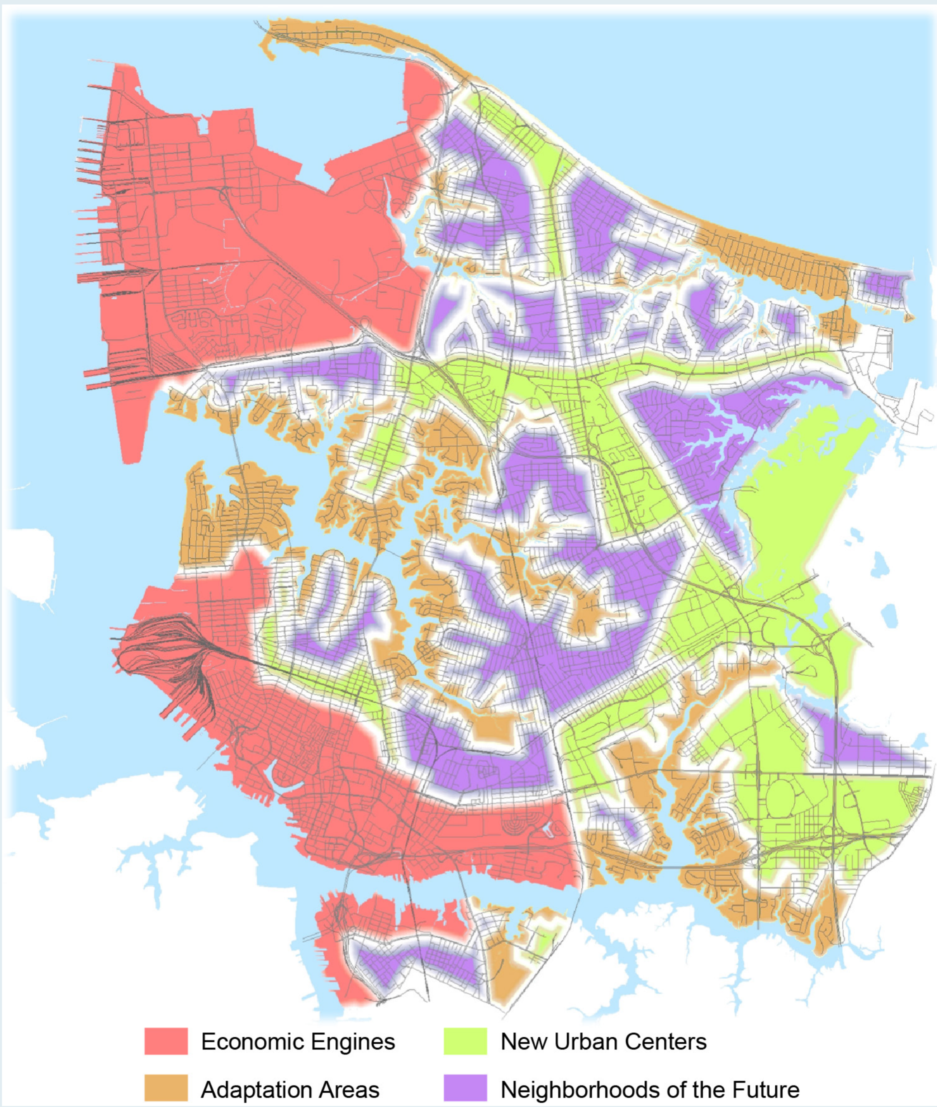

Figure 8.7: The City of Norfolk is building a long-term strategy to address the flooding challenges due to sea level rise. Green areas are at low risk of coastal flooding and have great potential for high-density, mixed-use, and mixed-income development. Red areas are home to key economic assets that are essential to the city's future. Brown areas are established neighborhoods that experience more frequent flooding. Purple areas are established neighborhoods at less risk of coastal flooding. (Descriptions in the legend are from the original City of Norfolk publication.) Source: City of Norfolk 2016.[120]

Case Study: Key Messages in Action—Norfolk, Virginia, *continued*

Recognizing these urgent and compelling needs, the Hampton Roads Adaptation Forum convened in 2012 to exchange knowledge and make recommendations to local government officials. Norfolk has become a member of the Rockefeller Foundation's 100 Resilient Cities, installed a chief resilience officer, and released a codified resilience strategy that outlines goals and metrics for the city.[121]

Given that the city is home to Naval Station Norfolk and other national security facilities, the Department of Defense has also contributed to plans for the city's future (Ch. 1: Overview, Figure 1.8). Naval Station Norfolk supports multiple aircraft carrier groups and is the duty station for thousands of employees.[122] Most of the area around the base lies less than 10 feet above sea level,[123] and local relative sea level is projected to rise between about 2.5 and 11.5 feet by the year 2100 under the Intermediate-Low global SLR scenario (considered likely under the lower [RCP4.5] and very low [RCP2.6] scenarios) and the Extreme SLR scenario (considered worst case under a higher scenario, RCP8.5), respectively.[36] The Navy is studying how flooding in Norfolk and Virginia Beach affects military readiness when sailors and other employees who live off-base are unable to reach the naval station for work.[124] Ultimately, the lessons learned in Norfolk—both the successes and challenges—are transferable to other coastal communities across the United States and its territories.

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Opening Image Credit

Natural "green barriers": NOAA.

Traceable Accounts

Process Description

The selection of the author team for the Coastal Effects chapter took into consideration the wide scope and relative sufficiency of the Third National Climate Assessment (NCA3) Coastal chapter. With input and guidance from the NCA4 Federal Steering Committee, the coordinating lead authors made the decision to convene an all-federal employee team with representation from key federal agencies with science, management, and policy expertise in climate-related coastal effects, and to focus the content of the chapter on Key Messages and themes that would both update the work conducted under NCA3 and introduce new themes. For additional information on the author team process and structure, refer to Appendix 1: Process.

A central component of the assessment process was a chapter lead authors' meeting held in Washington, DC, in May 2017. The Key Messages were initially developed at this meeting. Key vulnerabilities were operationally defined as those challenges that can fundamentally undermine the functioning of human and natural coastal systems. They arise when these systems are highly exposed and sensitive to climate change and (given present or potential future adaptive capacities) insufficiently prepared or able to respond. The vulnerabilities that the team decided to focus on were informed by a review of the existing literature and by ongoing interactions of the author team with coastal managers, planners, and stakeholders. In addition, the author team conducted a thorough review of the technical inputs and associated literature. Chapter development was supported by numerous chapter author technical discussions via teleconference from April to September 2017.

Key Message 1

Coastal Economies and Property Are Already at Risk

America's trillion-dollar coastal property market and public infrastructure are threatened by the ongoing increase in the frequency, depth, and extent of tidal flooding due to sea level rise, with cascading impacts to the larger economy. Higher storm surges due to sea level rise and the increased probability of heavy precipitation events exacerbate the risk. Under a higher scenario (RCP8.5), many coastal communities will be transformed by the latter part of this century, and even under lower scenarios (RCP4.5 or RCP2.6), many individuals and communities will suffer financial impacts as chronic high tide flooding leads to higher costs and lower property values. Actions to plan for and adapt to more frequent, widespread, and severe coastal flooding would decrease direct losses and cascading economic impacts. (*Likely, High Confidence*)

Description of evidence base

Significant impacts to coastal communities, properties, infrastructure, and services are already occurring in low-lying areas of the country such as Miami Beach and Fort Lauderdale in Florida; Norfolk, Virginia; and Charleston, South Carolina.[61,125,126,127,128]

Satellite and tide gauge data show that sea level rise (SLR) rates are increasing,[36] and research has shown that this increase is driven by emissions that are warming the planet.[129,130] The latest SLR science[7,36,48,52] finds that even if RCP2.6 were achieved, it is *likely* that global mean sea level will rise by 1.5 feet by 2100; under RCP8.5, a rise of about 3 feet is within the *likely* range for 2100.

Recent probabilistic studies and assessments of future SLR and rapid ice loss from Antarctica find that although a low probability, there is a possibility of upwards of 8 feet of rise by 2100 under a high-emission, extreme melt scenario.[36,37,49,50,51,52]

Applying digital elevation models to determine the extent and number of communities and the amount of property and infrastructure that would be impacted by different amounts of SLR illustrates the magnitude of investments that are at risk.[56,57,126,131,132,133,134] These same analyses demonstrate the savings that could be achieved by lowering emissions. Finally, implementing adaptation measures to ensure that public infrastructure is resilient to current and future flood scenarios will be tremendously expensive. To date there are few economic sectoral models that quantify damages under alternative climate scenarios,[57,134] so additional modeling work would be useful.

The importance of coastal economies and infrastructure to the overall national economy is well documented (for example, the National Oceanic and Atmospheric Administration's [NOAA] Economics: National Ocean Watch; NOAA port data), as are the economic ripple effects of impacts to property markets.[57,58,133,135,136] Similarly, much has been written about how the National Flood Insurance Program has subsidized development in risky areas and how raising flood insurance rates to be actuarially sound could make it impossible for many coastal residents to afford flood insurance.[58,137,138,139,140] The evidence for the economic savings provided by adaptation investments is still fairly limited but growing.[54,57,59,141]

Major uncertainties

The main source of uncertainty is in the magnitude of SLR that will occur and how it will vary across different regions, which depend in part on the amount and speed with which global society will reduce emissions. While global climate models and SLR models have improved since NCA3,[142] uncertainty remains about exactly how much SLR will occur where and by when with different emissions levels. Even though there is uncertainty about the magnitude, the probabilistic approach to the SLR technical report to the Fourth National Climate Assessment,[36] together with impacts already documented around the country from high tide flooding,[143] gives us *high confidence* of the threat to coastal property and infrastructure. Adaptive responses to SLR risk and impacts, including individual action and public policy development, are also significant sources of uncertainty. For example, there is uncertainty about future development patterns in coastal regions, including both new development and migration inland, which has the potential to change the magnitude of coastal property and infrastructure at risk. The U.S.-specific research on potential migration away from the coast due to SLR and other climate impacts is very limited.[102]

Future flood insurance policy is another specific source of uncertainty. Under the latest legislation (the Federal Emergency Management Agency's Homeowner Flood Insurance Affordability Act, 2017[140]), flood insurance rates are gradually rising; development of new policies related to affordability or to the requirement to carry flood insurance in order to have a federally backed mortgage could change behaviors.

While figures for the economic value of certain sectors dependent on the ocean and Great Lakes are available through NOAA's "Economics: National Ocean Watch,"[144] similar information for the economic and social value of other sectors, such as real estate and insurance/reinsurance, would be beneficial for the audience of this assessment report, especially decision-makers.

Description of confidence and likelihood

There is *very high confidence* that the frequency and extent of tidal flooding is already increasing and will continue to increase with SLR and that this flooding threatens the trillion-dollar coastal property market and public infrastructure. There is limited research using varied methods to quantify the direct and indirect economic impacts that will be experienced under different amounts of SLR. Nevertheless, there is a *high level of confidence* that these losses will be dramatic under SLR associated with the higher emission scenario (RCP8.5) and significant even under lower scenarios (RCP4.5 or RCP2.6), based on property values and geographic exposure to inundation. U.S. economic history provides strong evidence that extensive property market losses have the potential to impact businesses, personal wealth, and mortgage-related securities. Similarly, historic disaster events such as hurricanes and earthquakes provide a *very high level of confidence* that impacts to critical transportation and energy networks will harm the economy. Considering the uncertainty inherent in future human behavior and policy responses, including flood insurance policy, it is possible that individuals and institutions will act to reduce future flooding, to lessen the exposure and sensitivity of critical assets, and to create policies that assist individuals and businesses most impacted; hence, there is *medium confidence* that many coastal communities will be transformed by 2100 under any scenario and that many individuals will be financially devastated under lower emission scenarios (RCP4.5 or RCP2.6). Considering current exposure of assets and the latest SLR science, large economic losses in coastal regions that will generate cascading impacts to the overall economy of the United States are considered to be *likely*. The overall *high confidence* is the net result of considering the evidence base, the well-established accumulation of economic assets and activities in coastal areas, and the directional trend of sea level rise.

Key Message 2

Coastal Environments Are at Already at Risk

Fisheries, tourism, human health, and public safety depend on healthy coastal ecosystems that are being transformed, degraded, or lost due in part to climate change impacts, particularly sea level rise and higher numbers of extreme weather events (*highly likely*, *high confidence*). Restoring and conserving coastal ecosystems and adopting natural and nature-based infrastructure solutions can enhance community and ecosystem resilience to climate change, help to ensure their health and vitality, and decrease both direct and indirect impacts of climate change (*likely*, *high confidence*).

Description of evidence base

Multiple lines of evidence have determined that coastal environments are critical to support coastal fisheries, tourism, and human health and safety.[74,81,83,85,86,87,92,145,146,147] These ecosystems are some of the most threatened on the planet and are being transformed, degraded, or destroyed due to climate change (including rising temperatures, rising sea levels, and ocean acidification)[148,149,150,151,152,153] and due to other human stressors such as nutrient pollution, habitat and biodiversity loss, and overfishing.

There is growing evidence that one part of the solution to help coastal ecosystems and human communities be more resilient to climate change, including SLR and increasingly intense or

frequent storms, is to conserve or restore coastal habitats such as wetlands, beaches and dunes, oyster and coral reefs, and mangroves[74,75,81,83,85,86,87,88,92,145,146,154] because they help to attenuate waves, decrease wave energy, and reduce erosion.[81] In addition to restoring or protecting natural habitats, there is also a growing interest in, and body of research regarding expectations for, performance in using a combination of natural and built (called hybrid, or nature-based) features, such as living shorelines, to protect coastal communities.[83,88,90,91,155,156]

Major uncertainties

The exact amount of coastal habitat loss that is due to climate change versus other human stressors or multiple stressors can be hard to ascertain, because these stressors are all acting simultaneously on coastal habitats. Nevertheless, it is clear that climate change is one of the important stressors impacting coastal habitats and leading to the degradation or loss of these ecosystems, such as the loss of coral habitats to bleaching events due to rising ocean temperatures and the loss of coastal wetlands due to more intense storm events.

The use of natural and nature-based infrastructure (NNBI) to improve coastal resilience is being implemented in many different states (for example, the use of living shorelines is expanding in Maryland, North Carolina, New Jersey, Louisiana, and other states, and the Rebuild by Design competition is implementing a variety of coastal resilience projects in New York and New Jersey), although there remain some uncertainties about how much storm and erosion risk reduction is provided by different techniques or projects and in different settings. The efficacy of NNBI remains uncertain in many instances; comprehensive monitoring, particularly during and after storms, would be required to ascertain how well these features are functioning for protection services. This monitoring could inform future coastal resilience planning and decisions, including the benefits, costs, and/or tradeoffs involved in considering NNBI options.[157]

Description of confidence and likelihood

There is *high confidence* that coastal ecosystems are particularly vulnerable to climate change. They have already been dramatically altered by human stressors, as documented in extensive and conclusive evidence; additional stresses from climate change point to a growing likelihood of coastal ecosystems being pushed past tipping points from which they will not be able to recover. The overall *high confidence* is the net result of considering the evidence base, the dramatically altered ecosystems from human stresses, and the directional trend of sea level rise.

Key Message 3

Social Challenges Intensified

As the pace and extent of coastal flooding and erosion accelerate, climate change impacts along our coasts are exacerbating preexisting social inequities, as communities face difficult questions about determining who will pay for current impacts and future adaptation and mitigation strategies and if, how, or when to relocate. In response to actual or projected climate change losses and damages, coastal communities will be among the first in the Nation to test existing climate-relevant legal frameworks and policies against these impacts and, thus, will establish precedents that will affect both coastal and non-coastal regions. (*Likely*, *Very High Confidence*)

Description of evidence base

Reports and peer-reviewed articles are clear that socioeconomic challenges are being both driven and intensified by climate change.[33] Particularly on the coasts, where there are multiple risks to contend with, including hurricanes, SLR, shoreline erosion, and flooding, the high cost of adaptation is proving to be beyond the means of some communities and groups.[97,100,158] In areas where relocation is more feasible than in-place adaptation, coastal tribes of Indigenous people are at risk of losing their homes, cultures, and ways of life as they seek higher ground (Ch. 15: Tribes, KM 3).[98,159] New tools are being developed to quantify risks and vulnerabilities along the coast. For example, tools such as the Coastal Community Social Vulnerability Index[160] and the Coastal Economic Vulnerability Index[161] measure the social vulnerability of hurricane- or flood-prone areas to better quantify and predict how climate-driven changes are likely to impact marginalized groups. The Coastal Flood Exposure Mapper tool[162] supports communities that are assessing their coastal hazard risks and vulnerabilities with user-defined maps that show the people, places, and natural resources exposed to coastal flooding. The U.S. Environmental Protection Agency's Environmental Justice Screening and Mapping Tool provides consistent national data that allows the agency to protect the public health and environments of all populations, with a focus on traditionally underserved communities.[163] Moreover, involving diverse representation in the adaptation process through community-driven resilience planning[115] is likely to be a part of developing adaptation strategies that are fair and just.[99,164]

Major uncertainties

The main uncertainty for this Key Message is predicated on how different types of coastal effects (chronic flooding versus storms) will impact areas and communities along the coast. The degree of variation between communities means that it will be challenging to predict exactly which communities will be affected and to what extent, but the evidence thus far is clear: when it comes to climate-driven challenges and adaptation strategies, areas that have traditionally been underrepresented will continue to suffer more than wealthier or more prominent areas. Large-scale infrastructure investments are made in some areas and not others, and some local governments will not be able to afford what they need to do.

The variability in state laws and the pace at which those laws are evolving (such as shoreline management plans and setback policies for structures in the coastal zone) create major uncertainty.

Description of confidence and likelihood

There is *very high confidence* that structural inequalities in coastal communities will be exacerbated by climate change and its attendant effects (for example, storms, erosion). In the absence of clear policies and legal precedent, questions about land ownership and home ownership will persist.

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