6. Future Trends

Several long-term trends that are largely outside the control of Northeast ocean planners will affect the region's marine resources and the production of value in the coming decades. Climate change effects will alter the physical and chemical properties of the region's marine waters, and change the ecology of the region's coastal and marine ecosystems (see US Global Change Research Program, National Climate Assessment 2014; NOAA's Climate.gov web pages, and NERACOOS Ocean and Weather Climate pages). Sea level rise associated with climate change will change the Region's coastline and have implications for coastal infrastructure such as commercial and residential waterfront development in coastal towns, port infrastructure, and national security facilities. And demographic changes will bring slow and uneven population growth to the Region's coastal communities, affecting the number of people who participate in the ocean economy.

6.1. Climate change

Global climate change is expected to affect marine resources in the Northeast in at least three major ways: sea levels will continue to rise, inundating coastal areas; ocean waters will continue to warm, and salinity levels will change, modifying the suitability of marine habitats and the geographic range of some marine species; and ocean waters will become more acidic in response to rising CO_2 levels in the atmosphere, potentially affecting the health of marine species that depend on calcification.

Data from the NOAA tide gauge in Boston Harbor describe a rise in sea level of about 2.79 millimeters (mm)/year (0.11 inches/year) since 1921. This translates to a 28 cm (0.92 foot) increase over a 100-year period. Similar increases have been measured at long-term tide stations in Woods Hole and Nantucket. The mean sea level trends from these long-term stations are listed in Table 10. Analysis by NOAA indicates that the recent trend in mean sea level rise is increasing, with the rate from 1921-2006 at 2.63 mm/year (0.10 in/year) and the rate from 1921-2013 at 2.80 mm/year (0.11 in/year).

Station	Mean sea level trend and 95% confidence interval (millimeter/year)	(inch/year)	Period	Century rate (feet/100 years)
Boston, MA	2.79 ± 0.17	0.11 ± 0.007	1921-2012	0.92
Woods Hole, MA	2.81 ± 0.19	0.11 ± 0.007	1932-2012	0.92
Nantucket, MA	3.52 ± 0.42	0.14 ± 0.017	1965-2012	1.15

Table 10 Sea level rise trends, Massachusetts stations.
Source: MCZM 2013

Sea level rise along the Northeast region's coast is expected to accelerate as climate change effects (polar melting and ocean thermal expansion) accumulate over the course of the next 100 years. Most models predict seal level rise in the Region between 2 and 7 feet over the course of the coming century (Figure 50). A rise of 4 feet is expected to threaten $32 billion of real property, and put 84,000 people at risk of extreme flooding in the Northeast (http://thinkprogress.org/climate/2014/04/24/3430234/sea-level-rise-new-england/). Private and public entities across the region and the nation are formulating plans to deal with these changes; see for example the climate change planning pages of the City of

Boston, and US Department of Transportation work on resilience in marine transportation systems.

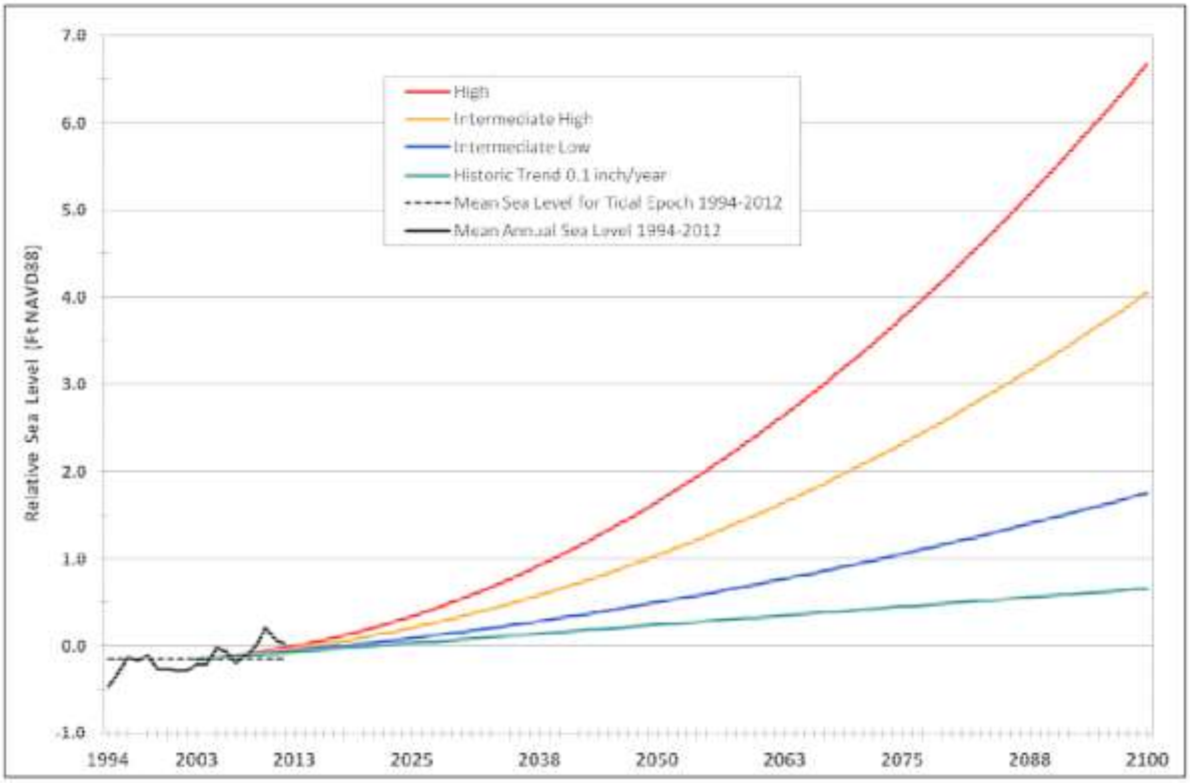

Figure 5. Relative sea level rise scenarios estimates (in feet NAVD88) for Boston, MA. Global scenarios from were adjusted to account for local vertical land movement with 2003 as the beginning year of analysis.

Figure 50 Sea level rise scenarios.
Source: MCZM 2013

Ocean water temperature has been rising more rapidly off the coast of the Northeast region than in most other parts of the global ocean. For example, sea surface temperature in the Gulf of Maine rose by 0.03 degrees Celsius (°C)/year from 1982 to 2004, roughly three times the global rate; and the warming has accelerated significantly since then (Figure 51) (Pershing *et al*. 2015). It is projected to continue to rise as a consequence of global climate change over the course of the next century, possibly by more than 2°C in Gulf of Maine bottom waters (Figure 52) (Hare *et al.* 2012).

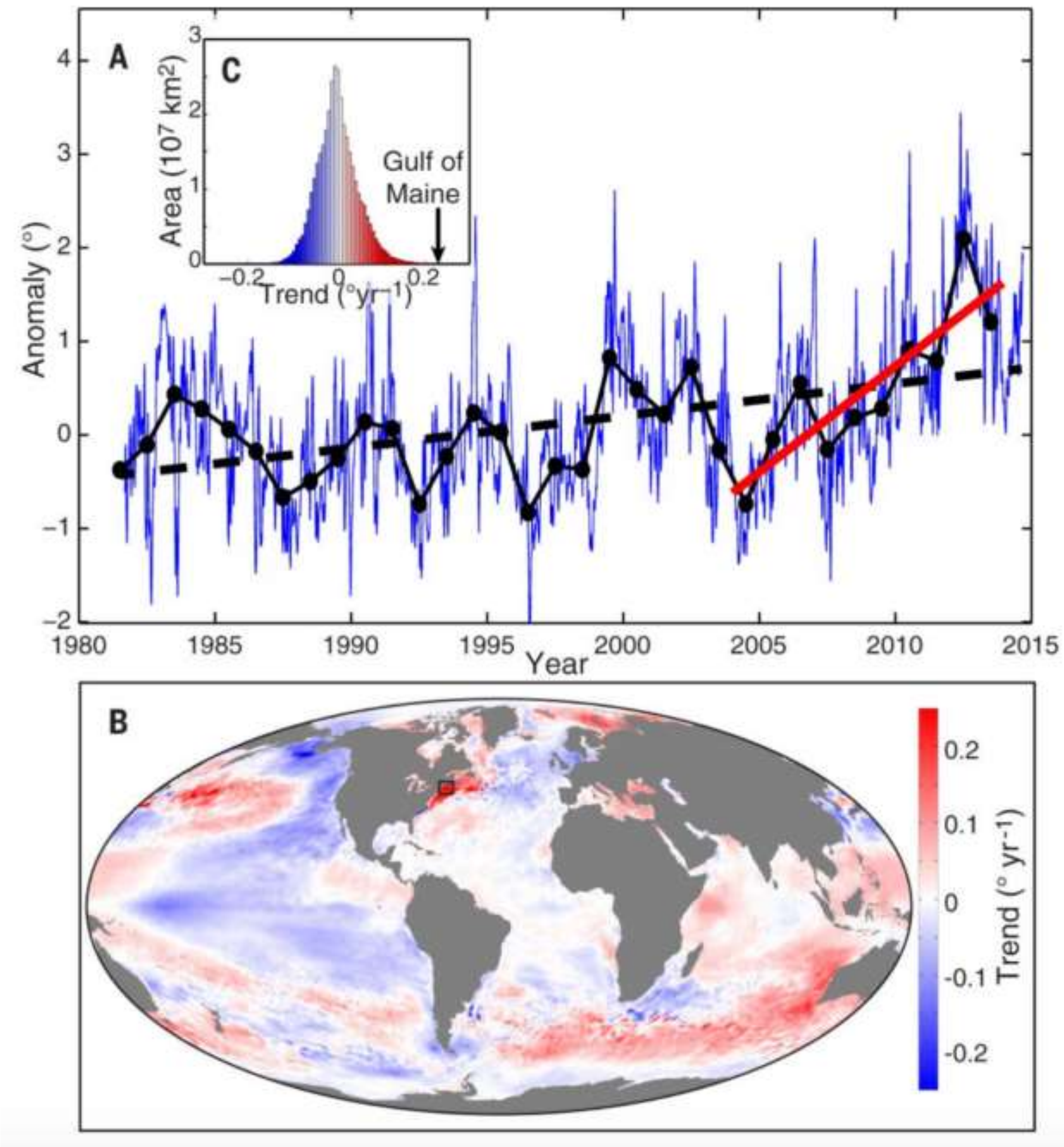

Figure 51 Sea surface temperature for the Gulf of Maine and global ocean.
Source: Pershing *et al.* 2015: (A) Daily (blue, 15 days smoothed) and annual (black dots) sea surface temperature (SST) anomalies from 1982-2013 with the long-term trend (black dashed line) and trend over the last decade (2004-2013). (B) Global SST trends (degrees C/year) over the period 2004-2013. The Gulf of Maine is outlined in black. (C) Histogram of global 2004-2013 SST trends with the trend from the Gulf of Maine indicated at the right extreme of the distribution.

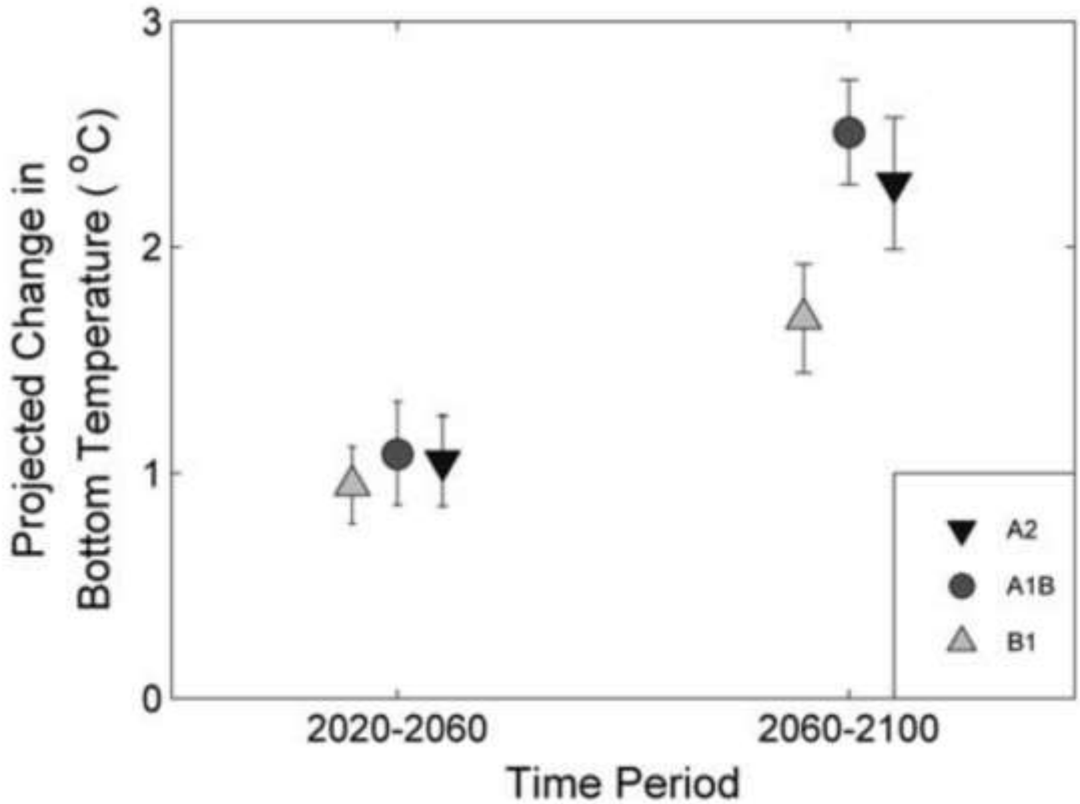

Figure 52 Projections for Gulf of Maine bottom water temperature.
Source: Hare *et al.* 2012: Based on an ensemble of eight Atmosphere-Ocean General Circulation Models for two time periods (2020-2060 and 2060-2100) and three emission scenarios (B1, A1B, and A2). Ensemble means and standard deviations are provided.

These temperature changes have already had measurable effects on marine species, and have been implicated, among other effects, in lobster population decline in southern New England (URI 2013) and failure of cod stock recruitment in the Gulf of Maine (Pershing *et al.* 2015). Further warming expected over the coming decades will likely affect additional biological populations and ecosystems in the Northeast, and lead to further changes in species ranges. For example, Hare *et al.* (2015) have modeled the change in suitable habitat in the Gulf of Maine for cusk under changing climate conditions.

As they become warmer, ocean and coastal waters of the Northeast are likely also to experience changes in salinity; this may exacerbate stresses on marine species (Mills and Pershing 2015). Salinity in the region's ocean waters is largely determined by ocean circulation patterns and precipitation. Strong flow from the Labrador Current brings cooler and relatively fresh water into the region, whereas stronger Gulf Stream flow provides warm, saline continental slope water. Melting and transport of Arctic sea ice caused a marked freshening of the region's waters during the 1990s after two large pulses of low-salinity water entered the region from the Arctic Ocean via the Labrador Sea (Smith *et al.* 2001, Häkkinen 2002, Greene *et al.* 2008, MERCINA 2012).

Precipitation affects salinity most strongly near the coast. For example, Balch *et al.* (2012) observed marked reductions in salinity in the coastal currents of the Gulf of Maine during extreme precipitation years since 2005. Across the Northeast, winter precipitation has been increasing at a rate of 0.15 inches per decade (Wake *et al.* 2006). More of this precipitation is falling as rain instead of snow (Frumhoff *et al.* 2006).

Arctic sea ice extent has been steadily declining since monitoring began in 1979; climate models predict that this trend will continue and that the Arctic Ocean will be nearly ice-free during the summer before mid-century (Wang and Overland 2009, Kirtman et al. 2013). As sea ice melts, increased freshwater from the Arctic will enhance the strength of the Labrador Current, and fresher water will move downstream towards the Northeast US Shelf. Most climate models also suggest that annual precipitation in the region will increase, particularly in the winters (Frumhoff et al. 2006), and that the combined effect of these two influences will result in surface waters in Gulf of Maine becoming fresher in the future, and those in Southern New England becoming saltier (ESRL 2015).

The acidity (pH) and carbonate chemistry (e.g. aragonite saturation state) of ocean and coastal waters influence the ability of calcifying organisms, including bivalve mollusks (oysters, clams, mussels, scallops) and crustaceans (lobster, crabs), to build and maintain their shells. The waters of the Gulf of Maine, in particular, are naturally acidic (low pH and aragonite saturation state) because of the region's strong freshwater inflow, geology, and water temperature (Figure 53). Rising CO_2 concentrations in the atmosphere are driving more CO_2 into ocean surface waters, lowering the pH and reducing aragonite saturation. This results in the acidification of ocean waters.

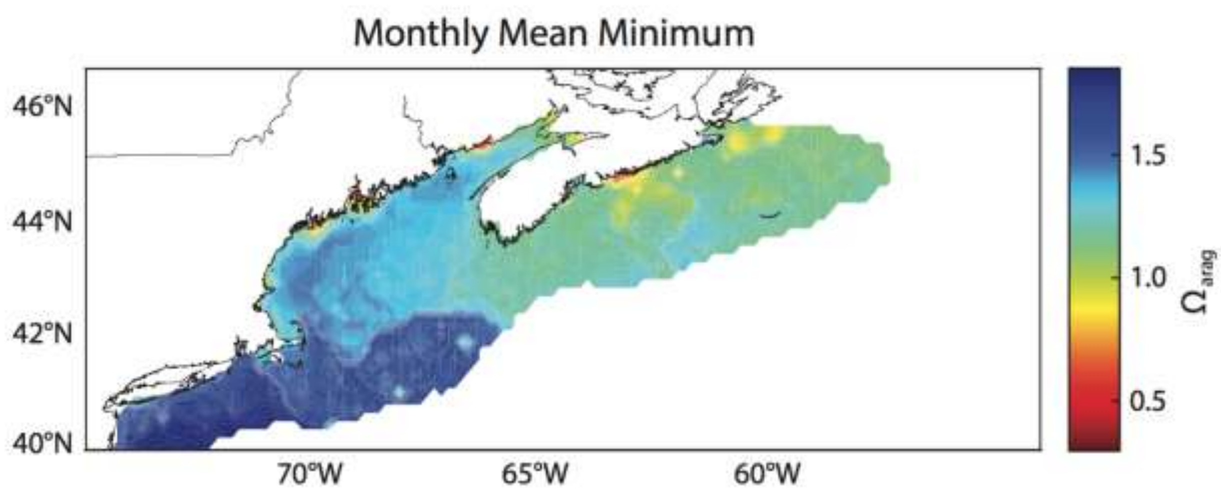

Figure 53 Mean minimum aragonite saturation conditions.
Source: Gledhill *et al.* 2015: Mapped distribution of minimum monthly averaged sea surface aragonite saturation state (Ω_{arag}). Long Island Sound is not mapped due to satellite land masking.

The acidification of ocean waters is expected to continue as atmospheric CO_2 concentrations rise in the coming century (Figure 54). Marine organisms respond to changing ocean chemistry in a variety of ways. Most marine calcifying organisms studied to date show decreased rates of calcification or even dissolution of shells, which is understood to result from decreased aragonite saturation. The increase in CO_2 or decrease in pH can also affect organisms' internal chemical balance, metabolic rate, immune response, organ development, and sense of smell. Gledhill et al. (2015) summarize the present knowledge about ocean acidification effects on marine organisms of commercial importance in the Northeast. Cooley *et al.* (2015) estimate that the Region's scallop industry may experience a 20% decrease in revenue by 2050 as a result of ocean acidification effects on the sea scallop population. Negative effects are likely to arise for other species, especially the early life stages of mollusks. While higher CO_2 has negative implications for many marine animals, it can be a positive change for organisms that rely on photosynthesis (marine plants and algae).

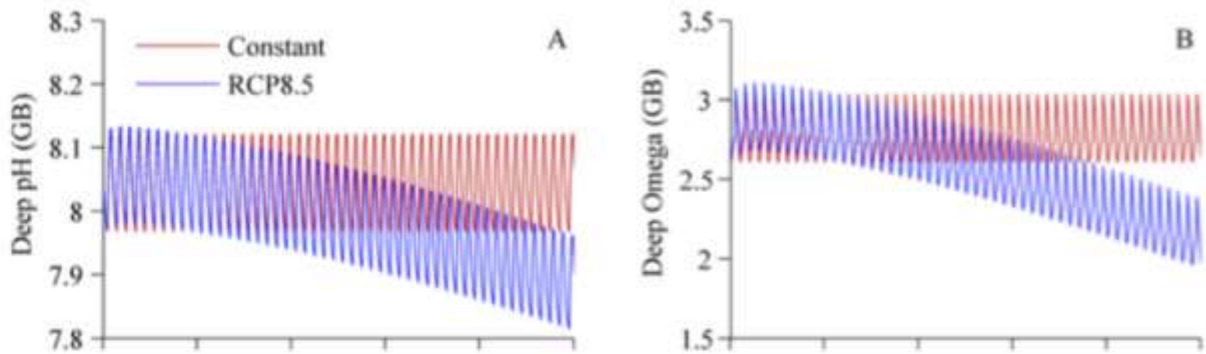

Figure 54 Ocean acidification projections for deep water in Georges Basin, 2000-2050.

Source: Cooley *et al.* 2015: Deep water pH and aragonite saturation (Omega) projections under constant climate (red) and a scenario in which carbon emissions continue to rise (RCP8.5 – the high emissions scenario from the Intergovernmental Panel on Climate Change's (IPCC) fifth Assessment Report, AR5 (2014).

Many near-shore coastal waters in the Northeast region are influenced by nutrient loading and significant freshwater inputs that can occasionally produce local conditions or "plumes" so low in pH as to be corrosive to calcium carbonate – that is, conditions where calcium carbonate shells begin to dissolve. Nutrient loading of coastal waters with nitrogen and phosphorous promotes marine plant growth; when these plants die and decompose, the intense respiration by bacteria and other organisms associated with plant decay can drive up local CO_2 concentrations, leading to what is known as coastal acidification. Coastal acidification generally exhibits higher frequency variability compared to open ocean acidification (Gledhill *et al.* 2015). The pH of water in coastal bays can vary by 1 to 2 pH units over the course of a day. The low pH events in nearshore waters are often accompanied by low dissolved oxygen conditions, exposing marine organisms to combined stresses from multiple sources.

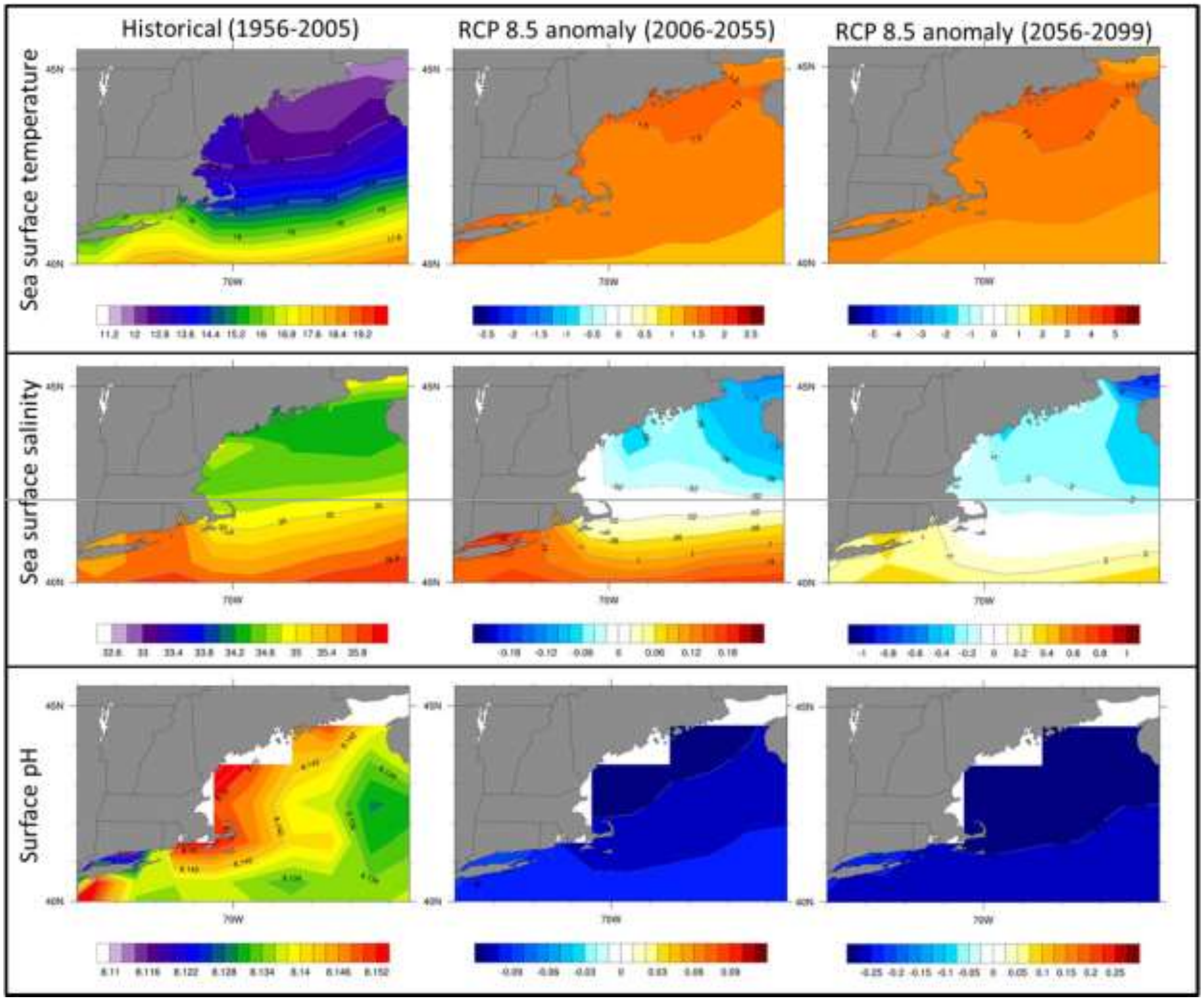

Figure 55 Sea surface temperature, salinity, and pH projections.
Source: ESRL (2015), using an average of all available models and the RCP8.5 climate scenario – the high emissions scenario from the Intergovernmental Panel on Climate Change's (IPCC) fifth Assessment Report, AR5 (2014).

Figure 55 illustrates historical observations (column 1) and future climate model predictions to 2055 (column 2) and 2099 (column 3) for sea surface temperature (row 1), sea surface salinity (row 2), and surface pH (row 3). These and other changes in physical and chemical conditions will affect physiological performance and habitat selection of organisms at different trophic levels in the ecosystem in complex ways. How this will affect a particular species generally depends on its physiological tolerance for environmental change, its life history strategies and needs, predator-prey relationships, and the influence of other stressors. Different species, and sometimes sub-populations within a species, may respond to environmental variability and climate change in different ways or at different rates; and responses are likely to vary based on not just one factor but the whole suite of ecosystem conditions the species encounters (Mills and Pershing 2015; Gledhill *et al.* 2015).

Since many commercially important shellfish species spend part or all of their life in these nearshore waters, coastal acidification, water temperature changes, and the response of marine organisms to changing coastal and ocean water conditions are important considerations for ocean planning to sustain the Northeast's seafood industries and healthy marine ecosystems.

6.2. Demographics

As described in section 3.4 above and Table 11 below, recent population growth in the Northeast region has varied significantly across states and towns, and generally been modest compared to the United States as a whole. The Region's population grew by 3.8% from 2000 to 2010, less than half of the growth for the nation as a whole.

	1970	1980	growth 1970-1980	1990	growth 1980-1990	2000	growth 1990-2000	2010	growth 2000-2010
Maine	992,048	1,124,660	*13.4%*	1,227,928	9.2%	1,274,923	3.8%	1,328,361	4.2%
New Hampshire	737,681	920,610	*24.8%*	1,109,252	20.5%	1,235,786	11.4%	1,316,470	6.5%
Massachusetts	5,689,170	5,737,037	*0.8%*	6,016,425	4.9%	6,349,097	5.5%	6,547,629	3.1%
Rhode Island	946,725	947,154	*0.0%*	1,003,464	5.9%	1,048,319	4.5%	1,052,567	0.4%
Connecticut	3,031,709	3,107,576	*2.5%*	3,287,116	5.8%	3,405,565	3.6%	3,574,097	4.9%
Vermont	444,330	511,456	*15.1%*	562,758	10.0%	608,827	8.2%	625,741	2.8%
New England	10,849,615	11,223,833	*3.4%*	11,979,015	6.7%	12,647,594	5.6%	13,116,504	3.7%
United States	203,211,926	226,545,805	*11.5%*	248,709,873	9.8%	281,421,906	13.2%	308,745,538	9.7%
New England as % of USA	5.3%	5.0%		4.8%		4.5%		4.2%	

Table 11 Population growth trends by state.
Source: NE Journal of Higher Education, 3 May 2012.
http://www.nebhe.org/thejournal/trends-indicators-demography/

Going forward, the Region's population is expected to grow slightly faster in the current decade (to 2020), and then slow its growth again to 2030 and 2040 (Table 12). The Region is expected to add about 1.5 million people by 2040. Like past growth, projected future growth is unevenly distributed: New Hampshire is expected to continue to grow more rapidly than other Northeast states (and faster than the nation as a whole); the other states are likely to grow more slowly than the national average, generally less than 5% per decade. All growth is expected to slow in the coming decades, both in the Region and in the nation as a whole.

population (millions)	2010	2020	2030	2040
Maine	1.33	1.39	1.45	1.50
New Hampshire	1.32	1.45	1.57	1.67
Vermont	0.63	0.66	0.70	0.72
Massachusetts	6.55	6.81	7.04	7.19
Rhode Island	1.05	1.09	1.11	1.13
Connecticut	3.57	3.72	3.86	3.95
NE Region	14.44	15.12	15.73	16.17
United States	308.8	335.6	361.0	382.2

growth, by decade	2010	2020	2030	2040
Maine	4.2%	4.8%	4.3%	3.0%
New Hampshire	6.5%	9.6%	8.5%	6.7%
Vermont	2.8%	5.2%	5.2%	3.8%
Massachusetts	3.1%	3.9%	3.4%	2.2%
Rhode Island	0.4%	3.4%	2.7%	1.5%
Connecticut	4.9%	4.3%	3.6%	2.4%
NE Region	3.8%	4.7%	4.0%	2.8%
United States	9.7%	8.7%	7.6%	5.9%

Table 12 Demographic projections by state.
Source: U. Virginia, Weldon Cooper Center for Public Service, *National Population Projections.*

The proportion of the population 65 and older is projected to peak in 2030, then plateau or decline slightly in most US states; but in several Northeast states, the older population will become and remain a significant proportion of state residents. Nationally, 18.4 percent of individuals are projected to be 65 or older by 2030; the proportion is expected to be higher in Maine (27 percent), Vermont (25 percent), and New Hampshire (24 percent).

Another consistent trend in the Northeast since 1990, and expected to continue in the coming decade, is the growing significance of traditional ethnic "minority" groups within the region's overall population. As Table 13 shows, this trend has been particularly pronounced in Connecticut, Massachusetts, and Rhode Island. By 2020, it is likely that nearly half of the population aged 25-29 will be minorities in these states (Coelen and Berger 2006).

	1990	2000	2010	2020
Connecticut	17.0	19.9	24.1	27.7
Maine	2.2	2.6	3.2	4.0
Massachusetts	12.5	15.2	19.1	27.7
New Hampshire	2.9	4.0	5.9	7.9
Rhode Island	10.8	14.2	19.8	25.1
Vermont	2.0	2.8	4.5	7.5

Table 13 Trends in minority population (% of total) by state
Source: Coelen and Berger (2006).

These population projections have implications for the recreation and tourism segments of the Northeast region's marine economy. Demand for recreation and visitor numbers are likely to rise roughly in proportion with the regional and national population; and larger numbers of residents in their retirement years may further increase visitor numbers. The implications for marine resource use of growing ethnic minorities in the Northeast are less clear.