Chapter 3

Global Climate Change

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Section 300.The Ocean SAMP in a Climate Changed World

1. Ecologically, economically, and culturally, Rhode Island is inexorably linked to the ocean and therefore faces a number of challenges from climate change that are specific to the coastal and marine landscape.

2. The climate of the Ocean Special Area Management Plan (Ocean SAMP) area has changed over the past century. Overall, both air and sea temperature in the region have been getting warmer, sea level has been rising, it has become wetter, the severity of storms is increasing, and the acidity of the sea has increased.[1]

3. Human activities since the start of the Industrial Age have caused a significant increase in greenhouse gases in the atmosphere. The most prevalent greenhouse gas in the atmosphere in terms of anthropogenic emissions, carbon dioxide has risen from a pre-industrial level of 280 parts per million (ppm) to 385 ppm in 2008, the highest it has been in 650,000 years. There is strong scientific consensus that carbon dioxide in the atmosphere warms the air and sea surface, accelerates sea level rise, makes the ocean more acidic, and causes shifts in precipitation and weather patterns, and leads to more extreme weather events, among other effects. These effects are already being witnessed globally and in Rhode Island and are projected to intensify in years to come.

4. Future projections of climate change include sea water warming and possible changes to offshore ocean circulation patterns, stratification, nutrient distribution, and plankton productivity. Alteration of these variables is expected to affect the ecological functioning of the Ocean SAMP region, create stress on marine plants and animals, shift geographic ranges of commercially important fish species northward, and change the timing of biological events. Other implications, such as accelerated sea level rise, more intense storms, sea surge, accelerated rates of coastal erosion and beach migration, more rain, salinity changes, and runoff and salt water intrusion into fresh water aquifers, all have consequences for coastal infrastructure and recreation associated with the Ocean SAMP, marine navigation and transportation, and the offshore marine ecology.

5. Concern over the effects of current and future impacts upon humans and the natural environment is being expressed at local and international levels. In Rhode Island, concern over climate change is one of the driving considerations behind the policy goal of 16 percent renewable energy in the state's electrical supply by 2019, and efforts to promote renewable energy (e.g. offshore wind energy) and energy efficiency.

6. Reducing greenhouse gas emissions, or "mitigation," is one of two proactive choices society can make to address climate change. Climate change mitigation is a human intervention to actively reduce the production of greenhouse gas emissions (e.g., through replacement of fossil fuels with renewable energy) or to remove the gases from the atmosphere (e.g., through planting additional vegetation on land and in water such as eel grass planting).

[1] What is presented here is a summary, references and support will come later in the text.

7. The other proactive choice that Rhode Island can make is “adaptation.” Adaptation is an adjustment in human or natural systems to reduce harm from climate change impacts or exploit beneficial opportunities. Beyond these two choices, the only other option is to wait for climate changes to occur and react to them. Reactive adaptation is likely to be less efficient and result in lost opportunities.

8. The Ocean SAMP is a tool for adaptive management, suited to address long-term and evolving phenomena such as climate change. Among some of the notable potential impacts of current and future climate change are an accelerated rate of erosion and deterioration of the state’s recreational beaches, flooding damage and loss of coastal infrastructure associated with Ocean SAMP uses, fatigue (weakening) and more severe damage to offshore installations and marine vessels, and the introduction of invasive species to the Ocean SAMP marine ecology. With advanced planning, the harm and costs associated with these potential impacts can be reduced and may be avoided.

9. This chapter looks at observed past climate-related trends across global and local scales, and at climate change projections as suggested by existing peer-reviewed studies and models. The chapter examines what these climate change trends mean for the marine ecosystem of the Ocean SAMP area and human activities related to the Ocean SAMP. That there will be changes is unequivocal in the scientific community, which relies upon proven data from the past. Making projections inherently includes uncertainty. However, it provides information for planning, backed by the best available science, which gives managers and citizens a tool to be proactive.

10. In other words, current assessment and informed analysis begins to “mainstream” climate change into the Ocean SAMP, recognizing that conditions will change and management must be adaptive in response. Mainstreaming means that climate concerns and adaptation responses are integrated into relevant policies and plans. This chapter only begins to overlay climate change on the Ocean SAMP. Assessing climate change vulnerabilities and defining adaptation goals and actions require an inclusive process over time.

Section 310.Climate Change Observed Trends: Global, U.S. Northeast, Rhode Island

1. Overall, both air and sea temperature in the state, region, and globally have been increasing, sea level has been rising, it has become wetter, the severity of storms is increasing, and the acidity of the sea has increased. A summary of observed and documented climate change trends described in this section at the global, regional, and state levels is given in Table 3.1. Since there are little or no data for the Ocean SAMP area, this is generally for the state of Rhode Island and its offshore waters.

Table 3.1. Summary of observed climate changes.

Climate Change Variable	Geographic Scale	Observations of Recent Change
Air Temperature	Global	• Global mean temperature has increased 0.74°C (1.33°F) over the last 100 years.
	U.S. Northeast	• Since 1900 the annual mean temperature has risen 0.83°C (1.5°F).
	Rhode Island	• Average annual temperature rose 0.94°C (1.7°F) from 1905 to 2006.
Ocean Temperature	Global	• The ocean has been warming consistently over the past 50 years, with 2007 as the warmest year on record.
	U.S. Northeast	• Annual average temperatures in the waters off the southern New England coast have increased by about 1.2°C (2.2°F) since the 1970s.
	Rhode Island	• In Narragansett Bay, sea surfaces temperatures have risen 2.2°C (4°F) since the 1960s.
Sea Level Rise	Global	• Globally, sea levels rose in the 20th century at an average rate of 1.8 mm (0.07 in) per year, a rate greater than that of the preceding eight centuries. • Between 1993 and 2003 this rate almost doubled to 3.4 mm (0.13 in) per year.
	Rhode Island	• In Newport, sea level has risen an average of 2.6 mm (0.1 in) per year since 1930.
Storminess	Global	• The severity of tropical cyclones has increased since the 1970s.
	U.S. Northeast	• The severity of tropical cyclones in the North Atlantic has increased.
Precipitation and Weather	Global	• Rainfall has decreased in the Northern Hemisphere subtropics and increased in mid-latitudes over the last 50 years.
	U.S. Northeast	• Studies have found a 5-17 percent increase in regional precipitation during roughly the last 100 years.
	Rhode Island	• Over the past 100 years, Rhode Island precipitation (rain and snow) has increased by 3 mm (0.12 in) per year. • Wind speed at T.F. Green Airport has significantly declined since at least the 1960s.
Ocean Acidification	Global	• Current pH on the surface of the ocean is 0.1 units lower than pre-industrial levels.

Note: Citations are provided in the text below.

310.1. Air Temperature is Increasing

1. Evidence shows that temperatures have been increasing locally and globally. The most recent report issued by the Intergovernmental Panel on Climate Change (IPCC 2007) states that the global average temperature has increased 0.74°C (1.33°F) over the last 100 years, with most of this increase during the last 50 years, and with the last decade (2000–2009) the warmest since instrumental records began in the mid 1800s (Allison et al. 2009).

2. Annual average temperature has increased similarly in the Northeastern U.S. and Rhode Island. Since 1900, the annual average temperature in the Northeastern U.S. has risen 0.83°C (1.5°F), with the majority of warming occurring in the past few decades (Frumhoff et al. 2007). Winter temperatures have risen even faster with a total increase of 2.22°C (4°F) between 1970 and 2000 (Frumhoff et al. 2007). In Rhode Island, National Weather Service data in Providence shows that the annual average temperature has risen 0.094°C (1.7°F) per decade from 1905 to 2006, and 1.14°C (2.5°F) between 1961 and 2005 (Figure 3.1) (Pilson 2008). Although lower temperatures might be expected outside of an urban area and near water, the trend line beginning around 1960 suggests a more rapid increase than that for the entire time series (1905–2006).

3. Increased air temperature increases sea surface temperature with numerous effects on marine ecology (see below). It also alters the timing of seasonal conditions, lengthening the amount of time with warmer temperatures and shortening the amount of time with freezing air temperatures. In the long run, warming may also produce other global changes that will affect the Ocean SAMP area, positively and negatively. These include, among others, the melting of the Greenland ice sheet and Arctic sea ice, and collapse of Atlantic currents that would result in serious societal costs of coastal land and infrastructure loss and major changes to the marine environment. However, the probability and timing of these large-scale occurrences is uncertain. This impact of climate change may have some benefits for tourism and recreation, fishing, and other Ocean SAMP uses that are more easily conducted in warmer weather. Shorter, warmer winters and reduced icing on vessels' gear and structures could be beneficial to winter navigation and shipping.

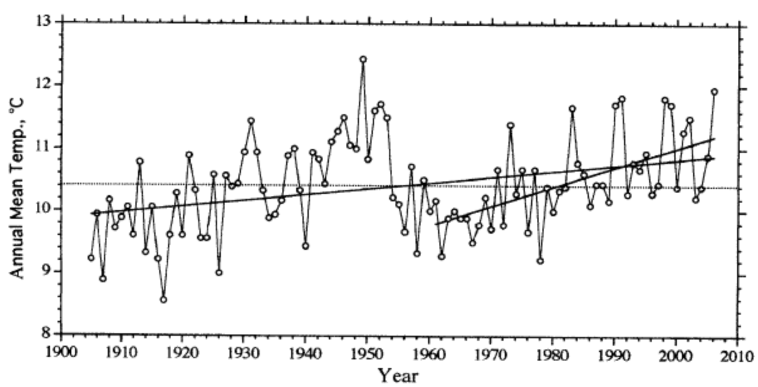

Figure 3.1. Annual mean temperature at the official weather service stations for Providence, R.I., from 1905 to 2006 (Source: Pilson 2008).The annual mean temperature from 1905 to 2006 is 10.41°C (18.74°F), with an increase of 0.094°C (0.17°F) per decade. From 1961 to 2006 the increase per decade was 0.31°C (0.56°). It should be noted that the temperature recording station was moved several times in the early 1900s within the Providence city limits, until it was located to the T.F. Green Airport in Warwick in 1953 where it has remained since.

310.2. Ocean Temperature is Increasing

1. Globally, the ocean has been warming consistently over the past 50 years, with 2007 as the warmest year on record, and June, July, and August 2009 the warmest months recorded (Allison et al. 2009). The increase in oceanic heat content from 1963 to 2003 in the upper ocean (top 700 m/2300 ft) has been found to be 50 percent higher than previously estimated (IPCC 2007; Domingues et al. 2008; Allison et al. 2009).

2. For nearby waters of the New England coast (Woods Hole, Massachusetts and Narragansett Bay), Oviatt (2004) found that since the 1970s annual average temperatures have increased by about 1.2°C (2.2°F). Nixon et al. (2004) estimated that coastal temperatures in Woods Hole have increased at an average rate of 0.04°C (0.07°F) per year from 1960 to 2002, amounting to a total increase of 1.7°C (3°F) during that time. Nixon et al. (2009) found significant variability in annual sea surface temperature in Narragansett Bay, but estimated that sea surface temperatures have risen 2.2°C (4°F) since the 1960s (Figure 3.2).

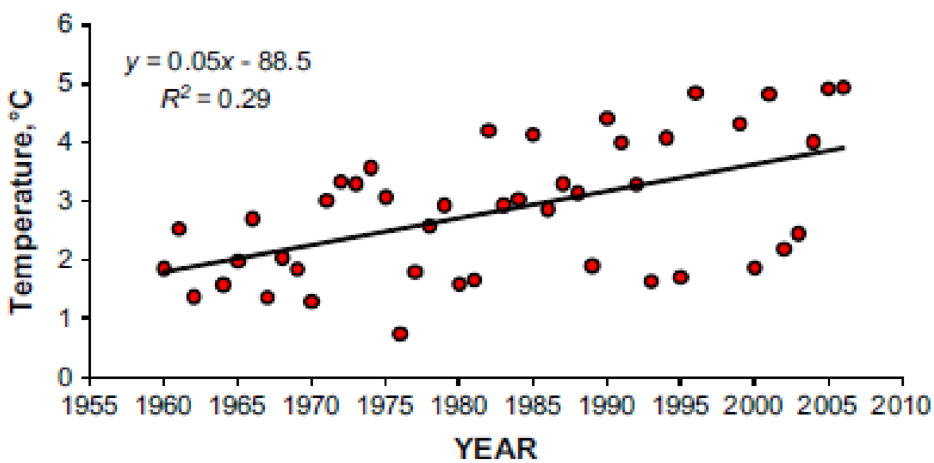

Figure 3.2. Mean surface water temperatures during December, January, and February in the middle of the West Passage of Narragansett Bay, R.I., near Fox Island (Source: Nixon et al. 2009).

3. The marine environment, including the Ocean SAMP marine environment, is very sensitive to changes in sea surface temperature. Increasing sea surface temperature affects the distribution and reproductive success of plankton, fish, and marine invertebrates, marine mammals, sea turtles, and seabirds. It is also partially responsible for harmful algal blooms (HABs), marine diseases, and the spread of invasive species. The relationship of sea surface temperature with marine ecology is discussed in Section 330 of this chapter.

310.3. Sea Level is Rising at an Accelerated Rate

1. Sea level rise is caused by two effects. The first is the global warming effect, which is a combination of thermal expansion of seawater and increased volume of water from melting mountain glaciers and polar ice sheets. There is a lag in thermal response of the oceans. Therefore, thermal expansion can be expected to increase for hundreds of years due to current observations of increased temperature. The second effect is caused by land

subsidence, or downward movement relative to sea level, due to the response of the earth's lithosphere (the outer, rigid shell of the earth) from ice or sediment loading, or the extraction of water or oil. The contribution of land subsidence to sea level rise varies spatially at regional and local scales (NAS 2008).

2. There is evidence that the coastline from Cape Cod to New Jersey is subsiding (Frumhoff et al. 2007; Yin et al. 2009). The precise rate of subsidence is uncertain. When subsidence is taken into account, Rhode Island's historic rate of relative sea level rise as observed at Newport is thought to be greater than the global average (CRMC 2007).

3. Since changes in global temperature directly influence sea level, global warming brings with it increased sea level with rates accelerating as well. Globally, sea levels have risen at an average 17 cm (6.7 in) over the past century, a rate greater than that of the preceding eight centuries (IPCC 2007). Between 1961 and 2003, global sea level rose at an average rate of 1.8 mm (0.07 in) per year (IPCC 2007). Between 1993 and 2003 this rate almost doubled to 3.4 mm (0.13 in) per year (Allison et al. 2009). These rates are equivalent to sea level rise of 18 cm (7 in) and 34 cm (13 in) per century, respectively.

4. The accelerated rate is likely due to loss of polar ice in Greenland and Antarctica and the addition of melt water in the sea (IPCC 2007; Cazenave et al. 2009) with Greenland polar melt water the primary cause of accelerated sea level rise. The current rate of sea level rise is 80 percent faster than what was projected for this time period by the IPCC Third Assessment Report (2001) (Allison et al. 2009).

5. Newport, R.I., tide gauge data is available for 1930–2008. During this time, sea level has risen 2.58 mm (0.10 in) per year. If this rate of sea level rise is extrapolated for a century (1908–2008), then sea level has risen 25.8 cm (10.2 in) in the last century (Figure 3.3).

6. The primary concern with sea level rise in the Ocean SAMP area is erosion, flooding, and loss of coastal habitat, beaches, and private and public land and infrastructure utility with offshore uses. Sea level rise will reduce the effectiveness and decrease the life of existing coastal structures such as seawalls and revetments, docks, roads, and bridges. The adverse effects of sea level rise on infrastructure, recreation, and tourism are discussed in more detail in section 340 of this chapter.

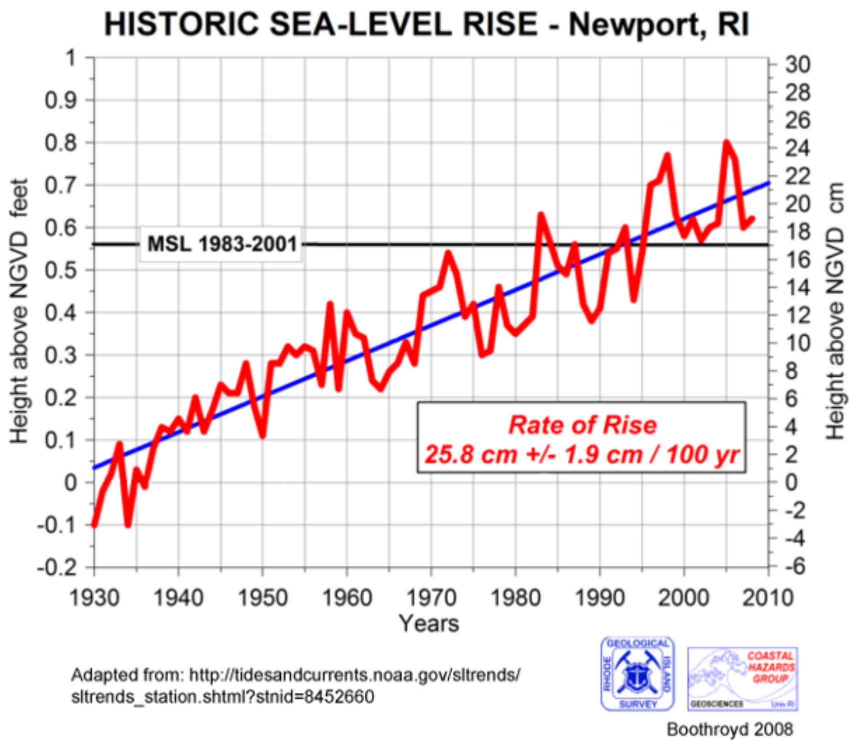

Figure 3.3. Observed sea level in Newport, R.I., from 1930 to 2008. Sea level data (collected by the National Oceanic and Atmospheric Administration from the Newport, R.I., tide gauge) are measured relative to the National Geodetic Vertical Datum of 1929 (NGVD 29) for mean sea level (MSL). NGVD 29 is a vertical control point historically used for measuring elevations, including the absolute change in sea level (incorporating both global and local dynamics) at the site. The rate of sea level rise is 25.8 cm (10.16 in) per 100 years. (Figure courtesy of J. Boothroyd, the University of Rhode Island). These data are available on line and continuously updated at: http://co-ops.nos.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660%20Newport,%20RI (NOAA/NOS 2008a).

310.4. Storminess is Increasing

1. The IPCC Fourth Assessment Report found a substantial increase in the severity of global tropical cyclones (hurricanes and typhoons) since the 1970s, with a strong link to the observed increase in ocean surface temperatures (IPCC 2007). There is evidence that storm intensity has increased in the North Atlantic in the last 30 years (Emanuel 2005; Webster et al. 2005; Emanuel et al. 2008; Holland 2009; Mann et al. 2009) and this correlates well with variations in tropical Atlantic sea surface temperature (Mann and Emanuel 2006; Holland and Webster 2007). Yin (2005) found that major storm tracks have been moving northward and attributed this to changing climate. Some studies have reported an increase in the number of tropical cyclones in certain areas, including, the North Atlantic (e.g. Hoyos et al. 2006; Mann and Emanuel 2006; Emanuel et al. 2008; Holland 2009; Mann et al. 2009).

2. Whether the characteristics of tropical cyclones have changed has been the subject of considerable investigation, often with conflicting results (Allison et al. 2009). Large amplitude fluctuations in the frequency and intensity of tropical cyclones greatly complicate

both the detection of long-term trends and their attribution to rising levels of atmospheric greenhouse gases. Trend detection is further impeded by substantial limitations in the availability and quality of global historical records of tropical cyclones. Therefore, it remains still uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes.

3. Rhode Island has been impacted by a number of major storms, and they represent a major coastal and marine hazard. In terms of wave height and storm surge, the Hurricane of 1938 was of the magnitude of the 100-year storm of record for Rhode Island (Pogue 2005). This means that there is a 1 percent probability of this size storm occurring in any single year. However, with more intense storms, the probability increases that any one storm will be greater than that currently defined as a 100-year storm.

4. Storms and associated storm surge cause damage to ports, seawalls and revetments, docks, roads, bridges, wastewater treatment plants and stormwater infrastructure. Storms can also damage wind turbines and other offshore infrastructure and affect sediment movement, altering beaches and coastal habitats as well as needs for dredging for marine transportation and port operations. Potential damage from increasing storm intensity and past damage to the ports of Providence and East Providence are described in more detail in section 340 of this chapter.

310.5. Precipitation and Weather Patterns are Changing

1. Globally, rainfall has decreased in the Northern Hemisphere subtropics and increased in mid-latitudes over the last 50 years (Zhang et al. 2007). Rainfall and wind patterns have also been changing over time in the U.S. Northeast and coastal New England. Frumhoff et al. (2007) reported that since 1900, precipitation has increased 5 to 10 percent in the northeastern U.S., with most of the increase historically occurring during fall, spring, and summer. In the last few decades, however, increases have also occurred in winter. However, more of this precipitation is falling as rain than snow. The New England Regional Assessment estimated a greater—16.8 percent—increase in precipitation between 1905 and 2006 in coastal New England (NERAG 2001).

2. Between 1905 and 2006 there has been a 32 percent increase in precipitation (rain and snow) in Rhode Island when all years, even extremely dry and wet years, are included (Figure 3.4) (Pilson 2008). This estimate is comparable to the New England Regional Assessment data if extremely dry and wet years are excluded (Pilson 2008). The increase in precipitation, as well as warmer winter temperatures, is related to the observed increase in cloudiness, which results in a decreasing amount of sunlight reaching Rhode Island (Nixon et al. 2009).

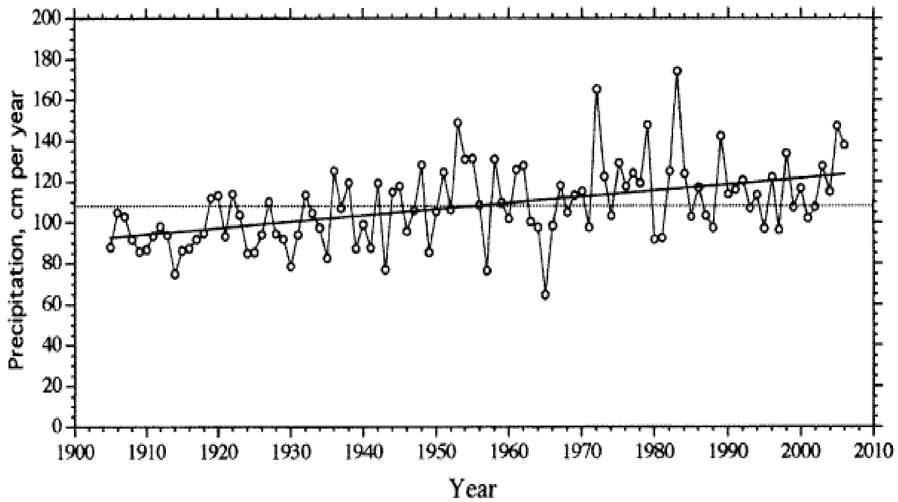

Figure 3.4. Total annual precipitation (rain and snow) at the weather stations in Providence, R.I., from 1905 to 2006. The rate of increase (slope of the simple linear regression) is 3.05 mm (0.12 in) per year. (Source: Pilson 2008).

3. In contrast to precipitation, average winter and summer wind speeds over land across New England have declined by 20 percent in the last 50 years (O'Donnel, in press). Other data also show a decline in annual mean wind speed in the northeastern U.S. (Pryor et al. 2009). For example, Figure 3.5 shows that wind speed recorded at T.F. Green Airport has significantly declined from 1964 to 2004 (Pilson 2008).

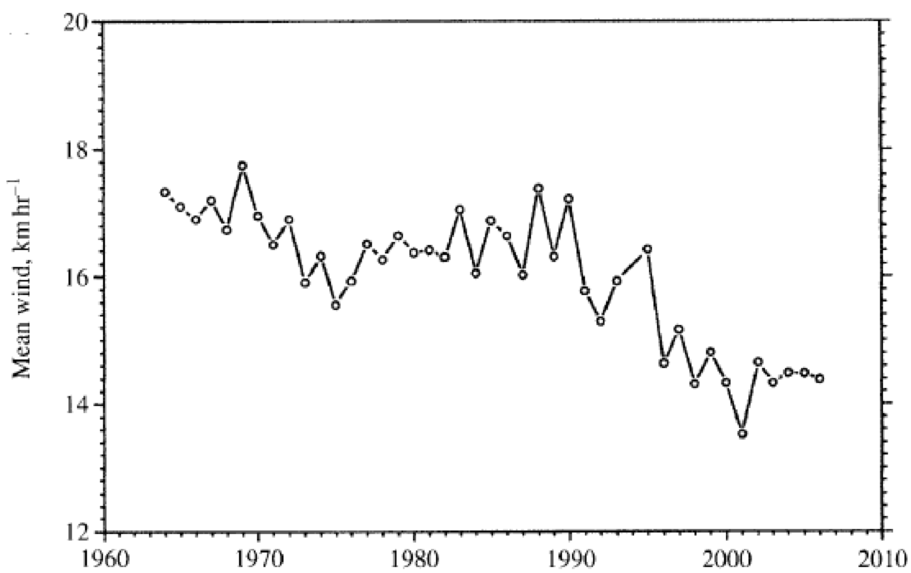

Figure 3.5. Annual average wind speed at T.F. Green Airport, R.I., from 1964 to 2006 (Source: Pilson 2008).

4. Increased precipitation matters to the Ocean SAMP because it increases river flow and transports pollutants and nutrients to coastal waters, which adversely affects ecology, coastal habitat, wildlife, and recreation and tourism associated uses of the Ocean SAMP area. Some

of the river flow to the marine environment enters Block Island Sound and Rhode Island Sound, altering salinity (critical to marine productivity) and transporting contaminants and nutrients. Decreasing wind speeds are of concern to the Ocean SAMP with respect to impacts on mixing and stratification.

5. The North Atlantic Oscillation (NAO) influences regional climate patterns of temperature, precipitation, and winds in the North Atlantic due to the interaction of the Icelandic low and Azores high pressure atmospheric cells. The principal winter weather effect of the NAO is on the jet stream, which determines primary seasonal storm tracks. In positive years, storms track straighter west-to-east and in negative years, storm tracks are deeply meandering. The NAO has a known effect on sea surface temperature through atmospheric wind-stress changes, which are associated with differences in water densities from different sources and can therefore affect ocean circulation (Delworth and Dixon 2000).

6. In addition, the Atlantic Multidecadal Oscillation (AMO) is an ocean fluctuation that also significantly influences weather patterns in the North Atlantic through an ocean heat flux and involves ocean-atmosphere interaction as well as variability in the strength of circulation (Knight et al. 2005; Delworth and Mann 2000). Hubeny et al. (2006) found evidence of a coupling between the atmosphere and ocean at multidecadal time scales based on photosynthetic estuarine pigments over the last millennium adjacent to Narragansett Bay, which suggests that the AMO could be attributed to changes in the atmosphere and the NAO is affected by solar variability.

7. Since 1972, the NAO has been primarily positive, with notable short-term negative periods (Delworth and Dixon 2000; Hurrell 1995). Based on climate reconstructions using historic data, the current trend appears to be unprecedented in recorded time (Hurrell 1995; Watanabe and Nitta 1998). The positive NAO index causes the Icelandic low pressure system to draw a stronger southwesterly circulation over the North American continent in the east, preventing Arctic air from meandering southward and resulting in less severe winters over eastern Canada and the northwest Atlantic (Thompson and Wallace 1998).

310.6. Ocean Acidification is Occurring

1. As concentrations of carbon dioxide increase in the atmosphere, more carbon dioxide is absorbed by the oceans, resulting in the lowering of seawater pH levels (reduced alkalinity). The increased acidity is due to the formation of carbonic acid as CO_2 dissolves in seawater.

2. Roughly half of the carbon emitted from human activities between 1800 and 1994 has been absorbed by the ocean (Sabine et al. 2004), and one-third of modern emissions is being absorbed (Feely et al. 2004; Canadell et al. 2007 in UNEP 2009; Cooley and Doney 2009; U.S.GCRP 2009). As a result, globally averaged marine surface atmospheric CO_2 has increased 13.2 percent since 1981 (NEFSC 2009). This has resulted in a reduction of surface ocean seawater pH levels by 0.1 pH units (U.S.GCRP 2009). Because pH units are expressed on a logarithmic scale, a change from one unit (e.g., from 8.0 to 7.0) represents a 10-fold change, and two units (e.g., 8.0 to 6.0) is a 100-fold change.

3. Broad-scale time series of ocean pH measurements are not currently available to assess the effects of ocean acidification in the Northeast continental shelf region (NEFSC 2009). However, correlation between atmospheric CO_2 and dissolved CO_2 in ocean waters is evident in regions where estimates of both are available (NEFSC 2009).

4. Acidification is a concern for marine animals, many of whom are valuable to the food chain, that have shells or skeletons made of calcium carbonate (such as quahogs, foraminifera, slippershell snails, sea stars, and coral). It is also a concern for corrosion of metals on vessels and infrastructure associated with marine transportation, navigation, ports and harbors. Increased acidification may also cause more rapid deterioration of historic and cultural assets on the seafloor (such as wrecks). The potential impacts of acidification are discussed in more detail in Sections 330 and 340 in this chapter.

Section 320.Future Climate Change Projections

1. Human activities have caused a significant increase in greenhouse gases in the atmosphere. The most prevalent greenhouse gas in the atmosphere, carbon dioxide, has risen from a pre-industrial level of 280 ppm to 385 ppm in 2005, the highest it has been in 650,000 years (IPCC 2007; Allison et al. 2009). The IPCC in its last report (IPCC 2007) and peer-reviewed science updates since then (Allison et al. 2009; UNEP 2009; U.S.GCRP 2009) conclude that this increase in carbon dioxide and other greenhouse gases is unprecedented, is driving climate change today, and will continue to do so long into the future.

2. Since climate change and associated impacts are long term and not necessarily linear phenomena, and since positive feedback loops can increase impact, modeling is essential for projecting into the future based on assumptions of future greenhouse gas emissions and atmospheric concentrations of greenhouse gases. Since the climate change landscape will continue to change, adaptive planning and management for climate change in the Ocean SAMP region needs to be cognizant now of projected future change.[2]

3. This section describes possible future changes as "projections" rather than "predictions." As defined by the IPCC, "climate predictions are the result of an attempt to produce an estimate of the actual evolution of the climate in the future. Since the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature" (Baede 2007). In contrast, climate projections are not based on an estimate of the actual evolution of climate, but rather are based on emissions scenarios (lower, intermediate and higher emissions scenarios). As defined by the IPCC, "climate projection is a projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models" (Baede 2007). Scenarios help move dialogue from a debate about exactly how the climate will change to the implications of the different scenarios of low to high degrees of change.

4. In the late 1990s, carbon dioxide emissions scenarios were developed by the IPCC, as outlined in the Special Report on Emissions Scenarios (SRES) in the IPCC Third Assessment Report (Nakicenovic et al. 2000). The SRES scenarios assumed varying degrees of reductions in CO_2 emissions and are based on five global models. The low emissions scenario (B1) assumes that reductions in CO_2 emissions would occur with resource efficient technologies. CO_2 concentrations in the atmosphere would reach 550 ppm by 2100 (about twice the pre-industrial level). The high emissions scenario (A1FI) assumes an increase in CO_2 emissions due to fossil fuel-intensive economic growth. CO_2 concentrations in the atmosphere would reach 940 ppm by 2100 (about three times the pre-industrial level). Since the scenarios were developed a decade ago, actual experience has shown that the rate of emissions has exceeded the high emissions scenario as a result of growing populations, per capita gross domestic product, and reliance on fossil fuels (Figure 3.6) (Raupach et al. 2007; Allison et al. 2009; UNEP 2009). To date there are no regions that are substantially

[2] Note that even if greenhouse gases were capped today, air and sea temperatures will continue to rise as a result of past emissions—as greenhouse gases in the atmosphere have a lifetime of between 10 and several thousand years (Solomon et al. 2009; UNEP 2009).

decreasing carbon in their energy supply (Raupach et al. 2007; UNEP 2009). In light of this, projections of climate change impacts under a low emissions scenario are becoming less likely as high rates of CO_2 emissions continue. It is important that decision-makers seriously consider and plan for impacts under a high emissions scenario.

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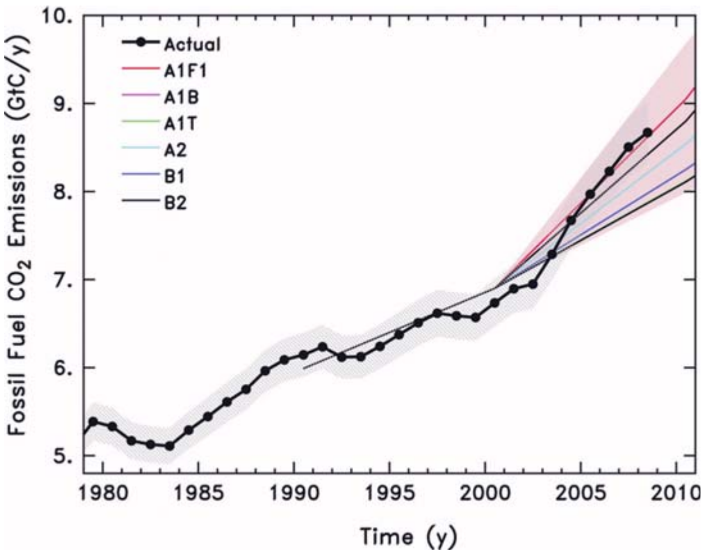

Figure 3.6. Observed global CO_2 emissions from fossil fuel burning and cement production compared with IPCC emissions scenarios (Le Quéré et al. 2009).The shaded area covers all scenarios used to project climate change by the IPCC. Actual emissions began following the high emissions scenario in 2006 A1FI is high emissions scenario; B1 is low emissions scenario. (Source: Allison et al. 2009)

5. Where available, this section presents projections for the low and high emissions scenarios with the widely used temporal benchmarks of mid-century and late-century (21^{st} century). In some cases, only end-of-century projections are found in the literature. The projections are global or regional. The grid scale of climate change models is approximately 2 degrees longitude-latitude, too coarse for Ocean SAMP scale projections.

6. With accelerating greenhouse gas emissions, changes in global climate trends have occurred faster than predicted, with no indication of a slow-down or pause, and future changes could be more severe and arise more quickly than predicted (Allison et al. 2009). An example of such a positive feedback loop affecting climate change is the release of methane, a greenhouse gas, from the melting of permafrost areas leading to further warming. Scientists warn that current and continuing climate change may lead to permanent and irreversible changes in natural systems. These are referred to as "tipping points" in which a critical threshold is reached where the state of a system is altered (Lenton et al. 2008; Schellnhuber 2009). There are a number of tipping points predicted to occur in the climate system, based on its current non-linear dynamics, and as revealed by past abrupt climate changes and climate models (Schellnhuber 2009). Among the tipping points are the complete disappearance of Arctic sea ice in summer, leading to drastic changes in ocean circulation and climate patterns across the whole Northern Hemisphere; acceleration of ice loss from the Greenland and Antarctic ice sheets, driving rates of sea level rise to 6 feet or more per

century; collapse of the Atlantic thermohaline circulation; and, ocean acidification from carbon dioxide absorption, causing massive disruption in ocean food webs (NRC 2002; Lenton et al. 2008; Overpeck and Weiss 2009).

320.1. Air Temperature Projections

1. Projections of greenhouse gas emission under low and high scenarios estimate global mean temperatures warming 2°C to 7°C (3.6°F to 12.6°F) by the end of the century (Figure 3.7) (Allison et al. 2009; Richardson et al. 2009). This range surpasses the estimated threshold range of 1°C to 3°C (1.8°F to 5.4°F) increases for dangerous climate tipping points, such as the melting of summer Arctic sea ice, Himalayan glaciers, and the Greenland ice sheet (Ramanathan and Feng 2008 in UNEP 2009). An increase above 2°C (3.6°F) is cited as being a threshold beyond which the consequences from global warming will cause severe environmental and societal disruptions worldwide (Richardson et al. 2009).

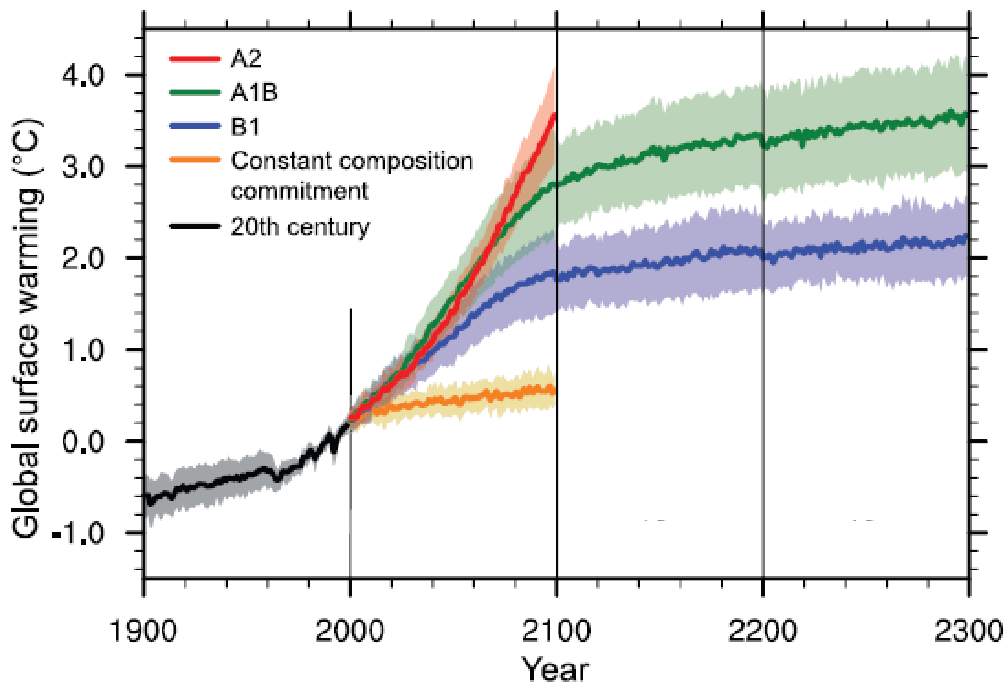

Figure 3.7. Mean values of projected surface warming (compared to the 1980–1999 base period) for the Special Report on Emmisions Scenarios (SRES) scenarios A2 (red – higher emissions), A1B (green – intermediate emissions) and B1 (blue – lower emissions). Projections when emissions are kept constant from 2000 levels are shown (orange). Lines show the multi-model means, shading denotes the ±1 standard deviation range (Source: IPCC 2007).

2. Temperature changes are also projected regionally. The late century projections for the U.S. Northeast are similar to global projections, but have a wider range when one looks at summer vs. winter change (See Table 3.2). The range for low to high emissions scenarios is from 2°F to 14°F (1.1°C to 7.8°C) (Frumhoff et al. 2007).

Table 3.2. Air temperature projection increases for U.S. Northeast.

Season	Low emissions scenario (B1)	High emissions scenario (A1FI)
2050 Projection		
Summer	1.1°C to 2.8°C (2°F to 5°F)	2.2°C to 4.4°C (4°F to 8°F)
Winter	2.2°C to 2.8°C (4°F to 5°F)	2.2°C to 3.9°C (4°F to 7°F)
2100 Projection		
Summer	1.5°C to 3.9°C (3°F to 7°F)	3.3°C to 7.8°C (6°F to 14°F)
Winter	2.8°C to 4.4°C (5°F to 8°F)	4.4°C to 6.7°C (8°F to 12°F)

Source: (Frumhoff et al. 2007)

320.2. Ocean Temperature Projections

1. By late century, sea surface temperatures in the U.S. Northeast are expected to increase by 2.2°C to 2.8°C (4°F to 5°F) or 3.3°C to 4.4°C (6°F to 8°F) under the low or high emissions scenario, respectively, though these increases vary for the different portions of the Northeast continental shelf (Table 3.3) (Frumhoff et al. 2007).

2. By late century, regional bottom temperatures in the northern Mid-Atlantic Bight are expected to increase 1.1°C (2°F) or 2.8°C to 3.9°C (5°F to 7°F) from the historic average (1970–2000), under the low or high emissions scenario, respectively. On Georges Bank, increases of 1.1°C (2°F) or 3.3°C (6°F) are expected, depending on the emissions scenario (Frumhoff et al. 2007).

Table 3.3. Ocean temperature change projections for U.S. Northeast, 2100.

Ocean Depth	Lower emissions scenario (B1)	Higher emissions scenario (A1FI)
Sea surface	2.2°C to 2.8°C (4-5°F)	3.3-4.4°C (6-8°F)
Bottom temperatures	1.1°C (2°F)	2.8-3.9°C (5-7°F)

Source: (Frumhoff et al. 2007)

320.3. Sea Level Rise and Flooding Projections

1. Great variability in sea level rise projections exists because of uncertainty of the contribution of melting sheet ice. Many analyses, including those in the Fourth Assessment by the IPCC do not account for the unexpected rates of rapid sheet ice breakup and melting that have occurred in recent years (Frumhoff et al. 2007; Allison et al. 2009). The contribution of the ice sheets to sea level rise was not included in the IPCC report because no IPCC consensus on ice sheet dynamics could be reached based on published literature at that time (Solomon et al. 2009; UNEP 2009). Increasingly, evidence is being presented in peer-reviewed literature indicating that this is a concern.

2. There is an unknown threshold beyond which a collapse of the polar ice sheets, especially Greenland's, will be inevitable and irreversible, which would add an additional several meters of sea level rise within the next millennium. This risk is growing, particularly under a high emissions scenario (Frumhoff et al. 2007; Solomon et al. 2009). This is one of the "tipping points" described earlier.

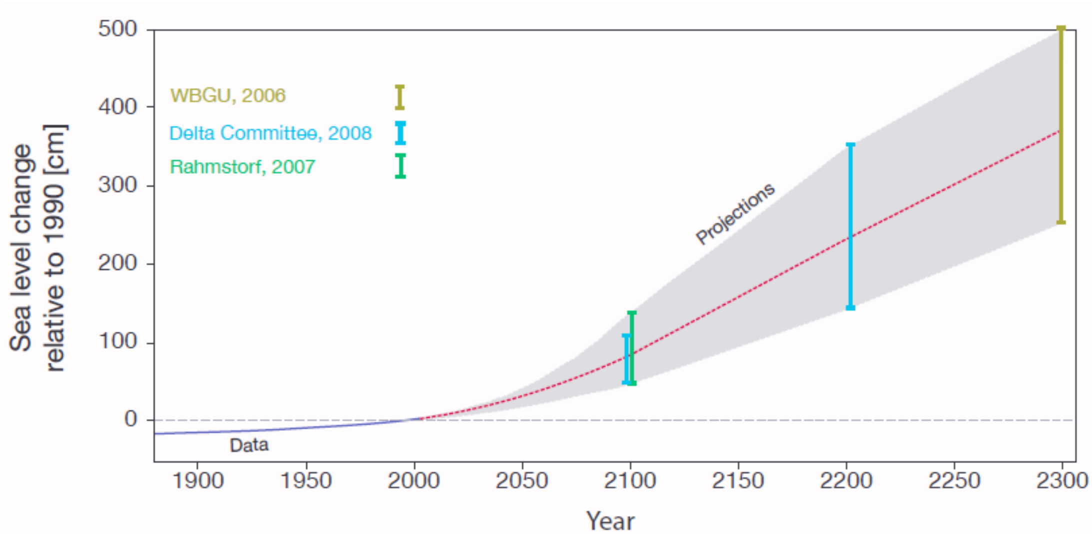

Figure 3.8. Projections of future global sea level rise to 2300. Historical data from Church and White (2006). Future projections are from Schubert et al. (2006) (represented as 'WGBU'), Rahmstorf (2007), and Vellinga et al. (2008) (represented as 'Delta Committee'), (Source: Allison et al. 2009).

3. Updated estimates of future global mean sea level rise are twice as large as the IPCC 2007 projections of 18 cm to 59 cm (0.6 ft–1.9 ft) for end of the century. New estimates of the increase in global sea level by the end of the century range from 0.5 m to 2 m (1.6 ft–6.6 ft) (Rahmstorf et al. 2007; Horton et al. 2008; Pfeffer et al. 2008; Allison et al. 2009; Richardson et al. 2009). These updated projections incorporate new observations of accelerated loss of mass from glaciers, ice caps, and the Greenland and Antarctic ice sheets.

4. Changes in the salinity and temperature of the ocean in the Arctic and North Atlantic will likely (90 percent probability) cause a slowdown of ocean circulation in the North Atlantic by the year 2100, which, among other effects, will lead to a more rapid rise in sea level along the northeastern U.S. coastline compared to other parts of the world (Figure 3.9) (IPCC 2007; Yin et al. 2009).

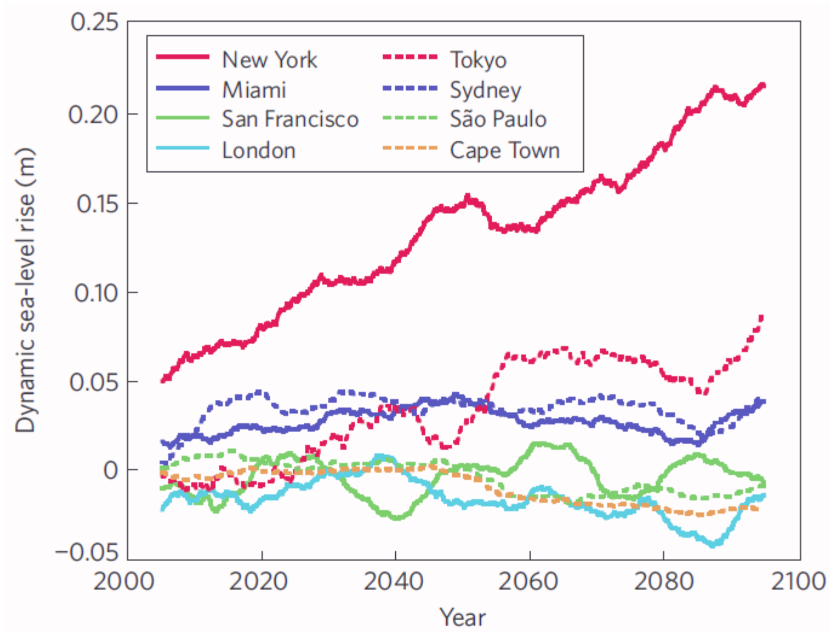

Figure 3.9. Projected dynamic sea level rise (10 year running mean) at coastal cities worldwide under the intermediate emissions scenario. These projections account for the amount of sea level rise caused by changes in large scale ocean currents alone and not other factors such as thermal expansion and ice sheet melting. (Source: Yin et al. 2009)

5. The Northeast Climate Impacts Assessment in 2006 projected increases in sea level of 6 cm to 33 cm (2.5 in to 13 in) by mid-century (under either emissions scenario), and 10 cm to 53 cm (4 in to 21 in) under the lower-emissions scenario and 20 cm to 84 cm (8 in to 33 in) under the higher-emissions scenario by late-century (Figure 3.10) (NECIA 2006). The assessment report indicates that these projections do not incorporate the recently observed high rates of continental ice melt, and should be considered to be at the lower range of possible future sea level rise.

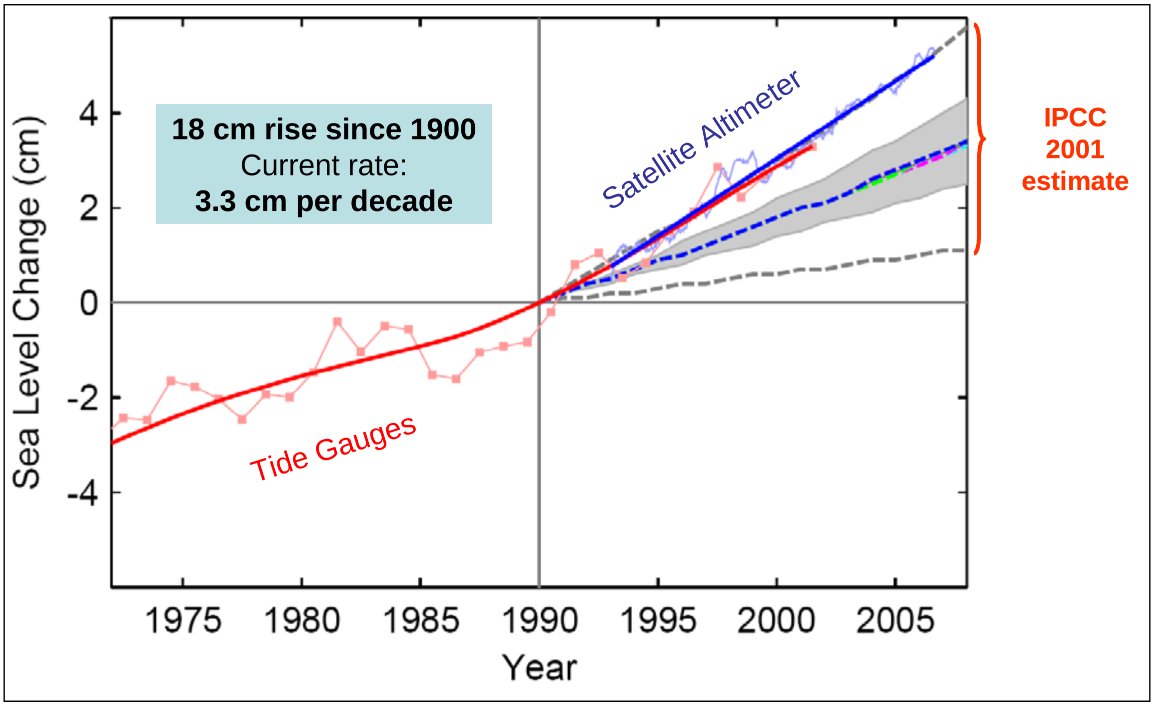

Figure 3.10. Observed and IPCC 2001 estimated global sea level rise. This figure illustrates the range of IPCC scenarios as of 2001 projections. Observations illustrate that sea level is rising at a rate slightly above the highest IPCC scenario (A1FI) from 2001 (Figure from Rhamstorf et al. 2007).

320.4. Storminess Projections

1. An observed increase in the strength of tropical cyclones and North Atlantic storms during the past few decades is linked to rising ocean temperatures. Future projections based on theory and high-resolution dynamic models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2 to 11 percent by 2100 (Knutson et al. 2010). Existing modeling studies also consistently project decreases in the globally averaged frequency of hurricanes by 6 to 34 percent. Balanced against this, higher-resolution modeling studies typically project substantial increases in the frequency of the most intense cyclones, and increases of the order of 20 percent in the precipitation rate within 100 km of the storm center.

2. Most climate models are incapable of reproducing the strongest hurricanes (Category 3 or higher). In a recent study, Bender et al. (2010) used a downscaling approach to model tropical cyclone activity through the end of the 21st century. They began by creating an average climate change projection based on 18 global climate models, and then fed this projection into a regional model with much higher resolution to simulate entire hurricane seasons. Finally, they used NOAA's operational hurricane prediction model to re-simulate each storm generated by the regional model—but at a still higher resolution—so that the very intense (Category 4 and 5) hurricanes could be simulated. These results are based on projections of a substantial warming of the tropical Atlantic hurricane regions over the 21st

century due to an increase in greenhouse gases. The projections used a standard future emission scenario from the IPCC. The models showed a decrease in the total number of hurricanes by the end of this century, yet still produced nearly a doubling of Category 4 and 5 hurricanes. The largest increase in intense hurricanes was seen in the Western Atlantic region (between 20°N and 40°N). Category 4 and 5 hurricanes making landfall account for approximately 48 percent of all hurricane damage in the U.S., despite accounting for only 6 percent of the total number of hurricanes that make landfall. Bender et al. (2010) estimate about a 30 percent increase in potential damage from the combined effect of fewer hurricanes overall and more very intense hurricanes.

3. According to the National Weather Service, high hurricane activity occurs during periods of warmer tropical Atlantic sea surface temperature. Given current and historical trends of sea surface temperature, it is likely that there will be above-normal Atlantic hurricane activity over the next several years.

4. A small increase in frequency of nor'easters is projected for the U.S. Northeast (Frumhoff et al. 2007). Currently 12 to 15 nor'easters (extra-tropical storms) hit the U.S. Northeast from November to March. It is estimated that under a high-emissions scenario, one additional nor'easter could affect the Northeast coast each winter by late century. Nor'easters drive destructive waves and currents, and transport sediment along the coastlines resulting in beach and bluff erosion and sediment re-suspension offshore. Movement of sediment could have adverse impacts on planktonic organisms and navigation.

320.5. Precipitation and Weather Pattern Projections

1. Climate change is projected to change the intensity and timing of annual precipitation in rain and snow in the U.S. Northeast, and the timing and length of seasons. By end of the century, under either the low or high emissions scenario, annual precipitation is projected to increase approximately 10 percent (4 in/10 cm per year). Winter precipitation could increase an average of 20 to 30 percent, depending on the emission scenario, with a greater proportion falling as rain rather than snow (Figure 3.11) (NECIA 2006). Little change is expected for summer rainfall, but projections are variable (Frumhoff et al. 2007).

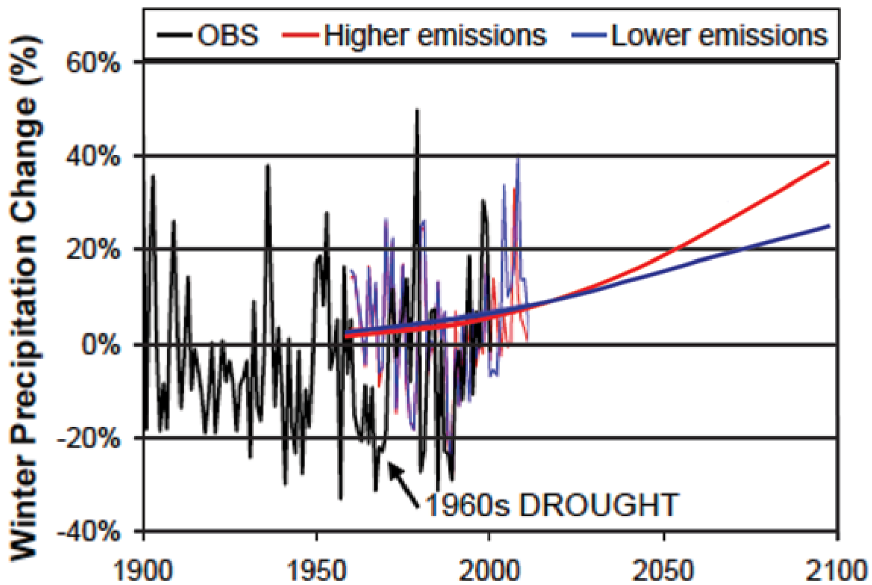

Figure 3.11. Observed and model-based winter precipitation as a percentage of change in the U.S. Northeast. The black line depicts average historical precipitation patterns from 1900–2000. The red line represents the predicted change in precipitation under the higher emissions scenario. The blue line represents precipitation changes under the low emissions scenario. The largest increase in precipitation is expected after 2050, particularly in the high emissions scenario. (Source: NECIA 2006).

2. In the Northeast, precipitation intensity (the amount of rain that falls on rain days) is projected to increase 8 to 9 percent by mid-century and 10 to 15 percent by late-century. In other words, wet days will become wetter (Table 3.4). The frequency of heavy-precipitation events is projected to increase by 8 percent by mid-century and 12 to 13 percent by late-century. Extreme precipitation events are defined as those with a larger precipitation total for one day than the smallest maximum annual precipitation event for each of the previous 59 years, the length of record assessed for this study (Madsen and Figdor 2007). These projections suggest that more of the annual rainfall total will come in heavy rainfall events. During the wettest five-day period of the year, 10 percent and 20 percent more rain will fall by mid- and late-century, respectively (Frumhoff et al. 2007).

3. Short and medium-term droughts (1 to 3 months and 3 to 6 months, respectively) are projected to increase slightly under the lower emissions scenario and dramatically under the higher emissions scenario by late century. Short-term droughts are projected to occur as frequently as once each summer under the higher emissions scenario in the New England states by late-century (Frumhoff et al. 2007; U.S.GCRP 2009).

4. By mid-century, summer-like conditions are projected to persist 16 or 27 days longer under the low and high emissions scenarios, respectively. Summer-like conditions are expected to be 21 or 42 days longer by late century under the two different emissions scenarios (Frumhoff et al. 2007; U.S.GCRP 2009).

5. Under a high emissions scenario, the length of the winter snow season is expected to be reduced to a week or two in Rhode Island and other southern Northeast states by late century (U.S.GCRP 2009).

Table 3.4. Precipitation and weather projections for U.S. Northeast.

Variable	Low emissions scenario (B1)	High emissions scenario (A1FI)
2050 Projection		
Precipitation intensity (amount of rain that falls on rain days)	8 to 9 percent increase	
Number of heavy precipitation events	8 percent increase	
Length of summer	16 days longer	27 days longer
Variable	Low emissions scenario (B1)	High emissions scenario (A1FI)
2100 Projection		
Annual precipitation	~10 percent increase (4 in/year)	
Winter precipitation	~20 percent increase, with a greater percent falling as rain than snow	~30 percent increase, with a greater percent falling as rain than snow
Summer precipitation	Little change	Little change
Precipitation intensity (amount of rain that falls on rain days)	10-15 percent increase	
Number of heavy precipitation events	12-13 percent increase	
Droughts	Slight increase	Dramatic increase. Short term drought (1-3 months) once each summer
Length of summer-like conditions	21 days longer	42 days longer
Winter snow season		Reduced to a week or two in Rhode Island

Source: Frumhoff et al. 2007

320.6. River Flow Projections

1. Most freshwater enters marine systems through rivers, rather than through direct precipitation or runoff (NEFSC 2009). The major freshwater influences for the Ocean SAMP area (as described further in the Chapter 2, Ecology of the SAMP Region, Section 250.3) are from Long Island Sound and the Connecticut and Thames Rivers. The Providence and Taunton Rivers are tidal bodies of water with the next most important influence upon the Ocean SAMP area. In the U.S. Northeast, river flow will likely increase from snow melting earlier and faster due to rising winter temperatures. Peak spring flow is projected to occur five days earlier during the next several decades, and 7 to 9 days earlier by mid-century (Frumhoff et al. 2007). By late century, peak flow is projected to occur 10 to 14 days earlier, depending on the emissions scenario (Frumhoff et al. 2007).

2. Under the high-emissions scenario, high-flow events are projected to be more frequent, especially in northern New England, as a consequence of snow melting faster and increases in winter precipitation. This will increase the risk of flooding (Frumhoff et al. 2007). High-flow events transport pollutants and nutrients to coastal waters, some of which may enter Block Island Sound and Rhode Island Sound.

3. By late-century under the high emissions scenario, low-flow periods are expected to arrive more than a week earlier in summer and extend several weeks later in the fall, with the lowest flow dropping 10 percent or more. Little change is expected under the low emissions scenario (Frumhoff et al. 2007).

320.7. Ocean Acidification Projections

1. The most recent IPCC report projects that by late century, globally, pH will drop 0.3 to 0.4 units from current levels (IPCC 2007). With the exception of rare events, a change of this magnitude has not occurred in the last 300 million years (Caldeira and Wickett 2003). Such ocean acidification is essentially irreversible over a time scale of centuries with physical and biological impacts upon marine organisms, especially shellfish, and marine infrastructure (U.S.GCRP 2009).

Section 330. Ecological Impacts of Climate Change

1. The Ocean SAMP area is an ecologically unique and complex region in that the Rhode Island Sound and Block Island Sound ecosystems are located at the boundary of two biogeographic provinces, the Acadian to the north and the Virginian to the south. This unique positioning is the source of interesting biodiversity comprised of a mix of northern, cold-water species and more southern, warm-water species. It makes the ecosystems of the Ocean SAMP area highly vulnerable to impacts from warming due to climate change (Chapter 2, Section 200 for more detailed discussion).

330.1. Pelagic and Benthic Ecosystems

330.1.1. Plankton Blooms

1. Climate changes such as warmer waters, increased cloudiness caused by an increase in storminess, and altered circulation patterns at both vertical and horizontal scales affect plankton (Frumhoff et al. 2007; IPCC 2007; Allison et al. 2009; Yin et al. 2009). Warmer waters allow for higher rates of grazing of phytoplankton by zooplankton (Keller et al. 1999). Phytoplankton form the foundation of marine food webs, and therefore changes in phytoplankton dynamics can have significant impacts on higher trophic levels.

2. According to the Ecosystem Status Report for the Northeast Continental Shelf Large Marine Ecosystem (NEFSC 2009), the northeast U.S. shelf ecosystem is affected significantly by climate change. However, the specific processes that result in changes in zooplankton community structure remain unresolved and the implications for the remainder of the ecosystem are unclear (NEFSC 2009).

3. There is no data on climate change and plankton blooms for the Ocean SAMP area. There is research and data on Narragansett Bay. The Bay may or may not be an analog to the Ocean SAMP area, but findings from research in the Bay are presented below to illustrate the types of marine ecosystem changes that can occur, partially due to warming waters.

4. Narragansett Bay has experienced a decline in the consistency of the winter-spring bloom of phytoplankton. The timing of the annual-cycle of phytoplankton has shifted from a prolonged, bay-wide, large winter-spring bloom to a less consistent, less intense, shorter winter bloom with short intense blooms in the spring, summer, or fall. Data show that at least since the 1970s, the biomass of phytoplankton has decreased significantly in Narragansett Bay (Li and Smayda 1998; Smayda 1998; Nixon et al. 2009). It has been hypothesized that these changes have been induced by climate change, specifically warming waters (Keller et al. 1999; Oviatt et al. 2003) and an increase in cloudy days (Nixon et al. 2009). Increased cloudiness limits phytoplankton growth because photosynthesis is light-dependant.

5. Because the bloom now occurs later in the year, warmer waters allow for higher rates of grazing by zooplankton (Keller et al. 1999). The increased grazing depletes the supply of phytoplankton that sinks to the bottom and provides food to the benthos. It has also been shown that sinking phytoplankton blooms in warmer weather have less nutritional value than cold weather blooms, which would further diminish the food supply of the bottom

community (Smetacek 1984). In addition, it has been shown that this decrease in organic matter reaching the bottom (resulting from the diminished phytoplankton bloom) can drastically alter fluxes of nutrients between the sediment and water column. This has important implications for the ecological functioning of Narragansett Bay (Fulweiler et al. 2007).

6. The above factors are projected to decrease food availability to juvenile bottom-dwelling fish due to declines in the bottom filter- and deposit-feeders that readily consume dead phytoplankton (Nixon et al. 2009). A significant decline (75 percent from 1980 to 2000) in winter populations of bottom-dwelling fish species has been observed in Narragansett Bay while species that dominate the water column have increased (though less dramatically), which could be attributed to the effects of warming waters (Oviatt et al. 2003; Collie et al. 2008).

7. Similar climate-induced changes affecting bottom-dwelling communities have been observed in areas like the Bering Sea and North Sea (Grebmeier et al. 2006; Kirby et al. 2007).

330.1.2. Stratification and Mixing

1. Codiga and Ullman (2010) described the "typical" annual cycle of density stratification and how it varies geographically across the Ocean SAMP area, including the importance of temperature and salinity in driving stratification (See Chapter 2, Section 230.3, for more detailed discussion). However, the impacts of changes in river flow, solar heating, wind strength, and storminess due to climate change upon stratification patterns cannot yet be predicted.

2. Warming waters due to changing climate have been reported as at least partially responsible for the increasing occurrence of harmful algal blooms (HAB) (Bricker et al. 2008). HABs are a rapid rise of phytoplankton to levels that pose threats to ecosystem and/or human health (see Chapter 2, Section 250.1.6, for a more detailed discussion). Harmful effects upon ecosystems can result from a massive die-off of phytoplankton and can lead to depleted oxygen in the water column, caused by microbes associated with the HAB, and create hypoxic (very little oxygen) or anoxic (no oxygen) that can stress or kill aquatic organisms. HABs are now frequently occurring along the coast of Maine and are becoming more common in Massachusetts waters; however, HABs have not been documented in the Ocean SAMP area to date.

3. Stratification of the water column means that oxygen rich water at the surface does not mix down to the oxygen-poor bottom layer, causing an environment for hypoxic conditions. Beardsley et al. (1985) and Codiga and Ullman (2010) each found seasonal stratification in the waters of the outer shelf and continental slope with strong stratification of the water column during the spring and summer and weakly stratified or mixed waters during the fall and winter. Wind power increases vertical mixing. If wind speed declines in the Ocean SAMP area, as historical evidence suggests from the Rhode Island mainland, this would reduce the wind mixing potential of the water column (Nixon et al. 2009). Stronger storms,

as projected, would increase the wind mixing potential of the Ocean SAMP area water column.

4. A decrease in water column mixing could also be a result of warmer surface water temperatures and increased inputs of freshwater from rivers (Pilson 2008). Higher water temperatures decrease the solubility of oxygen (the amount of oxygen that the water can hold) and increase stratification, which could contribute to the occurrence and/or severity of hypoxia (NBEP 2009, Pilson 1998). Also, as water temperatures rise, the respiration rates of organisms in the water increase, thus increasing the demand on oxygen supply.

330.1.3. Marine Fish and Invertebrates

1. There has been mounting evidence that over extended periods of time, even small increases in water temperature can significantly affect species composition, distribution, and abundances of fish communities (Murawski 1993, Genner et al. 2004, Perry et al. 2005, Frumhoff et al. 2007). Temperature influences the geographical distribution of marine communities, and has a direct effect on the location and timing of spawning, which in turn affects the subsequent growth and survival of commercially important species, such as flounder, lobsters, and cod (see also Chapter 2, Section 250.3). It is possible that warming waters, in addition to other stresses, may be a significant cause for the decline of ecologically and commercial important species (see also Section 340.5 of this chapter). Nye et al. (2009) found that 24 of 36 fish stocks assessed in the northwest Atlantic had a statistically significant response to warming water temperatures.

2. It has been projected that with warming, the general distribution of species will shift northward and there will be a vertical shift in species distribution to deeper water (e.g., cold-water species), causing a reduction of cold-water species while expanding the ranges of warm-water species (Nye et al. 2009). This projection is based on findings from analysis of a continuous, 40-year trawl survey (1968–2007) in the northwest Atlantic. As noted in Chapter 2, Section 250.3, Perry et al. (2005) have documented similar shifts in both commercially and non-commercially valuable species, with an average latitudinal shift in distance of 175 km (range from 48 km to 403 km). Other studies in the northwest Atlantic have documented geographical shifts of northern species moving northward and being replaced by warmer-water species (EAP 2009, Hare and Able 2007, Rose 2005, Drinkwater 2005, Nye et al. 2009, Frumhoff et al. 2007). Cold-water species that are at the southern extent of their range will be most impacted and may decline in abundance (Drinkwater 2005; Nye et al. 2009). There is evidence that along the northeastern coast of the U.S., shallow-water sedentary species such as yellowtail flounder, winter flounder, summer flounder, windowpane, and longhorn sculpin have already shifted their center of biomass north toward the pole (Nye et al. 2009). Other species, including American shad, fourspot flounder, goosefish, halibut, cod, alewife, cusk, red hake, and silver hake, have shown some of the largest northward distributional shifts, concomitant with a warming trend (Nye et al. 2009).

3. Observational data has also shown that as southern species shifted their range northward, favorable conditions for growth and recruitment resulted in increases in abundance and range expansion. Hare et al. (2010) modeled both exploitation and climate change projections on

Atlantic croaker (*Micropogonias undulatus*) and predicted a 60 to 100 percent increase of spawning biomass and a 50 km to 100 km northward shift of the center of the population by 2100. Northern species were found to shift northward slightly, contracting their range, or had shifted to deeper depths (Nye et al. 2009). It has also been hypothesized that the pelagic (water-column) fish communities will have higher rates of this northward distributional shift compared to demersal (bottom-dwelling) fish (Cheung et al. 2009).

4. A study in the North Sea found that species with faster life histories were able to respond to temperature changes by shifting their geographical distribution (Perry et al. 2005). Species with slower life histories are already more vulnerable to overexploitation by commercial fishing and will likely not be able to compensate for warming via a rapid demographic response. The differences in responses between fish of varying life histories may alter spatial overlap and disrupt species interactions (Perry et al. 2005). For example, previous work off the northeastern coast of the U.S. found that species with the largest responses in distributional shifts are key prey for non-shifting predator species (Murawski 1993). It has also been hypothesized that local extinctions of fish species will be most common in polar, subpolar, and tropical areas of the world (Cheung et al. 2009). Local extinctions in the North Atlantic along the U.S. and Canadian coasts were also projected to be higher than in other areas (Cheung et al. 2009)

5. In Narragansett Bay and Rhode Island Sound at the mouth of Narragansett Bay, dramatic shifts during the last half century in local fish populations associated with warming winter sea surface temperatures and fishing pressure have been observed (Oviatt 2004, Collie et al. 2008). Fish communities in the Ocean SAMP area may be especially vulnerable because of the area's location on the border of two biogeographic provinces: many species found at the edge of their geographical boundaries are more stressed, and as environmental conditions change their distribution shifts congruently (Sorte and Hoffman 2004, Harley et al. 2006). The increase in winter sea surface temperature is correlated with the decline of various species that reside in Rhode Island waters during the cold winter months (e.g., winter flounder, silver hake and red hake). These cold-water species may be in the process of being replaced by seasonal, southern migrants (e.g., butterfish and scup) that are increasingly abundant during summer months (Jeffries and Terceiro 1985, Jeffries 2001, Collie et al. 2008).

6. As noted in Chapter 2, Section 250.3, a further major shift in the Rhode Island Sound coastal fish community is from demersal (bottom-dwelling) fish species to smaller pelagic (water-column) southern fish species and large invertebrates (e.g., squid, crabs, lobster) (Oviatt 2004, Collie, in prep.). The shift from benthic to pelagic species began abruptly around 1980 and is consistent with similar benthic-to-pelagic shifts in other estuaries, such as Chesapeake Bay (Jackson et al. 2001, Attrill and Power 2002, Genner et al. 2004).

7. This shift has been attributed primarily to increasing sea surface temperatures and secondarily to fishing (Collie et al. 2008), with changes in food availability as another potential factor. An increase of the winter North Atlantic Oscillation (NAO) (resulting in warmer ocean temperatures) and the decrease of phytoplankton, are associated with the rapid shift from benthic to pelagic species since the 1980s, and are strongly correlated to changes

in the pelagic food web (Collie et al. 2008). During the NAO positive phase, ocean water and climate is warmer in the eastern U.S, south of Cape Cod, and Europe. It is projected that a positive NAO will dominate or have a strong presence during the next 50 to 100 years, especially in winter and under the high emissions scenario (Frumhoff et al. 2007), suggesting that the trends being observed will likely continue at regional scales, and could impact the Ocean SAMP area.

8. It is possible that warming waters may be a significant cause for the decline of commercially important winter flounder by changing the spring timing of when the sand shrimp, which preys on juvenile flounder, becomes active during the year (Jeffries 2001, Taylor 2003).

9. It has been observed that in recent years populations of the ctenophore *Mnemiopsis leidyi*, a comb jelly, have grown in size, and the timing of their annual arrival in local waters has shifted from late summer to early summer due to warming waters. This has caused a significant decline of *Acartia tonsa*, a once abundant copepod (a common type of zooplankton) in Narragansett Bay (Sullivan et al. 2001, Costello et al. 2006, Sullivan et al. 2007). *Cancer* crab, lobster, and some fish populations could also be affected by their larvae being consumed in larger quantities (Sullivan et al. 2001, Oviatt 2004).

10. Rising sea water temperature is expected to adversely affect lobster populations in the Ocean SAMP region due to distributional shifts northward and potential stresses such as increased incidence of disease (see Chapter 2, Section 260.3, and this chapter, Section 330.3.1). Temperature affects lobster physiology and behavior at all life stages, including molting, the settlement of post-larval lobsters, growth rates, and movement and seasonal migration (Frumhoff et al. 2007). Currently the southern limit of lobster along the Northeast coast is located near Long Island and northern New Jersey. As waters warm, this southern limit will move northward, possibly north of Rhode Island waters, causing a severe decline in the local fishery and an increase in the northern Gulf of Maine fishery (Frumhoff et al. 2007). According to a comparison of lobster distribution between the relatively colder period from 1965 to 1969 and the warmer period from 2000 to 2004, the center of lobster geographical density has already shifted north (Frumhoff et al. 2007).

330.1.4. Marine Mammals

1. Thirty-six species of marine mammals are known to occur in the Ocean SAMP area (Kenney and Vigness-Raposa 2009); they use the water for seasonal feeding or migrating to feeding and calving grounds (See Chapter 2, Section 250.4 for further discussion). No research showing direct impact to adult marine mammal populations as a result of climate in the Ocean SAMP area is known; however, studies showing indirect impacts are noted below.

2. Most of the marine mammals that occur in the Ocean SAMP area are wide-ranging and not resident in the area. However, some species may pass through and feed in the Ocean SAMP area, staying a few days, and others stay for weeks to several months. Therefore, changes to the marine ecosystem in Ocean SAMP waters due to climate change are less important than the effects of climate change impacts to a wider region. Although some of climate change impacts in this case are outside the domain of the Ocean SAMP, it is still important to be

aware of how climate change affects these marine mammals. Of the 29 large marine mammals that use the Ocean SAMP area, seven are listed as endangered under the Endangered Species Act, and therefore demand an extra level of attention. In addition, all marine mammals are provided protection from harassment under the Marine Mammal Protection Act.

3. The IPCC (2001) concluded that marine mammals (and seabirds) are highly sensitive to climate changes (IPCC 2001). Sea surface temperature and distribution of preferred prey, for example, are important determinants in the range of marine mammals (Learmonth et al. 2006, Kaschner et al. 2006). The range of some marine mammals that occur in the Ocean SAMP and require polar and cold temperature waters are expected to experience a loss in range as they move northward. Some of the marine mammals whose range is warm water (such as the West Indian manatee) will be more likely to enter the Ocean SAMP as their range is extended northward (Learmonth et al. 2006).

4. Species that rely on sea ice or the environment close to the ice edge as part of their habitat will be more vulnerable to climate change (e.g., ice-breeding seals). Climate change models predict reductions in sea ice concentrations. Among the 36 marine mammals identified in the Ocean SAMP range, ringed seal, gray seal, harp seal, and hooded seal are dependent on sea ice (Learmonth et al. 2006).

5. In general, species that are more adaptable to changing prey conditions will be less vulnerable to climate change. However, species such as the right whale that have a relatively narrow range of acceptable prey characteristics and feeding grounds closely linked to specific physical phenomena such as water structure, currents, and temperature, will be more likely to experience negative impacts of climate change (Learmonth et al. 2006; Simmonds and Isaac 2007).

6. Changes in prey distribution, abundance, and composition resulting from climate change are recognized by the IPCC (2001) as primary impacts of a changing climate on the marine mammals that feed from the top of the food chain. Marine mammals in general and baleen whales in particular (right whale, humpback whale, minke whale, Bryde's whale, sei whale, fin whale, and blue whale), require dense patches of prey such as copepods and other forms of plankton (Learmonth et al. 2006). Therefore, the distribution, abundance, and migration of these whales reflect the distribution, abundance, and movements of these dense prey patches (Learmonth et al. 2006). Changes in dominant copepod assemblages have been noted on both sides of the North Atlantic Ocean with increasing water temperatures (Beaugrand et al. 2002).

7. Changing water temperature and prey availability can also impact the reproductive success of marine mammals (IPCC 2007; Whitehead 1997). For example, a decrease in North Atlantic right whale calving has been related to abundance of the principal prey species of copepod, *Calanus finmarchicus*, and oceanographic changes influenced by the NAO (See Section 310.5 for further discussion about NAO; Greene and Pershing 2004). Intervals between right whale calves lengthened from 3 to 4 years between 1987 and 1992 to 5 to 6 years between 1993 and 1998 (Kraus et al. 2007). Kenney (2007) compared North Atlantic right whale

calving rates with three atmospheric indices including the NOA, and found each of these atmospheric cycles may be correlated with calving. Additionally, Learmonths et al. (2006) suggest a close correlation between food abundance, body fat condition, and fecundity in female fin whales that in years of food abundance at the summer feeding grounds might produce a calf in consecutive years, whereas in poor years the cycle can be extended to three years.

8. Research has linked the NAO, prey abundance, and right whale calving rates. Positive NAO conditions in the 1980s corresponded with favorable calving rates and negative conditions in the 1990s were linked with very low rates. The NAO atmospheric phenomenon has a dramatic effect on the amount of cool, fresh water moving downstream from the Labrador Sea to the Northeast (Pershing et al. 2001). In the winter of 1996, the NAO index exhibited its largest drop of the century. Resulting changes in the water in the Gulf of Maine determine zooplankton ecology. Green et al. (2003) found that major multi-year declines in calving rates have tracked those in *Calanus finmarchicus*, a copepod species that dominates the spring and summertime zooplankton biomass in the Gulf of Maine. The second multi-year decline corresponded with a precipitous drop in *C. finmarchicus* abundance with a record low three years in a row: six in 1998, four in 1999 and only one in 2000 (Kraus et al. 2007).

9. The IPCC (2007) concludes that there will be an increase in climate variability, which could lead to further variations in climate and impacts on the NAO. Since right whales require at least three years between births, increasing climate variability and corresponding NAO impacts may affect calving rates negatively (Green et al. 2003).

10. Finally, warmer sea temperature has been linked to increased susceptibility to disease, contaminants, and other potential causes of marine mammal death (Learmonth et al. 2006). Climate change has the potential to increase pathogen development and affect survival rates, disease transmission, and host susceptibility (Harvell et al. 2002).

330.1.5. Seabirds

1. How seabirds would be affected by climate change is an active area of research. The Third Assessment Report of the IPCC and many scientists since then found evidence of the sensitivity of seabirds to climate-ocean changes and concluded that survival and distribution impacts will occur as climates shift (IPCC 2001; U.S.FWS 2010; Wanless et al. 2007; Durant et al. 2004; Jenouvrier et al. 2009). It is known that changes in climate affect seabird behavior and populations in terms of food availability, nesting and feeding habitat, the ability to carry out courtship behavior, breeding, survival of young, and migration patterns. Seabirds that frequent the Ocean SAMP area may be affected by these impacts occurring both in and outside the Ocean SAMP. Each type of seabird (e.g., pelagics, sea ducks, gulls and relatives, and shorebirds) has a slightly different seasonal use of the area and, therefore, the impacts of climate change may affect them differently.

330.1.5.1. Nesting and Feeding Habitat

1. All 67 oceanic bird species (such as shearwaters and petrels found in the Ocean SAMP area) are among the most vulnerable birds on Earth to climate change because they don't raise

many young each year, they face challenges from a rapidly changing marine ecosystem, and they nest on islands that may be flooded as sea level rises (U.S.FWS 2010).

2. Those species that are found in the Ocean SAMP area that nest in coastal habitats are also vulnerable to sea level rise from climate change (U.S.FWS 2010). For example, piping plovers (federally threatened) and least terns (state threatened) could lose critical beach nesting habitat (pers. comm., P. Paton, URI). Vulnerable species that nest in salt marsh habitats in the Northeast include saltmarsh sharp-tailed sparrows (this species is only found nesting in Northeastern salt marshes), seaside sparrows, and willet (pers. comm., P. Paton, URI). Finally, species that nest on the ground on low offshore islands (e.g., roseate terns, federally listed as endangered, and common tern) would be extremely vulnerable to sea level rise and loss of critical nesting habitat, for example, that of Great Salt Pond on Block Island, which is a regionally important migratory shorebird stopover site (pers. comm., P. Paton, URI).

3. Coastal wetlands provide critical stopover habitat for migratory shorebirds that pass through the Ocean SAMP area. Most shorebird species forage on beaches and mudflats, or in low salt marshes (Koch and Paton 2009). Rhode Island provides valuable stopover habitat for a wide array of migratory species, particularly in the fall for species that breed throughout the tundra of Canada/Alaska and stop in Rhode Island and coastal New England to refuel before heading farther south to the southern U.S., Caribbean, and South America (pers. comm., P. Paton, URI). Beaches (e.g., Napatree Spit) and coastal ponds (Trustom Pond, Goosewing, and Ninigret) provide useful foraging habitat for these long- and short-distance migrants. Loss of this foraging habitat to sea level rise could have major impacts on shorebird populations. (pers. comm., P. Paton, URI).

330.1.5.2. Food Availability

1. Many of the seabirds that prey on fish and plankton are likely to have their food supply reduced or relocated if the predicted effects of climate change on lower trophic levels occur (Daunt et al. 2006; Frederiksen et al. 2006). There is no data on seabird impacts in the Ocean SAMP as a result of changes in food supply, but there is evidence elsewhere. The natural climate variability of El Niño Southern Oscillation (ENSO) events has provided insight into how sea surface temperature variation can result in significant change in the marine ecosystem. The population of sooty shearwaters and common murres off the west coast of North America greatly declined due to starvation during the 1997–1998 ENSO event (Mathews-Amos and Berntson 1999). Cormorants and pelicans experienced mass mortalities during the 1982–1983 ENSO event that were attributed to reduced nutrients in surface waters leading to decreased primary and secondary production (Glynn 1988). The common murre is a frequent winter visitor to the Ocean SAMP region. Double-crested cormorants are a common breeding species in Rhode Island (nesting in Narragansett Bay), and great cormorants are common in winter months in coastal Rhode Island.

330.1.5.3. Breeding

1. Time series data analysis of over 100 species of seabirds in the North Atlantic suggests a strong relationship between seabird breeding success and climate variables related to the

NAO, which influences sea surface, air temperatures, precipitation and other aspects of regional climate (Sandvik et al., 2008). The results suggest that sea surface temperature was the single most relevant parameter to breeding success of seabirds. Sea surface temperature affects the marine ecosystem and seabird food abundance, distribution and seasonality. A lack of food affects the reproductive success of seabirds with a reduction in numbers of eggs produced, those successfully hatching, and the number of breeding pairs (Wanless et al. 2005).

330.1.5.4. Migration Patterns

1. Climate change also affects the timing of arrival and departure of migratory seabirds, and average laying dates (Frederiksen et al. 2004; Crick 2004). Time series data of long-term arrival and passage of migrants are not available for the Ocean SAMP area. However, reported observations of some bird species in the United Kingdom have been increasingly later in the fall, implying a longer stay on breeding grounds (Sparks and Mason 2001). Also, warmer springs are associated with earlier arrivals and earlier breeding (Sparks et al. 2001). Depending upon prey resources utilized, climate-related alterations of the marine ecosystem could cause mismatches between migratory time and cycles in abundance of major prey species in the Ocean SAMP area (i.e., altered phenology).

330.1.6. Sea Turtles

1. Six species of sea turtles are known from the North Atlantic, with four—green, loggerhead, Kemp's ridley, and leatherback sea turtles—occurring rarely or occasionally in the Ocean SAMP area (Kenney and Vigness-Raposa 2009). All four are on the U.S. endangered species list. Warmer seawater temperatures may increase sightings of these sea turtles in Ocean SAMP boundaries, but this possibility has not yet been considered in models or other attempts to project climate change impacts to the Ocean SAMP area.

2. The major impact of global climate change on sea turtles that occur in the Ocean SAMP area is on their nesting and feeding grounds farther south outside the domain of the Ocean SAMP. This section summarizes these impacts outside the Ocean SAMP, recognizing that they are protected under the Endangered Species Act and therefore demand an extra level of attention.

3. Sea level rise will affect nesting areas on low-level sand beaches. All female turtles come ashore at nesting beaches, dig nests in the sand, lay their eggs, and then return to the sea. These areas of low-lying, sandy, coastal beaches, often key habitat for nesting sea turtles, are also areas that are most vulnerable to the impacts of sea level rise (Fuentes et al. 2009a). Erosion and inundation of beaches caused by rising sea level and more intense storms adds the potential for further dangers to nesting sites that are already threatened by people and animals. Coastal flooding can increase rates of egg mortality and decrease reproductive success as sea level rises closer to sea turtle nesting sites. The Outer Banks of North Carolina is especially prone to this because most beaches are backed by coastal development (e.g., seawalls, roads, etc.) or salt marsh, and increased storm surge and coastal land loss will threaten these beaches, which have nowhere to retreat (Hawkes et al. 2007).

4. Rising temperatures will affect incubating sea turtle eggs. The optimal temperature range for incubation is 25°C to 35°C (77°F to 95°F), with reduced hatchling success outside that range (Fuentes et al. 2009b). In addition, temperature during the middle third of incubation determines the sex of the hatchling. Hatchling sex ratio is 50:50 at 29°C (84°F), with more males at cooler temperatures and more females at warmer (Fuentes et al. 2009a). Vegetation (shading), beach slope, humidity, rainfall, and egg position in the nest can all influence incubation temperature and sex ratio (Hawkes et al. 2007).

5. Loggerhead turtles nest in North America from southern Florida to southern Virginia, and it is theorized that more males are born in the northern sites due to cooler temperatures (Mrosovsky and Provancha 1989). Loggerhead turtle nests in Florida are already producing 90 percent females owing to high temperatures, and if warming raises temperatures by an additional 1ºC (1.8°F) or more, no males will be produced there (Mrosovsky and Provancha 1989).

6. One study of loggerhead sea turtles at Bald Head Island in North Carolina found that increased sea surface temperature is associated with earlier nesting and longer nesting seasons. Modeling-predicted air and sea surface temperature increases indicate that nesting would need to be altered only a few days with a 1°C (1.8°F) increase and up to a week with a 3°C (5.4°F) increase (Hawkes et al. 2007). These results suggest that there is hope for sea turtle adaptation, especially along their northern nesting range, and that protecting these male-producing sites should be a priority for future management.

7. Adult sea turtle feeding patterns are also affected by climate change. Sea grass beds are declining for several reasons including pollution and increased sea temperatures from climate change, and water temperature is higher on inter-tidal sea grass flats, typically feeding grounds for green turtles (Short et al. 2006).

8. Leatherbacks may also shift their northern distribution due to increasing air and sea temperatures. McMahon and Hays (2006) investigated movements of one leatherback species, *Dermochelys coriacea*, using satellite telemetry, which revealed that habitat utilization remains within the 15°C isotherm (area with the same temperature) and has moved north along with the isotherm by 330 km in the summer position in the North Atlantic over the last 17 years.

9. Sea turtles have existed for more than 100 million years and have survived ice ages, massive sea level fluctuations, and major changes to the continents and the seas (Fuentes et al. 2009a). As a result, they may be able to respond to unfavorable nesting temperatures or inundation of beaches as they have in the past, by seeking out new nesting sites or modifying the seasonality of nesting. However, what is different today is the limited availability of new habitat due to steadily encroaching human development of coastal areas and the rapid rate of climate change.

330.2. Chemical Oceanography

330.2.1. Ocean Acidification

1. Marine animals that have shells or skeletons made of calcium carbonate (such as corals, quahogs, foraminifera, slippershell snails, and sea stars) may be impacted by further reductions in pH levels (increased acidity) (Cooley and Doney 2009). As ocean alkalinity decreases, the dissolution rate of calcium carbonate increases and less dissolved carbonate ions are available for animals to take up and use to form shells and skeletons (USGCRP 2009). Reduced alkalinity could also depress the metabolism of marine organisms with high metabolic rates, such as pelagic fishes and squid, which could lead to a decreased capacity to take up oxygen in the gills and cause asphyxiation in some fish, squid, and shrimp (TRS 2005, Fabry et al. 2008). Although the impacts to larval temperate fish are unknown, it has been observed in reef fish that decreases in pH can disrupt the olfactory cues used by larval fish to find suitable habitat for settlement, which could result in the reduction of population sustainability (Munday et al. 2009). Impacts to reproduction and larval development have already been shown in a lab setting, but additional possible impacts could include effects on immunity and on development at other life stages (Holman et al. 2004; Burgents et al. 2005; Fabry et al. 2008).

2. Recent laboratory research has shown that many organisms with calcium carbonate shells, such as periwinkles, oysters, urchins, and calcareous green algae, formed less calcium carbonate when the pH dropped below 8.2 (Ries et al. 2009). The same study also documented seven species whose rates of calcium carbonate formation increased and one species that had no response when exposed to lower pH levels (Ries et al. 2009). The impacts of ocean acidification may be highly varied among species.

330.3. Emerging Issues

330.3.1. Disease

1. Marine diseases are not widely studied in the Ocean SAMP area. However, increasing water temperatures and salinities due to changing climate are creating conditions that are favorable to the spread of disease organisms (Kennedy et al. 2002). Temperature change in general makes marine species more vulnerable to stress and disease, particularly if it occurs during critical periods of the species' life cycle.

2. Diseases in southern waters could extend northward and negatively impact local communities of marine plants and animals. For example, the American oyster, which had repopulated Narragansett Bay and the south shore salt ponds in the 1990s after being absent from commercial fisheries for nearly four decades, was severely afflicted by a southern oyster parasite causing the *Dermo* disease (Ford 1996, Cook et al. 1998). A 1998 disease survey found this parasite, which was rarely seen north of the Chesapeake Bay until the 1990s, in over half of the dead oysters (Cook et al. 1998). The spread of *Dermo* is attributed to warming waters that have extended the northern limit of the parasite's geographical range (Ford 1996, Cook et al. 1998, Oviatt 2004, Frumhoff et al. 2007).

3. Lobster shell disease is described in Chapter 2, Section 270.3. Though the cause of the spread of this disease is unknown, it has been speculated that anthropogenic forces are responsible,

including warmer water temperatures (Cobb 2006, Castro et al. 2006). Currently, the southern extent of the commercial lobster harvest appears to be limited by this temperature-sensitive disease, and these effects are expected to increase as near-shore water temperatures rise (Frumhoff et al. 2007). The disease was found in less than 1 percent of lobsters sampled in 1996 and by 2004 the percentage of diseased lobsters sampled grew to 20 to 40 percent (Cobb 2006). Though the disease is not always fatal, it has had negative consequences for lobster marketability. The persistence and increase in prevalence of the disease in recent years has serious implications for the sustainability of the lobster fishery, especially as marine waters continue to warm.

330.3.2. Invasive Species

1. An invasive species is an introduced, non-native species that survives when introduced to new ecosystem and does, or is likely to, cause harm to the ecosystem. Introduced species are recognized as one of the main anthropogenic threats to biological systems (Sala et al. 2000). As local and regional waters warm, additional warm-water species that once found the colder temperature inhospitable will be able to reproduce and spread (Frumhoff et al. 2007). Sorte et al. (2010) conducted a meta-analysis of marine species experiencing range shifts and found that 75 percent of the range shifts were in the northward direction, consistent with climate change scenarios. The expansion of the northward shift of warm water species may introduce new species into the Ocean SAMP area, and warmer temperature could prolong the stay of current seasonal migrants (Oviatt et al. 2003, U.S. EPA 2008a).

2. Invasive species that can breed in warmer winter waters may have an advantage over native species that breed in colder water (Stachowicz et al. 2002a). Additionally, as environmental changes affect native species composition and abundance, and potentially diversity, resistance to the establishment and spread of invasive species could decline (Stachowicz et al. 2002b). Resistance to invasive species may also be impeded by compound stressors such as anthropogenic disturbance (McCarty 2001) or the spread of new diseases (Harvell et al. 2002), in addition to the stress of temperature increases (Stachowicz et al. 2002b). It is also possible that certain non-native species could have minimal impacts to local marine ecosystems, and perhaps become acceptable or even desirable in future years (Walther et al. 2009).

3. There are no published data on invasive and introduced species in the Ocean SAMP area, but there is evidence of marine species coming from the south that have moved or are moving into New England, in some cases thought due to climate change (Carlton 2010) (see Table 3.5).

Table 3.5. Marine invasions coming from the south.

Species	Geographic Origin	Habitat	Notes
Lionfish (*Pterois miles* and *P. volitans*)	Indo-Pacific		An invasive warm-water species that feeds on juvenile fish. It is now found as far north as Rhode Island (Morris and Whitfield 2009).
Bryozoan *Zoobotryon verticillatum*	Unknown	Fouling	Ephemeral colonists detected in the Mystic River Estuary, Connecticut (Carlton 2010).
Sea squirt *Styela plicata*	Northwest Pacific	Fouling	Ephemeral colonists detected in the Mystic River Estuary, Connecticut and Long Island Sound (Carlton 2010).
Rapa whelk *Rapana venosa*	Japan	Benthos	Established in Chesapeake Bay (Carlton 2010).
Wedge clam *Rangia cuneata*	South Atlantic Bight/Gulf of Mexico	Benthos	Established in Hudson River (Carlton 2010).
Barnacle *Amphibalanus amphitrite*	South Pacific	Fouling	Colonizes New England in warm summers (Carlton 2010).
Barnacle *Amphibalamus subalbidus*	Chesapeake Bay and south	Fouling	Recorded in Charles River, Boston (Carlton 2010).
Isopod *Synidotea laevidorsalis*	Japan	Fouling	Detected in New York (Carlton 2010).

Section 340. Implications of Climate Change for Human Uses

1. Climate change affects all dimensions of human activity in multiple direct and indirect ways. This section reviews the ramifications—both potentially negative and positive—of climate change for the human uses expressed in other chapters. The Ocean SAMP's jurisdiction for management and regulation is offshore; however there are links between offshore and shore-side uses. Therefore, this chapter looks at the potential impacts of climate changes to both offshore uses and to selected shore-side uses as these would affect Ocean SAMP uses. The Rhode Island CRMP manages the shore-side uses more comprehensively.

2. There is little or no data and modeling of specific climate change impacts to human uses in the Ocean SAMP area. However, the direction and magnitude of the effects of climate change are becoming increasingly well understood. While it is possible to take these climate changes and overlay them on human uses to anticipate their general consequences, the complexity and uncertainty must be acknowledged and understood. As Figure 3.12 illustrates, the greater the number of climate change variables and direct and indirect interactions, the greater the uncertainty and complexity of climate change impacts. Added to the complexity is the fact that a number of these variables interact in a variety of ways, making the net impact of climate change drivers upon human uses unpredictable given the amount of research available at this time.

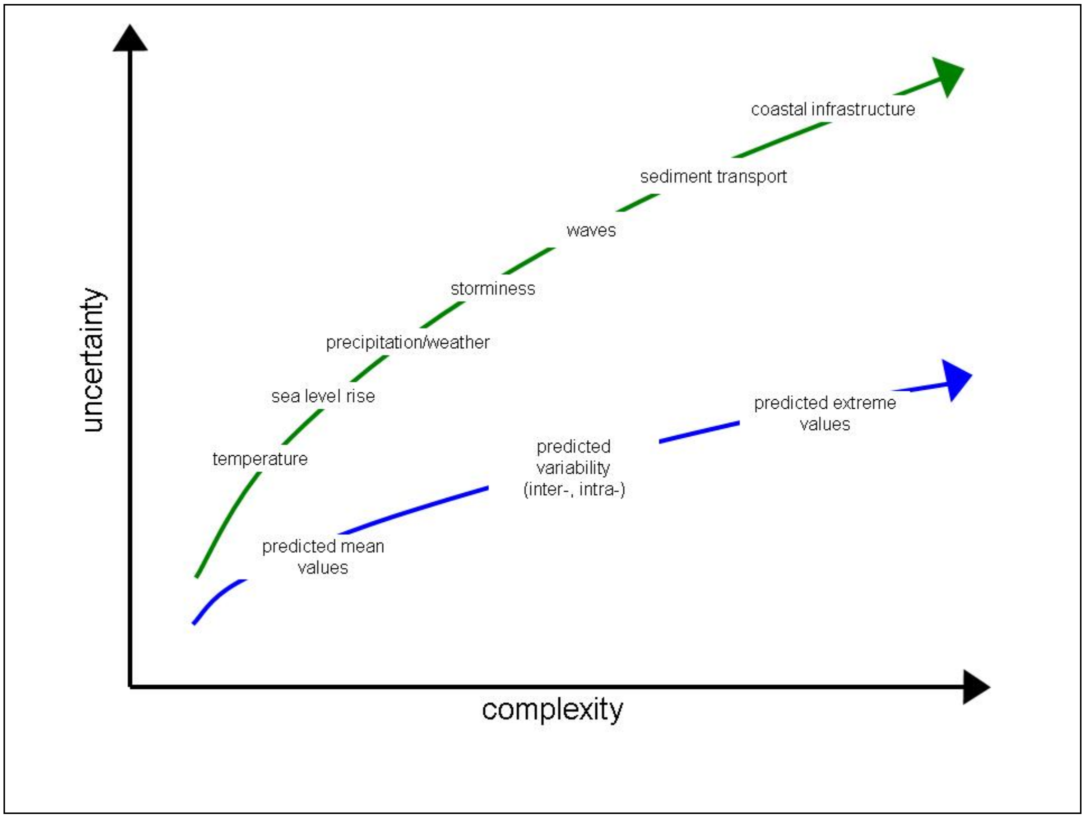

Figure 3.12. Complexity and uncertainty of linked climate change impacts (Adapted from PIANC 2008).

340.1. Marine Transportation, Navigation, and Related Infrastructure

340.1.1. Introduction

1. Marine transportation, navigation, and related infrastructure, as described in Chapter 7, include transport by sea of various types of goods and services as well as people, and involve related issues including navigational routes and ports and harbors. Chapter 7 describes the importance of transportation and navigation through the Ocean SAMP area for cargo ships, such as tankers, bulk carriers, tugs and barges; passenger ferries; naval vessels; government research, enforcement, and search-and-rescue vessels; and pilot boats. In addition, marine transportation is supported by a network of navigation features—including shipping lanes, traffic separation schemes, navigational aids, and other features that facilitate safe navigation—and adjacent land-based infrastructure, such as cargo handling facilities and storage areas in nearby ports.

2. Climate change may influence numerous aspects of the way marine transportation and navigation occurs in the Ocean SAMP area as well as the infrastructure that supports it. Table 3.6 presents a summary of the primary drivers of climate change with direct potential impacts to the user groups associated with marine transportation, navigation, and infrastructure.

3. There are many potential impacts. Among the most critical is an extended shipping season. A longer shipping season has positive implications for the shipping industry. Although it is projected that increasing air temperatures will reduce concern of icing in waterways and on vessels and infrastructure, it is not clear, given the potential for negative impacts to infrastructure and ports, what net impact this will have on shipping through the Ocean SAMP area.

4. Increased vulnerability of infrastructure will also be of significant concern to shipping and navigation. Coastal and offshore infrastructure may be subject to greater damage from more intense storms and increased decay from increasingly acidic seas (PIANC 2008). In addition, coastal infrastructure is more likely to be flooded by higher sea levels, and more coastal infrastructure will be exposed to higher wave loads and tidal fluxes, increasing fatigue and corrosion.

Table 3.6. Climate change impacts on marine transportation, navigation, and infrastructure affecting the Ocean SAMP area.

Climate Change Variable	Potential Impact	Marine Transportation	Navigation	Infrastructure
Increasing air temperatures	Extended shipping season and use of infrastructure (Neumann 2009)	+	n/a	+
	Degradation and shortened lifespan of ships and infrastructure	–	–	–
	Reduced icing in waterways and on vessels and infrastructure (PIANC 2008)	+	+	+
Increasing sea level	Increased exposure to infrastructure (corrosion)	–	n/a	–
	Increased likelihood of flooding/inundation of coastal infrastructure (Neumann 2009)	–	n/a	–
	Need for higher passing height for bridges (PIANC 2008)	–	–	–
	May increase navigability of waterways (TRB 2008)	+	+	+
Increase in storm intensity	Changing movements of sediment (erosion/accretion) (EPA 2008b)	–	–	–
	Increased degradation and vulnerability of infrastructure (coastal and offshore) (PIANC 2008)	–	n/a	–
	Loss/retreat of land (for associated infrastructure) (PIANC 2008)	–	n/a	–
	Increase in unsafe condition and poor visibility for navigation/transferring cargo (TRB 2008)	–	–	–
	More need for emergency planning and rescue (Neumann 2009)	–	n/a	–
Increasing precipitation and decreasing wind speed	May result in changing currents (PIANC 2008)	?	?	n/a
	Changes in sediment transport (erosion/accretion)	–	–	–
Longer summers and decreased snow season	Extended shipping season and use of infrastructure (Neumann 2009)	+	n/a	+
	Reduced icing on vessels and infrastructure (PIANC 2008)	+	+	+
More acidic ocean	Increasing corrosion rates of vessels and infrastructure (PIANC 2008)	–	n/a	–
Key: +: potentially positive effect –: potentially adverse effect n/a: no significant anticipated effect ?: unknown impact				

340.1.2. Increasing Air Temperature

1. Increased air temperatures will extend the length of the shipping season and allow for higher volumes of goods shipped at lower costs due to less severe cold weather (EPA 2008b).

2. Operations on vessels and associated shoreside infrastructure will need to account for higher temperatures in order to protect workers from extreme heat (EPA 2008b).

3. Air temperature increases will decrease the incidence and severity of icing in waterways and on vessels and infrastructure. On vessels, less icing will decrease the need for lowering freeboard to increase stability (Nicholls et al. 2008).

4. Higher air temperatures and corresponding elevated water temperatures will increase the likelihood that invasive species from ballast discharge survive in local waters (Kling and Sanchirico 2009).

5. Infrastructure can be affected by increased air temperatures as well, including more rapid deteriorating of paved areas and greater energy needed to cool stored goods (EPA 2008b).

340.1.3. Rising Sea Level

1. Sea level is already rising in the Ocean SAMP area, and is projected to rise at an increasing rate in the future. Sea level rise will reduce the effectiveness and decrease the life of existing coastal structures such as seawalls and revetments, docks, roads, and bridges (PIANC 2008). Sea level rise of the magnitude predicted could also potentially compromise onsite wastewater treatment systems, municipal sewage treatment plants, and stormwater infrastructure. Other risks associated with sea level rise include salt intrusion into aquifers and higher water tables that could compromise individual sewage disposal systems.

2. Higher sea levels increase the likelihood of flooding and inundation of coastal lands and infrastructure. Any given storm event will surge higher on land because the relative sea level is higher than in the past and be exacerbated in the future by more intense storms. This can affect the use of infrastructure in ports and harbors both over the short term (during a flooding event) and long term (extensive damage from inundation) and impact the ability for vessels to access the coast (for example, to unload cargo or pick up passengers) (Neumann 2009).

3. Higher flood levels and storage-area inundation may also inundate contaminated (or potentially contaminated) lands, and/or infrastructure not designed to withstand flooding. These areas could require new containment methods to prevent leaching (EPA 2008b).

4. According to Titus and Richmond (2001), Rhode Island has 47.1 square miles (mi^2) (122.0 square kilometers (km^2)) of land lying within 4.9 vertical feet (1.5 meters) of sea level with an additional 24 mi^2 (108.8 km^2) between 4.9 and 11.5 feet (1.5 and 3.5 meters). This 4.9-foot (1.5-meter) contour roughly represents the area that would be inundated during spring high water with a 2.3-foot (0.7 meter) rise in sea level. This sea level rise scenario is within current end-of-century projections.

5. By mid-century, the 100-year flood is expected to occur more frequently than every 25 years in nearby Woods Hole, Mass., under the high emissions scenario (Kirshen et al. 2008). By

late century, it is expected to occur more frequently than every two years. The 100-year storm commonly used by the National Flood Insurance Program standards is a flood event that has a 1 percent chance of being equaled or exceeded in any given year. The projections for Woods Hole indicate that the 1 percent annual chance flood will increase to 4 percent annual chance of occurring by mid-century and 50 percent by 2100, with associated increases in flooding and damages. These estimates are based on more recent sea level rise estimates that include a conservatively low degree of ice melt impacts.

6. When flooding overtops ports, there is large area of inland inundation because ports are typically built in flat, low-lying areas (EPA 2008b). Options for protection include, but are not limited to, elevating facilities, filling land, and/or installing shoreline protection structures. Each of these options would need to be analyzed on a case-by-case basis. Aggregate supply (sand and gravel) for armoring and fill is limited in Rhode Island due to municipal policies on sand and gravel mining and lack of publicly or privately owned land alternatives.

7. Increased sea level will reduce overhead clearance between the superstructure of ships and bridges in Narragansett and Mount Hope Bays, thereby limiting operations.

8. A corresponding potential positive impact of sea level rise may be increased navigability of waterways and a decreased need for dredging to accommodate larger-draft vessels (TRB 2008). This could positively benefit ships that pass through the Ocean SAMP area due to currently significant demands for dredging in several parts of Narragansett and Mount Hope Bays. Increased ease of navigability may also lead to an increase in shipping of goods to and from Rhode Island ports (TRB 2008).

340.1.4. Increasing Storm Intensity

1. Increased storm intensity can affect sediment movements due to increased wave heights, causing changes in erosion and accretion patterns. Differing sediment movements can affect needs for dredging, preferred shipping routes, and port operations (EPA 2008b).

Flooding and Storm Damage to R.I. Ports and Harbors

Providence: Providence's vulnerability to flooding stems from two main geographic features: its location at the head of Narragansett Bay and its low elevation downtown and along the port. During the Hurricane of 1938, Providence experienced a storm surge of more than 15 feet above mean tide level (MTL), with waves measuring 10 feet above the surge level. The hurricane flood waters inundated the city, damaged buildings and other infrastructure, and demolished the wharves of the inner harbor. Damage amounted to $16.3 million, equivalent to about $225 million in 2000 dollars (Providence 2000). In 1954, the downtown area was flooded by 12 feet of water (Vallee and Dion 1996). Damage is estimated to have been $25.1 million, about $134 million in 2000 dollars (Providence 2000).

East Providence - The worst coastal flooding in East Providence occurred in the 1938 and 1954 hurricanes, severely impacting the city's waterfront infrastructure. On two occasions the dock of the Gulf Oil Corporation was completely destroyed along with the connecting railroad. Large ships in the Providence River were torn from their moorings and tossed onto shore. For several days, debris blocked roads, railways, and waterways, creating hazardous conditions that hampered emergency and repair crews. Residential structures located along the waterfront were severely damaged or destroyed, while homes inland along the rivers were flooded (East Providence 2002).

2. Increased intensity in storms will increase periods of high waves, decreasing time for ships to unload at terminals and increasing berthing time for ships at terminals and delayed departures (EPA 2008b).

3. Increased time needed to unload cargo may result in the need for more area for anchoring of waiting vessels in port areas (EPA 2008b).

4. Additionally, offshore loading and unloading between vessels can only occur with waves below a certain height and longer than a certain wave period. With increased storm intensity, wave heights too large and with too short a wave period for transfer of goods (and personnel) will occur more frequently (EPA 2008b). This is critical since demand for natural gas in winter in Providence can be a bottleneck for distribution.

5. Increased storm intensity will also increase degradation and vulnerability of associated infrastructure. Movements of sediment due to increased storminess may also decrease safety of structures and increase probability of flooding through erosion of coastal land (PIANC 2008).

6. Increased storm intensity may lead to decreased regularity of port functions and increased need for storage capacity at container terminals (PIANC 2008). This may increase shipping delays due to suspended operations during intense storms and could decrease the reliability of marine shipping, impacting business of shippers and receivers of shipped goods (EPA 2008b).

7. More intense storms may also decrease visibility and accessibility to malfunctioning installations such as beacon lights (PIANC 2008).

8. Port security could be adversely impacted by increasingly intense storms and could result in less security (for example, malfunctioning video cameras, radar equipment, and perimeter fencing) (EPA 2008b). Alternatively, the threat to port security might be reduced due to increased storm intensity, with poor weather making it more difficult to operate equipment.

9. More intense storms, bringing more precipitation in short periods of time, will also require increased capacity of stormwater facilities adjacent to coastal infrastructure supporting port facilities (EPA 2008b).

10. Increased storm intensity will increase the likelihood of debris inhibiting navigation and/or anchoring at ports and harbors (EPA 2008b).

11. Unsafe conditions and poor visibility due to increased storm intensity may increase shipping delays and damage vessels. Using additional and enhanced aids to navigation—such as more buoys, with higher-intensity lights and more sound and electronic signals—can attempt to mitigate these impacts, but at a high cost. This may also increase the need for emergency planning and rescues, which will also incur considerable economic costs to the associated industries (TRB 2008).

340.1.5. Changing Precipitation and Weather

1. Changing precipitation and weather patterns may result in differing sedimentation and shoal formation, and may complicate navigation by either offsetting increased water levels or necessitating additional dredging (TRB 2008).

2. Decreasing wind speed could alter currents and change preferred shipping routes (PIANC 2008).

3. Changing weather combined with warmer water may cause marine organisms (phytoplankton, fish, and marine mammals) to move into existing preferred shipping lanes, causing possible problems for navigation and requiring relocating the lanes (EPA 2008b).

340.1.6. Ocean Acidification

1. Decreasing pH levels and the corresponding increase in carbonic acid in the seas may increase the rate of corrosion on vessels and infrastructure associated with marine transportation, navigation, and ports and harbors. However, increased corrosiveness is also dependent on other environmental factors that will likely be affected by climate change, including some that may have mitigating effects on corrosiveness. Existing structures and vessels may experience a shorter lifespan due to more corrosion (PIANC 2008).

340.1.7. Indirect Impacts

1. The impacts presented above are the most likely and most direct effects of the drivers of climate change upon marine transportation, navigation, and its supporting network and

infrastructure. Below is a description of some of the potential indirect and cumulative impacts predicted to affect marine transportation in the Ocean SAMP area.

2. Warmer temperatures may change the seasonality of energy demands, with less energy for heating needed in winter, and more energy for cooling in summer. The net effect on energy demand is not known, but it may influence the mix of energy needed and the seasonality and amount of regional marine oil and gas shipping through the Ocean SAMP area (PIANC 2008).

3. Climate change may affect insurance coverage and could increase premiums on insured property and vessels with combined impacts from increased sea level and storm intensity. Currently, the marine transportation insurance industry is very concerned about rising costs associated with climate change. In response, they are exploring other strategies for insuring vessels and infrastructure including shifting some of the risk to customers and providing technical support and price incentives for customers to decrease exposure to risks (EPA 2008b). It has been suggested that as insurance premiums rise, reflecting increasing risk, there will be greater incentive to incorporate adaptation measures to infrastructure (Klein 2010).

4. Caldwell and Segall (2007) report that as the mean high water mark moves inland due to sea level rise, the legal boundary between private and state-owned land also moves (reported in Kling and Sanchirico 2009). This may affect issues of ownership at ports in Rhode Island and complicate issues of planning for future impacts of climate change on coastal infrastructure if ownership of the lands upon which they lie is in question.

340.2. Recreation and Tourism

340.2.1. Introduction

1. Coastal recreation and tourism, as described in Chapter 6, includes but is not limited to cruise ship tourism, beach-related activities, surfing, boating, diving, and wildlife viewing. Climate change may impact people's decisions about destinations due to the implications of climate change on the coastal and marine landscape, ecosystem, and infrastructure (Agnew and Viner 2001). While the research in this area is sparse with respect to the impacts of climate change per se, the following is based on research on the effects of these potential impacts to the types of recreation and tourism related to the Ocean SAMP area. Table 3.7 presents a summary of the primary drivers of climate change with direct potential impacts to the user groups associated with recreation and tourism in the Ocean SAMP area.

Table 3.7. Climate change impacts on recreation and tourism affecting the Ocean SAMP area.

Climate Change Variable	Potential Impact	Boating and related activities	Beach related activities	Diving	Wildlife viewing
Increasing air temperatures	Allow for longer boating and cruise ship tourism seasons	+	+	+	+
Increasing sea level	(Partial) Inundation of beaches and unique coastal habitats	–	–	n/a	–
	Migration or loss of coastal lagoons, salt marshes and tidal salt flats	–	n/a	n/a	–
Increase in storm intensity	More severe storminess	–	–	–	–
	Increased erosion of beaches and unique coastal habitats	?	–	n/a	–
	Increased storm overwash and breaching	–	n/a	–	–
	Earlier hauling out of recreational boats	–	n/a	–	–
	More Block Island ferry service interruption	–	–	–	–
	More erosion causing sedimentation and shoaling of waterways	–	n/a	–	n/a
Increasing precipitation	Increased nutrients and land-based sources of pollution in the sea from runoff	–	–	–	?
	More cloudiness and decreased visibility	–	–	n/a	–
Decreasing wind speed	Decreased attractiveness for sailing and sailboat racing	–	n/a	n/a	n/a
Longer summers and decreased snow season	Extended summer season	+	+	+	?
	Warmer water will bring more algae (red tide) and jellies	n/a	–	–	?
	More periods of drought during summer could lead to water use restrictions	–	–	–	?
More acidic ocean	May adversely impact shellfish and alter food web dynamics including fish and sea bird communities	–	n/a	n/a	?
	Increased ocean acidity may increase decay rates of underwater structures	–	n/a	–	n/a
Key: +: potentially positive effect –: potentially adverse effect n/a: no significant anticipated effect ?: unknown impact					

2. Increasing air and sea temperatures may enhance recreation and tourism activities by extending the summer season. However, warmer water may introduce HABs and increase algae (red tide) and jellies, reducing water quality and the attractiveness of beach and other water recreational activities (Hoagland et al. 2002).

3. Sea level rise, reduced wind, more severe storms, and more winter precipitation and spring runoff may have negative consequences for recreation and tourism. Increased rainfall and runoff may increase nutrients and other land-based sources of pollution flowing into the sea, and may increase the overflow from combined storm and wastewater sewer systems (Dorfman and Rosselot 2009). This can compromise water quality, cause algal blooms, deplete oxygen in the sea (hypoxia) and lead to more beach closures. For example, in 2008 there was a significant increase in beach closures in Rhode Island compared with 2007. Although there was an increase in water quality sampling, the increase in closures also coincided with higher rainfall during the summer months in 2008 (Dorfman and Rosselot 2009).

4. More periods of drought are projected for the summer months. This will make freshwater more scarce and could lead to water use restrictions, creating difficulty for tourism infrastructure needs.

5. Recreation and tourism activities in the Ocean State are based on the unique landscape and natural character of the coast. Climate changes that alter the natural character, affecting coastal habitat, fish, shellfish, and seabirds, will have implications for tourism and recreation. Among the unique coastal habitats that characterize southern Rhode Island are the beaches, lagoons (salt ponds), salt marshes, and intertidal communities.

6. With increases in sea level and storminess, Rhode Island's shorelines will change significantly, potentially becoming less attractive and less accessible. Barrier beaches in particular, on the south shore, will be especially vulnerable to increased erosion and landward migration as sea level rises. Increased storminess will result in increased storm overwash, breaching of barrier beaches, and damage to shoreline real estate and development on beaches and lagoon shores. A higher sea level may cause the migration or loss of habitats such as coastal lagoons and tidal salt flats that provide multiple important ecosystem services (Anthony et al. 2009). It can also result in damage or loss to coastal parks, coastal public access points, and open space. Finally, salt water intrusion in coastal aquifers that can accompany sea level rise may increase coastal freshwater scarcity and failure of onsite wastewater treatment.

7. The network of coastal lagoons, locally referred to as salt ponds, that lie along Rhode Island's south shore are important shallow marine ecosystems with historically high productivity of commercially important fish and shellfish and provide habitat for resident and migrating shorebirds and water birds. These lagoons are particularly vulnerable to changes associated with accelerated sea level rise, storms and sea surge, temperature increases and runoff from more precipitation. As sea level rise accelerates, the barrier beaches will become narrower and steeper, shortening the length of inlets to the lagoons and increasing exchange with ocean water (Bird 1994).

8. Salt marshes are other ecologically important habitats that provide a variety of ecosystem services, serving as nurseries and feeding grounds for fish, shellfish, birds, and invertebrates, filtering pollutants from groundwater and runoff, and buffering adjacent land and infrastructure from storms, erosion, and flooding. Loss of salt marsh habitat will likely occur

due to accelerated sea level rise. The loss of salt marshes will negatively impact many shorebirds and commercially important species of fish and shellfish, allow more pollutants to reach coastal waters, and leave the coastline more vulnerable to storms and erosion (Frumhoff et al. 2007).

9. The retreat of beaches and the shoreline due to accelerated erosion loss and inundation may increase private property litigation. In addition, Phillips and Jones (2006) suggest that the combined impacts of warming, sea level rise, and coastal hazards will coincide with falling property values in coastal areas and loss of tourism revenue.

340.2.2. Boating

1. Boating includes but is not limited to recreational boating, sailboat racing, and sea kayaking in the Ocean SAMP area and adjacent waters (see Chapter 6). Additionally, the previous section covers climate change concerns for marine transportation, navigation, and related infrastructure, many of which also affect recreational boating (see Section 340.1 of this chapter).

2. In general, warmer temperatures and a longer boating season are positive impacts of projected climate change for boating (EPA 2008b).

3. Projections of greater storm intensity and more nor'easters could cause earlier hauling out of recreational boats. Increased storminess could also make it more difficult to service Block Island by ferry, potentially adversely affecting recreation and tourism opportunities (EPA 2008b). Increased storminess and less predictable weather negatively affect planning for regattas and sailboat races and reduce safety at sea. Storminess could also increase the costs of insurance premiums for marine insurance for marinas and recreational vessels.

4. Higher-intensity precipitation can cause more runoff and erosion. This in turn can cause sedimentation and shoaling of waterways, adversely affecting marine navigation (EPA 2008b; TRB 2008).

5. Reduced average wind speed decreases the attractiveness of the area for sailing and sailboat racing.

6. Ocean acidification adversely affects some marine life and may ultimately have a detrimental effect on recreational fisheries. As the ocean becomes more acidic, mussels, starfish, and even fish may be adversely impacted. Changes to these populations may affect food web dynamics, and therefore affect fish communities and seabirds as well.

340.2.3. Diving

1. Recreational diving in the Ocean SAMP area includes both offshore diving and shark cage diving. Popular diving locations include historical ship wrecks, interesting benthic communities, and popular shark sites, among others.

2. It is difficult to speculate how climate change will impact diving. Longer summers can be a positive impact, upon diving in extending the season. However, the resulting effects of climate change on marine life and ocean visibility for diving are unknown. As is the case for boating, more severe storms would be a negative impact.

3. Over the long run, more acidic seas may increase the rate of decay of underwater wrecks that attract recreational divers.

340.2.4. Wildlife Viewing

1. Wildlife viewing includes but is not limited to whale watching, birding (i.e., pelagic, shorebirds), and any other recreational activity whose main goal is to view wildlife. This includes all viewing both offshore and in coastal regions.

2. An increase in air temperature combined with an earlier spring and a later winter will give a longer season for wildlife viewing that occurs during the warm months. The shortened winter months with more precipitation and cloudiness may adversely affect viewing of seals and winter-migrating birds.

4. Barrier beaches in particular, such as Rhode Island's barrier beaches on the south shore, will be especially vulnerable to increased erosion and migration as sea level rises. The beaches serve as important habitat for shorebirds such as the piping plover and numerous coastal species (U.S.FWS 2010).

5. The impacts of changes in climate change variables will affect the number and range of marine mammals and seabirds in the Ocean SAMP area. Some species may become less abundant, and viewing of those will decline. Warm water species that are currently rare may become more abundant.

340.2.5. Cruise Ship Tourism

1. Most cruise ship tourism to Newport is concentrated in the fall. Warmer fall temperatures would have a positive impact on the cruise ship industry.

2. Since cruise ship tourism is concentrated in the fall hurricane season, increased storm intensity could adversely affect cruise ship tourism (See also Section 340.1).

340.2.6. Marinas, Yacht Clubs, and Boat Ramps

1. Sea level rise, combined with storms, and heavier winter precipitation and runoff may place some marinas, yacht clubs and boat ramps at risk of inundation, erosion, and storm damage (See also section 340.1). Adaptation actions would require investments that will increase costs of operation.

340.3. Renewable Energy

1. Climate changes could affect the design, construction, delivery and installation, maintenance, and operation of wind turbines and related infrastructure. Sea level rise, severe storms, and storm surge could damage coastal construction facilities of wind turbine components and adversely affect the delivery of parts by ship. Installation of support structures, foundations, wind towers, and wind turbines at sea could be more costly and difficult if climate becomes more unpredictable, and more intense storms and waves reduce windows of opportunity for delivery by boat to the site and installation. Maintenance over the life of the turbines could also be more difficult and costly. More intense storms will fatigue turbines and platforms more rapidly. Given the relatively long life span of wind turbines (about 30 years), design standards of platforms and blades should take future climate projections into account.

2. Although statistically significant decreases in wind speed have been documented on land at T.F. Green (See Section 310.5), it is not known how wind speed will change onshore in Rhode Island. In addition, different dynamics exist offshore in the Ocean SAMP area than exist at T.F. Green on the coast of Narragansett Bay. However, the U.S. Department of Energy's National Renewable Energy Laboratory mapped the wind resources of Rhode Island at the 50 meters (164 feet), using data provided by AWS TrueWind (See Chapter 8 Renewable Energy and Other Offshore Development, Section 810.3, and Figure 3.12 in that section), which indicate that wind speed ranges from Excellent to Superb for offshore wind turbines in the Ocean SAMP area.

340.4. Historical and Cultural Assets

1. Climate change drivers could impact the preservation and maintenance of historical and cultural assets in a variety of ways. Potential impacts include sea level rise and storm surge, which could increase erosion of coastal assets, while more severe storms and ocean acidification could increase damage to submerged assets. Due to the lack of research on the impacts of climate change on these assets, these issues will be targeted for future research in the Ocean SAMP area and results will be reported in future versions of this document.

340.4.1. Submerged

1. Decreasing pH levels in seas may increase the rate of corrosion of submerged vessels and other historic and cultural assets on the seabed.

340.4.2. Terrestrial

1. Two important historic assets in the Ocean SAMP region are the Southeast Light and North Light lighthouses on Block Island. Both are highly vulnerable to the effects of sea level rise, storms, and sea surge.

2. In 1874, when Southeast Light was built, it was located approximately 300 feet (90 meters) inland from the edge of the Mohegan Bluffs. However, due to severe erosion of the adjacent bluffs, by 1993 the lighthouse was only approximately 55 feet (17 meters) from the edge of the bluffs. Between August 10 and 28, 1993, the lighthouse was moved inland 360 feet (110

meters) to a location that geotechnical studies determined will be safe for more than a century (Reynolds 1997).

3. The location of North Light, at Sandy Point, is also subject to extensive erosion and has been rebuilt four times. The original building was constructed in 1829 on sand and gravel and subject to rapid erosion that washed it out to sea after a only few years. In 1837, its replacement, built 0.25 miles (0.4 kilometers) inland from the first site, was also lost to the sea due to erosion. In 1857, a third lighthouse was built farther inland followed by piers constructed in 1865 to fortify the structure from falling due to erosion. Noting that the structure was still highly vulnerable to coastal inundation, in 1866, Congress appropriated funds to build the fourth structure. The current lighthouse was built in 1867 and although it is 700 feet (210 meters) from the tip of Sandy Point, it is only two feet above mean high water (Lighthouse Friends 2010).

340.5. Fisheries Resources and Uses

1. As Chapter 5 discusses, commercial and recreational fisheries are important uses of the Ocean SAMP area that add economic, historic, and cultural value to Rhode Island. Therefore, climate change impacts to marine fisheries in this area are of great importance.

2. As noted earlier, Rhode Island Sound and Block Island Sound ecosystems are located at the boundary of two bio-geographic provinces. Due to this, the impacts of climate change are of special concern because the fishery is based on a mix of cold- and warm-water species.

3. This section does not cover the impacts of climate change on marine transportation, navigation, and related infrastructure for the marine fishery. This is covered in Section 340.1.

340.5.1. General Impacts on Marine Fisheries

1. The main climate change drivers impacting fish populations are discussed in Chapter 2, Ecology of the SAMP Region, Section 250.2, and above in Section 330.1.3. In addition, climate change impacts on disease and invasive species are covered above in Sections 330.3.1 and 330.3.2, respectively. Changes in temperature, circulation, salinity, and food availability affect the spawning and distribution of fish and may cause changes in preferred fishing grounds for certain stocks (Murawski 1993).

2. As discussed in Chapter 5, fishers who target the Ocean SAMP area often use a variety of gear types and are accustomed to modifying gear to target different stocks (for example, during different seasons). Therefore, if the types of fish in the Ocean SAMP area change, fishers may be able to adapt their fishing practices accordingly.

3. An exception is the lobster fishery. Lobstermen typically fish almost exclusively for lobster. With a northern movement of the species with increased water temperatures (as discussed in Section 330.1.2), and increased incidence of shell disease (see Section 330.3.1), lobster fishing is likely to decline.

4. As species move and targeted fish stocks change, there could be significant impacts on fishers and fisheries in the Ocean SAMP area. Potential impacts include (1) increased time and cost to travel to fishing grounds, (2) possibly reduced catch per unit effort, (3) possibly reduced market value of more abundant southern species compared with less abundant northern species, and (4) costs of altering gear.

340.5.2. Fisheries Most Likely to be Impacted by Climate Change

1. Species that are at or near the southern extent of their range in the Ocean SAMP area are likely to move north, decreasing in abundance and/or extent of time in which they can be caught by fishers in the Ocean SAMP area (Hare et al. 2010; Perry et al. 2005). Commercially valuable species most likely to be impacted in this way include:

   - American lobster (*Homarus americanus*)
   - Atlantic cod (*Gadus morhua*)
   - Silver hake (*Merluccius bilinearis*)

2. Species that are at or near the northern extent of their range in the Ocean SAMP area are likely to move north, increasing in abundance and/or extent of time in which they can be caught within the Ocean SAMP waters (Hare et al. 2010). The species most likely affected in this way include:

   - Atlantic croaker (*Micropogonias undulates*) (Hare et al. 2007)
   - Black sea bass (*Centropristis striata*)
   - Butterfish (*Peprilus triacanthus*)
   - Scup (*Stenotomus chrysops*)
   - Summer flounder (*Paralichthys dentatus*)

3. Warming sea temperatures in the Ocean SAMP area are likely to bring more fish species that are primarily, but not solely, targeted by recreational fishers. With increasing populations of these species, some of them may become targeted by commercial fisheries more often. Popular recreational fisheries species that are likely to occur more often include:

   - Atlantic bonito (*Sarda sarda*)
   - Bluefish (*Pomatomus saltatrix*)
   - False albacore (*Euthynnus alletteratus*)
   - Striped bass (*Morone saxatilis*)
   - Yellowfin tuna (*Thunnus albacares*)

340.6. Future Uses

1. The same wide array of climate changes and impacts would fall on potential future uses of the Ocean SAMP area and would need to be considered. Some potential future uses are climate sensitive (e.g. offshore aquaculture, protected areas, and biofouling) and potential

impacts could be adverse and positive (See Chapter 9 for further discussion of future uses). Due to the time-sensitive nature of climate change drivers, these impacts would have to be considered when these uses are proposed in order to consider the effects as accurately as possible.

Section 350. Climate Change Policy

1. The Coastal Resources Management Council ("Council") developed and adopted on January 15, 2008, Section 145 Climate and Sea Level Rise Policy. This policy is part of the federally adopted Rhode Island Coastal Resource Management Program (RICRMP). This is the controlling provision for the upland areas within the Council's jurisdiction and the immediate shoreline areas and seaward to a distance of 500 feet offshore. Section 350 is intended to be the controlling policy for the ocean waters from beyond the 500 foot mark out to the three-mile limit. Below is Section 145. C. Policies from the currently adopted RICRMP.

   145. C Policies:

   a. The Council will review its policies, plans, and regulations to proactively plan for and adapt to climate change and sea level rise. The Council will integrate climate change and sea level rise scenarios into its operations to prepare Rhode Island for these new, evolving conditions and make the state's coastal areas more resilient.
   b. The Council's sea level rise policies are based upon the CRMC's legislative mandate to preserve, protect, and where possible, restore the coastal resources of the state through comprehensive and coordinated long-range planning.
   c. The Council recognizes that sea level rise is ongoing and its foremost concern is the accelerated rate of rise and the associated risks to Rhode Island coastal areas today and in the future. Accordingly, for planning and management purposes, it is the Council's policy to accommodate a base rate of expected 3 to 5 foot rise in sea level by 2100 in the siting, design, and implementation of public and private coastal activities and to insure proactive stewardship of coastal ecosystems under these changing conditions. It should be noted that the 3 to 5 foot rate of sea level rise assumption embedded in this policy is relatively narrow and low. The Council recognizes that the lower the sea level rise estimate used, the greater the risk that policies and efforts to adapt sea level rise and climate change will prove to be inadequate. Therefore, the policies of the Council may take into account different risk tolerances for differing types of public and private coastal activities. In addition, this long-term sea level change base rate will be revisited by the Council periodically to address new scientific evidence.

350.1. General Policies

1. The Council recognizes that the changes brought by climate change are likely to result in alteration of the marine ecology and human uses affecting the Ocean SAMP area. The Council, therefore, supports the policy of increasing offshore renewable energy production in Rhode Island as a means of mitigating the potential effects of global climate change.

2. The Council shall incorporate climate change planning and adaptation into policy and standards in all areas of its jurisdiction of the Ocean SAMP and its associated land-based infrastructure to proactively plan for and adapt to climate change impacts of increased storminess and temperature change, in addition to accelerated sea level rise. For example,

when evaluating Ocean SAMP area projects and uses, the Council will carefully consider how climate change could affect their future feasibility, safety, and effectiveness. When evaluating new or intensified uses within the Ocean SAMP area, the Council will consider predicted impacts of climate change especially on sensitive habitats, most notably spawning and nursery grounds, of particular importance to targeted species of finfish, shellfish, and crustaceans.

3. The Council will convene a panel of scientists biannually to advise on findings of current climate science for the region and the implications for Rhode Island's coastal and offshore regions, as well as the possible management ramifications. The horizon for evaluation and planning needs to include both the short term (10 years) and longer term (50 years). The Science Advisory Panel for Climate Change will provide the Council with expertise on the most current global climate change related science, monitoring, policy, and development design standards relevant to activities within its jurisdiction of the Ocean SAMP and its associated land-based infrastructure to proactively plan for and adapt to climate change impacts of increased storminess, temperature change, and acidification in addition to accelerated sea level rise.

4. The Council will prohibit those land-based and offshore development projects that based on a sea level rise scenario analysis will threaten public safety or not perform as designed resulting in significant environmental impacts. The U.S. Army Corps of Engineers (ACOE) has developed and is implementing design and construction standards that consider impacts from sea level rise. These standards and other scenario analysis should be applied to determine sea level rise impacts.

5. The Council endorses the application of enhanced building standards in the design phase of rebuilding coastal infrastructure associated with the Ocean SAMP area, including port facilities, docks, and bridges that ships must pass under.

6. The Council endorses the development of design standards for marine platforms that account for climate change projections on wind speed, storm intensity and frequency, and wave conditions, and will work with the Minerals Management Service, Department of Interior, Department of Energy, and the Army Corps of Engineers to develop a set of standards that can then be applied in Rhode Island projects. The Council will reassess coastal infrastructure and seaworthy marine structure building standards periodically not only for sea level rise, but also for other climate changes including more intense storms, increased wave action, and increased pH in the sea.

7. The Council supports public awareness and interpretation programs to increase public understanding of climate change and how it affects the ecology and uses of the Ocean SAMP area.

350.2. Regulatory Standards

1. Public infrastructure projects shall provide an analysis of historic and projected (medium and high) rates of sea level rise and shall at minimum assess the risks for each alternative on public safety and environmental impacts resulting from the project.

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