Climate Trends

in the Casco Bay Region

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Overview

The Casco Bay region is vulnerable to all seven of the climate stressors identified by the US Environmental Protection Agency (US EPA): 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 document summarizes current scientific evidence of these trends within Maine and, where possible, within the Casco Bay watershed (which coincides closely with geographical boundary of Cumberland County).

Acknowledgments

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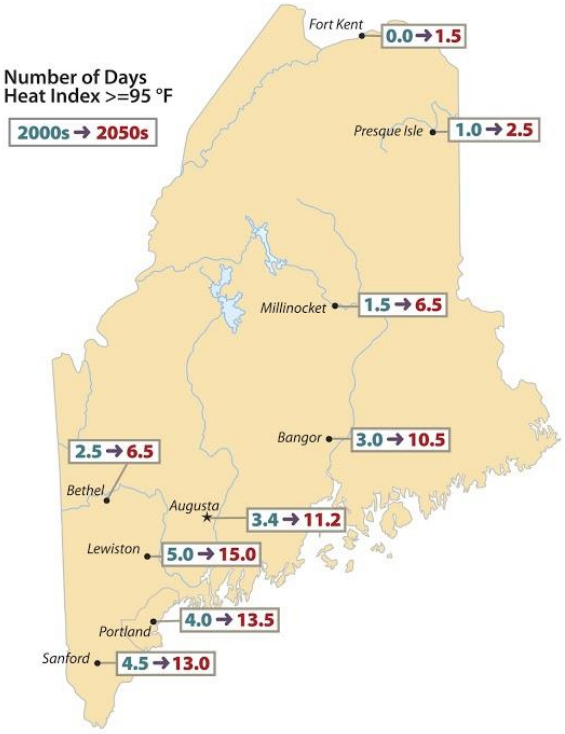
*Cover photo: [*Gabe Souza, *Portland Press Herald]* A deluge in Portland, Maine on September 30, 2015, coincided with a king tide, flooding sections of Bayside and the Old Port.

Warmer Summers

Between 1895 and 2014, 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).



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

The summer season is growing longer as well as hotter. Maine's warm season (when average daily temperatures remain above freezing) increased by two weeks from the early 1900s to the 2000s. Based on global climate models, scientists expect another two-week increase by 2050, whether or not greenhouse gas emissions continue unabated (Fernandez et al. 2015). Benefits from reduced emissions would emerge after the middle of this century.

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.

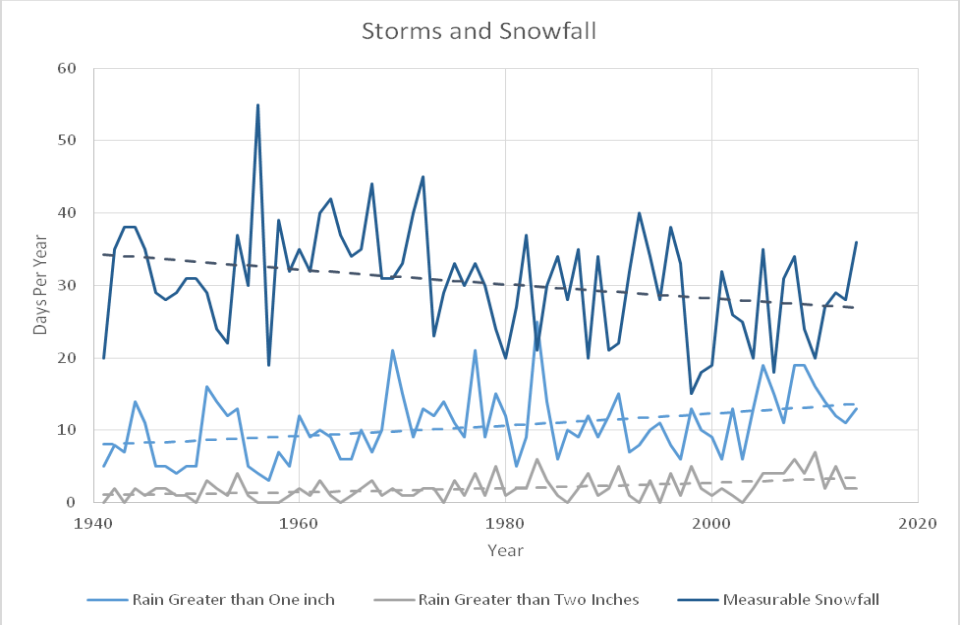
Warming air temperatures (in all seasons) will place additional stress on wildlife species already contending with invasive species, habitat loss, pollution and—in some cases—heavy harvesting (Stein et al. 2014). Ecosystem disruptions will affect human communities as well through the diminished capacity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



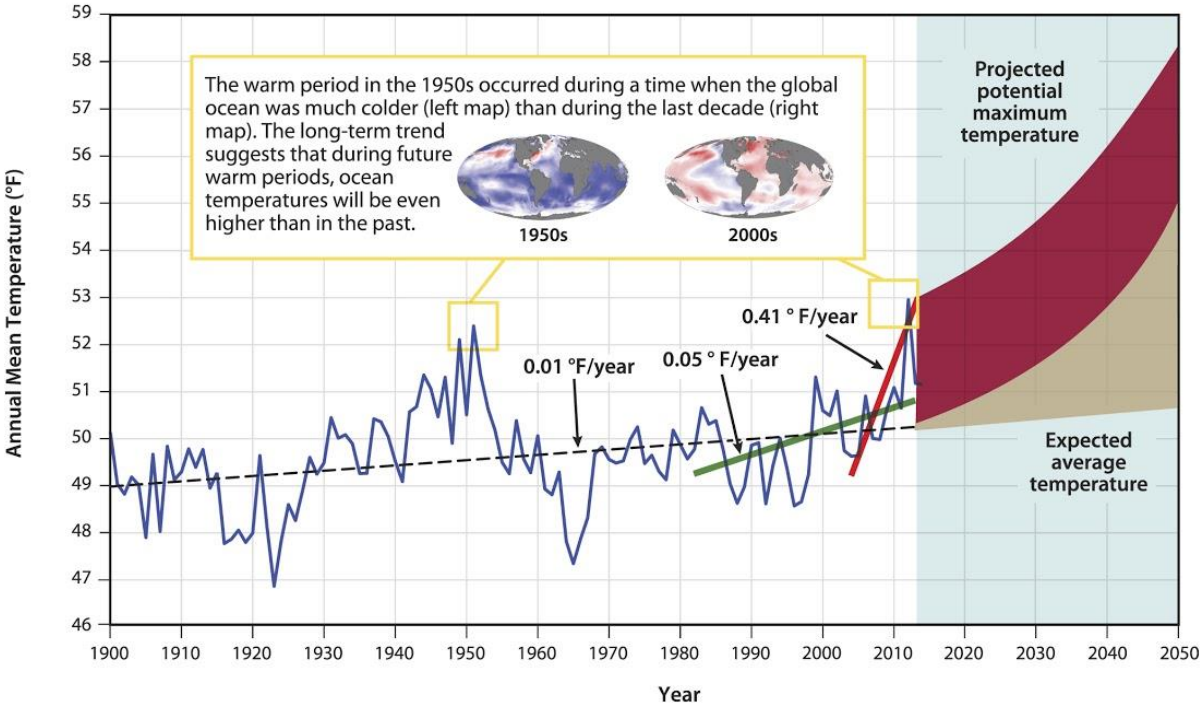
Source: http://www.cascobayestuary.org/wp-content/uploads/2015/10/Indicator_ClimateChange.pdf

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).

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).



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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). Diversifying the economy will be critical to the region's long-term vitality, given the commercial and cultural value of marine fisheries and the role they play in sustaining tourism (ULI 2014).

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).

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).

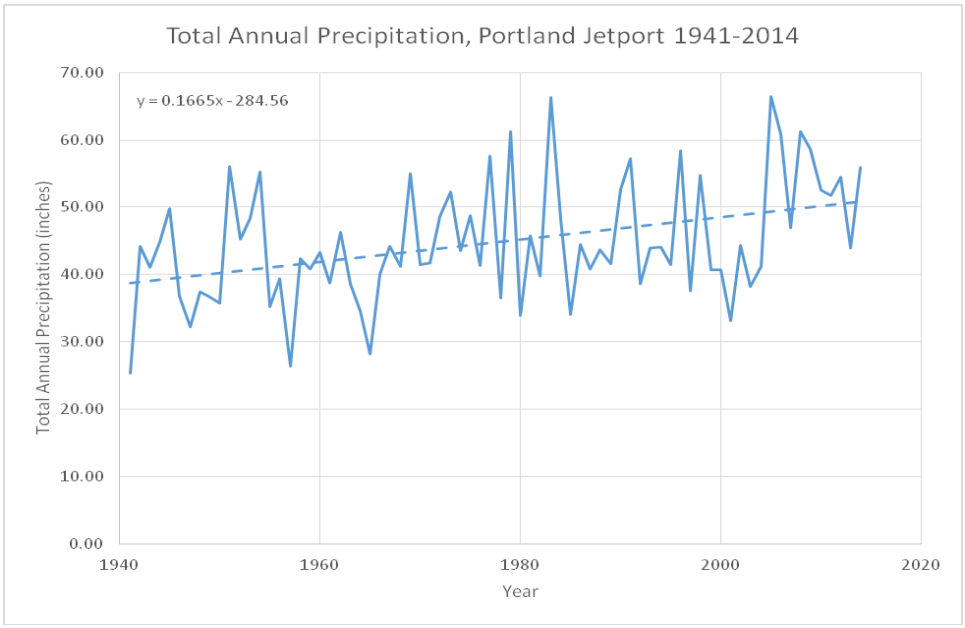
Increased Precipitation and Greater Storm Intensity and Frequency

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).



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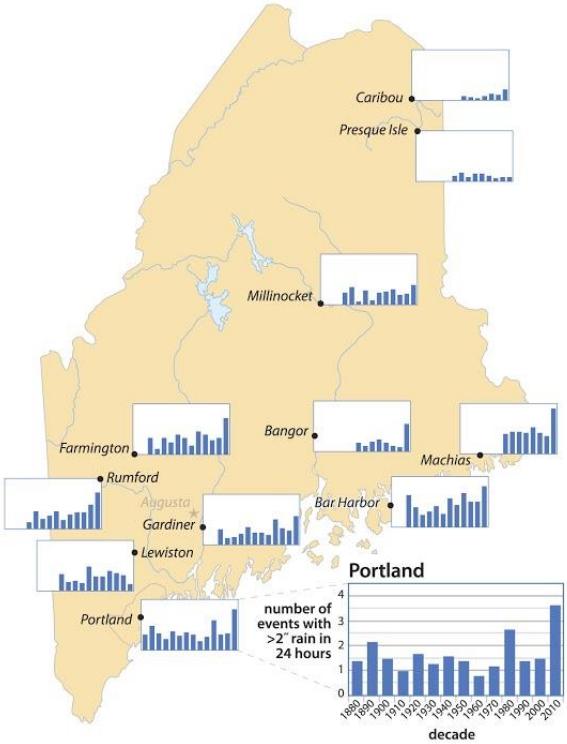

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NOAA's storm events database reveals a marked increase in the number of "extreme precipitation" events (categorized as coastal floods, flash floods, floods, heavy rain and tropical storms) within Cumberland County between 1995-2004 and 2005-2014. In 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).

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

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).

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. Habitat for the Asian tiger mosquito that can transmit WNV is expected to increase in the Northeast from the current 5 percent level to 16 percent within two decades and between 43 and 49 percent by the end of the century (Horton et al. 2014).

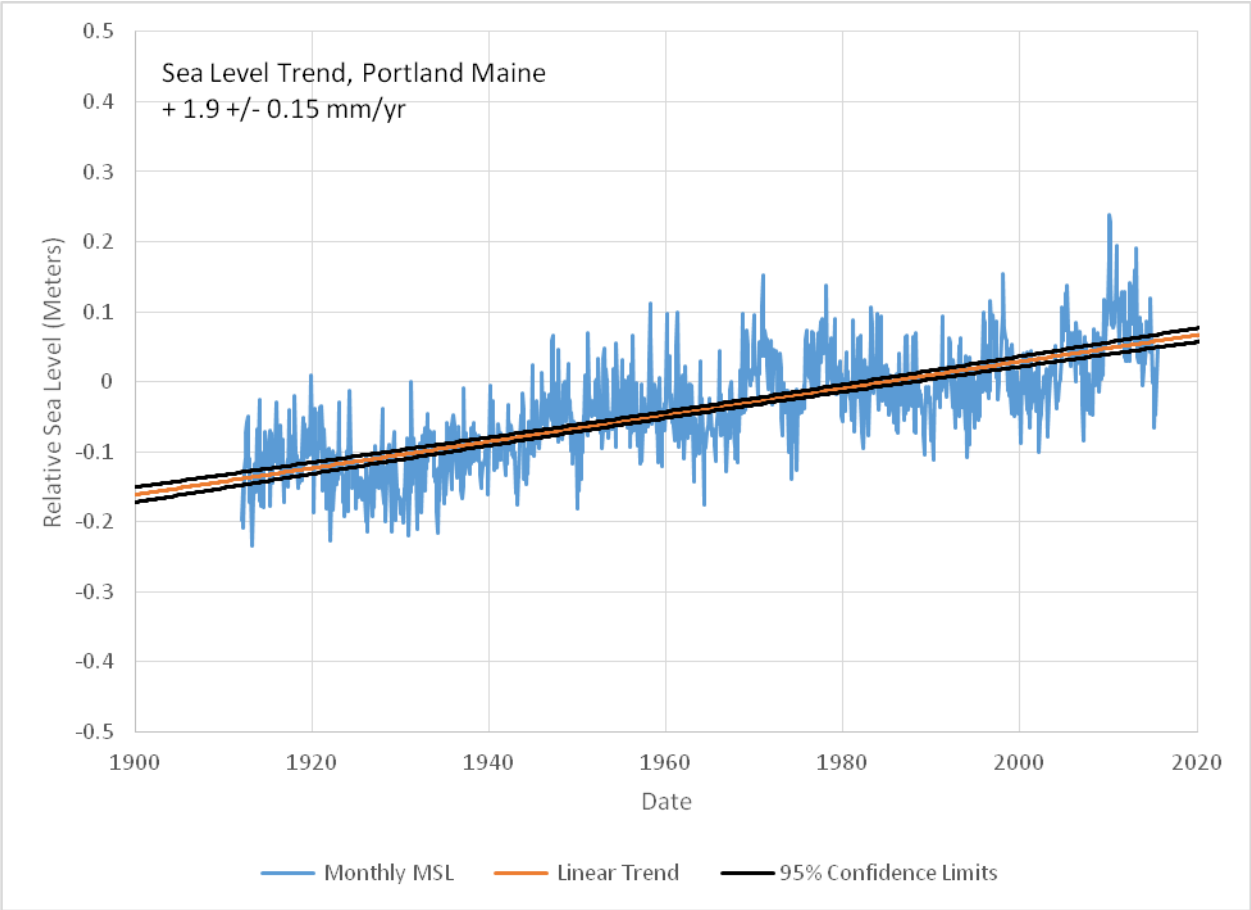
NOAA reports that Maine has experienced nine hurricanes in historical records, only five of which made landfall along the coastline. However, Maine has been affected by many lesser tropical storms (mapped at http://coast.noaa.gov/hurricanes/?redirect=301ocm). Hurricane Irene (in 2011) and Hurricane Sandy (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).



Data show seasonally corrected average Mean Sea Level (MSL) from 1912 through 2015. Linear prediction and confidence limits based on NOAA analysis. Data credit: NOAA Center for Operational Oceanographic Products and Services 2015.

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 recent 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 (CBEP) 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 CBEP 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 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 atmospheric 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 atmospheric deposition and stormwater runoff fuel greater net primary production and subsequent respiration as organic particles sink. 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 its 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).

Anticipating Greater Variability and Uncertainty

Many projected changes in climate variables are understood as 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.

- A rapid decline of Arctic sea ice over the last decade, particularly the destabilization of the West Antarctic Ice Sheet, could cause dramatic increases in global sea levels.
- Extinction rate 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.

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