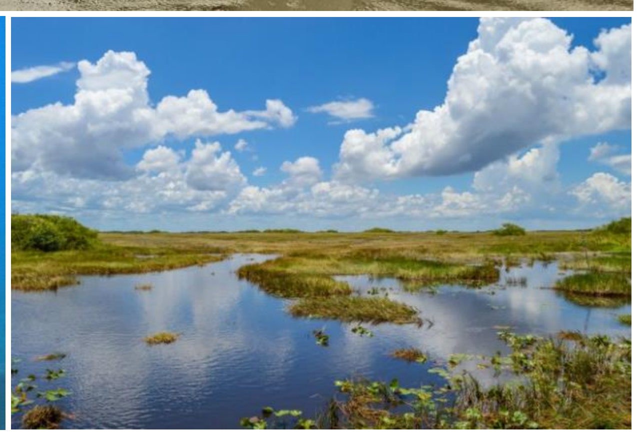
The State of Climate Adaptation in the Marine and Coastal United States, Territories, and Commonwealths

Rachel M. Gregg and Kathryn N. Braddock

2021



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Meeting the challenges of climate change

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Citation:
Gregg RM, Braddock KN. 2021. The State of Climate Adaptation in the Marine and Coastal United States, Territories, and Commonwealths. EcoAdapt, Bainbridge Island, WA.

Acknowledgements
Thank you to The Bernard and Anne Spitzer Charitable Trust for providing financial support. Thank you to Jessi Kershner, Claire Anderson, and Sally Ann Sims for providing research, writing, and editing support, and to Jessica Hitt for providing technical support. Finally, thank you to the numerous individuals who contributed materials, participated in interviews and surveys, and provided peer review for this project. We hope that our products will promote and support your adaptation efforts.

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Executive Summary

Climate change threatens the success and longevity of conservation, planning, and management. In marine and coastal environments, climate change-driven shifts are resulting in increasing ocean temperatures, changes in ocean chemistry, and rising seas, which affect species, habitats, infrastructure, cultures, and economies. Decision makers are faced with the challenge of developing and implementing response strategies that are suitable under changing climate conditions.

The field of climate adaptation is in a period of critical transition as it rushes to meet the needs of a growing user base struggling to address the challenges of climate change. The general concepts of adaptation have been well developed over the past decade. Now, practitioners must move from generalities to concrete actions, including implementation, monitoring, and evaluation of the effectiveness of adaptation efforts. EcoAdapt strives to facilitate this transition by providing relevant adaptation examples and a forum for knowledge sharing. Our State of Adaptation Program promotes adaptation action by providing real-life, practical adaptation case studies and reports to catalyze creative thinking and action. These assessments allow us to assess professionals' understanding and concerns about climate change, and identify the current beliefs, policies, and mechanisms that enable and restrict adaptation action.

In the 2011 report, *The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas*, we documented over 150 adaptation projects and initiatives from the United States, Canada, and Mexico (Gregg et al. 2011). The report concluded that the majority of activities underway were primarily focused on building awareness of how climate change may affect marine and coastal environments and adaptation planning, with some projects that had advanced into implementation. Progress has been made since then and this updated report shares lessons learned from completed projects, and identifies additional adaptation initiatives from different geographies and partners.

First, we provide a summary of climatic changes, including air and ocean temperatures, precipitation patterns and coastal storms, ocean circulation, sea levels, and ocean chemistry (e.g., pH, dissolved oxygen, salinity), and associated impacts on marine and coastal systems, including species, habitats, ecosystem services, and human communities.

Second, we provide an overview and examples of common barriers to adaptation noted by practitioners, such as funding and budgetary constraints, insufficient staff capacity and technical expertise, limited political will to mandate and enforce implementation, and lack of stakeholder awareness and engagement on climate change.

Third, we present adaptation examples by the following categories:

1. *Capacity Building*: Strategies include conducting research and collecting additional information, conducting training and planning exercises, improving public awareness

and education, developing tools and resources, and monitoring impacts and effectiveness of adaptation actions.

2. *Governance and Policy*: Strategies include developing adaptation plans and policies, creating new or enhancing existing policies, and developing adaptive management strategies.
3. *Infrastructure, Planning, and Development*: Strategies include improving existing or designing new infrastructure to withstand the effects of climate change, incorporating climate change into community and land use planning, creating or modifying development measures (e.g., removing shoreline hardening, encouraging low-impact development), and developing disaster preparedness plans and policies.
4. *Natural Resource Management and Conservation*: Strategies include enhancing areas under protection, restoring critical habitats, and reducing non-climate stressors.

Full case studies from the over 200 adaptation projects reviewed are available on the Climate Adaptation Knowledge Exchange (CAKEx.org).

The report concludes with a discussion of some notable trends from this latest review of marine and coastal U.S. adaptation. In general, most action is focused on the assessment and planning phases of adaptation with more moderate advancements in implementation and evaluation. Progress is being made, although likely not at the pace and scale required to keep up with changing conditions. Additional trends of note include a more intentional focus on advancing equitable adaptation; the use of unified climate projections in decision-making; integration of community concerns in adaptation projects led by conservation organizations; slower uptake and implementation of monitoring and evaluation; and the continuing critical role of the federal government in adaptation.

Marine and Coastal Climatic Changes and Impacts

Climate change alters the ability of marine and coastal ecosystems to function and provide the goods and services upon which species and humans depend. These ecosystem services include food, fresh water, flood and erosion control, climate sequestration and storage, cultural practices, recreation, primary production, and nutrient cycling, among others (MEA 2005). This section summarizes some of the primary climate-driven changes and impacts observed to date and projected to occur in marine and coastal regions of the United States. Changes considered include air and ocean temperatures, precipitation patterns and coastal storms, ocean circulation, sea levels, and ocean chemistry (e.g., pH, dissolved oxygen, salinity), and associated secondary impacts on marine and coastal systems, including species, habitats, ecosystem services, and human communities. The following tables summarize observed and projected future climatic changes, effects on marine and coastal systems, and geographic examples (Tables 1–5).

Table 1. Changes in air and ocean temperatures, effects on marine and coastal systems, and geographic examples.

Observed and Projected Changes	*Effects on marine and coastal systems*
Observed ● Air temperatures have increased by 0.8–1°C (1.4–1.8°F) in the United States relative to the beginning of the 20th century (Hansen et al. 2010; Wuebbles et al. 2017; IPCC 2021). ● The ocean has absorbed approximately 93% of the added atmospheric heat since the 1950s, increasing global sea surface temperatures by about 0.7°C (1.3°F) (Jewett & Romanou 2017). Since 1980, global sea surface temperatures have increased 0.6°C (1°F) (IPCC 2019). ● Marine heatwaves, or periods of hotter-than-usual ocean temperatures, have been documented for over a century (Hobday et al. 2018). Since the 1980s, marine heatwaves have doubled in frequency and have become more intense (IPCC 2021). Severe marine heatwaves have been observed along both the Atlantic and Pacific coasts of the United States (Mills et al. 2013; Bond et al. 2015; Di	*Ecosystems* ● Altered species' migration patterns ● Community shifts: changes in which species co-occur and in interactions among species (e.g., competition between native and invasive species) ● Phenological shifts: changes in development, age of sexual maturity, timing of spawning, growth, and survival ● Increased species' metabolic rates leading to higher consumption of oxygen and decreases in dissolved oxygen levels ● Reduction in species resilience due to thermal stress, leading to increased disease outbreaks ● Increased fitness for some native and non-native species, including insect outbreaks ● Increased risk of invasive species establishment ● Increased algal blooms and dead zones ● Loss of sea ice ● Increased frequency and severity of coral bleaching events ● Increased risk of wildfire and drought impacts on species and habitats ● Shifts in agricultural productivity: longer growing seasons ● Increased risk of extreme heat events *Ecosystem services* ● Loss of coastal protection from wetlands and coral reefs ● Loss of or alterations to fisheries as species' ranges shift (e.g., expanded fishing operations as sea ice melts, changes in gear requirements for new species)

Lorenzo & Mantua 2016). *Projected* ● Air temperatures in the United States are projected to increase between 1.2–5.7°C (2.2–10.3°F) by 2100, depending on the model projections used (IPCC 2021). ● Ocean temperatures are projected to increase between 1.3–2.7°C (2.3–4.8°F) by 2100 (Jewett & Romanou 2017). The frequency, intensity, and duration of marine heatwaves are likely to increase in a changing climate (Oliver et al. 2019; IPCC 2021).	● Loss of subsistence and culturally-valued species ● Economic losses ● Declines in naturally available water supplies <u>Sources</u>: Najjar et al. 2000; Ning et al. 2003; Roessig et al. 2004; Brander 2007; ISAB 2007; O'Connor et al. 2007; Brodeur et al. 2008; Daw et al. 2009; Beamish et al. 2010; Cazenave & Llovel 2010; Link et al. 2010; Najjar et al. 2010; Guidry & Mackenzie 2011; Johnson 2012; Pinsky & Fogarty 2012; Mills et al. 2013; Doney et al. 2014; Leong et al. 2014; Sanford et al. 2014; Sydeman & Thompson 2014; Gould et al. 2015; Hare et al. 2016; IPCC 2019; Yang et al. 2019; IPCC 2021
Regional examples of observed and projected impacts	
● Decreased winter sea ice and thawing permafrost in Alaska due to warmer air and water temperatures have enhanced coastal erosion rates as shorelines become more exposed to waves and storm surges as the ice retreats, damaging or destroying infrastructure (ACIA 2005; AFSC 2012). ● Melting sea ice will also increase freshwater runoff and could lead to decreased salinity levels. The Gulf of Alaska, for example, has already experienced decreased salinity due to melting sea ice (Royer & Grosch 2006). ● In New England, warming waters have been blamed for a collapsing cod fishery in the Gulf of Maine, where waters have warmed 99% faster than other areas in the country (Pershing et al. 2015). ● Increased water temperatures frequently favor the survival of invasive species that may stress native fish populations, such as the Atlantic oyster drill (*Urosalpinx cinerea*), which competes with Olympia oysters (*Ostrea lurida*) along the West Coast (Sanford et al. 2014). ● Melting sea ice is opening new shipping lanes in the Northwest Passage and the Northern Sea Route, placing Alaska at the forefront of new economic opportunities (e.g., fishing, oil and gas) as well as a potential site of conflict between Arctic nations trying to stake territorial claims (Forsyth 2018). ● Ocean temperatures in the northeast Caribbean increased 0.24°C (0.43°F) per decade (Gould et al. 2018).	

Table 2. Changes in precipitation and coastal storms, effects on marine and coastal systems, and geographic examples.

Observed and Projected Changes	*Effects on marine and coastal systems*
Observed ● In the past century, the United States has experienced an overall 4% increase in average annual precipitation (Easterling et al. 2017), including an overall increase in extreme precipitation events over the past	*Ecosystems* ● Altered reproductive timing and success of salmon and other anadromous and marine species ● Increased coastal dead zones from increased nutrient-rich runoff ● Increased coastal erosion

three to five decades (Walsh et al. 2014). ● Heavy precipitation events have increased in frequency and intensity since the 1950s (IPCC 2021). *Projected* ● It is generally expected that winter and spring precipitation will increase in the northern United States (Horton et al. 2014; Easterling et al. 2017), while the southwestern and Caribbean regions will experience drier conditions (Walsh et al. 2014; Easterling et al. 2017; Gould et al. 2018). ● An increase in the frequency and intensity of extreme precipitation events in the United States is projected (Easterling et al. 2017; IPCC 2021). It is projected that extreme daily precipitation events will increase about 7% for each 1°C of global warming (IPCC 2021). ● Hurricanes and tropical storms are likely to increase in intensity (e.g., increased strength of tropical storms in the Pacific [Murakami et al. 2013] and the Caribbean, Gulf Coast, and eastern coast of the United States [IPCC 2021]) while overall global projections indicate little to no change or even a decrease in frequency of these storms (Kossin et al. 2017; IPCC 2021).	● Altered water quality from salinity changes and pollution loading from non-point sources ● Increased nutrient and sediment loads in coastal areas downwind or downriver of fires due to increased wildfire frequency and intensity ● Increased inundation or degradation of important coastal habitats, such as tidal marshes, mangroves, and shallow coral reefs that fish use for protection, spawning, and rearing of juveniles ● Escalations in freshwater runoff causing increased water stratification in estuaries and coastal waters, reducing primary productivity rates and nutrient upwelling *Ecosystem services* ● Decreased water supply in drought-prone or snowmelt-dependent areas ● Damage to coastal property, port, and fishing infrastructure ● Economic stress on fishermen and boat operators as well as subsistence and traditional fishing communities <u>Sources:</u> Twilley et al. 2001; Kennedy et al. 2002; Roessig et al. 2004; Daw et al. 2009; Najjar et al. 2010; Berry et al. 2011; Anderson et al. 2013; Needham et al. 2012; Carter et al. 2014; Gould et al. 2015; Grecni et al. 2021
Regional examples of observed and projected impacts	
● Since 1970, there have been observed increases in the intensity, frequency, and duration of North Atlantic hurricanes (Carter et al. 2014; Kossin et al. 2017), and increased tropical storm frequency in the Pacific Ocean since 1966 (Chu 2002). ● More frequent and intense winter storms have been observed in the coastal Northeast and Northwest (Walsh et al. 2014). ● In the Southeast, the frequency of extreme precipitation events has increased by 10–25% over past 20 years (Kunkel et al. 2013). ● Decreased precipitation and higher air temperatures increased wildfire frequency, duration, and the wildfire season in the West (Westerling et al. 2006). ● Total annual precipitation of the heaviest 1% of events (between 1901–2016) increased by 18% in Southeast United States and up to 38% along the Atlantic Coast (Hayhoe et al. 2018).	

● More frequent and intense storms will increase runoff in the Mid-Atlantic, Southeast United States, and the Gulf of Mexico. The "dead zone" in the Gulf may expand in size due to increased nutrient and pollutant loads being carried in the Mississippi River (Rabalais & Turner 2019). ● Over the course of one month in 2017, Hurricanes Harvey, Irma, and Maria destroyed several coastal communities in the Gulf Coast and Caribbean, causing between $335–475 billion in damages (Willingham 2017). Hurricane Irma was the strongest ever recorded in the Atlantic Ocean and Hurricane Maria was the strongest storm to hit Puerto Rico in a century (Fritz 2017). After these hurricanes, Puerto Rico and the U.S. Virgin Islands experienced a decrease in population size as families were displaced to the U.S. mainland (Artiga et al. 2018). ● In 2020, four hurricanes—Laura, Sally, Delta, and Zeta—made landfall in Gulf Coast communities in Louisiana and Alabama. The wind, storm surge, and rainfall impacts from these events were felt across eastern Texas, Mississippi, Georgia, Florida, and Arkansas. The impacts from the hurricanes resulted in 58 deaths and $32.7 billion worth of damages (NOAA NCEI 2021).

Table 3. Changes in ocean circulation patterns (e.g., natural climatic variability, upwelling, winds), effects on marine and coastal systems, and geographic examples.

Observed and Projected Changes	*Effects on marine and coastal systems*
Observed ● Ocean circulation patterns, driven by ocean currents (e.g., Gulf Stream) and thermohaline circulation, are critical to the transport of heat, oxygen, nutrients, and carbon throughout the global oceans. Interannual and interdecadal climatic variability, such as the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), influence ocean circulation, winds, upwelling patterns, temperatures, and precipitation and storms. ● There has been an observed increase in the intensity of ENSO events: the 1982–83 and 1997–98 El Niño events were the strongest observed in the past century (Hansen et al. 2006; Cai et al. 2015). ● From 2001–2014, there was intensification of the Pacific trade wind systems, resulting in increased ocean heat transport and rate of global temperature change (Collins et al. 2019). ● There is some evidence that the Atlantic Meridional Overturning Circulation (AMOC), which controls circulation patterns in the Atlantic Ocean, has weakened over time (Jewett & Romanou 2017; IPCC 2019). *Projected* ● The frequency and intensity of ENSO events may increase as climate patterns (e.g.,	*Ecosystems* ● Incidents of coral bleaching ● Altered species distribution and migration patterns ● Shifts in species composition ● Population declines from decreased food availability and habitat loss ● Geographic shifts in water salinity ● Decreased productivity in coastal upwelling areas ● Loss of fog-dependent coastal forests ● Widespread fish kills ● Changes in timing of phytoplankton and zooplankton production ● Limited prey availability for fish larvae and fish populations ● Disruption to the ecological connectivity of coral reef populations, further limiting the ability of corals to recover after bleaching events *Ecosystem services* ● Altered structure and productivity of fisheries ● Extreme weather-related damage to property and coastal areas ● Declines in net primary productivity due to increased water column stratification and suppressed vertical mixing ● Fluctuations in fish stocks

increased temperatures, decreased winds) shift (Barange & Perry 2009; Yeh et al. 2009; Collins et al. 2019). ● Potential intensification of upwelling and stronger coastal winds in the California Current (Brady et al. 2017; Xiu 2018). ● The formation of North Atlantic Deep Water that drives ocean circulation may weaken and result in greater water column stratification (Rahmstorf 2006). ● The AMOC is very likely to weaken over the 21st century in response to increased greenhouse gas concentrations and influxes of freshwater from Greenland's ice sheet, which may affect the ability of the AMOC to absorb heat and carbon dioxide (Schmittner et al. 2005; Cheng et al. 2013; IPCC 2019). The Gulf Stream is also projected to weaken over the 21st century (IPCC 2021).	● Reduced carbon dioxide uptake Sources: Glynn et al. 2001; Behrenfeld et al. 2006; Lehodey et al. 2006; ISAB 2007; Brodeur et al. 2008; Schindler et al. 2008; McIlgorm et al. 2010; Rabalais et al. 2010; Keener et al. 2012; Auth et al. 2011; Glynn et al. 2014; Reynolds et al. 2014; Sydeman & Thompson 2014; Grecni et al. 2021
Regional examples of observed and projected impacts	
● Changes in seasonal wind patterns along coasts have delayed and/or decreased upwelling events along the West Coast, decoupling trophic interactions and productivity (Barth et al. 2007). ● Less frequent, more intense upwelling events have been observed in the California Current System (Sydeman et al. 2014). Changes in upwelling strength and ENSO and PDO cycling have also been shown to affect the timing and composition of fish larvae in this system (Brodeur et al. 2008; Auth et al. 2011), highlighting the potential for increased shifts and variability in fish populations and changes in dominant species driven by changes in ocean circulation. ● Previous ENSO events have led to large increases in sea surface temperature (2–3°C [3.6–5.4°F]) along the California coast (Sydeman & Thompson 2014).	

Table 4. Changes in sea levels, effects on marine and coastal systems, and geographic examples.

Observed and Projected Changes	*Effects on marine and coastal systems*
Observed ● Since 1900, global mean sea levels increased by ~15–25 cm (~5.9–9.8 inches) (IPCC 2021). Since 2006, sea level rise increased by 0.35 cm (0.14 inches) per year (IPCC 2021). *Projected* ● Global sea levels are projected to rise between 0.28–1.01 m (0.92–3.3 ft) by 2100 and 0.37–1.88 m (0.98–6.2 ft) by 2150, with a potential increase of 2 m (6.6 ft) by 2100 and 5 m (16.4 ft) by 2150	*Ecosystems* ● Saltwater inundation will stress coastal freshwater species ● Shifts in species distribution and interactions among species ● Loss or change in location and distribution of coastal breeding grounds and habitat ● Altered oceanic current patterns and rates ● Inundation of coastal ecosystems including wetlands and barrier islands ● Changes (both loss and gain) in habitat availability and types (e.g., marsh migration) ● Land subsidence and erosion

under continued very high greenhouse gas emissions and ice sheet loss in the Antarctic and Greenland (IPCC 2021). ● Low-lying coastal areas, such as islands in the Pacific and Caribbean, and along the Atlantic and Gulf coasts are acutely vulnerable to sea level rise, particularly cities such as Miami, New Orleans, Charleston, and Virginia Beach (Carter et al. 2014; Marra & Kruk 2017; Runkle et al. 2018).	*Ecosystem services* ● Salinization of water supplies ● Increased economic vulnerability of fisheries-dependent communities ● Damage to critical infrastructure (e.g., energy systems, utilities, ports) ● Declines in aquaculture ● Loss of tribal cultural and archaeological sites ● Loss of public access to coastlines <u>Sources:</u> Twilley et al. 2001; Ning et al. 2003; Daw et al. 2009; Najjar et al. 2010; Anderson et al. 2013; Gould et al. 2015; Laird 2018; Grecni et al. 2021
Regional examples of observed and projected impacts	
● Observed rates of sea level rise vary throughout the country based on topography and land subsidence and uplift (Walsh et al. 2014). For example, the rate of sea level rise in the Northeast Atlantic has been higher than global rates in the past few decades (Sweet et al. 2017), leading to greater coastal flooding (Horton et al. 2014). ● Coastal freshwater forests in the Southeast and in the Gulf of Mexico are undergoing dieback from increasing saltwater intrusion as sea level rises and regional lands subside; in some areas, mangroves are expanding landward (Doyle et al. 2010). ● Some areas may be experiencing faster rates of sea level rise due to land subsidence (Mitchum 2011). For example, Louisiana is experiencing relative sea level rise of ~0.9 cm (0.37 inches) per year (Ingram et al. 2013) and over 1,880 mi^2 (~4,869 km^2) of wetlands have been inundated since 1930 (Carter et al. 2014). Land subsidence driven by groundwater withdrawals has caused the Chesapeake Bay region to experience the highest rate of sea level rise along the Atlantic Coast over the last few decades (Eggleston & Pope 2013). ● Forced migration of entire coastal communities, such as the Native Villages of Shishmaref, Kivalina, Shaktoolik, and Newtok on the west coast of Alaska, because of increased erosion as a result of sea ice cover and its buffering effects against storms and high energy waves (ACIA 2005). ● In Humboldt Bay, California, over 50 cultural sites of importance (e.g., ceremonial and gathering areas) to the native Wiyot Tribe are vulnerable to inundation from sea level rise (Laird 2018). ● A 3.2-foot rise in sea levels would likely damage over 550 cultural sites and 25,000 acres of coastal land, and displace nearly 20,000 residents in the Hawaiian Islands (Hawaiʻi Climate Change Mitigation & Adaptation Commission 2017).	

Table 5. Changes in ocean chemistry (e.g., pH, salinity, dissolved oxygen), effects on marine and coastal systems, and geographic examples.

Observed and Projected Changes	*Effects on marine and coastal systems*
Observed ● Since the 1980s, ocean surface pH has declined by 0.017–0.027 pH units per decade (IPCC 2019). ● Ocean salinity is influenced by freshwater input from precipitation, ice meltwater, and	*Ecosystems* ● Decreased reproductive and recruitment success ● Shifts in species composition and distribution

rivers (Boyer et al. 2007; Cazenave & Llovel 2010). Global ocean surface salinity increased 5.3% from 1950–2010 (Jewett & Romanou 2017). Salinity levels in the western North Atlantic have increased slightly since 1967 and held relatively steady in the Gulf of Mexico and Caribbean Sea (Boyer et al. 2007), and decreased in the Gulf of Alaska due to melting sea ice (Royer & Grosch 2006). ● The oxygen content of ocean waters is influenced by circulation and precipitation patterns that can intensify water stratification and reduce vertical mixing. It is estimated that between 1970–2010 that 0.5–3.3% of oxygen was lost from the ocean surface to 1,000m (~3,281 ft) (Bindoff et al. 2019). Over the last 50 years, oxygen declines have been observed in inland seas, estuaries, and coastal waters (Jewett & Romanou 2017). The Gulf of Mexico and the South Atlantic regions have the largest percentage of water bodies with hypoxic zones in the United States (51% and 55% in the 2000s) (CENR 2010). *Projected* ● Ocean surface water pH may decrease an additional 0.3–0.4 pH units by 2100 (Orr et al. 2005; Feely et al. 2009; Feely et al. 2012; Bopp et al. 2013). ● Salinity levels may decline due to large freshwater inputs from melting sea ice as temperatures rise (Burkett & Davidson 2012). It is projected that the Pacific Ocean may freshen and the Atlantic may get saltier over the 21^{st} century (IPCC 2021). ● Dissolved oxygen in oceans could decrease by 3.2–3.7% by 2100 (IPCC 2019). Higher decreases are expected in some regions; for example, the North Pacific may experience an up to 17% decrease under the highest emissions scenario (Jewett & Romanou 2017).	● Changes in development, age of sexual maturity, timing of spawning, growth, and survival ● Altered prey availability (plankton) ● Changes in shell or skeleton growth rates and morphology ● Declines of pteropods – the basis of the marine food chain ● Decrease rates of coral reef formation ● Cascading trophic shifts ● Increased risk of invasive species establishment ● Reduced habitat complexity (increased erosion / decreased growth/ recruitment) ● Increased algal blooms ● Increased dead zones ● Limited availability of preferred prey ● Shoaling (or shallowing) of the calcium carbonate saturation depth, serving to decrease the area in the water column where it is energetically favorable to form calcium carbonate structures *Ecosystem services* ● Loss of coral reefs and supported fisheries (e.g., oyster hatcheries) ● Declines in fish populations and fishery productivity ● Decreased water quality ● Increased vulnerability of coastal communities and infrastructure Sources: Wannamaker & Rice 2000; Cooley & Doney 2009; Doney et al. 2009; CENR 2010; Kelly et al. 2011; Barton et al. 2012; Feely et al. 2012; Johnson 2012; Keener et al. 2012; WA State Blue Ribbon Panel on Ocean Acidification 2012; Griffis & Howard 2013; Kroeker et al. 2013; Mora et al. 2013; Chapin et al. 2014; Doney et al. 2014; IWG 2014; Leong et al. 2014; Wijgerde et al. 2014; Grecni et al. 2021
Regional examples of observed and projected impacts	
● Increased regional ocean acidification has been observed in the North Pacific due to seasonal upwelling of deep CO_2-rich waters (Feely et al. 2002).	

- Changes in estuarine and ocean salinity have been observed due to higher freshwater inputs from melting ice and increased precipitation in Alaska (Harris et al. 2017).
- The northern Gulf of Mexico hypoxic zone, caused by decreased DO concentrations, is the second largest in the world (Griffis & Howard 2013), and can extend up to 23,000 km^2 during the summer (Rabalais & Turner 2019).
- Increases in salinity have caused the salinization of drinking water supplies; for example, the City of Hallandale Beach in Florida had to abandon six of their eight drinking water wells (Berry et al. 2011).
- West Coast aquaculture operators have experienced lower productivity and higher mortality rates due to ocean acidification and hypoxia (Barton et al. 2012; WA State Blue Ribbon Panel on Ocean Acidification 2012).
- Certain regions, such as the coastal waters of Alaska and along the West Coast, will experience stronger acidification impacts due to cold waters with relatively high levels of CO_2 (Feely et al. 2012; Walsh et al. 2014).
- In tropical coral reef regions, such as the Pacific Islands and the Caribbean, acidification will limit reef formation and further exacerbate degradation from bleaching events (NRC 2010; IWG 2014).

Marine and Coastal Adaptation Challenges

Climate change poses significant challenges to marine and coastal resources and communities. Adaptation refers to efforts to avoid, minimize, and recover from the effects of climate change, including activities to reduce harmful impacts (e.g., inundation of coastal infrastructure) and/or take advantage of potential opportunities (e.g., longer growing seasons).

Over the last decade, significant progress has been made in the earlier phases of adaptation (e.g., building awareness, conducting assessments, planning potential strategies) while the actual implementation and evaluation of adaptation measures and projects has advanced more moderately. Adaptation progress in marine and coastal systems has been hindered by a number of factors. How these factors challenge on-the-ground decision-making is not uniform across all geographies and sectors (e.g., physical characteristics of some coastal areas may prevent landward retreat of wetlands), however, it is useful to identify the ways in which practitioners are limited by barriers. Common barriers noted in our interviews and surveys included:

- Lack of funding or budgetary constraints;
- Lack of institutional mandates to take adaptation action and/or insufficient staff capacity to respond;
- Lack of political will from government agencies to encourage and enforce implementation; and
- Lack of stakeholder awareness, support, and engagement as a result of inertia, skepticism, and/or other priorities.

Technical barriers include limitations in the availability and applicability of adaptation options for implementation; for example, what can be done and with what resources (e.g., availability of and access to information, internal staff capacity, and technical expertise, assistance, or knowledge). For example, the unique and complex hydrological and ecological nature of the Mississippi River Delta has complicated efforts to address storm surge flooding in New Orleans. During Hurricane Katrina, storm surge overtopped levees and was funneled through the Mississippi River Gulf Outlet, causing 15-feet deep floodwaters in local neighborhoods. The Lake Borgne Surge Barrier was constructed to limit saltwater inundation while a complementary pumping system helps to minimize freshwater flooding in the city.[1] These and other infrastructure elements (e.g., roads, flood control structures) have reduced the supply of sediment to the area, causing coastal lands in Louisiana to subside and making the area more vulnerable to sea level rise.

[1] Inner Harbor Navigation Canal Lake Borgne Surge Barrier: Resilient Storm Protection for New Orleans

Financial barriers to adaptation include the near- and long-term costs as well as the availability and flexibility of funding sources. In general, significant upfront capital investment is needed for infrastructure-based adaptation solutions (e.g., seawalls, storm surge barriers, saltwater intrusion barriers), which are associated with high maintenance costs and typically require continual reinvestment (Azevedo de Almeida & Mostafavi 2016; Bertule et al. 2018). Nature-based approaches, such as coastal wetlands, coral and oyster reefs, and green infrastructure, have been noted to be more cost-effective in terms of upfront and maintenance costs (Bertule et al. 2018; Reguero et al. 2018). Federal government assistance programs are available to support recovery from climate-related disasters, but tend to disproportionately favor wealthy individuals and communities (Howell & Elliott 2019). For example, several Native Alaskan coastal villages are in critical need of relocation due to thawing permafrost and increased storm surge exposure. Some of these villages, such as Newtok, Kivalina, and Shishmaref, have actively pursued relocation to different sites for over 20 years, but due to estimated costs ranging from $80–400 million, these efforts have been put on hold in favor of short-term shoreline protection measures. To date, Shishmaref has spent over $25 million on measures such as seawalls.[2]

Social or cultural barriers to adaptation may arise from conflicting interests of stakeholders and/or sectors (e.g., public vs. private landowners, public resistance, disproportionate effects on vulnerable groups). This category also includes cognitive barriers to risk perception and willingness to change individual and collective behaviors to address climate change. Some adaptation approaches may exacerbate existing inequities, leading to the displacement and forced relocation of individuals and communities, especially those already subject to a legacy of discriminatory practices. Community input and engagement early on in the adaptation planning process is critical to match adaptation actions to specific community needs (Azevedo de Almeida & Mostafavi 2016). For example, the City of Virginia Beach leveraged a number of tools to engage residents and other coastal stakeholders (e.g., developers) in the development of their Sea Level Wise strategy.[3] The city conducted public listening sessions, convening residents to better understand local-level issues with respect to flooding. During these sessions, the city gathered residents' pictures of flooding events and cross-referenced with sea level rise projections as a means to validate models.

Governance barriers include the presence and flexibility of regulations and policies, and clarity on who is responsible for on-the-ground implementation in a particular area. Decision-making in a changing climate is also challenged by uncertainty in terms of which adaptation strategies are best suited for different conditions (Eriksen et al. 2011), variable planning horizons for near- (e.g., El Niño events, king tides) and long-term (e.g., sea level rise) stressors (Ju et al. 2019), and other competing or different priorities in coastal communities (e.g., availability of affordable housing and rising property values) (Gibbs 2016; Gregg & Braddock 2020). Some existing policies and regulations are not conducive to accommodating climate adaptation measures (e.g., the federal Stafford Disaster Relief and Emergency Assistance Act provides funds in

[2] Relocating the Native Village of Shishmaref, Alaska Due to Coastal Erosion

[3] Preparing the City of Virginia Beach for the Impacts of Climate Change

response to, rather than in advance of, disasters [Perls 2020] and does not include slow-onset events such as sea level rise, drought, and erosion [Horn et al. 2021]). In many cases, adaptation has been hindered by the extent to which individuals communities and agencies can implement strategies on their own parcels of land. For example, the Boston Water and Sewer Commission (BWSC) is an independent entity that provides water and sewer services to the City of Boston, but does not own the land where existing utility structures are sited and where new structures may be needed to better address climate change. New structures such as dams as well as wastewater systems updates may be needed on privately-owned lands. While BWSC is working closely with the city and local partners that also share a sense of urgency to address sea level rise, how and where new infrastructure can and will be built remains unclear.[4]

[4] Addressing the Impacts of Sea Level Rise on Water Utilities: Boston Water and Sewer Commission

Adaptation in Practice

This section presents examples from our survey of marine and coastal adaptation projects in order to illustrate how different practitioners are planning for and responding to climate change. Titles of available case studies are provided in the footnotes and the full list of adaptation projects can be found in Appendix A, grouped by geographic region. In addition, full case studies are available on the Climate Adaptation Knowledge Exchange (CAKEx.org).

In order to assess trends, we delineate four broad categories by which to review example adaptation strategies (Gregg et al. 2011, 2012, 2016, 2017, 2018):

1. *Capacity Building*: Strategies include conducting research and collecting additional information, conducting training and planning exercises, improving public awareness and education, developing tools and resources, and monitoring impacts and effectiveness of adaptation actions.
2. *Governance and Policy*: Strategies include developing adaptation plans and policies, creating new or enhancing existing policies, and developing adaptive management strategies.
3. *Infrastructure, Planning, and Development*: Strategies include improving existing or designing new infrastructure to withstand the effects of climate change, incorporating climate change into community and land use planning, creating or modifying development measures (e.g., removing shoreline hardening, encouraging low-impact development), and developing disaster preparedness plans and policies.
4. *Natural Resource Management and Conservation*: Strategies include enhancing areas under protection, restoring critical habitats, and reducing non-climate stressors.

Capacity Building

Building the ability of individuals, organizations, and communities to prepare for, respond to, and recover from the effects of climate change is critical to enabling effective adaptation strategy design, implementation, and evaluation. Capacity to engage in adaptation and effectively adjust to climate change is frequently dictated by factors such as institutional or organizational support, funding, the quantity and quality of information, technological resources and technical skills, and social determinants such as economic and social stability.

Design or reform institutions to address climate change

Institutional support is frequently mentioned as a key requirement for effective climate adaptation by practitioners. This may include creating new institutions (e.g., organizations, committees), enhancing existing institutions by increasing organizational capacity (e.g., hiring adaptation experts), and coordinating planning and management across jurisdictions (e.g., information sharing, formal partnerships).

- The Gulf of Mexico Sea Grant Programs and the National Oceanic and Atmospheric Administration Gulf of Mexico Regional Collaboration Team created a climate change Community of Practice for extension, outreach, and education professionals in the Gulf of Mexico.[5] Since 2010, the Community of Practice has hosted annual meetings to discuss opportunities for collaboration in the region. These meetings are used by members to coordinate engagement with target audiences (e.g., local government officials, community planners, meteorologists, science educators, and city attorneys) to effectively communicate climate change impacts and adaptation measures. The Gulf of Mexico Community of Practice consists of over 300 members across 132 organizations, businesses, and local governments.

- The Southeast Florida Regional Climate Change Compact between Broward, Miami-Dade, Palm Beach, and Monroe counties is frequently touted as a hallmark of local government mitigation and adaptation coordination.[6] The partnership collaborates through its Regional Climate Action Plan, which provides implementation plans on topics such as agriculture, energy, natural systems, public health, economic resilience, emergency management, social equity, transportation, and water management. In addition to the plan, the partnership has hosted leadership summits to maintain engagement and advance progress on climate action. At the 2017 summit, the local economic development community and county mayors convened to sign a statement pledging their intent to collaborate on building regional economic resilience through stronger public-private partnerships.
- The Puerto Rico Climate Change Council was created out of a 2010 roundtable on climate change hosted by the Puerto Rico Coastal Zone Management Program (PRCCC 2021). The Council aims to use the best available scientific knowledge to assess the island's habitats and communities that are most susceptible to climate change, to develop and prioritize adaptation strategies, and to share these findings and recommendations with the community, other management agencies, the media, and businesses. Membership in the council includes over 140 partners from the scientific, management, and planning communities.
- The Water Utilities Climate Alliance is a coalition formed to help water utilities prepare for and respond to the impacts of climate change and protect water supplies.[7] This partnership of 12 water providers develops resources to support climate-informed decision-making by water utilities and serves as a network for members to exchange lessons learned.

Conduct research, studies, and assessments

This strategy includes conducting targeted research and assessing impacts and vulnerability to identify how climate change is affecting marine and coastal environments to better inform decision-making. *Targeted research* aids adaptation initiatives by establishing baselines from which to measure change or by addressing uncertainties that may hinder progress. These programs include science, traditional ecological knowledge, and citizen science efforts. *Impacts assessments* provide information on specific climatic changes of concern and consequences

[5] Sea Level Rise in the Gulf of Mexico: Awareness and Action Tools for the Climate Outreach Community of Practice
[6] Southeast Florida Regional Climate Change Compact
[7] Water Utility Climate Alliance

that may be used to inform management. *Vulnerability assessments* help managers evaluate what resources (e.g., species, communities, buildings) are at risk and why by examining what climate and non-climate stressors a resource faces (*exposure*), the degree to which those stressors affect a resource (*sensitivity*), and the resource's ability to cope with or respond to stressors (*adaptive capacity*).

- The King County Wastewater Treatment Division manages 77 major wastewater facilities, 40 of which are located adjacent to tidally-influenced water bodies in Washington.[8] An estimated one to two billion gallons of salt water enter the wastewater system every year, and sea level rise coupled with storm surge could make low-lying facilities prone to additional flooding in the future. The division evaluated the vulnerability of its facilities to flooding from sea level rise and intense storms in combination with concerns about aging infrastructure and capacity requirements. While approximately twenty facilities are at risk, the probability of imminent damage was determined to be low according to the projections used at the time. The division is now using updated sea level rise projections from the Washington Coastal Resilience Project to re-evaluate the vulnerability of these assets, and has determined that sea level rise will be the primary consideration in treatment plant retrofits and site selection.
- The Delaware Coastal Management Program created a statewide Sea Level Rise Initiative.[9] Scientists and managers worked together to compile information on potential vulnerabilities to and adaptation options for existing infrastructure and coastal habitats. Studies focused on sediment transport and accretion rates, developing a coastal monitoring network, gathering historical storm and tidal information, and developing coastal inundation maps. Products include a series of reports sharing sea level rise adaptation strategies that now serve as guidance for both state and local adaptation efforts.
- The indigenous Qikiktagrugmiut people of Kotzebue, Alaska, developed a study to document traditional knowledge on observed changes in weather patterns, snow and ice characteristics, and hunting activities over a 50-year period.[10] Changes identified by tribal elders included warmer temperatures and more extreme variations in temperatures, as well as shifts in game composition. Some of these and other projected changes were not viewed as necessarily negative as a late freeze-up may create tougher travel conditions but allow for better hunting opportunities. The entire study was conceived, developed, and conducted by tribal members and employees.
- As a biodiversity hotspot, the Hawaiian Islands are host to various research projects that aim to better understand and protect valuable species, habitats, and ecosystem services. However, the community stewards of these resources are often not engaged in research processes. In an effort to support more meaningful partnerships between researchers, natural and cultural resource practitioners, and the communities who care for and rely on local resources, the University of Hawaiʻi, Heʻeia National Estuarine Research Reserve, and Kuaʻāina Ulu ʻAuamo spearheaded the formation of the Kūlana

[8] Vulnerability of King County, Washington Wastewater Treatment Facilities to Sea Level Rise
[9] Delaware Sea Level Rise Adaptation Initiative
[10] Documenting Traditional Ecological Knowledge in Northwest Alaska

Noiʻi, or research guidelines, to promote collaborative, mutually-beneficial knowledge exchange.[11] The guidelines include best practices collected from insights of the Kuaʻāina Ulu ʻAuamo Research Committee, Molokaʻi Climate Change Collaboration, and a literature review of other collaborative research efforts in Native Hawaiian, Native American, and Aboriginal Canadian communities.

Conduct training and planning exercises

This strategy includes gathering stakeholders in trainings and workshops to understand how the climate is changing, evaluate how climate change is likely to affect resources of concern, and develop adaptation strategies and actionable plans for implementation.

- The National Oceanic and Atmospheric Administration's Center for Sponsored Coastal Ocean Research invited over 50 coastal zone managers and stakeholders from North Carolina to participate in a workshop to help plan for and mitigate the regional climate change impacts of future sea level rise and increased storm intensity.[12] The purpose of the workshop was to use stakeholder input to help scientists design management products such as user-friendly mapping and modeling tools to facilitate planning for the effects of long-term sea level rise. This effort served as a pilot project for the broader Effects of Sea Level Rise Program (formerly known as the Ecological Effects of Sea Level Rise Program), which has expanded to include projects in California, Florida, Hawaii, and Maryland.
- Nuestra Casa, a non-profit organization dedicated to supporting Latino families in East Palo Alto and surrounding cities in San Mateo County, California, trains community members to become climate justice and equity leaders.[13] Their training programs center personal experience and local expertise as a means to identify community vulnerabilities, needs, and strengths, and enable residents to become more informed and effective advocates. The Environmental Justice program was created to listen to community members' concerns and aid in the creation of community-developed solutions for consideration by government officials in local policies and plans. Examples include providing feedback on local development projects by the Metropolitan Transportation Commission, supporting the development of an environmental justice and social equity amendment to the San Francisco Bay Plan, and establishing collaborative partnerships with local public agencies such as the Bay Area Regional Health Inequities Initiative to address climate change.
- The National Marine Sanctuary of American Samoa convened a community vulnerability assessment and adaptation planning workshop series in 2016 to engage stakeholders that rely on the sanctuary's resources, including village leaders, residents, resource managers, scientists, local government officials, and business owners (Score 2017). The sanctuary includes important marine and coastal habitats and species across Tutuila, Aunuʻu, Taʻū, and Swains islands as well as Rose Atoll, including coral reefs, mangroves,

[11] A Coastal Adaptation Case Story: The Kūlana Noiʻi and Community-Research Partnerships
[12] Planning for the Impacts of Sea Level Rise and Climate Change in North Carolina
[13] A Coastal Adaptation Case Story: The Nuestra Casa Environmental Justice Program

reef fish, sharks and rays, sea turtles, and giant clams. The workshops included training on climate science and adaptation planning, and provided opportunities for discussion between the community members about individual and collective actions that could be taken. For example, while the scientific and management community has long recognized the value of mangroves in stabilizing shorelines and providing critical fish habitat, these services are not highly valued by the public. In addition, mangroves are protected through various local and territorial regulations, but these policies are rarely enforced. Therefore a key adaptation strategy for the group was creating a mangrove education and outreach campaign to raise awareness of the habitat's benefits and encourage local enforcement of mangrove protection guidelines.

Increase/improve public awareness, education, and outreach efforts

This strategy includes engaging the public in the climate conversation through formal and informal mechanisms (e.g., curricula, websites, presentations), particularly as a means to amplify public buy-in and support for adaptation measures.

- The Tampa Bay Estuary (Florida) and Coastal Bend Bays and Estuaries (Texas) Programs published the Gulf Coast Community Handbook in 2012.[14] The handbook acts as a toolkit of options for the incorporation of climate change impacts into restoration efforts. It provides specific adaptation strategies and recommendations to communities to help them make informed decisions regarding their restoration priorities. The document illustrates how climate change can be incorporated into habitat restoration projects to enhance long-term resilience.
- The University of the Virgin Islands, through the Virgin Islands Established Program to Stimulate Competitive Research (VI-EPSCoR) and the Virgin Islands Marine Advisory Service (VIMAS), is connecting local communities to ecosystem restoration, natural resources, hurricane impact education, and environmental stewardship opportunities (VI-ESPCoR 2021). For example, the Ridge to Reef project identifies how human activities impact the natural resilience of the Virgin Islands' coral reefs and coastal ecosystems, and incorporates STEM education for underrepresented students and workforce training initiatives.

Create/enhance technical resources and tools

This strategy includes creating or improving resources that may support climate-informed decision-making, such as forecasting and modeling tools, decision support tools, guidance documents, and maps.

- The Rhode Island Coastal Resources Management Council is charged with regulating activities along the state's coastline.[15] The Council has created several resources, such as the Coastal Hazard Application, which aims to guide development away from vulnerable coastal areas by increasing awareness of the potential hazards of sea level rise, storm

[14] Creating a Gulf Coast Community Handbook for Restoration and Adaptation
[15] Planning for Sea Level Rise in Rhode Island's Coastal Management Program

surge, and coastal erosion among the development community (e.g., property owners, builders, realtors, financial institutions and insurers). The application is required for all proposed new and substantially improved buildings and infrastructure in the coastal zone.

- The U.S. Environmental Protection Agency's Creating Resilient Water Utilities Program provides tools and technical assistance to help water utilities prepare for climate change.[16] These tools include the Climate Resilience Evaluation and Assessment Tool, which assists utilities in assessing risks from climate change on critical assets; the Resilient Strategies Guide for Water Utilities, which guides users through the identification and prioritization of mitigation and adaptation strategies; and the Storm Surge Inundation Map, which allows users to explore the potential effects of flooding caused by hurricanes.
- The Nature Conservancy created the Coastal Resilience program to help planners, managers, and other decision makers visualize future climate scenarios and identify adaptation options.[17] An interactive mapping tool allows users to visualize different inundation and flooding scenarios; analyze the potential ecological, social, and economic impacts of each scenario; and identify adaptation options that minimize losses to natural and human communities. First piloted in Long Island Sound, the program now includes projects in 17 coastal states as well as locations in Caribbean, Mexico, and Central America.

Create/enhance financial and investment mechanisms

Adequate financial resources are necessary to fund adaptation planning, implementation, and evaluation efforts. The availability and flexibility of funding, or lack thereof, is frequently noted as a barrier in adaptation projects. This strategy includes measures to mainstream adaptation funding in organizational and agency budgets, diversify funding sources, and provide assistance to vulnerable individuals and communities—both direct funding as well as support on complex federal and state disaster recovery assistance applications. Other investments may include workforce development programs (e.g., green jobs creation and training) and related efforts to transform employment opportunities in a changing climate.

- The San Diego Foundation manages and distributes funds to address a variety of community issues in the area. The Climate Initiative supports regional efforts to increase community awareness of climate change.[18] The Foundation is supporting scientific research to inform public policy, partnering with local governments to address climate change, and funding climate action planning by local cities and public agencies. Since 2006, the San Diego Foundation has invested more than $3.5 million in these efforts. Some funded efforts include: the City of San Diego's Climate Action Plan; the City of

[16] Creating Resilient Water Utilities Program

[17] Coastal Resilience: Visualizing Climate Change Impacts and Coastal Hazards and Implementing Solutions in Long Island Sound

[18] The San Diego Foundation's Climate Program

Chula Vista's Water Stewardship Plan; and the City of Imperial Beach's Sea Level Rise Assessment.

- The New York Climate Smart Communities program is a partnership between local communities and state agencies designed to address climate change.[19] Communities voluntarily sign a Climate Smart Communities Pledge and can go through an additional certification process, which allows communities to qualify for funding to support the implementation of mitigation and adaptation actions. As of 2021, 70 certified communities are part of the program, most of which are located along the Atlantic and Great Lakes coasts.
- The Massachusetts Department of Fish and Game's Division of Ecological Restoration provides technical and financial assistance to local partners to plan and implement projects that incorporate climate adaptation into habitat restoration projects to build community resilience.[20] Through a competitive process for project selection, applicants can obtain technical and project management assistance and incentive funding.

Monitor and evaluate environmental and climatic conditions and adaptation effectiveness

Monitoring and evaluation are key elements of the climate adaptation process. This strategy includes monitoring to document environmental or climatic changes and associated effects on resources of concern and provide early warning signals for necessary management interventions, as well as evaluation to understand if adaptation strategies are being implemented and with what degree of effectiveness. To date, less effort has been dedicated to evaluating adaptation effectiveness.

- Tybee Island is located off the southeastern coast of the United States, about 20 miles from the City of Savannah and within Chatham County, Georgia. The area has historically flooded due to extreme weather and tidal events and is vulnerable to continued flooding from sea level rise and increased storms. Georgia Sea Grant and the City of Tybee Island partnered on a sea level rise adaptation plan.[21] Since its release in April 2016, every strategy has been implemented. The city and partners are also implementing several monitoring activities to evaluate: (1) the success of the plan's recommended living shoreline project; (2) how the dunes are responding to restoration and reestablishment of plant communities; and (3) how municipal well pumps are performing in light of flooding.
- The Nature Conservancy manages the Port Susan Bay Preserve in Washington State. Coastal erosion caused by water diversions, development, flooding, and sea level rise have changed the geomorphology of the ecosystem over time. In response, staff and volunteers have removed invasive species, reintroduced large woody debris, and removed a dike to increase the area of tidal marshland.[22] Monitoring has shown that

[19] New York's Climate Smart Communities Program

[20] Helping Massachusetts Coastal Communities Adapt to Climate Change

[21] Tybee Island Sea Level Rise Adaptation Plan

[22] Effects of Sea Level Rise in Port Susan Bay, Washington

while marsh restoration and sediment accretion occurred much slower than was expected, current accretion rates are projected to keep pace with rising sea levels.

- The Hawaii Ocean Resources Management Plan provides a framework for marine and coastal management that considers ecological, cultural, and economic needs throughout the archipelago.[23] The plan is updated every five years using up-to-date science and stakeholder input. The most recent plan, released in 2020, focuses on promoting the connections between land-use activities and the sea, Native Hawaiian ecological knowledge, collaboration and stewardship, and climate adaptation. Partners track progress towards implementation using a variety of metrics. Examples include the number of county general plans and county development plans that include adaptation; the number of shoreline erosion studies and maps completed/updated; and miles of beaches conserved or restored using nature-based practices. The Ocean Resources Management Plan Dashboard tracks the implementation of the plan's management priorities. For example, as of 2020, nearly all counties in Hawaii incorporated climate change adaptation into two or more plans.

Governance and Policy

Climate change has far-reaching impacts across jurisdictions and scales. Mainstreaming adaptation into policies and plans is important in order to adequately respond to climate change, and governmental and organizational mandates can amplify climate-informed decision-making.

Develop/implement adaptation plans

Most adaptation plans typically identify potential climate change impacts of concern, adaptation goals and strategies, and guidelines for the implementation of adaptation actions.

- The Greater Farallones National Marine Sanctuary and partners collaborated to evaluate the climate vulnerability of 44 marine and coastal resources of importance to the north-central California.[24] The study area included the entirety of the Greater Farallones and Cordell Bank sanctuaries and the northern extent of the Monterey Bay National Marine Sanctuary. Building off of this assessment, the Greater Farallones National Marine Sanctuary released a climate adaptation plan in 2016. The plan is a product of recommendations developed by the Sanctuary Advisory Council and includes 26 strategies, including measures to protect the region's most vulnerable offshore species (e.g., deep sea coral species, baleen whale species, and pteropods and other water column indicator species) and prioritize the implementation of living shorelines. The Sanctuary worked through the Resilient Lands and Waters Initiative and alongside partners such as Marin County to identify priority sites for these strategies.

[23] Hawaiʻi Ocean Resources Management Plan: Planning for natural, cultural, and socioeconomic needs

[24] Climate Change Effects and Management Responses in the Greater Farallones and Cordell Bank National Marine Sanctuaries

- The Broward County Climate Change Task Force was created to develop recommendations for the Board of County Commissioners on climate mitigation and adaptation strategies.[25] The Broward Climate Change Action Plan, first released in 2010, included a series of recommendations with the analysis of sea level rise projections, greenhouse gas emissions and sources, and a coastal vulnerability assessment. In 2015, the Action Plan was updated to include about 100 strategic actions to address the economic, environmental, and social impacts of climate change. All of the actions (e.g., 95 actions, 23 high-priority actions) of the 2015 Action Plan have been completed, and a recent update was completed in 2020. The updated plan includes county-wide efforts to address mitigation and adaptation options for transportation, infrastructure, and energy systems.

Create new or enhance existing policies or regulations

Policies and regulations can mandate adaptation action. Many existing policies have been adjusted to account for the reality of climate change; however, when existing mechanisms are unavailable or insufficient, new policies may be required.

- The Washington Department of Natural Resources manages 2.6 million acres of state-owned aquatic lands and has a legal obligation to prepare for climate change impacts, such as sea level rise, ocean acidification, and erosion, as it holds these lands in the public trust.[26] In preparing for sea level rise, the department has to consider jurisdictional issues and property ownership concerns because they have no existing authority over upland regions that may be inundated over time, which decreases the department's ability to proactively plan for climate change. The department is working to implement policies to increase resilience (e.g., reduce non-climate stressors, encourage restoration and conservation), encourage new uses of state-owned aquatic lands (e.g., wind and tidal energy capabilities), and facilitate managed retreat (e.g., assist property owners in creating buffers to allow landward migration, utilize rolling easements). In 2020, the department released an internal climate resilience plan, and is working to build the scientific knowledge base that can best inform recommendations for landowners, policies, and leases.
- The New Jersey Office of Planning Advocacy uses the Development and Redevelopment Plan to guide local land-use policies and ordinances.[27] The department reviews amendments regularly and prioritizes community endorsements of the plan. To satisfy the requirements to get a land-use plan endorsed, communities must complete a rigorous stakeholder outreach process. In 2019, Governor Phil Murphy signed an Executive Order mandating the inclusion of climate change impacts (e.g., sea level rise and flooding) for the plan endorsement process. Municipalities interested in undergoing the plan endorsement process are required to develop climate resilience plans. The department is working with communities to craft land-use ordinances that include

[25] Broward County Climate Change Task Force and Climate Change Initiatives
[26] Preparing for Climate Change on State-Owned Aquatic Lands in Washington State
[27] New Jersey Climate Change Adaptation Using Community Plan Endorsements

strategies to reduce vulnerabilities to flooding and extreme tidal flux, such as reducing the amount of impervious surface along the coast, protecting wetlands, and restoring coastal sand dunes.
- In February 2013, the Broward County Board of Commissioners added a Climate Change Element to the county's comprehensive plan.[28] The element focuses on efforts to improve coordination and preparedness to better respond to climate change impacts on transportation, the built environment, natural systems, and water resources and services. Policy 19.3.13 of the Climate Change Element mandates that the county work with local municipalities to designate Adaptation Action Areas (AAAs), defined by Florida Statue 163.3177(6)(g)10 as areas that experience flooding due to extreme tides, storm surge, and sea level rise. Designation of AAAs helps counties prioritize funding for adaptation planning and investment. While Florida amended state law in 2012 to define AAAs and suggest them as an optional component of local comprehensive plans, Broward County was the first to take advantage of this new planning tool.

Develop/implement adaptive management strategies

Adaptive management is an iterative process wherein practitioners test specific actions to determine what approaches work best and why and make adjustments as needed. Adaptive management options are particularly useful in situations of high uncertainty.

- The South Bay Salt Pond Restoration Project is the largest tidal restoration project on the West Coast, and will transform 15,100 acres to a mosaic of tidal wetlands and managed pond habitats that can buffer the area against sea level rise, flooding, and erosion.[29] The project uses an adaptive management approach to implement restoration in multiple phases. Lessons learned from each phase of the project inform future phases and determine the final habitat configuration, and each restoration target is associated with triggers (e.g., indications that targets are not being met) and potential actions to change course if needed. The project team uses monitoring and a tracking scorecard to indicate if progress on restoration activities are meeting expectations or not. For example, targeted Phase 1 studies found that restoration activities successfully led to the return of several marsh species (e.g., salt marsh harvest mice), migratory waterbirds, and native fish species.
- The Alligator River National Wildlife Refuge is located in Dare and Hyde Counties, North Carolina. A pilot project was created to evaluate the effects of different adaptation strategies on areas impacted (or likely to be impacted) by sea level rise.[30] Strategies tested included: creating oyster reefs to dissipate wave energy, installing water control structures to prevent saltwater intrusion, and planting salt- and flood-tolerant vegetation to enhance future shoreline stability and counteract expected habitat loss. The partners created over 1,900 ft of oyster reef habitat, protected 11 miles of

[28] Broward County Climate Change Task Force and Climate Change Initiatives
[29] South Bay Salt Pond Restoration Project
[30] Alligator River National Wildlife Refuge/Albemarle-Pamlico Peninsula Climate Adaptation Project

shoreline, installed two large check valve structures to limit saltwater intrusion, and planted 20,000 flood-tolerant trees across 40 acres. The project has since expanded to encompass Pocosin Lakes and Great Dismal Swamp where restoration recommendations and strategies for communities impacted by sea level rise are the primary focus. Several efforts are underway to test adaptation strategies in the expanded area, including continued oyster habitat creation and marsh restoration.

- An adaptation pathways approach is being used by the City of Santa Cruz wherein management options are associated with desired outcomes and triggers to identify potential adjustments that can be made if needed. This approach helps balance concerns about uncertainty in terms of climate projections and sociopolitical changes over time in climate adaptation planning. For example, adaptation pathways were identified for the protection, conservation, and restoration of the city's beaches in the *Beaches Climate Adaptation Policy Response Strategy Technical Report* (Clark et al. 2020). Adaptation pathways for the West Cliff pocket beaches include (1) using beach nourishment in the near-term at select beaches, (2) upgrading stormwater infrastructure, (3) maintaining or repairing shoreline armoring to protect infrastructure and/or retain sand within priority beaches, and (4) implementing a managed retreat strategy. The city may implement only some or all of these strategies over time in order to protect highly-valued pocket beaches for as long as is feasible given climate change.

Develop emergency preparedness and response plans and policies

Climate change may exacerbate natural disasters and emergencies, including droughts, floods, and severe storms that will harm people, infrastructure, and ecosystems. Disaster preparedness plans can help communities identify risks and develop response and recovery options, while climate-informed emergency services (e.g., police, fire, medical) policies will also help to reduce impacts.

- The Cape Cod Commission developed disaster preparedness materials, including the Cape Cod Emergency Preparedness Handbook, to assist local officials and residents prepare for coastal hazard risks.[31] The Commission coordinates and helps local communities develop hazard mitigation plans. The 2010 Multi-Hazard Mitigation Plan for Barnstable County addresses the county's vulnerability to flooding, wind, snow and ice, drought, earthquakes, hurricanes, sea level rise, shoreline erosion, increased coastal storms, and increased precipitation. By assisting towns in developing local plans, the Commission can help towns qualify for pre- and post-disaster planning funds. The Commission has since expanded its climate adaptation work to include stakeholder engagement on coastal vulnerabilities, a socioeconomic analysis of coastal ecosystem services (e.g., property values), and the development of the Cape Cod Coastal Planner, which helps users identify hazards of concern and available adaptation options.
- Waveland, Mississippi is a small town in the Gulf of Mexico where many residents live less than 15 meters above sea level. Frequent floods and resulting costs of insurance rates and home repairs are driving residents out of the city. The city developed a hazard

[31] Disaster Preparedness and Response Planning in Barnstable County, Cape Cod

mitigation plan to address risks, including climate change (e.g., storm surge, sea level rise), coastal/canal bank erosion, floods (e.g., 100/500 year floods and localized flooding), and hurricanes/tropical storms.[32] Since the plan's release in 2013, the City of Waveland has begun to implement priority projects to ameliorate municipal risk. For example, since 90% of the city lies in a special flood hazard area, the city is implementing a $6.9 million project aimed at improving floodwater drainage. Implementation is ongoing but progress has been constrained by limits in staffing and funding.

- The City of Santa Cruz has been a leader in climate change action for nearly three decades.[33] The first formal plan that identified climate change as a major threat to the city was the Local Hazards Mitigation Plan 2007–2012. It identified floods, drought, coastal erosion, and wildfires as climate-related threats and identified response strategies. The city adopted an updated version of the plan in 2017 and released a climate adaptation plan in 2018. Together, these plans prioritize key actions such as the protection of coastal water infrastructure, relocating city building out of flood zones, and monitoring wastewater and stormwater pumping stations.

Infrastructure, Planning, and Development

This category includes strategies such as protecting critical coastal infrastructure, and creating or modifying coastal development measures (e.g., removing shoreline hardening, encouraging low-impact development) to increase shoreline resilience.

Make infrastructure resistant or resilient to climate change

This strategy includes incorporating climate change considerations into the design, retrofitting, and development of infrastructure, such as coastal roads and buildings, utility systems, and other structures (e.g., docks, piers, aquaculture facilities).

- In the 1980s, the Massachusetts Water Resources Authority began to plan for a new wastewater treatment plant on Deer Island in Boston Harbor.[34] The treatment plant's effluent is discharged through a gravity-fed pipe into the harbor. Planners were concerned that projected sea level rise would disrupt the gravity-fed pipe, requiring the installation of pumps. The planners decided to elevate portions of the wastewater treatment plant by 1.9 feet to accommodate for projected sea level changes through 2050—the planned life of the facility—making it one of the first climate-informed infrastructure designs. More recent sea level rise projections indicate that the decision to elevate the plant will likely protect the infrastructure over the next century, well beyond the facility's planned lifetime.
- The downtown area of Olympia, Washington was built on reclaimed land created with hydraulic fill within Budd Inlet, and is 18–20 feet above sea level.[35] During extremely

[32] Waveland's Climate-Informed Local Hazard Mitigation Plan Update
[33] City of Santa Cruz Climate Action Program
[34] Proactive Incorporation of Sea Level Rise into the Design of the Deer Island Wastewater Treatment Plant
[35] Planning for Sea Level Rise in Olympia, Washington

high tides, however, the water's edge can reach 18 feet. Under different sea level rise scenarios, these high tides could transport saltwater through the city's stormwater system and into the city, flooding streets and causing water damage. In some parts of the city where there are combined stormwater and wastewater systems, higher sea levels could flood the pipes, potentially exceeding the capacity of Olympia's wastewater treatment facility and causing wastewater contamination. City planners have established priority implementation actions to respond to these risks, including consolidating the number of stormwater outfalls and installing underground water pumps.

- The Inner Harbor Navigation Canal Lake Borgne Surge Barrier, the largest civil engineering project in the history of the U.S. Army Corps of Engineers, was designed to reduce storm surge and flood risk for New Orleans after devastating flooding during Hurricane Katrina.[36] The 26-foot-high, 10,000-foot-long storm surge barrier minimizes 100-year flood risk, and features three navigational gates that can be raised in anticipation of storm surge. One of these gates is also buoyant, allowing it to adjust to storm surge changes associated with sea level rise. The surge barrier relocated the focal point of flood protection infrastructure away from the city center, and eliminated the need to elevate 30 miles of existing levees and floodwalls. The barrier operates as part of the $14.5 billion Hurricane Storm Damage Risk Reduction System. During Hurricane Ida in August 2021, the barrier functioned effectively, preventing flooding into the city.
- Brooklyn's Seagate Rehabilitation and Nursing Center is elevated almost 30 feet above ground to accommodate flooding. In addition, the facility's emergency power supply is capable of maintaining power to all systems and equipment during power outages. During Superstorm Sandy, the center was able to withstand the floodwaters, the emergency power supply supported services for four days during the local power outage, and staff and patients were able to safely shelter in place during the storm due to the center's sufficient supply of food and medical supplies (Gregg et al. 2019).

Create or modify shoreline development measures

This strategy includes incorporating climate change into shoreline management, including shoreline armoring (e.g., rip rap, bulkheads), natural and green infrastructure (e.g., "living" shorelines, vegetation buffers), and policy and planning measures (e.g., managed retreat, setbacks, low-impact development, limiting development in vulnerable areas). Protective barriers such as bulkheads and seawalls may temporarily reduce risks associated with coastal flooding, but impede natural accretionary processes, exacerbate erosion, and require continual maintenance. Natural infrastructure approaches (e.g., coral reefs, oyster reefs, coastal wetlands) provide various ecosystem services and are typically associated with lower maintenance costs. Policy measures, such as setbacks, zoning, and managed retreat, require extensive coordination with residents and industry, but can be effective tools for maintaining coastal communities in light of climate change.

[36] Inner Harbor Navigation Canal Lake Borgne Surge Barrier: Resilient Storm Surge Protection for New Orleans

- Save The Bay in Providence, Rhode Island, has worked on several coastal habitat restoration projects to increase coastal resilience to storm surge and sea level rise.[37] Efforts are ongoing to reestablish native salt marsh plant communities, and decrease the height and vigor of the invasive *Phragmites australis*. Additional efforts include dam removal projects and creating bay-friendly backyards. Over 650 dams in Rhode Island have been constructed for the purposes of water and power supply and recreation. Save The Bay has partnered with federal, state, and local groups to remove dams to restore natural habitat and wildlife, improve natural sediment fluxes and beach nourishment, and improve water quality (e.g., temperatures, dissolved oxygen levels). Save The Bay also educates local landowners on environmentally-friendly landscape designs and practices. The *Bay-Friendly Living* guide provides recommendations to homeowners on how to limit polluted water runoff and increase watershed resilience.
- Despite the long-term use of stabilizing structures, the City of Pacifica, California has battled chronic flooding and coastal erosion for decades.[38] In the early 1990s, the city partnered with the California Coastal Conservancy, Pacifica Land Trust, and Philip Williams and Associates to develop a managed retreat strategy. The project focused on restoring natural processes and habitats through the removal and/or relocation of structures, expansion of tidally influenced wetlands, and restoration of eroding banks. To further protect its coastline, the city is developing a sea level rise adaptation plan in addition to updating its Local Coastal Program to account for sea level rise.
- Kailua Beach, located on the island of Oahu, is at risk from a number of threats including overdevelopment and sea level rise.[39] The University of Hawaiʻi Sea Grant College Program, Hawaiʻi Department of Land and Natural Resources, and the Office of Conservation and Coastal Lands developed a comprehensive beach and dune management and land-use development plan for Kailua Beach. The plan provides long-term recommendations and strategies for adapting to climate change. Based on the model projections, in the next 50 years the dune morphology will change at Kailua Beach, although not substantially. In the next 100 years, however, with approximately three feet of sea level rise, the dunes could shift behind existing homes. One potential adaptation option is the use of a coastal construction control line that is established to prohibit seaward development; this line could be adjusted every five years to account for beach changes.
- Newtok, a coastal Native Alaskan community, has been attempting to relocate due to ongoing shoreline erosion from ice melt, coastal storms, and thawing permafrost.[40] Newtok is currently building a new village (Mertarvik) on higher ground nine miles away for its 400 residents. Funding constraints have limited progress on relocation efforts. For example, the Innovative Readiness Training Program constructed an access road from the barge landing to the new village site in 2010, and in 2011, they started working on an evacuation shelter to protect the current village and community members from

[37] Increasing Coastal Resilience through Restoration and Education in Narragansett Bay, Rhode Island
[38] Restoration and Managed Retreat of Pacifica State Beach
[39] Kailua Beach and Dune Management Plan
[40] Relocating the Village of Newtok, Alaska due to Coastal Erosion

flooding. However, construction of the evacuation shelter and relocation efforts were temporarily halted due to funding constraints as well as internal political disputes. Part of the funding issue, according to local experts, was that neither the state nor federal government acknowledge that climate change qualifies for disaster relief funds (i.e. Stafford Act). Funds have been gathered in a piecemeal fashion from sources such as the State of Alaska, Bureau of Indian Affairs, Denali Commission, and Housing and Urban Development, and are being used to build the Mertarvik Evacuation Center and new housing units. In 2018, the Federal Emergency Management Agency partnered with the Alaska Division of Homeland Security and Emergency Management to buy seven homes, allowing approximately 50 residents to move.

- The village of Taholah, one of two major tribal population centers of the Quinault Indian Nation, is located at the confluence of the Quinault River and the Pacific Ocean. Increased coastal and riverine flooding are combining to damage existing infrastructure and erode available space. The existing village is home to about 660 residents in 175 homes, along with a school, post office, stores, and tribal office spaces. The tribe decided to relocate the lower portion of the village to about 120 feet above sea level via a Relocation Master Plan. The upland relocation site was selected by considering the Federal Emergency Management Agency's 1-in-100-year flood zone and the tsunami hazard zone (Quinault Indian Nation Community Development and Planning Department 2017). Buildings are under construction at the new site, including a community center, school, and housing. H.R. 4502, an appropriations bill recently passed in Congress, included funds to support tribal relocation efforts.

Develop climate-informed communities/community-led adaptation

Local engagement and planning are key to the implementation of adaptation measures. Community-led efforts enable residents to engage in problem solving and develop local solutions that are reflective of a community's unique characteristics. This includes opportunities to reflect on how social determinants, such as cost of living, race, transportation options, and general environmental quality, affect a community's ability to cope with climate change, and build the capacity of residents and community leaders to implement adaptation measures.

- The Galveston Bay Report Card provides a scientific assessment of the Bay's health in order to inform and engage community members on actions that protect and preserve the estuary.[41] Residents indicated that they wanted to learn more about how climate change is impacting Galveston Bay, particularly changes in water temperatures, sea level rise, pH, dissolved oxygen, and freshwater flows. The Report Card aims to raise public awareness and promote collective action (e.g., reducing personal energy usage, volunteering on oyster reef restoration). In 2019, the Report Card Champion Program was created to train local community groups and students on how to better advocate for the protection and conservation of the Bay.

[41] The Galveston Bay Report Card: Coastal Adaptation Initiative

- The Gulf Restoration Network (now Healthy Gulf) is an environmental advocacy organization that seeks to unite residents to protect and restore natural resources.[42] By empowering local communities, taking legal action against industries that have degraded Gulf Coast and community resilience, and monitoring government action to ensure sustainable management of contemporary natural resources, Healthy Gulf is restoring and maintaining the natural systems that both define and protect Gulf Coast communities. The Sustaining Coastal Communities Initiative and the Defending Wetlands Initiative are helping regional communities restore natural features to enhance storm protection and resilience. A large part of these initiatives focuses on corporate accountability, demanding that corporate activities that have increased community vulnerability to climate change impacts be rectified. For example, Healthy Gulf is ensuring that fines from the BP Deepwater Horizon oil spill are used for coastal restoration projects that enhance resilience. Healthy Gulf also works directly with communities impacted by unsustainable corporate and governmental practices, and has helped file several lawsuits to hold companies accountable for resilience losses.

Natural Resource Management and Conservation

Incorporating climate adaptation into natural resource management and conservation is key to decrease vulnerability and increase resilience of ecosystems and the services they provide, such as food, nutrient and water cycling, flood and erosion control, cultural values, and recreational opportunities.

Incorporate climate change into restoration efforts

Restoration activities generally increase the resilience of ecosystems to different stressors. For example, coastal habitats such as tidal wetlands act as natural buffers to coastal flooding; restoring degraded habitats can help recover their ability to provide critical ecosystem services such as flood protection, water quality abatement, and recreational opportunities.

- The Louisiana Coastal Protection and Restoration Authority first developed a statewide coastal restoration and hurricane protection plan in 2007 to coordinate federal, state, and local efforts to restore habitats and develop structural storm protection measures.[43] Terrebonne Parish, the second largest parish in Louisiana, scaled these state-level recommendations to community-level actions and priorities. The Comprehensive Plan for Coastal Restoration in Terrebonne Parish presents a systematic way to rate, prioritize, and implement restoration and protection projects aimed at enhancing coastal resilience. The Terrebonne Parish Office of Coastal Restoration and Preservation is using the comprehensive plan to help justify and obtain grants to implement priority projects. The Terrebonne Parish Adaptation Strategy, released in 2019, prioritizes coastal restoration and protection projects as the state is losing land faster than it can be restored.

[42] Using Advocacy to Enhance Gulf Coast Resilience

[43] Systematically Prioritizing Restoration Projects in Terrebonne Parish, Louisiana

- Waiheʻe Refuge, a 277-acre plot of land located on the north shore of Maui, was purchased by the Maui Coastal Land Trust in 2004.[44] The coastal refuge is home to wetlands, marine riparian habitat, and one of the largest remaining, intact sand dune systems in all of Hawaiʻi. It is also acutely vulnerable to sea level rise and erosion. Managers elected to avoid the use of hardened shorelines and instead focus on habitat restoration efforts, including removing invasive plants and replanting with native species, to increase the site's resilience to climate change. When the land trust first acquired the Waiheʻe Refuge, roughly 95% of the plants found on the site were considered to be invasive species. Native and endangered bird species have since returned to the site, including the aeʻo (Hawaiian stilt) and ʻalae keʻokeʻo (Hawaiian coot).

Enhance habitat connectivity and areas under protection

This strategy includes improving the management of existing protected areas and refugia, increasing the size and amount of protected areas (including multiple forms of each habitat type and a diversity of habitat types), and maintaining functional networks of connected terrestrial and aquatic habitats. Many coastal habitats are fragmented by human-caused modifications such as roads and other development. Maintaining the existence of protected habitats, climate refugia, and connections between these areas helps to ensure that species can move for the purposes of reproduction, food, and shelter, particularly as climate change drives shifts in species' ranges (e.g., higher elevations, greater depths). This includes protecting space for upland or inland coastal habitat migration via conservation easements and other land acquisition measures, and identifying and protecting climate refugia or areas that are likely to maintain more stable climate conditions over time.

- The Tongass Conservation Strategy created a large network of old-growth forest within the coastal Tongass National Forest to prohibit timber harvest and road construction.[45] The reserve network was created to protect species of concern and to maintain viable wildlife populations associated with old-growth forests. While climate change was not an explicit driver of the development of the reserve network, the protected lands may act as a source of resilience in the future. Large tracts of interconnected lands could allow species to migrate as the climate shifts. In 2020, the Trump Administration re-opened the forest to clear-cut logging and eliminated roadless-rule protections, which was then quickly reversed in 2021 by the Biden Administration.
- The State of Maryland pioneered a green infrastructure assessment mapping tool called GreenPrint to assess the relative ecological importance of land parcels and help managers prioritize land acquisition and restoration priorities.[46] A new layer of information was added to indicate climate vulnerabilities and adaptation opportunities, such as areas likely to be inundated by 2050. Building off of GreenPrint, the Department of Natural Resources identified priority Wetland Adaptation Areas where wetlands will

[44] Waiheʻe Refuge Restoration Project
[45] The Tongass National Forest Conservation Strategy
[46] Integrating Climate Change Adaptation Strategies into Maryland's Coastal Land Conservation Targeting

likely migrate inland as sea level rises. These tools help users review state conservation easements and acquisitions for site-level attributes that support climate change adaptation, such as storm surge abatement and restoration opportunities to increase coastal ecosystem health and/or carbon sequestration potential.

Reduce local climate or related change

Reducing local change reduces the vulnerability of natural systems. For example, reducing deforestation and increasing riparian cover can reduce the risk of localized flooding and erosion, while local sea level rise rates may be slowed by reducing water and oil/gas withdrawals or restoring natural sedimentary processes.

- The shorelines of Aramburu Island, a 17-acre wildlife preserve in Marin County, are slowly eroding and sea level rise and increasingly severe storms are expected to exacerbate the problem.[47] Restoration project leads used sediment renourishment, invasive species removal, and native species planting to reduce erosion and increase sand and gravel habitat extent in the area.
- The Oro Loma Sanitary District constructed a horizontal levee storm surge barrier as a way to address concerns about flood control, water quality, and habitat quality in light of sea level rise and coastal flooding.[48] Rather than a vertical wall, a horizontal levee uses natural vegetation planted on a graduated slope to buffer wave energy. As sea levels rise, the levee will enhance sediment accretion, filter pollutants from wastewater treatment effluent, and serve as upland transitional habitat. This project, completed in 2017, was developed as a demonstration site and is approximately 165 meters in length. In 2019, the East Bay Dischargers Authority received funds from the San Francisco Bay Water Quality Improvement Fund to develop, design, and permit the First Mile Horizontal Levee Project, which seeks to build off of the success of the Oro Loma horizontal levee concept.

Reduce non-climate stressors likely to interact with climate change

Marine and coastal environments and communities are already subjected to numerous non-climate stressors, which may make them more vulnerable to the effects of climate change. The cumulative effects of stressors, such as water withdrawals, pollution, and invasive species, reduce the overall resilience of natural habitats.

- The Baldwin County, Alabama Grasses in Classes program worked with students to grow native plants for wetland and dune restoration projects.[49] They removed the invasive common reed (*Phragmites*) and replanted black needle rush (*Juncus romerianus*) and smooth cordgrass (*Spartina alterniflora*) at the Weeks Bay National Estuarine Research Reserve. In addition, the students helped to maintain and monitor native plant nurseries, and assisted scientists with monitoring at restoration sites when possible.

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[47] Aramburu Island Ecological Enhancement Project
[48] Using Horizontal Levees to Buffer the Effects of Sea Level Rise in San Francisco Bay
[49] Alabama's Baldwin County Grasses in Classes Program

Thousands of volunteer hours have been dedicated to grass and shoreline restoration projects at Bicentennial Park, Little Lagoon, and Boggy Point as well as sites around Weeks Bay, Gulf State Park, 5 Rivers Delta Resource Center, Camp Beckwith, Perdido Pass Beach, and the Bon Secour National Wildlife Refuge. This pilot project has been adapted to other programs in Florida and Maryland.

- The North Pacific Fishery Management Council adopted a precautionary approach to commercial fishing activities within the Exclusive Economic Zone of the State of Alaska, which includes the Gulf of Alaska, Bering Sea and Aleutian Islands, and the Chukchi and Beaufort Seas.[50] Observed northward shifts in the ranges of commercial species and uncertainty about ecosystem responses to climatic changes prompted the Council to establish limits to minimize bycatch, seasonal restrictions, and gear requirements (e.g., bottom trawling prohibition) to diminish potential negative effects on mammals, birds, and habitat. The Council has also created some protected areas to protect sensitive habitats (e.g., deep sea corals) and areas where scientific information is limited (e.g., Chukchi and Beaufort Seas).
- The San Francisco Estuary Invasive *Spartina* Project aims to limit or eliminate non-native cordgrasses from tidal and salt marshes through targeted outreach, mapping, and monitoring.[51] With sea level rise, salt marshes and mudflats are expected to migrate inland, giving *Spartina* ample opportunity to colonize newly-created spaces. The eradication of *Spartina* from the San Francisco Estuary may prevent large-scale losses of native marshes and mudflats that can withstand the effects of sea level rise and coastal flooding. In 2016, biologists determined that nearly 97% of invasive *Spartina* had been eradicated compared to 2005 levels. A regionwide monitoring effort has been established to map the extent and rate of invasive *Spartina* spread and to monitor the effectiveness of the project's efforts.

[50] Using a Precautionary Approach to Manage North Pacific Fisheries Under Uncertainty
[51] San Francisco Estuary Invasive Spartina Project

Lessons Learned

The first State of Adaptation report, which reviewed over 150 marine and coastal projects in North America, concluded that the majority of adaptation activities were focused on building capacity and adaptation planning. Since that report was released in 2011, several of those projects have been completed, while others are ongoing or have been expanded to new geographies. Additional adaptation initiatives have been launched both by project leads that have completed their initial efforts and new players in the field. In general, there is a continued focus on assessment and planning for climate change in many marine and coastal projects with moderate advancements in the implementation and evaluation of activities. Progress is being made, although not at the pace and scale required to keep up with changing conditions. Additional trends of note from our survey include:

- Focusing on advancing equitable adaptation;
- Consensus-based use of climate projections in decision-making;
- Integration of communities in adaptation projects led by conservation organizations;
- Slower uptake and implementation of monitoring and evaluation; and
- Continuing critical role of the federal government in adaptation.

Focusing on advancing equitable adaptation. More adaptation projects are considering the differential impacts of climate change on individuals and communities in different regions of the United States. Sea level rise, flooding, drought, and extreme heat and weather events can damage coastal infrastructure and homes, pose threats to public health and safety, affect local economies, disrupt access to food, water, and critical services (e.g., hospitals, utilities, transportation), and cause the temporary or permanent displacement of individuals and communities. Social factors, such as race and ethnicity, age, gender, economic stability, and education, contribute to both the vulnerability of and adaptation options available to communities. Meaningfully engaging community members in processes that affect where and how people live is an emerging part of the community adaptation planning framework. For example, Catalyst Miami, an anti-poverty non-profit organization, created the Community Leadership on the Environment, Advocacy, and Resilience (CLEAR) Program to train local climate justice leaders.[52] After completing the program, graduates are invited to develop proposals for climate-related community projects, which are eligible for funding by Catalyst Miami.

Consensus-based use of climate projections in decision-making. Many local governments are moving towards consensus in projections used for decision-making. By moving away from a county-by-county, project-by-project approach towards programmatic consistency on what and how climate science should be factored into decision making, these communities are developing and implementing complementary adaptation plans. For example, the Southeast Florida Regional Climate Change Compact released a Regionally Unified Sea Level Rise Projection to guide coastal planning in Broward, Miami-Dade, Monroe, and Palm Beach

[52] A Coastal Adaptation Case Story: Catalyst Miami's Community Leadership on the Environment, Advocacy, and Resilience (CLEAR) Program

counties.[53] The projection was first released in 2011 and updated in 2015 and 2019. The latest update provides sea level rise projections through 2120, ranging from 10–17 inches by 2040, 21–54 inches by 2070, and 40–126 inches by 2120. Similarly, the Washington Coastal Resilience Project developed community-level sea level rise projections for 171 locations in coastal Washington, which have been adopted by several counties in the state to inform decision-making.

Integration of communities in adaptation projects led by conservation organizations. Many conservation organizations that once focused almost exclusively on habitats and species have shifted to accommodate an added community focus because getting the local community engaged and invested has transformed the longevity of climate adaptation programs. For example, Mass Audubon is the largest private landholder and conservation organization in Massachusetts. Major activities include acquiring land to protect wildlife habitat and provide open space for residents, including purchasing and restoring land in Plymouth to allow coastal wetlands and salt marshes to migrate inland in response to sea level rise.[54] More recent climate-related efforts are focused on convening community members through programs such as Youth Climate Summits and Climate Cafés to become climate-informed activists.

Slower uptake and implementation of monitoring and evaluation. While many marine and coastal adaptation plans and projects note the importance of including a monitoring and evaluation component, there are few examples of implementation. There are many more examples of projects that track climatic changes and progress on implementation than those that track the effectiveness of approaches. The field would benefit from learning how individual strategies and actions have proven successful—or not. Sharing what has not worked and why may help others avoid similar pitfalls. For example, the Wellfleet Bay Wildlife Sanctuary in Cape Cod, Massachusetts, initiated an oyster reef habitat restoration project on the intertidal flats of Lieutenant Island.[55] The project was initiated to boost local populations of the wild American oyster (*Crassostrea virginica*) and to restore oyster reef habitat in order to protect the local shoreline from increased storm surges, sea level rise, and coastal erosion. Less than a year after the oyster reefs were installed, winter ice floes destroyed the reefs. Project leads realized that the installation site was appropriate to combat slow-onset events such as sea level rise and erosion, but too exposed to succeed during stronger winter events. Mass Audubon is now seeking funding for additional oyster reef habitat restoration projects in more protected areas of Wellfleet Bay.

Continuing critical role of the federal government in adaptation. While local action is required for adaptation, federal support and action cannot be understated. The collective technical and financial capacity of the federal government is key to the advancement of climate adaptation and mitigation action in the United States. Over the last decade, federal action on adaptation has been highly variable. President Obama enacted a number of executive orders, which

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[53] Southeast Florida Regional Climate Change Compact
[54] Incorporating Climate Change into Research and Management at Mass Audubon
[55] Wellfleet Bay Oyster Reef Habitat Restoration Project

mandated the evaluation of climate vulnerability and the creation and implementation of agency climate adaptation plans. The Trump Administration then halted or terminated several of these efforts in favor of energy development on federal lands by Executive Order 13783, *Promoting Energy Independence and Economic Growth*. Funding was also stripped from many federal climate programs that provide critical services to tribal, state, and local governments and nongovernmental entities, such as the Landscape Conservation Cooperatives (LCCs), which were largely eliminated or placed on indefinite hiatus since 2017. In some cases, federal programs found a way to survive these cuts; for example, the Climate Adaptation Science Centers (CASCs) have been a consistent presence due to their ongoing partnerships with regional universities. These centers facilitate scientific research, modeling, forecasting, and monitoring of climate impacts on the nation's resources and serve as information centers for stakeholders in eight U.S. regions: Alaska, North Central, Northeast, Northwest, Pacific Islands, South Central, Southeast, and Southwest. For example, the Pacific Islands Climate Adaptation Science Center has been a key player in the effort to fund and coordinate research in the broader region, which includes the Hawaiian Islands and the U.S.-affiliated islands of American Samoa, the Commonwealth of the Northern Mariana Islands, Guam, the Federated States of Micronesia, the Republic of the Marshall Islands, and the Republic of Palau.

The Biden Administration has launched ambitious efforts to confront climate change. Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad*, centers climate change as an urgent issue requiring immediate action, and a critical element of foreign and domestic policy. The order requires each agency to submit climate action plans for review by the National Climate Task Force, White House Council on Environmental Quality, and Office of Management and Budget, and to report on implementation progress annually. On October 7, 2021, 23 agencies released adaptation and resilience plans to guide federal action on climate change. While these latest efforts at the federal level show promise, executive orders can be revoked. The policy whiplash of the last decade is unsustainable in a changing climate, and more durable climate adaptation action at the federal level may only happen with legislation.

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Appendix A. Adaptation case studies by geographic region.

North Atlantic

- Adaptation Planning and Action in the Mystic River Watershed: https://www.cakex.org/case-studies/adaptation-planning-and-action-mystic-river-watershed
- Adapting People and Nature to Maine's Changing Climate: https://www.cakex.org/case-studies/adapting-people-and-nature-maines-changing-climate
- Addressing the Impacts of Sea Level Rise on Water Utilities: Boston Water and Sewer Commission: https://www.cakex.org/case-studies/addressing-impacts-sea-level-rise-water-utilities-boston-water-and-sewer-commission
- Albemarle-Pamlico National Estuary Partnership's Climate Ready Estuaries: https://www.cakex.org/case-studies/albemarle-pamlico-national-estuary-partnerships-climate-ready-estuaries-project
- Assessing Impacts and Developing Adaptation Strategies for Connecticut's Natural and Built Environments: https://www.cakex.org/case-studies/assessing-impacts-and-developing-adaptation-strategies-connecticut's-natural-and-built-environments
- Assessing the Risk of 100-year Floods in the Lamprey River Watershed of New Hampshire Resulting from Climate Change and Land Use: https://www.cakex.org/case-studies/assessing-risk-100-year-freshwater-floods-lamprey-river-watershed-new-hampshire-resulting-climate-change-and-land-use
- Barnegat Bay Climate Change Adaptation Strategy Development: https://www.cakex.org/case-studies/barnegat-bay-climate-change-adaptation-strategy-development
- City of New Castle, Delaware Coastal Resiliency Action Plan: https://www.cakex.org/case-studies/city-new-castle-delaware-coastal-resiliency-action-plan
- ClimAID: Developing a Climate Change Impacts and Adaptation Assessment for New York State: https://www.cakex.org/case-studies/climaid-developing-climate-change-impacts-and-adaptation-assessment-new-york-state
- Climate Change Vulnerability Assessment for Long Island Sound via Sentinel Monitoring: https://www.cakex.org/case-studies/climate-change-vulnerability-assessment-long-island-sound-sentinel-monitoring
- Climate Change, Coastal Flooding, and Environmental Justice in Urban Boston Communities: https://www.cakex.org/case-studies/climate-change-coastal-flooding-and-environmental-justice-urban-boston-communities
- Climate-informed Watershed Restoration on the Elizabeth River: https://www.cakex.org/case-studies/climate-informed-watershed-restoration-elizabeth-river
- Coastal Adaptation Planning for the Town of Groton, Connecticut: https://www.cakex.org/case-studies/coastal-adaptation-plan-town-groton-connecticut
- Coastal Community Resilience in Maine: https://www.cakex.org/case-studies/coastal-community-resilience-maine

- Coastal Resilience Initiatives in Virginia: https://www.cakex.org/case-studies/coastal-resilience-initiatives-virginia
- Coastal Resilience: Visualizing Climate Change Impacts and Coastal Hazards and Implementing Solutions in Long Island Sound: https://www.cakex.org/case-studies/coastal-resilience-visualizing-climate-change-impacts-and-coastal-hazards-and-implementing-solutions-long-island-sound
- Delaware Sea Level Rise Adaptation Initiative: https://www.cakex.org/case-studies/delaware-sea-level-rise-adaptation-initiative
- Disaster Preparedness and Response Planning in Barnstable County, Cape Cod: https://www.cakex.org/case-studies/disaster-preparedness-and-response-planning-barnstable-county-cape-cod
- From PlaNYC to OneNYC: A Comprehensive Sustainability Plan for New York City: https://www.cakex.org/case-studies/planyc-onenyc-comprehensive-sustainability-plan-new-york-city
- Helping Massachusetts Coastal Communities Adapt to Climate Change: https://www.cakex.org/case-studies/helping-massachusetts-coastal-communities-adapt-climate-change
- Identifying and Reducing Climate Risks to Water Resources in an Eastern Virginia Water Utility: https://www.cakex.org/case-studies/identifying-and-reducing-climate-risks-water-resources-eastern-virginia-water-utility
- Identifying Opportunities for Climate Adaptation in the Delaware Estuary: https://www.cakex.org/case-studies/identifying-opportunities-climate-adaptation-delaware-estuary
- Implementation of Maryland’s Climate Action Plan: https://www.cakex.org/case-studies/implementation-maryland’s-climate-action-plan
- Including a range of climate effects in planning for Rhode Island’s coastal zone and state waters: https://www.cakex.org/case-studies/including-range-climate-effects-planning-rhode-island’s-coastal-zone-and-state-waters
- Incorporating Climate Change into Research and Management at Mass Audubon: https://www.cakex.org/case-studies/incorporating-climate-change-research-and-management-mass-audubon
- Incorporating Climate Change into the Casco Bay Estuary Partnership: https://www.cakex.org/case-studies/incorporating-climate-change-casco-bay-estuary-partnership
- Increasing Coastal Resilience through Restoration and Education in Narragansett Bay, Rhode Island: https://www.cakex.org/case-studies/increasing-coastal-resilience-through-restoration-and-education-narragansett-bay-rhode-island
- Increasing Water Management Capability at Great Dismal Swamp National Wildlife Refuge to Enhance Resilience: https://www.cakex.org/case-studies/increasing-water-management-capability-great-dismal-swamp-national-wildlife-refuge-enhance-resilience

- Integrating Climate Change Adaptation Strategies into Maryland’s Coastal Land Conservation Targeting: https://www.cakex.org/case-studies/integrating-climate-change-adaptation-strategies-maryland’s-coastal-land-conservation-targeting
- Integrating Climate Change into the Massachusetts State Wildlife Action Plan Using an Expert Panel-based Vulnerability Assessment: https://www.cakex.org/case-studies/integrating-climate-change-massachusetts-state-wildlife-action-plan-using-expert-panel-based-vulnerability-assessment
- Marshes for Tomorrow Initiative in Coastal Maine: https://www.cakex.org/case-studies/marshes-tomorrow-initiative-coastal-maine
- Maryland’s Coast-Smart Communities Initiative: https://www.cakex.org/case-studies/marylands-coast-smart-communities-initiative
- Massachusetts Bays Program: An Evaluation of Salt Marsh Vulnerability to Climate Change: https://www.cakex.org/case-studies/massachusetts-bays-project
- Municipal Adaptations to Create Resilient Beach Communities in Southern Maine: The Coastal Hazard Resiliency Tools Project: https://www.cakex.org/case-studies/municipal-adaptations-create-resilient-beach-communities-southern-maine-coastal-hazard-resiliency-tools-project
- New Jersey Climate Change Adaptation Using Community Plan Endorsements: https://www.cakex.org/case-studies/new-jersey-climate-change-adaptation-using-community-plan-endorsements
- New York's Climate Smart Communities Program: https://www.cakex.org/case-studies/new-york%E2%80%99s-climate-smart-communities-program
- Oyster River Watershed Culvert Study: https://www.cakex.org/case-studies/oyster-river-watershed-culvert-study
- Planning for Sea Level Rise and Storm Surge in Worcester County, Maryland: https://www.cakex.org/case-studies/planning-sea-level-rise-and-storm-surge-worcester-county-maryland
- Planning for Sea Level Rise in Rhode Island’s Coastal Management Program: https://www.cakex.org/case-studies/planning-sea-level-rise-rhode-island’s-coastal-management-program
- Preparing for Climate Change in New York City’s Water Utilities: https://www.cakex.org/case-studies/preparing-climate-change-new-york-city%E2%80%99s-water-utilities
- Preparing for Sea Level Rise and Climate Change Impacts in Maine: https://www.cakex.org/case-studies/preparing-sea-level-rise-and-climate-change-impacts-maine
- Getting Wise to Rising Seas in Virginia Beach: https://www.cakex.org/case-studies/getting-wise-rising-seas-virginia-beach
- Proactive Incorporation of Sea Level Rise into the Design of the Deer Island Wastewater Treatment Plant: https://www.cakex.org/case-studies/proactive-incorporation-sea-level-rise-design-deer-island-wastewater-treatment-plant

- Rising Waters: Helping Hudson River Communities Adapt to Climate Change: https://www.cakex.org/case-studies/rising-waters-helping-hudson-river-communities-adapt-climate-change
- Scenic Hudson Land Trust: Prioritizing Lands in Light of Sea Level Rise: https://www.cakex.org/case-studies/scenic-hudson-land-trust-prioritizing-lands-light-sea-level-rise
- Sea Level Rise and Climate Science Program in Coastal Virginia: https://www.cakex.org/case-studies/sea-level-rise-and-climate-science-program-coastal-virginia
- Sea Level Rise Guidance for Somerset County, Maryland: https://www.cakex.org/case-studies/sea-level-rise-guidance-somerset-county-maryland
- Sea Level Rise Technical Guidance for Dorchester County, Maryland: https://www.cakex.org/case-studies/sea-level-rise-guidance-dorchester-county-maryland
- Sentinel Monitoring of Salt Marshes in the Chesapeake Bay National Estuarine Research Reserve in Virginia: https://www.cakex.org/case-studies/sentinel-monitoring-salt-marshes-chesapeake-bay-national-estuarine-research-reserve-virginia
- Sentinel Monitoring of Salt Marshes in the Narragansett Bay National Estuarine Research Reserve: https://www.cakex.org/case-studies/sentinel-monitoring-salt-marshes-narragansett-bay-national-estuarine-research-reserve
- Sentinel Monitoring of Salt Marshes in the Wells National Estuarine Research Reserve: https://www.cakex.org/case-studies/sentinel-monitoring-salt-marshes-wells-national-estuarine-research-reserve
- Town of Bowers Beach, Delaware Coastal Resiliency Efforts: https://www.cakex.org/case-studies/town-bowers-beach-delaware-coastal-resiliency-action-plan
- Wellfleet Bay Oyster Reef Habitat Restoration Project: https://www.cakex.org/case-studies/wellfleet-bay-oyster-reef-habitat-restoration-project

Southeast/Caribbean

- A Climate Change Action Plan for the Florida Reef Tract: https://www.cakex.org/case-studies/climate-change-action-plan-florida-reef-tract-2010-2015
- A Coastal Adaptation Case Story: Catalyst Miami's Community Leadership on the Environment, Advocacy, and Resilience (CLEAR) Program: https://www.cakex.org/case-studies/coastal-adaptation-case-story-catalyst-miami
- Adaptation Behavior on the Front Line of Climate Change and Accelerating Sea Level Rise in the Florida Keys: https://www.cakex.org/case-studies/adaptation-behavior-front-line-climate-change-and-accelerating-sea-level-rise-florida-keys
- Alligator River National Wildlife Refuge/Albemarle-Pamlico Peninsula Climate Adaptation Project: https://www.cakex.org/case-studies/alligator-river-national-wildlife-refugealbemarle-pamlico-peninsula-climate-adaptation-project

- Broward County Climate Change Task Force and Climate Change Initiatives: https://www.cakex.org/case-studies/broward-county-climate-change-task-force-and-climate-change-initiatives
- Climate Change and the Florida Keys: https://www.cakex.org/case-studies/climate-change-and-florida-keys
- Climate Variability and Water Supply Planning in Tampa Bay: https://www.cakex.org/case-studies/climatic-variability-and-water-supply-planning-tampa-bay
- Coral Reef Ecosystem Studies (CREST) Project: https://www.cakex.org/case-studies/coral-reef-ecosystem-studies-crest-project
- Developing a Coastal Resilience Assessment for the Cape Fear River Basin: https://www.cakex.org/case-studies/developing-coastal-resilience-assessment-cape-fear-river-basin
- Florida Energy and Climate Commission: https://www.cakex.org/case-studies/florida-energy-and-climate-commission
- Florida Fish and Wildlife Conservation Commission: Planning for Climate Change: https://www.cakex.org/case-studies/florida-fish-and-wildlife-conservation-commission-planning-climate-change
- Florida Governor's Action Team on Energy and Climate Change: Developing an Energy and Climate Action Plan: https://www.cakex.org/case-studies/florida-governor's-action-team-energy-and-climate-change-developing-energy-and-climate-action-plan
- Florida Oceans and Coastal Council: https://www.cakex.org/case-studies/florida-oceans-and-coastal-council
- Florida Planning Toolbox: Climate Change Tools: https://www.cakex.org/case-studies/florida-planning-toolbox-climate-change-tools
- Florida Reef Resilience Program: https://www.cakex.org/case-studies/florida-reef-resilience-program
- Florida Resilient Coastlines Program: https://www.cakex.org/case-studies/florida-resilient-coastlines-program
- Florida's Climate Change Community Toolbox: https://www.cakex.org/case-studies/floridas-climate-change-community-toolbox
- Incorporating Climate Change Impacts into Activities in Charlotte Harbor, Florida: https://www.cakex.org/case-studies/incorporating-climate-change-impacts-activities-charlotte-harbor-florida
- Indian River Lagoon and City of Satellite Beach, Florida Adaptation Project: https://www.cakex.org/case-studies/indian-river-lagoon-and-city-satellite-beach-florida-adaptation-project
- Miami-Dade Climate Change Advisory Task Force and Climate Change Initiatives: https://www.cakex.org/case-studies/miami-dade-climate-change-advisory-task-force
- Natural Defenses for Natural Risks: South Carolina's North Coast Resilience Project: https://www.cakex.org/case-studies/natural-defenses-natural-risks-south-carolina%E2%80%99s-north-coast-resilience-project

- North Carolina Climate Change Initiative: https://www.cakex.org/case-studies/north-carolina-climate-change-initiative
- North Carolina Sea Level Rise Risk Management Project: https://www.cakex.org/case-studies/north-carolina-sea-level-rise-risk-management-project
- North Florida Land Trust Conservation Priorities: https://www.cakex.org/case-studies/north-florida-land-trust-conservation-priorities
- Peatland Restoration for Climate Resilience and Carbon Sequestration: https://www.cakex.org/case-studies/peatland-restoration-climate-resilience-and-carbon-sequestration
- Planning for Change in Chatham County, Georgia: https://www.cakex.org/case-studies/planning-change-chatham-county-georgia
- Planning for the Impacts of Sea Level Rise and Climate Change in North Carolina: https://www.cakex.org/case-studies/planning-impacts-sea-level-rise-and-climate-change-north-carolina
- Responding to Sea Level Rise under the Comprehensive Everglades Restoration Plan: https://www.cakex.org/case-studies/responding-sea-level-rise-under-comprehensive-everglades-restoration-plan
- Response to Florida Shelf Ecosystems to Climate Change: The FlaSH Project: https://www.cakex.org/case-studies/response-florida-shelf-ecosystems-climate-change-flash-project
- Sea Level Rise Adaptation Report for the City of Wilmington, North Carolina: https://www.cakex.org/case-studies/sea-level-rise-adaptation-report-city-wilmington-north-carolina
- Sea Level Rise Strategy for Miami-Dade County: https://www.cakex.org/case-studies/sea-level-rise-strategy-miami-dade-county
- Sentinel Monitoring of Salt Marshes in the North Carolina National Estuarine Research Reserve: https://www.cakex.org/case-studies/sentinel-monitoring-salt-marshes-north-carolina-national-estuarine-research-reserve
- South Carolina's Shoreline Change Initiative: https://www.cakex.org/case-studies/south-carolina's-shoreline-change-initiative
- Southeast Florida Regional Climate Change Compact: https://www.cakex.org/case-studies/southeast-florida-regional-climate-change-compact
- The Florida Climate Pledge and Community Outreach Initiatives: https://www.cakex.org/case-studies/florida-climate-pledge-and-community-outreach-initiatives
- The South Florida Sea Level Rise Project: https://www.cakex.org/case-studies/south-florida-sea-level-rise-project
- Tybee Island Sea Level Rise Adaptation Plan: https://www.cakex.org/case-studies/tybee-island-sea-level-rise-adaptation-plan
- Using Outreach to Catalyze Small Changes in Climate Change Adaptation on Bald Head Island, North Carolina: https://www.cakex.org/case-studies/using-outreach-catalyze-small-changes-climate-change-adaptation-bald-head-island-north-carolina

Gulf of Mexico

- Alabama’s Baldwin County Grasses in Classes Program: https://www.cakex.org/case-studies/alabama’s-baldwin-county-grasses-classes-program
- Building Coastal Resilience in Louisiana: Lake Pontchartrain Multiple Lines of Defense Strategy: https://www.cakex.org/case-studies/building-coastal-resilience-louisiana-lake-pontchartrain-multiple-lines-defense-strategy
- Coastal Bend Bays and Estuaries Program Comprehensive Conservation and Management Plan Update: https://www.cakex.org/case-studies/coastal-bend-bays-and-estuaries-program-comprehensive-conservation-and-management-plan-update
- Creating a Gulf Coast Community Handbook for Restoration and Adaptation: https://www.cakex.org/case-studies/creating-gulf-coast-community-handbook-restoration-and-adaptation
- Ecological Effects of Sea Level Rise in the Florida Panhandle, Coastal Mississippi and Coastal Alabama: https://www.cakex.org/case-studies/ecological-effects-sea-level-rise-florida-panhandle-and-coastal-alabama
- Enhancing Flood Resilience with the Greater New Orleans Urban Water Plan: https://www.cakex.org/case-studies/enhancing-flood-resilience-greater-new-orleans-urban-water-plan
- Gulf of Mexico Regional Sediment Management Master Plan: https://www.cakex.org/case-studies/gulf-mexico-regional-sediment-management-master-plan
- Inner Harbor Navigation Canal Lake Borgne Surge Barrier: Resilient Storm Surge Protection for New Orleans: https://www.cakex.org/case-studies/inner-harbor-navigation-canal-lake-borgne-surge-barrier-resilient-storm-surge-protection-new-orleans
- Mission-Aransas National Estuarine Research Reserve’s Ecosystem Based Management Project: https://www.cakex.org/case-studies/mission-aransas-national-estuarine-research-reserves-ecosystem-based-management-tools-project
- Oyster Reef Breakwater Restoration Project on Alabama’s Gulf Coast: https://www.cakex.org/case-studies/oyster-reef-breakwater-restoration-project-alabama’s-gulf-coast
- Restoration in Lower Plaquemines Parish: Maximizing Co-benefits for Protecting Critical Infrastructure and Communities through Ecosystem Resilience: https://www.cakex.org/case-studies/restoration-lower-plaquemines-parish-maximizing-co-benefits-protecting-critical-infrastructure-and-communities-through-ecosystem-resilience
- Restoring Three Mile Creek via a Comprehensive Watershed Management Plan: https://www.cakex.org/case-studies/restoring-three-mile-creek-comprehensive-watershed-management-plan
- Sea Level Rise in the Gulf of Mexico: Awareness and Action Tools for the Climate Outreach Community of Practice: https://www.cakex.org/case-studies/sea-level-rise-gulf-mexico-awareness-and-action-tools-climate-outreach-community-practice

- Systematically Prioritizing Restoration Projects in Terrebonne Parish, Louisiana: https://www.cakex.org/case-studies/systematically-prioritizing-restoration-projects-terrebonne-parish-louisiana
- The Galveston Bay Report Card Coastal Adaptation Initiative: https://www.cakex.org/case-studies/galveston-bay-report-card-coastal-adaptation-initiative
- Using Advocacy to Enhance Gulf Coast Resilience: https://www.cakex.org/case-studies/using-advocacy-enhance-gulf-coast-resilience
- Waveland's Climate-Informed Local Hazard Mitigation Plan Update: https://www.cakex.org/case-studies/waveland's-climate-informed-local-hazard-mitigation-plan-update

West

- A Coastal Adaptation Case Story: The Nuestra Casa Environmental Justice Program: https://www.cakex.org/case-studies/coastal-adaptation-case-story-nuestra-casa
- Adapting to Climate Change in Olympic National Forest: https://www.cakex.org/case-studies/adapting-climate-change-olympic-national-forest
- Adapting to Rising Tides in San Francisco Bay, California: https://www.cakex.org/case-studies/adapting-rising-tides-san-francisco-bay-california
- Adapting to Sea Level Rise in Hayward, California: https://www.cakex.org/case-studies/adapting-sea-level-rise-hayward-california
- Adding the Impacts of Climate Change to Strategic Plan: Big Sur Land Trust: https://www.cakex.org/case-studies/adding-impacts-climate-change-strategic-plan-big-sur-land-trust
- Alameda County Flood Protection and Salt Pond Restoration: https://www.cakex.org/case-studies/alameda-county-flood-protection-and-salt-pond-restoration
- Aramburu Island Ecological Enhancement Project: https://www.cakex.org/case-studies/aramburu-island-ecological-enhancement-project
- Bay Area Ecosystems Climate Change Consortium: https://www.cakex.org/case-studies/bay-area-ecosystems-climate-change-consortium
- California Department of Water Resources Climate Change Initiatives: https://www.cakex.org/case-studies/california-department-water-resources-adaptation-strategy
- California Energy Commission's Climate Change Research Initiatives: https://www.cakex.org/case-studies/california-energy-commissions-climate-change-research-program
- California's Climate Change Adaptation Strategy: https://www.cakex.org/case-studies/californias-climate-change-adaptation-strategy
- City of Santa Cruz Climate Action Program: https://www.cakex.org/case-studies/city-santa-cruz-climate-action-program

- Climate Change Adaptation Planning in San Luis Obispo County: https://www.cakex.org/case-studies/climate-change-adaptation-planning-san-luis-obispo-county
- Climate Change Adaptation Planning in the City of Chula Vista, California: https://www.cakex.org/case-studies/climate-change-adaptation-planning-city-chula-vista-california
- Climate Change Effects and Management Responses in the Greater Farallones and Cordell Bank National Marine Sanctuaries: https://www.cakex.org/case-studies/climate-change-effects-and-management-responses-gulf-farallones-and-cordell-bank-national-marine-sanctuaries
- Climate Change Impacts and Adaptations in the Rogue River Basin: https://www.cakex.org/case-studies/climate-change-impacts-and-adaptations-rogue-river-basin
- Creating Climate Ready Communities: Adapting to the Impacts of Climate Change on the Oregon Coast: https://www.cakex.org/case-studies/creating-climate-ready-communities-adapting-impacts-climate-change-oregon-coast
- Designing Salt Marsh Conservation Strategies in Elkhorn Slough National Research Reserve: https://www.cakex.org/case-studies/designing-salt-marsh-conservation-strategies-elkhorn-slough-national-estuarine-research-reserve
- Developing a Washington State Climate Change Impacts Response Strategy: https://www.cakex.org/case-studies/developing-washington-state-climate-change-impacts-response-strategy
- Developing Adaptation Strategies for Oregon's Estuaries: https://www.cakex.org/case-studies/developing-adaptation-strategies-oregon%E2%80%99s-estuaries
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Recommended Citation

Gregg RM, Braddock KN. 2021. The State of Climate Adaptation in the Marine and Coastal United States, Territories, and Commonwealths. EcoAdapt, Bainbridge Island, WA.

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