CASCO BAY
CLIMATE CHANGE VULNERABILITY
SUMMARY REPORT

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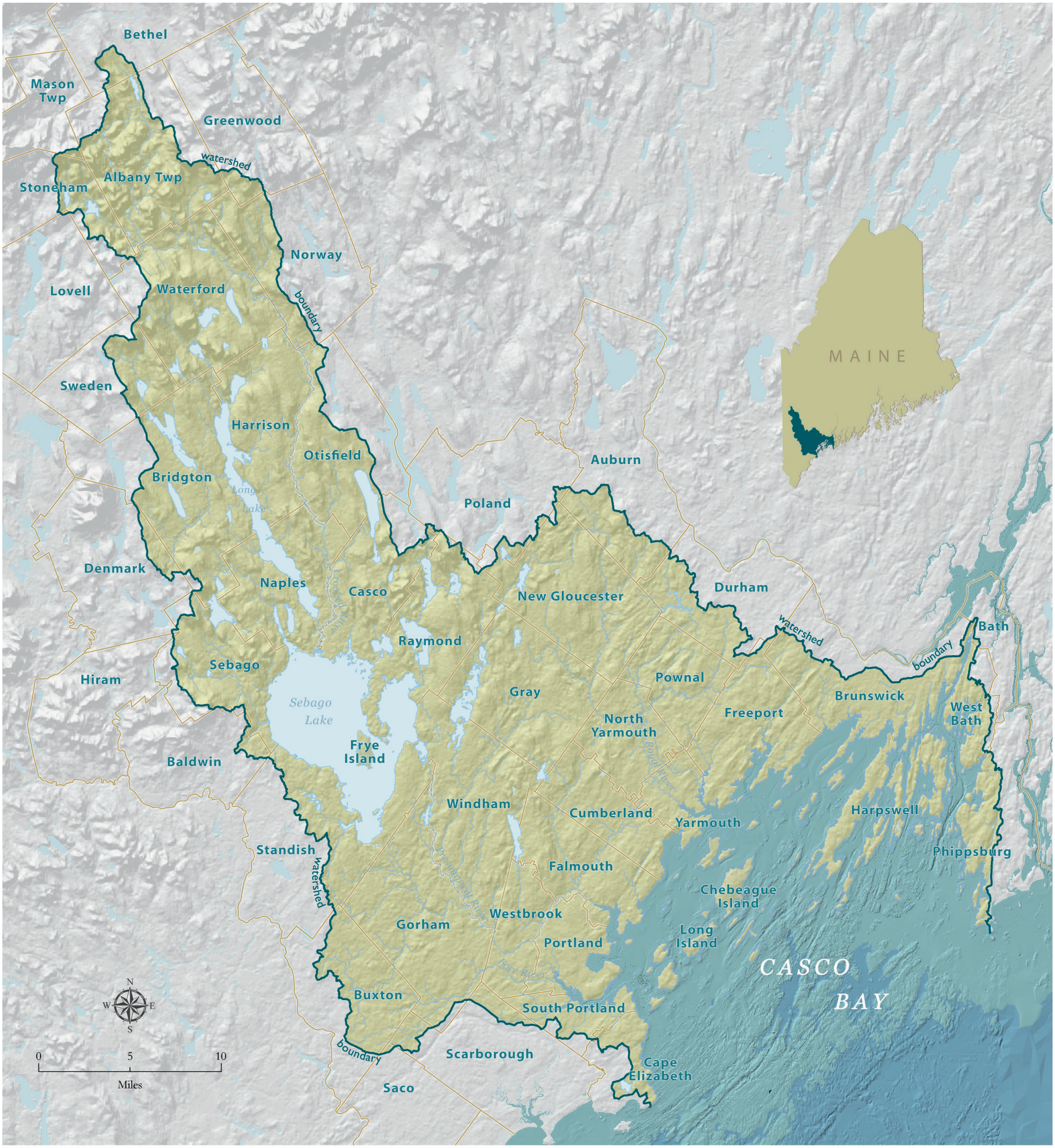

Map of Casco Bay and its watershed. Dark green line indicates watershed boundary.

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On the cover: A September 2015 storm that brought 5.6 inches of rain to Portland, coinciding with an astronomically high tide, caused extensive flooding and damage in Bayside and the Old Port. *Photo by Gabe Souza/Portland Press Herald*

INTRODUCTION

In 2016, Casco Bay Estuary Partnership (CBEP) released its revised Comprehensive Conservation and Management Plan as the *Casco Bay Plan 2016-21*. The Casco Bay Plan details the Goals, Strategies, and Actions that guide CBEP's efforts to sustain a healthy bay. It focuses on four Goals:

Goal 1: Protect, restore and enhance key habitats that sustain ecological health

Goal 2: Reduce nutrient pollution and its impacts, including coastal acidification

Goal 3: Foster resilient communities and their connections to Casco Bay

Goal 4: Mobilize collective knowledge and resources to support Casco Bay

To work toward those Goals, CBEP will implement a total of 32 Actions. The complete *Casco Bay Plan 2016-21* is available at www.cascobayestuary.org/planning-for-casco-bays-future.

Recognizing that climate change has important implications for implementation of the Plan, CBEP undertook a risk-based climate change vulnerability assessment based on the approach outlined by the US Environmental Protection Agency in its *Workbook for Developing Risk-Based Adaptation Plans*. The objective was to facilitate successful implementation of the Plan by adjusting activities as needed to account for climate change-related risks. The assessment considered the potential impacts of seven classes of climate change stressors on Plan implementation: warmer summers, warmer winters, warmer water, increasing drought, increasing storminess, sea level rise, and ocean acidification.

This report summarizes information from the climate change vulnerability assessment to help support climate adaptation efforts by municipalities, organizations, and individuals of Casco Bay and its watershed—from Cape Elizabeth to Phippsburg and from Portland to Bethel.

Section 1: Climate Trends in the Casco Bay Region
As a foundation for the climate vulnerability assessment, CBEP began by summarizing scientific evidence of climate stressors within Maine and within the Casco Bay watershed. Natural Choices LLC prepared the "Climate Trends in the Casco Bay Region" report presented in Section 1.

Section 2: Management of Climate Change Risks
Focusing on the seven classes of climate change stressors (see above), CBEP identified potential risks to implementation of the Casco Bay Plan's Actions and estimated the probability and consequence of each risk. CBEP worked with Waterview Consulting to define 25 Risks of Primary Concern (Table 1, p. 15) through a peer-review process that involved more than 40 experts (Table 2, p. 39) in a broad range of relevant fields. Section 2 discusses the Risks of Primary Concern and approaches to address them.

Section 3: Climate Adaptation Resource Guide for Casco Bay Communities
To support adaptation to climate change, CBEP and Natural Choices LLC produced the Climate Adaptation Resource Guide for Casco Bay Communities presented in Section 3. The Guide includes information about toolkits and viewers, organizations working on climate adaptation, model municipal projects and products, and key characteristics of climate-smart conservation.

Section 4: References and Further Reading

SECTION ONE

Climate Trends in the Casco Bay Region

Overview

The Casco Bay region is vulnerable to seven important climate stressors highlighted by the US Environmental Protection Agency: warmer summers; warmer winters; warmer waters; increased drought; increased storminess (evident in higher total precipitation, frequency and intensity); sea level rise; and ocean acidification (US EPA 2014). These climate stressors do not operate in isolation. Compounding their impacts are factors such as population growth, habitat fragmentation and destruction, and resource depletion that can further tax ecosystems and species.

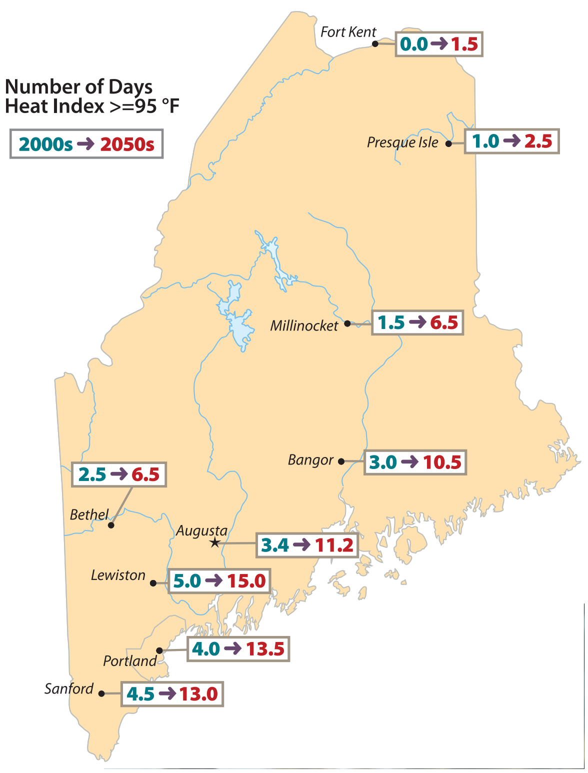
This section summarizes scientific evidence of these trends within Maine and, where possible, within the Casco Bay watershed, which coincides closely with the geographical boundary of Cumberland County.

Warmer Summers

Between 1895 and 2014, the average annual temperature across Maine warmed by about 3°F (Fernandez et al. 2015). Portland, during this same time period, warmed by about 4°F (National Climatic Data Center). By mid-century, models employed by the Intergovernmental Panel on Climate Change (IPCC) predict that annual air temperatures across Maine will rise another 3 to 5°F (Fernandez et al. 2015). Downscaled climate modeling done for the Casco Bay watershed in 2009 predicts mid-century temperature increases of 2 to 6°F (depending on future greenhouse gas emissions) and end-of-century temperatures in the 3 to 8°F range (Wake et al. 2009). Under a high-emissions scenario, summer temperatures could experience a dramatic change up to 10°F warmer (Wake et al. 2009).

A high-emissions scenario drives the number of days with temperatures over 90°F up to 60 each year, with potentially dangerous impacts on human health and the electricity grid (Wake et al. 2009). Portland's average number of extremely hot days—those with a heat index equal to or greater than 95° F—is expected to increase by mid-century from the current average of 4 to 13.5 days annually (Fernandez et al. 2015). Continued high emissions could raise that number to 35 by the end of the century—with the hottest day for Portland under this scenario reaching 114°F (Wake et al. 2009).

Warming air temperatures and more frequent heat waves pose public health concerns. In the event of heat waves, the Casco Bay region has limited air conditioning and no cooling centers. Higher temperatures can exacerbate unhealthy ground-level ozone, airborne allergens, and the spread of vector-borne diseases like babesiosis, anaplasmosis and Lyme disease. The rising incidence of these diseases, which are linked to a warmer and wetter climate, has transformed the way that Maine residents work and play outdoors.



Source: Maine's Climate Future—2015 Update
http://climatechange.umaine.edu/research/publications/climate-future

Warming air temperatures (in all seasons) will place additional stress on wildlife species already contending with invasive species, habitat loss, pollution and—in some cases—heavy harvesting (Stein et al. 2014). Ecosystem disruptions will affect human communities as well through the diminished capacity of natural systems to provide functions like water filtration and pollination (Stein et al. 2014).

Warmer Winters

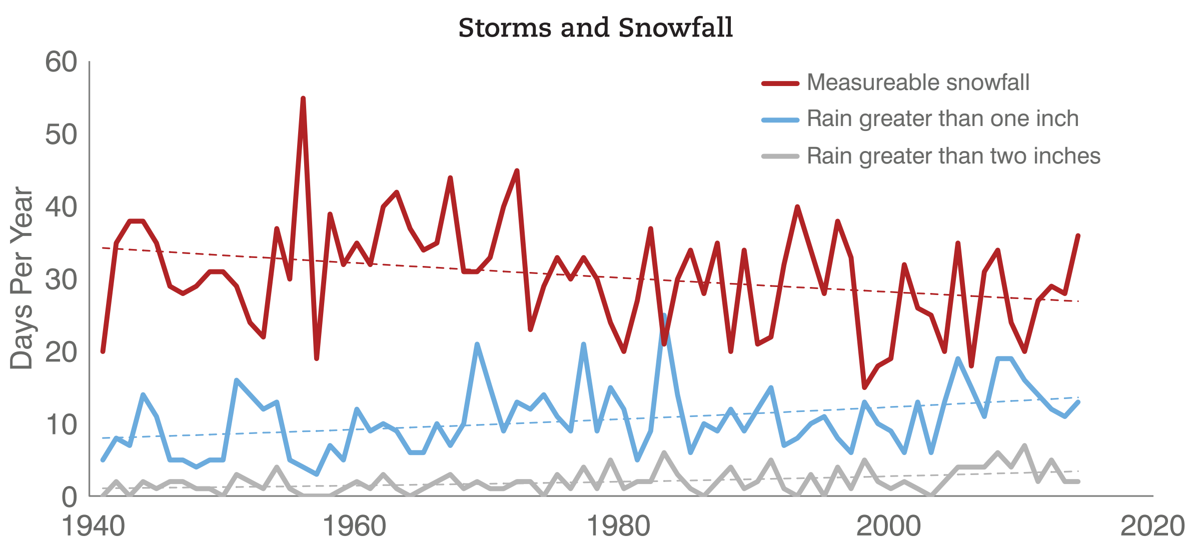
Historical data for the Portland Jetport (from the National Centers for Environmental Information) confirm that air temperatures have been increasing gradually for decades, and that winters are warmer than they were a generation ago (CBEP 2015). Recently, Maine winters have been warming at a faster rate than summers (Fernandez et al. 2015).

Rising minimum temperatures have reduced the number of freezing days and very cold days (with temperatures below zero) (CBEP 2015). By the end of this century, climate scientists anticipate that Portland will have 15 to 30 fewer days with minimum temperatures below 32°F (Wake et al. 2009). Along the coast, days with temperatures below zero could drop from the current 10 days per year to 1 if emissions remain high (Wake et al. 2009).

Days with measurable snowfall have declined about 20 percent in the past 65 years as more winter precipitation arrives as rain (CBEP 2015). Over the last century, the duration of snowpack through Maine's winter has decreased by about two weeks, and climate models suggest that another two weeks could be lost by mid-century (Fernandez et al. 2015). Climate scientists project that total winter snow loss along Maine's southern coast could exceed 40 percent by mid-century (2035-2054) relative to the recent climate (1995-2014) (Fernandez et al. 2015).

Based on historical records, Sebago Lake ice-out in the spring occurs 23 days earlier than it did in 1807 (reflecting a pattern in southern Maine and New Hampshire of ice-outs averaging 16 days earlier from 1850 to 2000) (Wake et al. 2009).

A 2012 study using regional climate models found temperature changes of 2-3°C (3.6-5.4°F.) warmer for the period from 2041 to 2070, with winter changes exceeding 3°C for more than half of the northeastern US (Rawlins et al. 2012). The National Climate Assessment predicts that Maine winters will be wetter as well as warmer, with a 10-20 percent increase in precipitation (Horton et al. 2014).



Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

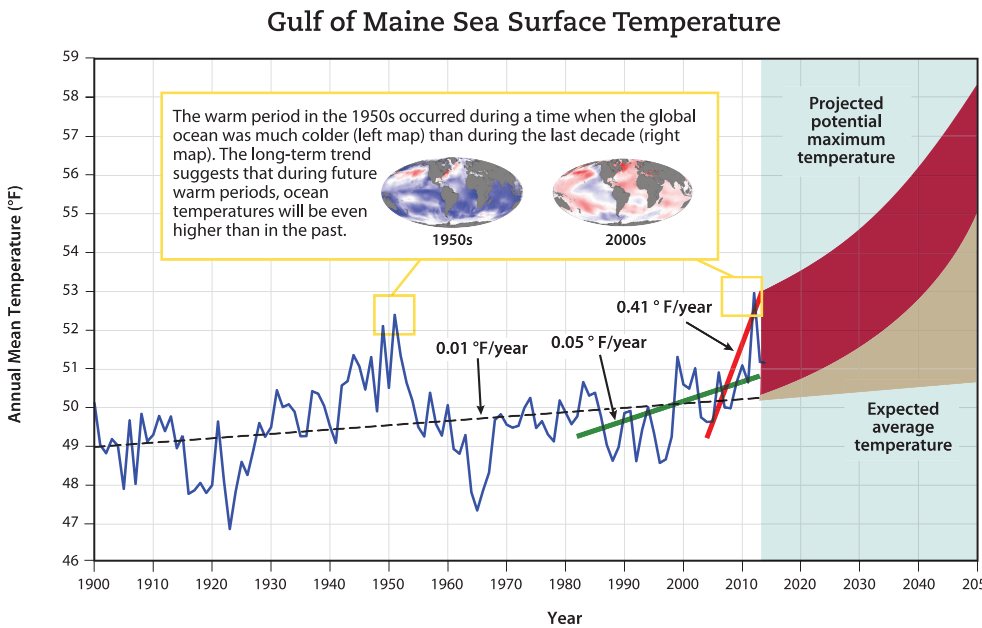
Warmer Waters

The Gulf of Maine warmed faster between 2004 and 2013 than 99 percent of the world's ocean, according to a recent study (Pershing et al. 2015). During that period, warming within the Gulf of Maine reached a rate of 0.41°F (0.23° C) per year. Since the mid-1990s, water temperatures in Casco Bay have increased about 3°F (CBEP 2015).

In 2012, Casco Bay was subject to an "ocean heat wave"—the largest and most intense such event that the Northwest Atlantic has experienced in three decades—which stretched from North Carolina to Iceland (with especially marked warming in the Gulf of Maine) (Mills et al. 2013). In response to a 1-3°C (1.8-5.4°F) temperature increase (on par with what could be expected by the end of this century), marine species showed marked changes in their seasonal cycles and distribution, abundance, growth and mortality (Mills et al. 2013). During the 2012 heat wave, lobsters moved inshore several weeks earlier than normal—causing a spike in landings that outstripped market demand and led to a price collapse (Mills et al. 2013).

As regional species shift in response to warmer (and more acidic) coastal waters, many traditional fisheries—including the iconic lobster—may be disrupted. To date, some of the most marked shifts in range have occurred in sought-after finfish species like winter flounder, Atlantic cod and silver hake (Mills et al. 2013). As climate change progresses, raising the incidence of temperature extremes in coastal waters, failure to anticipate these events and adjust fisheries management accordingly could exacerbate their economic and social impact (Mills et al. 2013).

Warmer water temperatures—in combination with other factors such as increased CO_2 and runoff from extreme precipitation events—could foster growth of harmful algal blooms in both freshwater lakes and coastal waters (US EPA Office of Water 2013). An extensive outbreak of *Alexandrium fundyense* (red tide) in 2005 caused closures that resulted in $18 million of lost shellfish sales in Massachusetts and Maine (NOAA 2013).



Source: Maine's Climate Future—2015 Update, http://climatechange.umaine.edu/research/publications/climate-future

Increased Drought

If global emissions remain high, climate scientists anticipate that the frequency of short-term (one- to three-month) droughts across most of New England will increase—changing from an average now of once every 2-3 years to once annually by late in the century (Frumhoff et al. 2007).

From 1996 through September 2015, the coast of Maine (Climate Division 3) has had only two droughts recorded by the Northeast Regional Climate Center—one of 2 months duration in 1999 and one of 9 months duration in 2001-2002 (NRCC 2015). If greenhouse gas emission levels remain high, the Portland area could go from a current average of 4 months of drought in a 30-year period to more than 12 months. If emissions dropped precipitously, little or no change in drought frequency is expected (Wake et al. 2009).

According to the 2010 Cumberland County Hazard Mitigation Plan, the greatest risk of drought is in communities that rely on groundwater wells, river or smaller lake supplies. Those dependent on Sebago Lake (including most of the communities in Greater Portland) have a "fairly low degree of risk to drinking water quantity and quality resulting from drought" (CCEMA 2010, 4-22).

Increased Precipitation and Greater Storm Intensity and Frequency

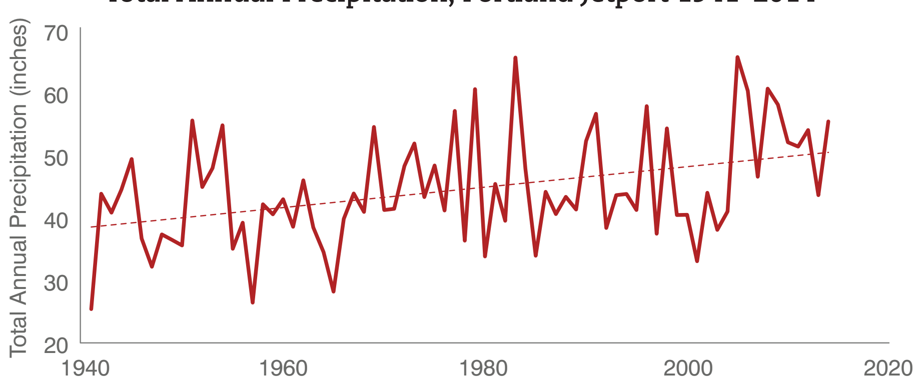
Maine is experiencing increases in both total annual precipitation and extreme precipitation events, raising concerns about flooding, damage to infrastructure like road–stream crossings, increased discharges from combined sewer overflows, and greater stormwater runoff impacts (CBEP 2015).

From 1895 to 2014, annual average precipitation in Maine increased by about 0.50 inches per decade (National Climatic Data Center, 2015). For Portland, the historical rate of increase was about 0.75 inches per decade. Since about 1960, there has been a much more rapid increase, with a rate of 1.92 inches per decade.

In recent decades, the Northeast has experienced a greater recent increase in extreme precipitation than any other US region. The Northeast saw more than a 70 percent increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1 percent of all daily events) between 1958 and 2010 (Horton et al. 2014). Intense rain events typically occurred about once a year in the early 1940s, but are now occurring in Portland about three times a year (CBEP 2015).

Climate models predict that precipitation will continue increasing across the Northeast through at least 2050, with a 4-5 percent increase expected along Maine's southern coast (Fernandez et al. 2015).

Total Annual Precipitation, Portland Jetport 1941–2014

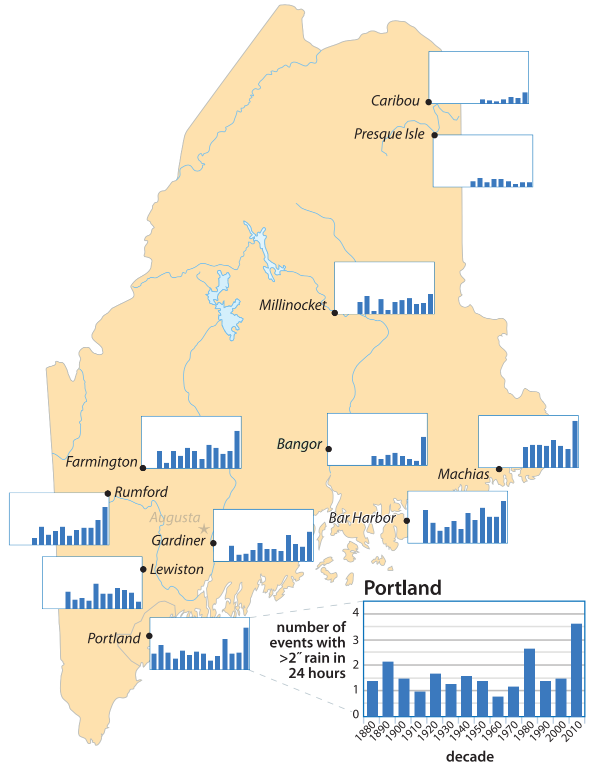


Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

NOAA's storm events database reveals a marked increase in the number of "extreme precipitation" events (categorized as coastal floods, flash floods, floods, heavy rain and tropical storms) within Cumberland County between 1995-2004 and 2005-2014. In the earlier decade, there were 21 days with events, 11 of them involving property damage. In the last decade, that number rose to 55 days, 35 of which involved property damage (NOAA NCDC 2015).

Increases in both annual and extreme precipitation raise the danger of flooding, the leading hazard for Cumberland County (CCEMA, 2010). According to FEMA data, the County had ten disaster declarations between June 2005 and April 2015, all associated with flooding (some with additional storm hazards such as snow, wind and landslides). The County's 2010 Hazard Mitigation Plan identifies four high-priority hazards: flooding, severe winter storms, wildfire and severe summer storms. That Plan identifies 24 "repetitive loss" properties (that have experienced repeated flood damage under the National Flood Insurance Program), all but three of them residential. Due to increased flooding in certain areas, utilities have already been required to relocate transmission lines and other electrical power infrastructure (DeLong 2015).

Stormwater runoff carries toxic contaminants and excess nitrogen and phosphorus into local waters—lowering dissolved oxygen (leading to fish kills), stimulating harmful algal blooms, altering ecological communities and aggravating coastal acidification in Casco Bay. Release of untreated sewage in extreme precipitation events can carry pathogens into swimming waters, raising risks of waterborne disease (Horton et al. 2014). Two of Casco Bay's most urban swimming beaches have ongoing water-quality challenges, with 20 percent of samples from one beach exceeding the allowable fecal bacteria threshold (CBEP 2015).



Extreme Precipitation Events

Source: Maine's Climate Future—2015 Update, http://climatechange.umaine.edu/research/publications/climate-future

Increased precipitation, in combination with warmer temperatures, can aggravate the spread of Lyme disease, babesiosis, anaplasmosis and West Nile Virus (WNV), vector-borne diseases linked to late spring and early summer moisture. In Maine, the arboviruses like WNV and Eastern Equine Encephalitis (EEE) are tied to seasonal increases in abundance of the virus in wild birds and the mosquito population, so they are also tied to midsummer moisture and possibly to temperature. Habitat for the Asian tiger mosquito that can transmit WNV is expected to increase in the Northeast from the current 5 percent to 16 percent within two decades and between 43 and 49 percent by the end of the century (Horton et al. 2014).

NOAA reports that Maine has experienced nine hurricanes in historical records, only five of which made landfall along the coastline. However, Maine has been affected by many lesser tropical storms (mapped at http://coast.noaa.gov/hurricanes). Hurricane Irene (in 2011) and Hurricane Sandy (in 2012) did not exert their full force in Maine, but they confirmed the Northeast region's vulnerability to heavy rains, storm surge and flooding. Storm surge associated with nor'easters and tropical cyclones poses a particular concern at times of extreme high tides.

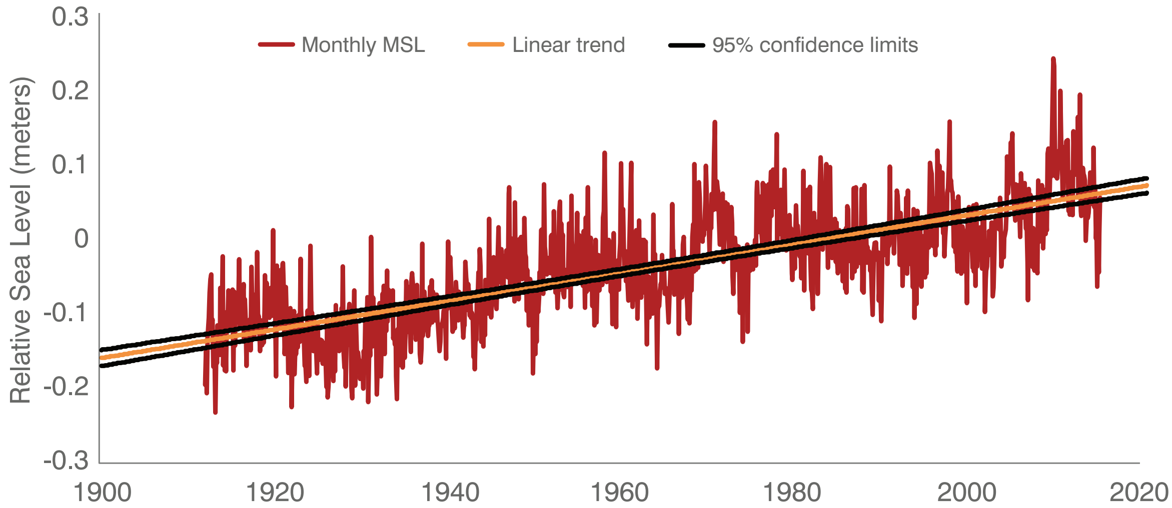
In New York and New Jersey, the storm surge from "Superstorm" Sandy forced water levels up over 11 feet. As a result of Sandy, the Maine Geological Survey released Potential Hurricane Inundation Maps, which approximate potential inundation from Category 1 and 2 hurricanes making landfall at the mean tide level and at high tide (MGS 2015a).

Tropical cyclones have generally grown more intense. Warmer air temperatures and increased water vapor, along with warmer sea-surface temperatures, provide more fuel to tropical storms, increasing their wind speeds (NASA 2015). Warming ocean temperatures could also cause more frequent high-intensity storms carrying more precipitation (Freedman 2013).

Sea Level Rise

Over the past century, Portland's tide gauge has shown an average annual increase in sea level of 1.9 mm per year (7.5 inches per century), close to global changes over that period. Sea level at that site during the past two decades has been rising 130 percent faster than this historical rate (ULI 2014).

Sea Level Trend, Portland Maine, 1912–2015



Data show seasonally corrected average Mean Sea Level, MSL, from 1912 through 2015. Linear prediction and confidence limits based on NOAA analysis.

Data: NOAA Center for Operational Oceanographic Products and Services 2015

Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

Based on sea level rise curve scenarios from the US National Climate Assessment, the Maine Geological Survey currently estimates that Casco Bay could potentially experience a 2- to 4-foot rise in sea level by the end of this century. The U.S. Global Change Research Program makes similar projections for the northeastern US (Horton et al 2014). The Maine Geological Survey has statewide potential sea level rise/storm surge inundation maps that depict potential inundation from 1-, 2-, 3.3-, and 6-foot sea level rise scenarios on top of the Highest Annual Tide (MGS, 2015b).

A discussion paper by James Hansen and other climatologists suggests that sub-surface ocean warming could lead to more rapid disintegration of West Antarctic ice sheets, elevating sea levels substantially sooner than previously predicted, with a rise of several meters (upwards of 10 feet) potentially within 50 to 100 years if high levels of greenhouse gas emissions continue (Hansen et al. 2015).

Even modest increases in sea level will increase coastal flooding, erosion, and damage to infrastructure (such as roads, bridges and ports, power and water facilities). Sea level rise and storm surge are a particular concern in densely developed low-lying areas and in settings where erosion threatens the stability of coastal bluffs. Maps identifying bluff areas most vulnerable to erosion are available for some towns bordering Casco Bay: Portland, Yarmouth, Freeport, Brunswick, South Harpswell and Phippsburg (MGS 2015c).

Abrupt sea level changes have already exacerbated local flooding in the Casco Bay region. The highest monthly mean sea levels recorded at Portland since 1912 occurred in January through April 2010 (Slovinsky 2015). A recent study found that Portland had the highest abrupt change in sea levels (on the order of 5 inches) along the entire eastern US coast (Goddard et al. 2015). This rise was attributed to a slowdown in the Gulf Stream combined with a strongly negative North Atlantic Oscillation.

Coastal communities that begin preparing for higher sea levels can save money and resources long-term. According to a 2005 study, every dollar invested in mitigating storm-surge effects on coastal communities saves US taxpayers four dollars in losses from natural hazards (Multihazard Mitigation Council 2005). Numerous communities around Casco Bay (including Cape Elizabeth, Freeport, Harpswell, Portland and South Portland) have undertaken vulnerability assessments—in conjunction with the Maine Geological Survey and Greater Portland Council of Governments (GPCOG)—and some have identified and begun implementing adaptation strategies.

Significant portions of the Portland and South Portland waterfront are highly vulnerable to sea level rise and storm surge, making it cost-effective to pursue short-term actions to protect infrastructure. Casco Bay Estuary Partnership commissioned a study of flood risk in Portland's Back Cove neighborhood that projected flooding would cause hundreds of millions of dollars in cumulative damages by mid-century if no protective actions are undertaken (Merrill et al. 2012).

A vulnerability assessment completed by GPCOG, with data from the Maine Geological Survey, found that with a 2-meter rise in sea level, 9 wastewater facilities in Portland and South Portland would be at risk (Yakovleff 2013a). Many of the urban area's major grocery stores are in settings prone to coastal flooding. Even small increases in sea level rise can increase the recurrence interval of the more destructive storm events, with a 1-foot rise reducing the interval from a 100-year to a 10-year event (Yakovleff 2013a).

Tidal wetlands provide a wide array of social benefits, including flood storage and protection, buffering from storm surge, erosion control, water-quality improvements and wildlife habitat. A Baywide, community-based study led by Casco Bay Estuary Partnership found that sea level rise could increase the damage that tidal restrictions cause to wetlands, reducing their resilience and undermining their structural integrity through increased scouring (Bohlen et al. 2013). The study concluded that many tidal wetlands could migrate into adjacent freshwater wetlands if faced with moderate increases in sea level.

As sea levels rise, salt water can contaminate coastal aquifers. Around Casco Bay, much of the population on islands and peninsulas depends on groundwater from private wells. Oak Ridge National Laboratory did preliminary modeling involving representative bedrock aquifers in the region, and found that even under best-case conditions, wells near shore (particularly on islands and peninsulas) are vulnerable to contamination by saltwater intrusion (Guiang and Allen 2015).

Ocean Acidification

Approximately 26-27 percent of human emissions of CO_2 is being absorbed by the ocean (Le Quéré et al. 2014). When marine waters absorb carbon dioxide, they become more acidic. The ocean is acidifying at a rate at least 100 times faster than at any other time in the past 200,000 years (Hönisch et al. 2012). Waters in the Gulf of Maine have relatively low pH (compared to marine waters farther south on the Eastern Seaboard), making them particularly susceptible to acidification (Walberg et al. 2103). And being relatively cold, they more readily absorb CO_2 (Woodard 2015).

The changes occurring in Casco Bay waters are a result of global ocean acidification (from changes caused by atmospheric CO_2) and coastal acidification, which occurs when excess nitrogen from wastewater, atmospheric deposition and stormwater runoff fuel greater net primary production and subsequent respiration as organic particles sink and decompose. This process results in higher CO_2 and lower pH in commercially valuable benthic areas.

Significant freshwater input along the New England coast can reduce the buffering capacity of its embayments, making them more vulnerable to coastal acidification (Salisbury et al. 2008). One study of Casco Bay during a particularly wet June (2005) found more “corrosive waters” in the Kennebec River plume by the Bay’s eastern edge (Gledhill 2015). The threat of corrosive river plumes may intensify in coming years due to increased volume and intensity of precipitation events.

The acidity of Gulf of Maine waters is expected to grow markedly in coming decades, increasing faster than the average for global seas (Gledhill et al 2015). Increasingly acidic waters can impair marine creatures at all levels of the food web, affecting their ability to grow, resist disease and reproduce. The resilience of the Gulf’s marine ecosystem has already been compromised by the loss of large predatory fish (Kinsey 2015).

More acidic coastal waters make it especially difficult for juvenile shellfish to build and maintain shells, jeopardizing the future of Maine’s shellfish industry and aquaculture operations. Maine is heavily reliant on shellfish, with 87 percent of the value of its commercial fish catch based on species such as lobsters, clams, scallops and oysters (Gledhill et al. 2015).

Research involving juvenile clams from Casco Bay suggests that increased acidification can reduce their probability of settlement and make their shells susceptible to dissolution (Green 2013, Green 2009, Salisbury et al. 2008). In limited studies, finfish have also shown effects from high CO_2 exposure but they appear to be longer-term and sub-lethal (Frommel et al. 2012).

Early research into ocean acidification’s effects on zooplankton and phytoplankton appears mixed, and little regional research has been done assessing its effects on macroalgae and sea grass. Research to date has focused primarily on single species at one life stage subject to a single stressor at a fixed level. Future studies will need to account for more ecosystemic complexity—with multiple species and life stages, multiple stressors and variable pH levels (Breitburg et al. 2015).

The Northeast Coastal Acidification Network (NECAN) formed in 2013 to review and assess relevant scientific data, identify knowledge gaps, and set monitoring and research priorities. It has elevated scientific and public understanding of this climate stressor throughout New England, but there remains an urgent need for further monitoring and biological response studies within the region (Gledhill 2015).

Because coastal Maine is very vulnerable to effects of ocean and coastal acidification, the Maine Legislature in 2014 created the Commission to Study the Effects of Coastal and Ocean Acidification to make recommendations on research and adaptation needs to the coastal community. The Commission's report led to the formation in 2016 of a volunteer group called the Maine Ocean and Coastal Acidification (MOCA) Partnership. With the assistance of NECAN, MOCA has been very active in working with stakeholders to follow-up on the Study Commission's recommendations to reduce the impacts or adapt to ocean and coastal acidification.

Anticipating Greater Variability and Uncertainty

Many projected changes in climate variables are described in terms of averages. Yet the increased variability in the climate system raises the prospect of more extreme events—like record-breaking heat, drought and heavy rainfall. The region has already experienced some unexpected extremes, such as a 5-inch spike in sea level in 2009-2010 (Goddard et al. 2010) and an ocean heat wave within the Gulf of Maine in 2012 (Mills et al. 2013).

The increased occurrence of these unusual events makes adaptation more challenging—for both human communities and ecosystems. Greater understanding of climate variability and potential impacts can help communities evaluate and minimize risks.

The climate system itself could pass certain tipping points or thresholds. "A key characteristic of these changes," a National Research Council Committee wrote in 2013, "is that they can come faster than expected, planned, or budgeted for…" (NRC 2013). Abrupt changes in the climate system—happening over decades or even years—have occurred routinely throughout Earth's history.

Several abrupt changes already underway are of particular concern.

- Rapid decline of Arctic sea ice and potential destabilization of the West Antarctic Ice Sheet could cause dramatic increases in global sea levels.
- Extinction rates among terrestrial and marine species are increasing rapidly, and continued warming may accelerate this trend.
- Disruption of the Atlantic meridional overturning circulation (AMOC), the large oceanic conveyor of which the Gulf Stream current is a part, could cause sudden spikes in sea level, disruptions to marine ecosystems, and changes in

> the ocean's capacity to store heat and carbon (NRC 2013). A conspicuous region of cooling south of Greenland, possibly linked to melting of the Greenland ice sheet, may be due to a reduction in the AMOC which could weaken further in coming decades with continued melting (Rahmstorf et al. 2015).

While abrupt changes to the climate system cannot be forestalled, monitoring key variables and modeling future scenarios can help identify areas of greatest vulnerability.

SECTION TWO

Management of Climate Change Risks

Overview

Focusing on seven classes of climate change stressors—warmer summers, warmer winters, warmer water, increasing drought, increasing storminess, sea level rise, and ocean acidification—Casco Bay Estuary Partnership (CBEP) identified potential risks to implementation of the Actions in the *Casco Bay Plan 2016-21* and estimated the probability and consequence of each risk.

CBEP worked with Waterview Consulting to define 25 Risks of Primary Concern (RoPCs) (Table 1, p. 15) through a peer-review process that involved more than 40 experts (Table 2, p. 39) in a broad range of relevant fields.

This section discusses the Risks of Primary Concern, identifies approaches for managing each risk, and details possible adaptation reactions related to that approach

For a detailed description of the risk analysis process, see the complete report in the Resources/Publications section of CBEP's website.

Table 1: Climate Change Risks of Primary Concern (RoPCs) to Implementation of *Casco Bay Plan 2016–2021*

Risks Related Principally to Habitat

H-1: Warmer waters in rivers and streams in summer exceed thermal tolerances for some native aquatic species, leading to population declines and local extinction.

H-2: Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries resources and increases in some invasive species, pathogens, pests, and disease vectors.

H-3: Rising seas and increased storm intensities cause greater demand for protection of coastal properties via shoreline hardening (which would reduce habitat value and scope for wetland migration), and therefore the need to facilitate better solutions such as living shorelines.

H-4: More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.

H-5: Acidification, both in the water column and in tidal flats, caused by global and local factors leads to reduced growth and survival of some species.

H-6: Higher temperatures increase respiration rates in eelgrass, reducing net productivity and increasing mortality.

H-7: Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point.

H-8: Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants.

Risks Related Principally to Water Quality

W-1: Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.

W-2: Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients) increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.

W-3: Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.

W-4: Increased runoff and Combined Sewer Overflow (CSO) discharges from more intense storms increase transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.

W-5: More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.

(Continued)

Table 1 (Continued)

W-6: More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.

W-7: Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.

Risks Related Principally to Community

C-1: Storm surge and coastal flooding shortens the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.

C-2: Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.

C-3: Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.

C-4: More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, and lead to more frequent catastrophic failure of banks and bluffs, causing economic and social harm.

C-5: Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.

C-6: Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.

Risks Related Principally to Implementation

I-1: Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.

I-2: Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.

I-3: Community ability to fund water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.

I-4: Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.

Risks Related Principally to Habitat

H-1 Warmer waters in rivers and streams in summer exceed thermal tolerances for some native aquatic species, leading to population declines and local extinction.

Warmer waters are already having an effect in Maine on cold-water fish like brook trout. Impacts on other fish, including anadromous species, are likely to increase in decades to come.

Increases in air temperature will increase stream temperatures, but stream temperature reflects more than air temperature. Stream temperatures are influenced by surrounding land uses, presence of sunlight and shade on streams, and groundwater inflow. Thus while we are unable to completely eliminate increasing stream temperatures, we can reduce or delay their severity and impacts.

We can:

- Protect and restore cold water refugia, including areas of groundwater discharge to streams and rivers;
- Work to improve fish passage between tributary streams and larger waters like lakes and rivers, increasing access of cold-water species to cooler waters during the warmest part of the summer;
- Protect riparian and floodplain forests surrounding headwater streams, brooks, and rivers, to increase shading of the streams;
- Encourage use of stormwater control technologies that reduce the probability of discharge of heated waters from asphalt surfaces or retention ponds directly to vulnerable streams.

We can also mitigate the impact of stream temperature on populations of fish species of concern by supporting those populations in other ways. For example, one way to reduce the impact of rising temperatures on anadromous fish is to restore fish passage to our streams and rivers. Increases in migratory fish populations due to fish passage improvements would mask emerging changes due to elevated temperature. And the substantially larger populations possible—especially on our larger rivers—would be both less vulnerable to extinction, and more able to adapt to changing conditions.

Local communities could change ordinances to provide better protection of riparian zones, improve culverts near stream-river junctions, and extend protections to groundwater discharge areas, but such changes are likely to be controversial.

H-2 Warmer ocean water temperatures cause shifts in species' geographic ranges and the community structure of Casco Bay's ecosystem, leading to declines in some existing fisheries resources and increases in some invasive species, pathogens, pests, and disease vectors.

It is hard to overstate the importance of climate impacts on species ranges in shaping the marine resource economy of Maine in coming decades. The northern shrimp fishery has been closed since 2014, principally because the species has shifted its range northward. Lobstermen report increasing numbers of black sea bass turning up in their traps, and the State approved a limited fishery for this mid-Atlantic species in 2014. Scientists have expressed concern that Maine's lobster fishery may be susceptible to rapid declines like those in southern New England, where the American lobster is all but commercially extinct. In 2016, lobster represented 73.9% of the value of all fisheries in Maine, and the prosperity of Maine's island and small coastal communities is highly dependent upon lobster.

We can do little at the Casco Bay scale to affect shifts in the ranges of marine species, which reflect changing ocean conditions developing at regional and continental scales. We can, however, take steps to minimize impact of these shifts on fisheries, coastal economies, and coastal ecosystems. We can reduce the impact of ecosystem change on coastal communities by working with those communities to facilitate economic adaptation. For example, we can work to facilitate emerging fisheries or support development of locally owned, environmentally sound aquaculture businesses.

Numerous invasive marine species are already present in Casco Bay. Some invasives, like the green crab, the common periwinkle, and the orange sheath tunicate (*Botrylloides violaceus*) are found in significant numbers throughout the Bay. Invasives are already imposing significant impacts on coastal ecosystems and fisheries.

Unfortunately, our ability to block invasive species in the marine environment is limited. Several invasives of concern are already present in the Gulf of Maine, but are not known to have established in Casco Bay. Such species may not yet have been introduced to Bay waters, or conditions in the Bay (such as cold winters) may limit their numbers. Either way, options for active management to reduce the probability of their arrival are few.

We can:

- Monitor presence and abundance of invasive species, so we know what is present and identify emerging threats;
- Provide education for boat owners, marina operators and others about impacts of invasive species, and actions they can take to reduce their spread;
- Seek tools to manage populations or reduce economic and ecological impacts of invasives.

Finally, we can mitigate the impact of invasive species on the health of Casco Bay by protecting the Bay's health in other ways—from reducing nutrient pollution to protecting important coastal habitats.

H-3 Rising seas and increased storm intensities cause greater demand for protection of coastal properties via shoreline hardening (which would reduce habitat value and scope for wetland migration), and therefore the need to facilitate better solutions such as living shorelines.

CBEP is already working with the Maine Coastal Program and other partners to facilitate environmentally preferable strategies for protecting eroding shorelines in Maine. This effort, which is expected to last several years, will develop and test "living shorelines" technologies that work in Maine. The initiative will also involve working with regulatory agencies to seek solutions to regulatory barriers that sometimes provide disincentives for landowners to use creative approaches to protecting their property.

Shorelines can also be protected against hardening over a period of decades by legal means, including:

- Direct fee acquisition of shoreline properties;
- Use of easements (conservation easements, rolling easements) to limit shoreline construction;
- Shoreline protection policies that limit construction of hardened shorelines;
- Shoreline protection policies that limit construction of residences and infrastructure in vulnerable locations.

Policy change may be needed as part of a coordinated response to this RoPC.

H-4 More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting fish migration.

We can do little to affect seasonality of river flows at the local scale, and we are likely to have to accept the impacts such changes may have on migratory fish. However, impacts at the population level can be mitigated by supporting anadromous fish populations in other ways. As with efforts to mitigate the impact of rising stream and river temperatures on migratory fish (see RoPC H-1) we can continue to work to restore and maintain access of migratory fish to their breeding habitats and protect water quality in the lake and riverine habitat, where many migratory species are most vulnerable.

H-5 Acidification, both in the water column and in tidal flats, caused by global and local factors leads to reduced growth and survival of some species.

While we can do little at the local level to reduce the magnitude of acidification caused by global CO_2 levels, we can work to combat local processes that exacerbate the problem. High nutrient levels in the Bay contribute to growth of planktonic algae, which often leads to increased production of algae and, indirectly, CO_2. That CO_2, in turn, produces local acidification that just adds to the global phenomenon. One of the most effective ways we can reduce the impact of acidification on Casco Bay is to reduce nutrient loading to the Bay. Excess nutrients have many other negative effects on the Bay's health, so reducing nutrients would have numerous other benefits.

Other actions to reduce the impact of acidification on the Bay and on our communities could include:

- Support efforts to improve understanding of coastal acidification and its impacts on the Bay and on important local fisheries, including aquaculture;
- Experiment with ways to reduce impacts of acidification on key resources, like shellfish;
- Work with communities to identify strategies for diversifying local economies.

H-6 Higher temperatures increase respiration rates in eelgrass, reducing net productivity and increasing mortality.

In coming years, eelgrass in Casco Bay is likely to be confronted with multiple stressors, from green crab population booms (like the one that caused extensive loss of eelgrass in 2013) to poor water clarity due to elevated nutrient levels in the Bay. The type of long-term reductions in net eelgrass productivity expressed in this RoPC are likely to slow growth and recovery of eelgrass, and thus act synergistically with other stressors to make it increasingly difficult in the future to maintain healthy eelgrass in the Bay.

We have few options for avoiding this risk, but we can seek ways to reduce or delay impacts of the loss of eelgrass by working to protect existing eelgrass beds, improve water quality and seek opportunities to enhance eelgrass populations via restoration, replanting, and integration of eelgrass into "living shorelines" projects.

In the long term, if eelgrass productivity does decline, we will need to reevaluate the viability of simple restoration and planting projects, in light of slower plant growth. In another generation, we may need to consider options that may be controversial today, such as importing more heat-tolerant eelgrass genotypes from the mid-Atlantic or creating eelgrass "reserves" to maintain local sources of plant material for natural recruitment and restoration.

H-7 Climate change leads to changes in marine and coastal food webs, altering species composition, making coastal ecosystems less resilient to other stressors like invasive species, elevated nutrients and habitat destruction, and raising chances of the ecosystem hitting a tipping point.

Climate change will act synergistically with other stressors, making the Bay more susceptible to other challenges. Thus a key part of responding to a changing climate must be to protect the Bay's health in other ways. A healthier Bay will respond more constructively to change than will a Bay already facing challenges. Climate change does not overshadow other efforts to protect the Bay; it makes them even more important.

The challenge for Casco Bay in coming decades is not just climate change, but coastal change—the synergistic effect of multiple stressors affecting the coast simultaneously with a changing climate. The principal local response to coastal change, perhaps paradoxically, thus must be to focus even more strongly on how we reduce and eliminate other threats to the Bay's health.

The other way to respond to this RoPC will be to put more resources into understanding and monitoring the Bay. Better monitoring will help us detect and characterize change as it begins, providing more time to respond—both to protect the Bay itself and to assist coastal communities with adapting to a changing Bay, and with better information to do so. Better science will help us identify more effective strategies for protecting the health and resilience of the Bay as it continues to change.

H-8 Sea level rise and altered hydrology in tidal wetlands (due to multiple climate stressors) shifts species composition, causes both gains and losses of tidal wetland area, and makes the wetlands more susceptible to invasion by invasive plants.

Casco Bay's tidal wetlands will change in numerous ways in coming decades. With thousands of acres of tidal wetlands scattered in hundreds of sites around the Bay, a comprehensive response to these changes is all but impossible. Luckily, most changes are likely to be gradual, allowing us to develop and evaluate strategies for responding to this RoPC as we come to understand them better.

Initial studies suggest that loss of tidal wetlands in Casco Bay due to sea level rise in the next 50 to 100 years are likely to be less severe than losses projected to our south. The geomorphology of Casco Bay and the relatively undeveloped nature of most of its shoreline gives many of our wetlands space to move, at least for a while. But in the long run—exactly when depends on the rate of sea level rise—Casco Bay's steep shorelines mean most Casco Bay wetlands will have nowhere to go.

In coming years it will be important to consider what we understand about the future of Casco Bay wetlands in designing and implementing coastal restoration and protection projects. There may be little point in investing in wetland restoration if the restored marsh has an expected lifetime of only a few decades. Conversely, forecasts for the Gulf of Maine suggest severe population bottlenecks for saltmarsh sparrows by the middle of the century. Casco Bay's tidal wetlands, while small by regional standards, are relatively resilient to moderate sea level rise. They may provide a valuable refuge for these salt marsh breeding birds through the decades of the mid twenty-first century.

In the interim, we can work to improve our understanding of changes in Casco Bay's tidal wetlands and experiment with restoration methods. We have already used simple models to characterize future wetland loss, and we are in the process of establishing sentinel monitoring sites in Casco Bay tidal wetlands to allow us to track changes in our salt marshes. We can continue to assess the potential of methods that are being tested elsewhere for improving the resilience of our tidal wetlands.

Risks Related Principally to Water Quality

W-1 Higher intensity storms make it more likely that stormwater control devices will prove too small to perform as designed, reducing effectiveness, and degrading downstream water quality.

The consequences of this risk can be mitigated by use of climate-responsive designs for stormwater control devices. However, this effort is likely to be slow, as climate responsive designs are not well understood or broadly accepted by the development community.

A particularly promising approach to mitigating this risk will be to expand use of "Low Impact Development" and "Green Infrastructure" approaches to stormwater management. As these design philosophies integrate site hydrology and natural processes into site design, and make more extensive use of small, decentralized stormwater management tools, they are more resilient than traditional designs.

Because of the relatively slow rate of population growth in our region, a high proportion of our developed landscape was urbanized decades ago, before the advent of modern stormwater design criteria. Thus many stormwater control devices are undersized by today's standards. Moreover, the structures are aging and may provide little water quality benefit. Climate change will just make that situation worse. Adaptation to this RoPC thus will also entail efforts to install stormwater controls in existing developed landscapes.

CBEP can support these efforts by:

- Working with communities to increase awareness of the impact of stormwater on Casco Bay;
- Encouraging adoption of stormwater control measures in general, and encouraging designs that incorporate forecasts and uncertainties about future storm intensities into present-day designs;
- Facilitating use of climate-responsive designs and technologies like green infrastructure and low impact development;
- Helping to address long-term funding needs for water infrastructure.

W-2 Higher water temperatures make the Bay more susceptible to nutrients (via algae growth, thermal stratification, and rapid recycling of nutrients), increasing risk of harmful algae blooms, decreased water clarity, lower dissolved oxygen, and fish kills.

This RoPC makes it more important than ever to focus on reducing nutrient loads entering the Bay. The combination of climate change and a growing human population in the Casco Bay watershed make risks to the health of the Bay due to nutrient enrichment one of the most concerning long-term threats to the health of the Bay. (See also the related RoPC H-7).

W-3 Large storms increase stormwater volumes and infiltration into aging sewer lines, thus sending larger volumes of more dilute wastewater to treatment plants, reducing effectiveness of nutrient removal.

Wastewater treatment plant engineers and operators can take steps to reduce nutrient concentrations in each plant's effluent, but if water volumes increase due to changes in precipitation patterns, so will total discharges of nutrients to the Bay. Plant upgrades that allow substantial reductions in effluent nutrient concentrations, however, can be costly.

Potential responses include:

- Support efforts to reduce volumes of water entering sewer lines by reducing inflow and infiltration into sewer systems and assessing benefits of storm sewer separation (while weighing the nutrient removal benefits of providing even partial treatment for stormwater);

- Continue to reduce the average nutrient concentrations in treatment plant effluent;
- Continue to reduce other sources of nutrients entering the Bay (see RoPC W-2 and H-7).

W-4 Increased runoff and Combined Sewer Overflow (CSO) discharges from more intense storms increase transport of nutrients and other pollutants to downstream waters, including lakes and the Bay, degrading water quality.

Nutrient enrichment is likely to be among the most important threats to the health of the Bay in coming years. And runoff—in our region principally from urban areas—is among the most important sources of nutrients. More rain and larger storms both tend to wash more nutrients to the Bay, and climate forecasts suggest both more rain and more intense storms in the future.

While we can do little at the local level to affect future precipitation patterns, we can work to reduce the yield of nutrients—especially nitrogen—entering the Bay per unit rainfall.

We can reduce the impact of increased runoff by (among other strategies):

- Implementing better stormwater management programs at the local level;
- Installing "stormwater retrofits" into existing developed landscapes where existing stormwater infrastructure is inadequate or does a poor job of removing nitrogen;
- Encouraging the use of stormwater control approaches—like "green infrastructure"—that reduce nitrogen flow to downstream waters;
- Educating the public and policy makers about the effects of runoff on the Bay;
- Encouraging homeowners to avoid or minimize the use of fertilizers on their lawns;
- Continuing to reduce the frequency and size of combined sewer overflow events.

W-5 More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, causing release of pollutants into rivers and coastal water.

The primary way to reduce the impacts of this RoPC should be to reduce risks of flooding of coastal and river valley communities, thus reducing risk of release of pollutants. A secondary approach will be to move pollutants out of flood-prone areas in advance of storms. Communities, businesses, and residents can take steps to move vulnerable assets (and associated pollutants) out of harm's way, via investment in flood protection infrastructure and gradual disinvestment in vulnerable assets. Zoning, insurance, planning and risk management policies can create disincentives for placing vulnerable assets or potential pollutants into flood-prone areas.

CBEP and our partners can support these efforts via outreach and education, especially by communicating the best available science to help communities assess the magnitude of storm-related risks. We can also encourage coastal and river valley communities to invest in infrastructure or disinvest in vulnerable assets to reduce potential flooding impacts.

CBEP can play a role in publicizing flood risks and the benefits of various flood risk mitigation strategies.

W-6 More winter precipitation falling as rain, earlier snow melt and less predictable precipitation lead to a shorter and less predictable spring season of high river flows, affecting timing and magnitude of nutrient inputs to the Bay.

Shifts in timing of river and stream flow over the past several decades are well documented in Maine. We can do little at the watershed scale to avoid or reduce these shifts in timing, and the implications for coastal ecosystems are not well understood. Consequently, any action to address this RoPC is premature. The best responses available to us involve overall efforts to protect and enhance the health of the Bay, especially working to reduce nutrient loading to the Bay and protect water quality.

W-7 Increased storm intensity and rising seas lead to more erosion from uplands, shores, banks and bluffs, increasing both turbidity and nutrient flows, degrading water quality.

A high proportion of erosion from uplands is caused or exacerbated by human activity, such as construction, agriculture, logging, clearing land, poor landscaping practices, and so on. Legal and policy tools, from zoning and permit requirements under state and federal law, to Department of Agriculture conservation programs, help reduce soil erosion. Such tools will continue to be important for limiting erosion in the future.

On the other hand, erosion of shores and banks is a normal process, and thus responding to possible increases in their erosion must be measured and responsible, considering the interplay of sediment erosion, deposition and transport in the context of the geomorphology of Casco Bay and its tributaries.

A number of strategies can mitigate the severity of this RoPC, including:

- Support efforts to reduce soil erosion, including education, policy development, and enforcement of existing policies;
- Reduce land cleared of vegetation during site development. Existing vegetation significantly reduces erosion, and can provide other important services, including water quality benefits and habitat for wildlife;
- Work to develop environmentally sound approaches to shoreline protection (see RoPC H-3), where appropriate;
- Reduce other water quality challenges that will exacerbate or act synergistically with increased sediment inputs to the Bay and other local waters;
- Expand use of stormwater management practices like green infrastructure that reduce nutrient loading to the Bay.

Risks Related Principally to Community

C-1 Storm surge and coastal flooding shorten the life of transportation and utility infrastructure, from roads and port facilities to sewer lines and sewage treatment plants, reducing economic productivity and increasing private and public sector costs.

To a large extent, other organizations—especially local government, businesses, and homeowners—will absorb these costs. Costs can be reduced by planning for climate change and taking appropriate actions to reduce or mitigate climate impacts. CBEP can support these efforts by facilitating access to the best available information on future risks.

C-2 Rising seas flood stormwater pipes and reduce drainage capacity of stormwater infrastructure, increasing risk of flooding.

A major storm in September of 2015 dropped several inches of rain in Portland during an unusually high astronomical tide. The storm, which flooded portions of Forest Avenue and Marginal Way, showed what can happen when tides and rainfall conspire to overload capacity of urban drainage infrastructure. Climate forecasts suggest more intense storms in future, while rising seas are likely to reduce drainage capacity. Responses to increased risk of short-term urban flooding include redesigning stormwater conveyances to carry more water, elevating roadway intersections and other infrastructure above flood levels, or accepting infrequent flooding of vulnerable areas.

C-3 Rising seas make waterfront facilities like piers and other commercial and recreational access points inoperable, or require expensive repairs and investment to maintain functionality, affecting marine industries and quality of life.

This is a significant long-term risk to the character of waterfront, water-dependent, and island communities in our region. Businesses and local communities will have the primary role in addressing this risk. CBEP communities and partners can play a supporting role in helping waterfronts to adapt to climate change and sea level rise by facilitating adaptation efforts, encouraging climate preparedness, and sharing credible scientific assessments of emerging risks.

C-4 More frequent severe storms and sea level rise increase flooding of coastal and river valley communities, and lead to more frequent catastrophic failure of banks and bluffs, causing economic and social harm.

This is a complex risk that embeds a variety of mechanisms by which a changing climate may generate economic and social harm. Control of this risk is also complex, and will generally prove site and situation specific. Thus, the best near-term approach to addressing this RoPC will be to carefully assess local risks, and develop plans to help reduce community exposure to related harm.

C-5 Complexity of multiple demands for adaptation to climate change may overwhelm ability of local governments to respond constructively to change.

This risk will be influenced both by the severity of future climate impacts and by the capacity of communities to respond constructively to impacts that do occur. The best way to address this risk may be to work to mitigate other climate risks while also supporting the ability of communities (including local governments) to understand, prepare for, and respond to climate-induced changes. For example, communities can work to develop or maintain robust governance structures, support civil discourse, or increase community conversations and connections to increasing social capital.

C-6 Increased probability of failure of culverts due to greater storm intensities requires more frequent culvert replacement, driving up infrastructure costs.

Owners of potentially affected infrastructure should be encouraged to design structures for the climate of the future, not the climate of the past. While larger culverts are initially more expensive than smaller structures, designs should be based on an estimate of lifetime costs. Appropriate cost-benefit analysis should be based on a realistic assessment of future failure probabilities. Mechanisms are needed to incorporate trends, forecasts, and uncertainty into design practice (e.g., regularly updated flood return frequency analyses, and engineering guidance on incorporating climate change into design practice).

Risks Related Principally to Implementation

I-1 Uncertainty about the future of the Bay, due to inability to predict climate impacts caused by multiple interacting stressors, increases both complexity and cost of monitoring programs.

CBEP needs to build broad-based coalitions and institutional frameworks to facilitate long-term monitoring and long-term funding of monitoring. This is likely to require reducing investment in some other activities, as well as finding novel ways of funding long-term monitoring.

I-2 Unpredictable weather leads to an increased need for monitoring of episodic events like severe storms and their effects, increasing both total and event-triggered monitoring costs.

See discussion of RoPC I-1.

I-3 Community ability to fund water quality infrastructure and other environmental projects is decreased by need for disaster recovery, infrastructure replacement and costs of climate adaptation.

This risk is relatively long-term. The principal near-term strategy for addressing this RoPC will be to encourage climate adaptation planning.

I-4 Multiple climate stressors (warmer summers, winters, and water; increasing drought and storminess; sea level rise; ocean acidification) make it difficult for managers and regulators to understand emerging issues, and to respond quickly and constructively to a changing coastal ocean.

CBEP can and should continue to work with regulators and policy makers to ensure that responses of regulatory and legal structures keep up with changing climate. The long-term response to this RoPC is likely to include legal and policy innovation.

SECTION THREE

Climate Adaptation Resource Guide for Casco Bay Communities

Prepared by Natural Choices in December 2015.
Contact information updated by CBEP in May 2017.

Toolkits and Viewers

Adaptation Toolkit for Public Officials
http://www.maine.gov/dep/sustainability/climate/adaptation-toolkit/public-official.html

Gulf of Maine Council Climate Network Community Toolkit
http://www.gulfofmaine.org/2/climate-network-community-toolkit/

New England Environmental Finance Center Climate Change Tools
http://efc.muskie.usm.maine.edu/pages/climate%20change_tools.html

Sustain Southern Maine Climate Change Resources
http://sustainsouthernmaine.org/developing-our-action-plan-climate-change/

Envisioning Change: Mapping Sea-level Rise in Casco Bay
http://media.usm.maine.edu/~slc/

Climate Solutions Mapping Project for Maine
http://climatesolutionsme.org/

NOAA's Digital Coast Sea-Level Rise Viewer
http://coast.noaa.gov/digitalcoast/tools/slr

Surging Seas Sea Level Viewer
http://sealevel.climatecentral.org/

Maine Geological Survey Sea-Level Rise/Storm Surge Viewer
http://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml

Maine Beginning with Habitat Viewer
http://webapps2.cgis-solutions.com/beginningwithhabitat/

Maine Beginning with Habitat Toolbox
http://www.beginningwithhabitat.org/toolbox/about_toolbox.html

Maine Coastal Program--Coastal Erosion and Sea Level Rise Resources
http://www.maine.gov/dacf/mcp/environment/coastal-erosion.htm

Maine Coastal Program Resources for Local Climate Change Planning
http://www.maine.gov/dacf/municipalplanning/technical/climate.shtml

Maine Stream Habitat Viewer
http://mapserver.maine.gov/streamviewer/streamdocDisclaimer.html

Community Resilience Tools
http://www.seagrant.umaine.edu/extension/coastal-community-resilience

EPA Water Utility Response On-the-Go (Mobile)
http://watersgeo.epa.gov/responseotg/

EPA's RAINE Database (Resilience and Adaptation in New England)
http://www.epa.gov/raine/searching-raine-database

Environment America's Extreme Weather Map
http://environmentamerica.org/page/ame/hitting-close-home-global-warming-fueling-extreme-weather-across-us

Organizations Working on Climate Adaptation within the Region

Casco Bay Estuary Partnership
The Partnership supports climate adaptation throughout the Casco Bay watershed through training programs, research, publications and other collaborative actions (featured in its Casco Bay Plan 2016-2021). It also helps support the ocean acidification monitoring station at Southern Maine Community College. Climate-related publications include:

- Climate Trends in the Casco Bay Region (2015)
- Climate Change in the Casco Bay Watershed: Past, Present Future (2009)
- Geomorphology and the Effects of Sea Level Rise on Tidal Marshes in Casco Bay (2012)
- Sea Level Rise and Casco Bay's Wetlands: A Look at Potential Impacts (a report with maps targeted to each of ten different municipalities around the Bay—in the CBEP Publications Library)
- State of the Bay 2015 Climate Change Indicator

Contact: Marti Blair, 207-780-4306, cbep@maine.edu

Casco Bay Regional Resiliency Assessment Program
This cooperative, non-regulatory program to assess the resilience of critical infrastructure, led by the Department of Homeland Security Office of Infrastructure Protection, involved gathering and analyzing data (e.g., facility vulnerability assessments and modeling). A regional resiliency report was completed for the Casco Bay region and can be found here.

Cumberland County Emergency Management Agency
Cumberland County EMA is charged with developing and periodically updating the county's Hazard Mitigation Plan. This Plan is reviewed and approved by the Maine Emergency Management Agency and the Federal Emergency Management Agency (FEMA) before being formally adopted by towns. In the final stages of the Plan process, CCEMA staff members attend select board meetings in every community—providing an opportunity for discussion of climate adaptation planning. By signing the Plan, communities are eligible to have competitive projects funded at 75 percent through FEMA.

The Cumberland County Hazard Mitigation Plan was updated in 2017. CCEMA's planner, Margaret Cushing, led this process in cooperation with municipalities throughout the county. She is the primary CCEMA staff person dedicated to hazard mitigation: the other six employees focus on response to disasters.

Contact: Margaret Cushing, 207-892-6785, cushing@cumberlandcounty.org

Cumberland County Soil and Water Conservation District
CCSWCD helps to coordinate the Interlocal Stormwater Group (ISWG), a regional partnership in which 14 municipalities share strategies for reducing stormwater pollution and complying with related Clean Water Act permits. ISWG communities work cooperatively to educate youth, municipal officials, developers and citizens about water quality and stormwater.

Contact: Jami Fitch, 207-892-4700, jfitch@cumberlandswcd.org

Friends of Casco Bay
Friends of Casco Bay's 2015 report, A Changing Casco Bay, covers impacts of nitrogen pollution and coastal acidification, and includes actions that individuals can take to make a difference.

Contact: Mary Cerullo, 207-799-8574, mcerullo@cascobay.org

Greater Portland Council of Governments
Through its Sustain Southern Maine initiative, GPCOG completed a regional sea-level rise vulnerability assessment and shared climate change adaptation recommendations.

A Casco Bay Environmental Planning Assessment completed by GPCOG in 2012 summarizes planning activities and land-use regulations based on a survey of ten communities bordering Casco Bay. Sections of that plan most relevant to climate adaptation include shoreland zoning, stormwater management, impervious surface limits, LID techniques, drinking water protection and floodplain management. This report is being updated and will be finalized in July 2017.

The Cumberland County Climate and Energy Plan, prepared by GPCOG and adopted by the Cumberland County Commissioners in 2012, outlines ways that municipalities and communities can reduce energy use and minimize greenhouse gas emissions.

GPCOG frequently assists communities around the region with adaptation planning, and is currently working with Chebeague Island to assess the vulnerability to sea-level rise of a current and potential wharf site. Summaries of three past coastal resiliency projects—in Cape Elizabeth, Freeport and South Portland, are available on the environmental planning page of the GPCOG website.

Contact GPCOG at 207-774-9891 or 1-800-649-1304.

Gulf of Maine Research Institute
GMRI is exploring new technologies and business models to sustain the long-term health of the region's coastal economy in the face of significant fisheries changes. It recently received a $6.5 million grant from NASA to create a new educational program to upgrade the technical infrastructure at its center for interactive learning, enabling classrooms in Maine and nationwide to investigate how climate change is affecting their local region and the rest of the world. The new programming will be offered by the 2018-2019 school year.

Its scientists are tracking temperature changes within the Gulf of Maine and their impact on marine species. A recent article in Science magazine highlight the Gulf's warming and its impact on cod populations. Other projects related to adaptation at GMRI include an aquatic survey to monitor the Casco Bay ecosystem, sampling fish and plankton near the Presumpscot River estuary over a ten-year period; and Gulf of Maine Lobster Forecasting

Contact: Elijah Miller, 207-228-1667, emiller@gmri.org

Island Institute
Island Institute currently has three projects that relate to climate adaptation in Casco Bay. A new pilot project is testing ocean acidification remediation at Paul Dobbins' Ocean Approved kelp farm off Chebeague Island. Island Institute scientist Susie Arnold and Nichole Price from Bigelow Laboratory are deploying sensors for pH, CO_2, dissolved oxygen, temperature and salinity in and around the kelp farm to determine if kelp has the capacity to locally remediate ocean acidification (and whether it is beneficial to collocate kelp and shellfish).

Island Institute is partner in a Coastal Community Grant Program project (supported by the Maine Coastal Program) in which Greater Portland Council of Governments is helping Chebeague Island conduct a sea-level rise vulnerability assessment.

The Institute is also working with island communities on economic diversification in light of fisheries changes. It is offering a six-month Aquaculture Cohort program introducing island residents to shellfish and seaweed aquaculture (with about half of the registrants currently coming from Casco

Bay). Participants in this Institute project may also elect to participate in a Maine Sea Grant "Aquaculture in Shared Waters" training program.

Contacts: Susie Arnold, Marine Scientist and Nick Battista, Marine Programs Director, 207-594-9209, sarnold@islandinstitute.org and nbattista@islandinstitute.org

Maine Coastal Program

The Maine Coastal Program (MCP), housed at the Maine Department of Agriculture, Conservation and Forestry provides funds to regional councils and communities around Casco Bay through two competitive grants program. Municipalities in Maine can apply each year to help fund municipal and regional projects in Maine's coastal zone through the Coastal Community Grant Program and Shore and Harbor Planning Grant Program.

With support from MCP, South Portland updated its comprehensive plan language; Cape Elizabeth completed a stormwater study of its town center and revised its shoreland zoning ordinance; and Yarmouth, Freeport and Brunswick received introductory presentations on sea-level rise. Chebeague conducted a vulnerability assessment of its ferry landing at the Stone Pier, and a review of its comprehensive plan (in conjunction with GPCOG).

The MCP has a webpage of resources on planning for climate variability and one on coastal erosion and sea level rise. It lists past projects funded through its Coastal Community Grant Program.).

Contacts: Ruta Dzenis (Coastal Community Grants), 207-287-2851, ruta.dzenis@maine.gov. Claire Enterline (Shore and Harbor Management Grants), 287-1493, claire.enterline@maine.gov.

Maine Geological Survey

Maine Geological Survey (MGS), in conjunction with the Maine Coastal Program (MCP) and Regional Planning Organizations, has worked with roughly half of the municipalities bordering Casco Bay (specifically Cape Elizabeth, South Portland, Portland, Freeport, Harpswell and Phippsburg) to complete sea-level rise vulnerability assessments using a scenarios-based approach. Additional assessments of mainland communities bordering Casco Bay are included in the Sustain Southern Maine Sea Level Rise Vulnerability Assessment. Phippsburg worked with MGS and MCP on a study of marsh migration and road impacts that involved extensive public outreach.

MGS has several upcoming projects of relevance to Casco Bay communities:

- A NOAA Project of Special Merit, titled Building Resiliency along Maine's Bluff Coast, is focusing on Casco Bay bluff erosion hazards--helping municipalities learn new ways of managing bluffs and reexamine their commitment to setbacks. This project is being done in conjunction with Cumberland County Soil and Water Conservation District.
- Through a 2-year NOAA Coastal Management Fellowship project, MGS and MCP is engaging municipalities with a resiliency self-assessment, in addition to using existing incentives to participate or increase their scores in the National Flood Insurance Program Community Rating System. Currently only Cape Elizabeth (Class 9) and Portland (Class 8) are participating in this incentive based program (which provides a 5 percent discount for each class-level increase) based on policies such as shoreland zoning with open space provisions; meeting or exceeding state freeboard standards; building code standards; comprehensive plans and MS4 stormwater measures.
- MGS has created statewide GIS layers that can viewed online (http://www.maine.gov/dacf/mgs/hazards/coastal/index.shtml) showing existing highest annual tide; scenarios of sea-level rise or storm surge with layers for 1-foot, 2-foot, 1 meter and 6-feet; and a hurricane inundation layer for Category 1 and 2 storm events.

Contact: Peter Slovinsky, 207-287-2801, peter.a.slovinsky@maine.gov

Maine Sea Grant
In addition to its Coastal Community Resilience website, Maine Sea Grant has several resources to help municipalities and landowners with climate preparedness.

- Maine Property Owner's Guide to Managing Flooding, Erosion and Other Coastal Hazards website: http://www.seagrant.umaine.edu/coastal-hazards-guide

Maine Audubon
In conjunction with Manomet Center for Conservation Sciences and others, Maine Audubon has completed two studies of climate change and biodiversity, available online at http://maineaudubon.org/publications-resources/. Maine Audubon helped found the Stream Smart Program, which provides ongoing trainings for public works directors, contractors, planners, engineers, landowners and conservation volunteers and professionals on how to build and upgrade road-stream crossings in ways that sustain wildlife habitat, improve public safety (especially as more extreme precipitation events occur), and minimize risk of washouts and storm damage.

Contact: Sarah Haggerty, 207-781-2330 x225, shaggerty@maineaudubon.org

Manomet Center for Conservation Sciences
Manomet has prepared climate adaptation plans for two sites in the Casco Bay watershed (Maquoit Bay and in the Sebago Lake watershed) and has published a list of funding resources for climate adaptation work. More information and publications are available at https://www.manomet.org/program/climate-services/climate-change-adaptation.

Contact: Eric Walberg, 207-721-9040, ewalberg@manomet.org

Maine Coast Heritage Trust
MCHT's booklet, Conservation Options: A Guide for Maine Landowners, offers an array of strategies for open space protection. It also has a flyer on the Public Benefits of Conserved Lands.

Contact: Warren Whitney, 207-729-7366, wwhitney@mcht.org

Maine Department of Environmental Protection Water Bond Funds
The Maine Department of Environmental Protection has begun disbursing funds from a $10 million Water Bond that voters approved in November 2014. More than $5 million is dedicated to funding vital public improvement projects including stream crossing or culvert upgrades, and $400,000 is set aside for state wetland restoration. Projects are intended to reduce the risk of culvert failure; incorporate provisions for climate change, flood protection and resiliency; remove barriers to fish passage; and restore wetlands that provide wildlife habitat. RFP information is on the Maine DEP website.

Contact: Bill LaFlamme, 207-215-9237, william.n.laflamme@maine.gov

Maine Department of Inland Fisheries and Wildlife (MDIFW)
In 2015, MDIFW collaborated with more than 100 conservation partners to revise Maine's Wildlife Action Plan, several sections of which relate to climate change adaptation. Table 3-3 on page 13 of Element 3 lists links to PDFs containing Species of Greatest Conservation Need and habitat information for four different sub-categories of climate change. The Conservation Actions chapter has additional climate-related recommendations.

Contact DIFW at 207-287-8000

Natural Resources Council of Maine
NRCM hosts climate-related forums, encourages business engagement (see http://www.nrcm.org/projects-hot-issues/clean-air-clean-energy/federal-climate-and-energy-issues/become-a-maine-businesses-for-climate-action/).

Contact: Dylan Voorhees, 207-430-0112, dvoorhees@nrcm.org

New England Environmental Finance Center (NEEFC)
The New England Environmental Finance Center helps communities in New England develop capacity to plan and finance climate adaptation and resiliency programs.

The NEEFC's report Climate Adaptation and Resiliency Planning for New England Communities: First Steps and Next Steps (2016) includes a process guide for communities including tools and financing options related to climate change adaptation and resiliency planning and financing. NEEFC developed a financing options directory of federal and state funding and financing sources for climate adaptation projects in each New England state. See the Executive Summary here and read the Full Report here.

NEEFC also developed the COAST model to help cities and towns estimate the costs of projected sea level rise and storm surge damages, as well as the avoided costs of various adaptation measures. Click here to access the COAST tool.

Contact: Martha Sheils, 207-228-8164, Martha.sheils@maine.edu

NOAA Coastal Services Center
In addition to its sea level-rise viewer, NOAA's Digital Coast site offers many other adaptation resources, including on-site trainings and webinars.

Contact: Rebecca Newhall, 978-281-9237, Rebecca.newhall@noaa.gov

NOAA National Centers for Environmental Information, Eastern Region Office
The Regional Climate Services Office provides various resources to assist planning and decision-making, including a quarterly Climate Impacts and Outlook bulletin for the Gulf of Maine region and monthly webinars related to regional weather and climate.

Contact: Ellen Mecray, 508-824-5116, ext. 263, ellen.l.mecray@noaa.gov

The Nature Conservancy Maine Chapter
TNC's Maine Chapter has habitat restoration projects underway in both inland and nearshore portions of the Casco Bay watershed, as well as a marine program (exploring a potential permit banking strategy for ground fisheries and working to increase more volunteer monitoring of diadromous fish runs along the coast).

It has two habitat restoration specialists who work statewide, who work helping communities to increase the size of culverts to enhance fish passage, improve stream function, maintain habitat diversity and better withstand large storms. Its staff is also working on projects to increase nearshore resilience through eelgrass planting, saltmarsh restoration and oyster cultivation. Ongoing monitoring of these experimental sites will help provide guidance for more far-reaching efforts. TNC also participates in the Stream Smart Program, helping to change the state's culture of road-building and maintenance, and in the statewide Stream Connectivity Work Group.

TNC also works on policy measures to advance climate adaptation such as carbon credits and sustainable energy.

Contact: Jeremy Bell, 207-729-5181, jbell@tnc.org

University of Maine Climate Change Institute
The University of Maine Climate Change Institute conducts research and graduate education focused on variability of Earth's climate, ecosystems, and other environmental systems, and on the interaction between humans and the natural environment. The Institute has numerous resources to help understand climate trends and impacts, and houses information sources such as Maine's Climate Future 2015 Update and tools such as the Climate Reanalyzer. The Institute is developing a Climate Futures initiative to further bridge science and tools to provide decision-support frameworks for planning and management in a changing climate.

Contact: Betty Lee, 207-581-2190, bliqcs@maine.edu

USFWS Gulf of Maine Coastal Program Habitat Resilience
The U.S Fish and Wildlife Service (USFWS) Gulf of Maine Coastal Program has completed a resilience literature review that looks at the intersection of ecological and social resilience in adaptive management. The report identifies important ecological and social factors that foster greater resiliency, including overlapping governance and strong organizational relationships, diversity and ecological variability, and understanding of ecosystem functions.

The Gulf of Maine Coastal Program contributes to building more resilient landscapes and communities through its habitat protection and restoration programs (e.g., providing technical assistance to replace culverts with structures that restore passage for aquatic species and protect municipal infrastructure).

Contact: Jed Wright, 207-781-8364 (ext.12), jed_wright@fws.gov

Wells Reserve Coastal Training Program
The CTP at Wells National Estuarine Research Reserve offers science-based trainings to local and regional decision-makers on topics such as land use, climate change (sea-level rise) and green infrastructure.

Contact: Christine Feurt, 207-646-1555 ext. 111, cfeurt@wellsnerr.org

Model Municipal Projects and Products

Cape Elizabeth rewrote its shoreland zoning ordinance to add 3 vertical feet over the Highest Astronomical Tide in its development review (http://www.capeelizabeth.com/government/rules_regs/ordinances/zoning/zoning.pdf). With funding support from the Maine Coastal Program, it has also created a new stormwater plan for its town center that could serve as a model for other communities. It will be available by the end of 2015: contact Town Planner Maureen O'Meara at Maureen.omeara@capeelizabeth.org.

South Portland has completed a detailed vulnerability assessment with assistance from GPCOG, made significant strides with mitigation measures, and put language on sea-level rise into its comprehensive plan (http://www.southportland.org/files/4113/7279/7365/Final_Plan_Adopted_10-15-12_without_Appendices.pdf)

Georgetown (which lies just outside the Casco Bay watershed boundary) received support from the Maine Coastal Program to complete a Climate Change Adaptation Report that could serve as a model for other communities. Providing a thorough overview of threats and detailed localized responses, it includes recommendations at both municipal and individual levels. It is online at http://gtownconservation.com/wp-content/uploads/2015/08/Georgetown-Adaptation-Report-ALL-chapters-FINAL-8.75x11.25-v10forPDFonlineV2.pdf.

Harpswell provides all new town residents with A Resident's Conservation Guide to Casco Bay, a short handbook that offers guidance on Bay-sensitive landscaping, pest management, boating practices and household actions. The guide (online at http://www.harpswell.maine.gov/vertical/Sites/%7B3F690C92-5208-4D62-BAFB-2559293F6CAE%7D/uploads/A_Residents_Conservation_Guide_to_Casco_Bay_Rev_1.3_120613_-_on-line.pdf). Harpswell also developed an Open Space Plan that helps guide development to appropriate areas while fostering preservation of twelve "focus areas" that are critical to water resources, wildlife and commercial fish species. The Plan is online at http://www.harpswell.maine.gov/index.asp?SEC=33C20AD8-07E9-4F5C-9AE7-A26DC9701C19&Type=B_BASIC.

Key Characteristics of Climate-Smart Conservation

Link actions to climate impacts
Conservation strategies and actions are designed specifically to address the impact of climate change in concert with existing threats; actions are supported by an explicit scientific rationale.

Embrace forward-looking goals
Conservation goals focus on future, rather than past, climatic and ecological conditions; strategies take a long view (decades to centuries) but account for near-term conservation challenges and needed transition strategies.

Consider broader landscape context
On-the-ground actions are designed in the context of broader geographic scales to account for likely shifts in species distributions, to sustain ecological processes, and to promote collaboration.

Adopt strategies robust to uncertainty
Strategies and actions ideally provide benefit across a range of possible future conditions to account for uncertainties in future climatic conditions, and in ecological and human responses to climate shifts.

Employ agile and informed management
Conservation planning and resource management is capable of continuous learning and dynamic adjustment to accommodate uncertainty, take advantage of new knowledge, and cope with rapid shifts in climatic, ecological, and socioeconomic conditions.

Minimize carbon footprint
Strategies and projects minimize energy use and greenhouse gas emissions, and sustain the natural ability of ecosystems to cycle, sequester, and store carbon.

Account for climate influence on project success
Considers how foreseeable climate impacts may compromise project success; generally avoids

investing in efforts likely to be undermined by climate-related changes unless part of an intentional strategy.

Safeguard people and nature
Strategies and actions enhance the capacity of ecosystems to protect human communities from climate change impacts in ways that also sustain and benefit fish, wildlife, and plants.

Avoid maladaptation
Actions taken to address climate change impacts on human communities or natural systems do not exacerbate other climate-related vulnerabilities or undermine conservation goals and broader ecosystem sustainability.

(From the National Wildlife Federation's Climate-Smart Conservation, 2014)

SECTION FOUR

References and Further Reading

Table 2: Peer Reviewers of Climate Change-Related Risks
Forty-four experts in a broad range of relevant fields participated in the peer review process to identify climate change-related Risks of Primary Concern to Casco Bay Plan implementation.

Name	Affiliation
Sue Adamowicz	*U.S. Fish and Wildlife Service*
Will Ambrose	*Bates College*
Ted Ames	*Maine Center for Coastal Fisheries*
Tom Ballestero	*University of New Hampshire*
Nick Battista	*Island Institute*
Kathleen Bell	*University of Maine*
Damian Brady	*University of Maine*
David Burdick	*University of New Hampshire*
Phil Colarusso	*U.S. EPA*
William DeLong	*Dept. of Homeland Security*
Nathan Dill	*Ransom Consulting*
Keith Evans	*University of Maine*
Susan Farady	*University of New England*
John Field	*Field Geology Services*
Gary Fish	*Maine Board of Pesticides Control*
Mark Green	*St. Joseph's College*
Brian Helmuth	*Northeastern University*
Glenn Hodgkins	*U.S. Geological Survey*
Landis Hudson	*Maine Rivers*
Lewis Incze	*University of Maine*
Eileen Johnson	*Bowdoin College*
Teresa Johnson	*University of Maine*
Steve Jones	*University of New Hampshire*
George Lapointe	*George Lapointe Consulting*
Lynne Lewis	*Bates College*
Robert Lilieholm	*University of Maine*
Kathy Mills	*Gulf of Maine Research Institute*
Hilary Neckles	*U.S. Geological Survey*
Cathy Ramsdell	*Friends of Casco Bay*
Jeff Runge	*University of Maine*
Fred Short	*University of New Hampshire*
Aaron Strong	*University of Maine*
Theresa Theodose	*University of Southern Maine*
Andrew Thomas	*University of Maine*
Carol Thornber	*University of Rhode Island*
Christine Tilburg	*Ecosystem Indicator Partnership*
Thomas Trott	*Suffolk University*
Barbara Vickery	*The Nature Conservancy*
Don Witherill	*Maine Dept. of Environmental Protection*
Jed Wright	*U.S. Fish and Wildlife Service*
Laura Zitske	*Maine Audubon*
Anonymous reviewers (3)	

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Further Reading Related to the Casco Bay Climate Change Risk Assessment

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