CLIMATE CHANGE AND ITS EFFECTS ON ECOSYSTEMS, HABITATS AND BIOTA

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2010

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Gulf of Maine Council on the Marine Environment

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The Gulf of Maine Council on the Marine Environment was established in 1989 by the Governments of Nova Scotia, New Brunswick, Maine, New Hampshire and Massachusetts to foster cooperative actions within the Gulf watershed. Its mission is to maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations.

Cover photo: Northern right whales (NOAA)

Cover map (background) courtesy of Census of Marine Life/Gulf of Maine Area Program

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1. Issue in Brief

The Earth's climate is changing as a result of increasing anthropogenic emissions of greenhouse gases (GHGs; IPCC 2007a,b). Globally, the atmosphere and the oceans are warming. Atmospheric warming and melting of sea ice are altering the physical oceanography of the Gulf of Maine, while higher levels of atmospheric carbon dioxide (CO_2) may alter ocean chemistry, all of which will have effects on the ecosystem. Pressures on the aquatic environment as a result of atmospheric warming include increases in water temperature, decreases in salinity and changes in hydrography (Figure 1). Sea level rise is also an important pressure on coastal habitats and ecosystems. These pressures interact with each other and with additional pressures that are unrelated to climate change. These physical pressures may have negative impacts on some species within the Gulf of Maine, but may enhance the productivity of other species. Because the responses to these pressures will vary by species, the overall ecosystem will likely look profoundly different in the future as compared to the current ecosystem structure and species assemblage of the Gulf of Maine. Our ability to adapt to these changes will depend largely on measures taken to mitigate the ecosystem effects of climate change.

LINKAGES

This theme paper also links to the following theme papers:

- Climate Change and Its Effects on Humans
- Land Use and Coastal Development
- Watershed Status
- Coastal Ecosystems and Habitats

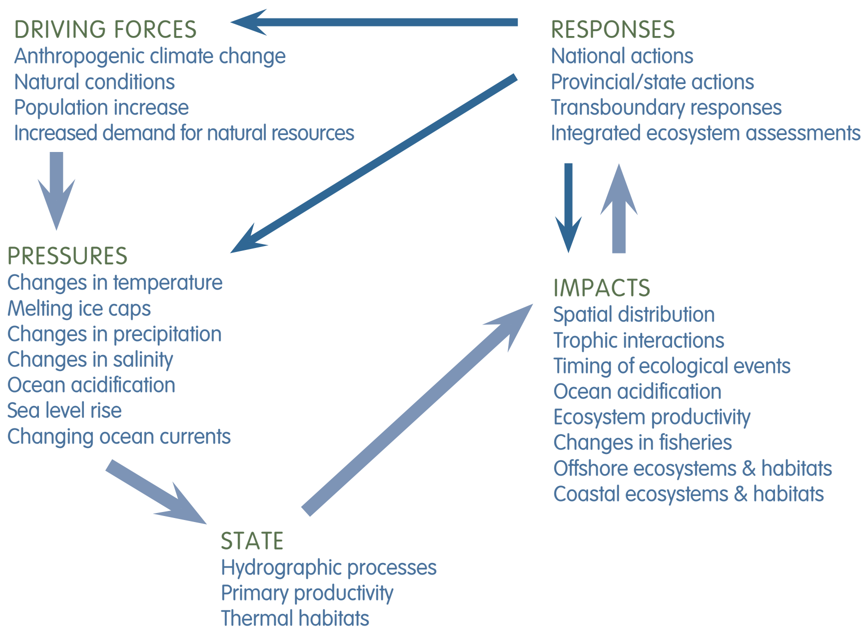


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to climate change and its effects on ecosystems in the Gulf of Maine. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

2. Driving Forces and Pressures

2.1 Anthropogenic Climate Change

Evidence indicates that the Earth is currently going through an unprecedented, and accelerated, period of global warming (IPCC 2007a). Global climate scenarios examined by the Intergovernmental Panel on Climate Change (IPCC) forecast global mean temperature increases of 1.1°C to 6.4°C by 2100 (IPCC 2007a). Increases in anthropogenic emissions of gases (e.g., carbon dioxide, methane) into the atmosphere, and a resultant enhanced greenhouse effect, have been shown to be the major driving force behind the observed trend of accelerated global warming that has taken place over the last century (IPCC 2007a,b; see theme paper on *Climate Change and its Effects on Humans*).

2.2 Population and Economic Growth

Although natural release of greenhouse gases occurs, anthropogenic releases are considered to be the main drivers of climate change. These in turn are influenced by increases in human population, coastal development and economic activity. The link between climate change and economic development is well established (Sanderson and Islam 2007; IPCC 2007a). While population growth puts demands on natural resources and leads to development of natural areas, economic development also contributes to the increase in greenhouse gases. Population changes and economic activities in and around the Gulf of Maine have been described in *The Gulf of Maine in Context*. Expendable income is an indicator of economic development in an area. The increase in income for the Gulf of Maine watershed is around the national averages of the US and Canada where the median household income has increased by about 31% and mean disposable income has increased by about 43% since 1972. Disposable income is expected to continue to increase over the next ten years by about 5% per year (http://www.bls.gov/emp/ep_table_404.htm). The average income in the Northeast is increasing steadily and is above the national average in Massachusetts and New Hampshire.

2.3 Natural Conditions

The physical oceanography of the Gulf of Maine is described in detail in *The Gulf of Maine in Context*. The Gulf of Maine hydrography is strongly influenced by the Labrador Current. The Labrador Current flows southward along the continental slope past Labrador and Newfoundland where its low salinity, nutrient-poor waters meet the relatively saline and nutrient-rich waters of the Gulf Stream (Figure 2). Much of the ecology on a broad scale is dependent on the interplay of the Labrador Current and the northern wall of the Gulf Stream. Waters moving into the continental shelf area derived from the Labrador Current and Gulf Stream are termed Labrador slope water (LSW) and warm slope water (WSW) respectively. When the waters from the Labrador Current are strong, Gulf of Maine water temperatures decrease and WSW is displaced southward. Water that originates from the cold Labrador Current enters the Gulf of Maine and circulates in a counter-clockwise direction. When the Labrador Current is weak, more warm water from the Gulf Stream enters the Gulf of Maine.

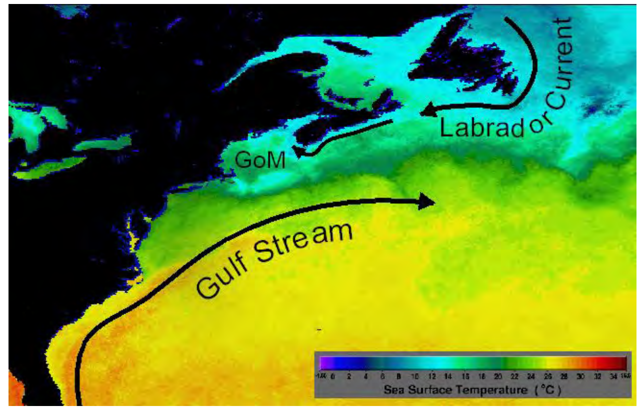


Figure 2: Satellite imagery of sea surface temperature and the location of the Gulf Stream, Labrador Current, and Gulf of Maine (GoM).

Source: SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE, http://oceancolor.gsfc.noaa.gov

Increasing temperatures due to anthropogenic climate change may be exacerbated by natural climate cycles in the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO). The AMO is a natural cycle in North Atlantic sea surface temperature that fluctuates from warm positive phases and cold negative phases every few decades. Currently we are in a positive AMO phase, perhaps exacerbating the warming trend. However, as we enter a negative AMO phase in the next decade, it may offset some of the effects of global warming. The NAO fluctuates on a shorter time scale than the AMO, but in recent years has also been consistently in a positive phase that is synergistic with climate warming trends. Scientists are still studying how natural cycles like the NAO and AMO interact with anthropogenic climate change and how these natural phenomena and hydrography might change with increasing greenhouse gas emissions.

2.4 Sea Temperature

Since the peak of the last ice age, about 20,000 years ago, the global mean air temperature has risen 4°C to 7°C, leading to an increase in sea surface temperatures (SST) in most of the world's oceans (IPCC 2007b). The rate of increase of coastal sea surface temperatures in the Gulf of Maine is similar to the rise in global mean SST of about 0.7°C over the last century (Trenberth et al. 2007; Shearman 2010). However, the rate of increase has accelerated in recent years and regional studies indicate that sea surface temperatures in this region have increased by about 0.23°C from 1982 to 2006 (Belkin 2009). While there is variability in temperatures from year to year, coastal temperatures have increased steadily over the last 40 years, but are not necessarily higher than they were in the 1950s (Figure 3). Climate scenarios examined by the Intergovernmental Panel on Climate Change (IPCC 2007b) project a global mean temperature increase of 1.1°C to 6.4°C by 2100. Global climate models predict an increase in temperature in the Gulf of Maine and surrounding regions by 2°C to 4°C by 2080 (Fogarty et al. 2007a).

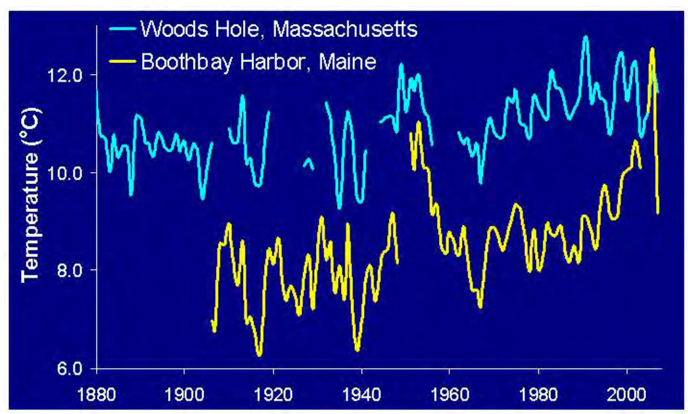


Figure 3: Coastal water temperature taken from two harbors within the Gulf of Maine region.

2.5 Salinity

Recent work documents a decrease in salinity or "freshening" of Scotian Shelf and Gulf of Maine waters (Greene et al. 2008). One of the main reasons for this is the melting of Arctic sea ice. This melting will increase the global input of freshwater resulting in changes in salinity and circulation in the ocean system. Sea ice extent (the area of the ocean covered by at least 15% sea ice) shows a clear decrease since 1979 (Figure 4). Arctic sea ice volume has also decreased and global climate models predict that this trend will continue such that sea ice volume will be half what it is today (US National Snow and Data Center April 14, 2010). As sea ice melts, a large pulse of freshwater increases the strength of the southward flowing Labrador Current and reduces sea surface salinity.

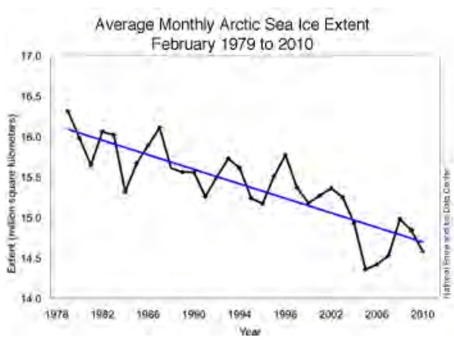


Figure 4: Decrease in average monthly Arctic sea ice extent 1979–2010.
Source: US National Snow and Ice Data Center

Another influence on the decrease in salinity in the Gulf of Maine is increased precipitation. Many climate models predict that there will be an increase in all forms of precipitation for the Gulf of Maine area (Wake et al. 2006), increasing river flow and terrestrial runoff into the Gulf. This input of freshwater will be especially large in the spring when there is typically high river flow as pack ice melts within the watershed (see Wake et al. 2006). These inputs of fresh surface water make vertical mixing of the water column more difficult, hindering bottom water to be mixed into the surface layers of the Gulf of Maine. This stratification prevents nutrients from being brought into the surface layer that phytoplankton need to grow. Reductions in available nutrients will affect phytoplankton productivity, the base of the food web and these effects will cascade up to larger organisms like fish and marine mammals.

2.6 Ocean Acidification

Until recently, it was assumed that the ocean's ability to absorb CO_2 would buffer the effects of climate change and that the chemistry of the ocean would not change even at very high levels of CO_2. The ocean has absorbed approximately 50% of the CO_2 emitted since pre-industrial times, but at the levels that CO_2 are expected to reach in the future, the buffering properties of the ocean will likely be surpassed, pH will decrease and oceanic waters will become more acidic. There are very few time series of pH globally and none for the Gulf of Maine region; however, Brewer (1997) estimates that surface ocean pH has decreased by 0.1 units since the 1980s and is predicted to decline by another 0.3-0.4 units by the end of the century.

2.7 Sea Level Rise and Storm Events

During the 20th century, the global mean sea level rose 17±5 cm (as opposed to about 6 cm in the 19th century) (IPCC 2007b; UNEP 2009). Projections for the

21st century by IPCC (2007b), excluding future rapid dynamical changes in ice flow, range from 18 cm to 59 cm by 2100. More recent projections (Rhamstorf 2007) estimate that a global mean sea level rise of up to 120 cm by 2100 could occur for strong warming scenarios. Relative sea level rise in the Gulf of Maine is due to the combined effect of an increased global mean sea level, and the additional effect of regional subsidence of the Earth's crust. The subsidence is a manifestation of the crust's long-term response to the end of the last ice age, referred to as 'glacial isostatic adjustment' (Leys 2009). In the Gulf of Maine, subsidence rates are not uniform and are estimated to be from 0 cm to 20 cm/century (Peltier 2004).

The effects of sea level rise are exacerbated by storm surge from storm events. The storm surge is the height difference between the water level due to astronomical tides and the total water level at the peak of the storm. It is due to storm winds piling water onshore, low atmospheric pressure, wave setup, possible resonant effects within a bay and the coastal response to all these factors (Parkes et al. 1997). A rise in sea level would allow storm surges to reach further inland. Climate change could cause an increase in the intensity of storms in the northern hemisphere, as well as a possible northward shift of storm tracks (McCabe et al. 2001; Wang et al. 2006).

3. Status and Trends

3.1 State of Hydrographic Processes

The thermal habitats and nutrient regime of the Gulf of Maine are largely determined by ocean currents in the Gulf. The relative strength of the Labrador slope water (Labrador Current) and warm slope water (Gulf Stream) changes from year to year, influencing the ecology and population dynamics of species within the Gulf of Maine. However, in the last 20 years the position of the Gulf Stream has been consistently further north (Figure 5), although currently, the Labrador Current is relatively strong due to greater sea ice melt. Long range forecasts in the Gulf of Maine predict that water temperatures will increase in the Gulf of Maine, but how the hydrography will change is unknown. The interplay of the Gulf Stream and Labrador slope water is the paradigm within which we currently understand the broadscale ecology of the Gulf of Maine marine ecosystem. With climate change the very processes scientists have studied in order to understand ecosystem dynamics may operate completely differently leading to great uncertainty in how the ecology of the Gulf of Maine will change at a longer time scale.

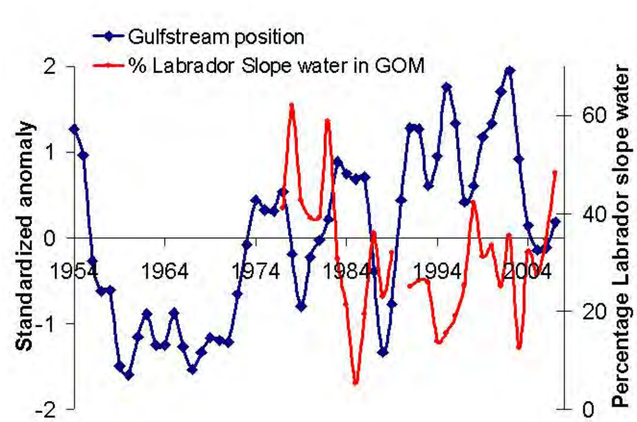


Figure 5: Relationship between the Gulf Stream position and Labrador slope water in the Gulf of Maine 1954–2004.

Source: Joyce et al. 2009; EAP 2009

3.2 Thermal Habitats

Thermal habitat is defined as the amount of water within a given temperature range. For cold-blooded species found in coastal and marine waters, temperature is one of the most important factors controlling growth, development, and survival and is a major factor in determining where these organisms are, how and when they make seasonal migrations, and ultimately the rate of population growth. Most species in the Gulf of Maine prefer temperatures in the 5-15°C range. Along the Northeast shelf of the US, including the Gulf of Maine, thermal habitat between 5-15°C has decreased over the last twenty years, but the coldest and warmest habitats have been increasing (Figure 6). Thus, there is a habitat "squeeze" for most of the species in the Northwest Atlantic.

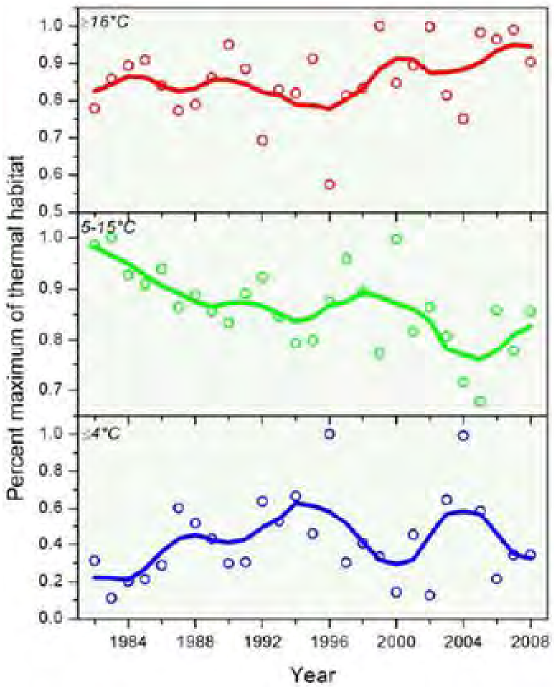


Figure 6: Change in thermal habitat along the US Northeast coast over time.
Source: www.nefsc.noaa.gov/omes/OMES

3.3 Primary Productivity

Phytoplankton form the basis of the Gulf of Maine food web, and any effects of climate change on primary productivity will have effects on all aspects of the food web. The effect of climate change on primary productivity will depend on how temperature, salinity, and hydrography changes in each region. Limited analysis in the Northeast region suggests that there has been an increase in primary productivity in the region from 1958–2002, but there has been a shift in phytoplankton species from large diatoms to small dinoflagellates (Leterme et al. 2005). There may also have been a change in the timing of the occurrence of different phytoplankton species. Diatoms have increased in January and March, but dinoflagellates have increased in spring. Recent analysis has shown that the nutrient regime in the Gulf of Maine has changed since the 1970s. Deep water in the Gulf of Maine has become fresher, cooler, and has lower nitrate and higher silicate concentrations (Townsend et al. 2010). These changes are caused by accelerated rate of melting of the Arctic ice sheet and a freshening of the Labrador Current that enters the Gulf of Maine. How this change will alter the phytoplankton community is uncertain, but in general higher silicate favors diatom production. Diatoms are thought to increase overall ecosystem productivity because of their relatively large size in comparison to small dinoflagellates.

4. Impacts

4.1 Shifts in Spatial Distribution

Organisms can respond in several ways to the changes in temperature, salinity and hydrography, but a shift in spatial distribution is the hypothesized first response (Walther et al. 2002; Parmesan and Yohe 2003). If waters warm or habitat becomes unfavourable, mobile marine organisms may move to more favourable habitat. Shifts in spatial distribution in fish have been detected in the Northwest Atlantic on both short and longer-term temporal scales (Rose et al. 2000). Over the last forty-years about half of the fish stocks studied, have shifted their center of biomass northward and/or are now found at deeper depths (Nye et al. 2009). However, the temperature at which these species have been found over those same forty years has not changed. This suggests that fish are remaining within their preferred temperature range by shifting to higher latitudes and to depths where water temperature is cooler and more stable. Species in the Gulf of Maine exhibit poleward shifts in distribution, but because north-south movements are somewhat limited by the shape of the Gulf coastline many species have also shifted to deeper depths to compensate for warming water temperatures. Of 36 fish stocks examined, over half are shifting to greater depth or moving northward (Nye et al. 2009). Figure 7 shows an example of one species, red hake, shifting northward in the Gulf of Maine.

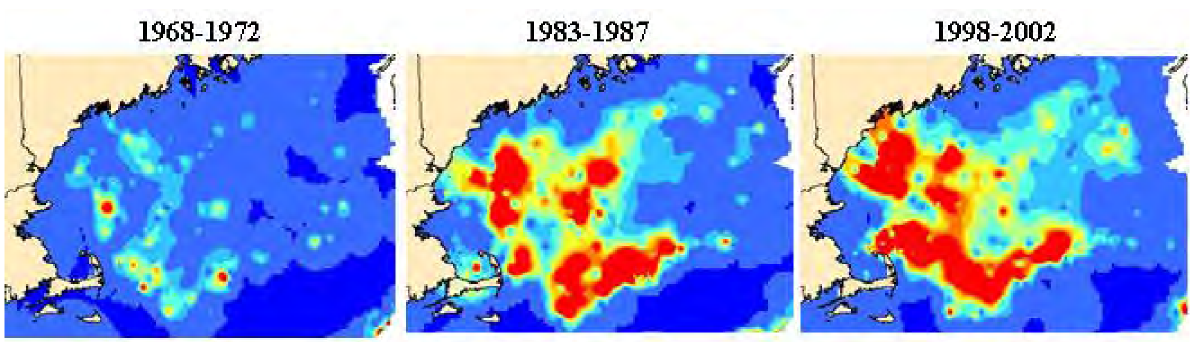


Figure 7: Northward shift in spatial distribution and increase in biomass of red hake in the Gulf of Maine. Warm colors (orange and red) indicate higher biomass while cooler colors (blues) indicate low biomass.

Modified from Nye et al. 2009

Distributions of microscopic planktonic organisms may shift because they are at the mercy of ocean currents. Due to melting of sea ice in the Arctic, flow of Pacific waters into the Arctic Ocean becomes unobstructed and vice versa. With an invasion of Pacific water, some species of phytoplankton have become more common in the Arctic and North Atlantic. For instance, *Neodenticula seminae* is primarily located in the Pacific Ocean, but in 1999 this Pacific organism was found in the Labrador Sea for the first time in 800,000 years (Figure 8; Reid et al. 2007). Now this species is a common and abundant member of the phytoplankton community in the North Atlantic and has extended its range southward. While this species has not reached the Gulf of Maine, southward expansion of cold-water species is expected because of increased flow of the Labrador Current and a lack of obstruction by sea ice. In the Northwest Atlantic boreal plankton have shifted farther south (Johns et al. 2001; Reid and Beaugrand 2002; Reid et al. 2007), but in the Northeast Atlantic subtropical and temperature plankton are shifting further north by as much as 1000 km (Beaugrand et al. 2002). Because the Gulf of Maine is at the edge of boreal and temperate ecosystems, there could be both northward shifts of temperate species and southward shifts of Arctic.

Figure 8: A Pacific Ocean phytoplankton species, *Neodenticula seminae,* now found thriving in North Atlantic waters.

4.2 Changes in Community Assemblages

Changes in salinity have changed phytoplankton and zooplankton assemblages in the Gulf of Maine region in the 1990s. Phytoplankton production increased and was followed by an increase in the number of small zooplankton (Kane and Prezioso 2008; Greene and Pershing 2007). *Calanus finmarchicus* is a relatively large phytoplankton and because it has large stores of energy-rich lipids it is a major food item of many fish species and the primary food source of the endangered right whale. The biomass of small *Calanus finmarchicus* increased in recent years, but larger *Calanus finmarchicus* did not. In general, the zooplankton assemblage has changed from large zooplankton to smaller zooplankton (Kane and Prezioso 2008; Ecosystem Assessment Program 2009). A shift to a smaller zooplankton community structure may have important consequences to animals at higher trophic levels. These animals must now consume greater numbers of phytoplankton and perhaps forage for longer periods of time to meet their energetic demands. Furthermore, the arrival of right whales and their reproductive success is dependent on the abundance and distribution of *Calanus finmarchicus* in the Gulf of Maine (Pershing et al. 2009). Changes in the magnitude and timing of the peak abundance of this species may alter whale migration, behavior, and population abundance.

The fish and invertebrate assemblage has changed along the Northeast US coast such that the Gulf of Maine looks more similar to what southern ecoregions looked like in the past. In the Gulf of Maine and along the Northeast US coast, there has been a shift in dominance by more "cold-water" species to more "warm-water" species. Warm-water species are more abundant and/or have shifted their distribution northward into northern ecosystems, including the Gulf of Maine

(Ecosystem Assessment Program 2009; Lucey and Nye in review). An indicator of this shift from warm-water to cold-water species is the community preferred temperature. Higher values indicate higher abundances of warm water species relative to cold-water species (Figure 9).

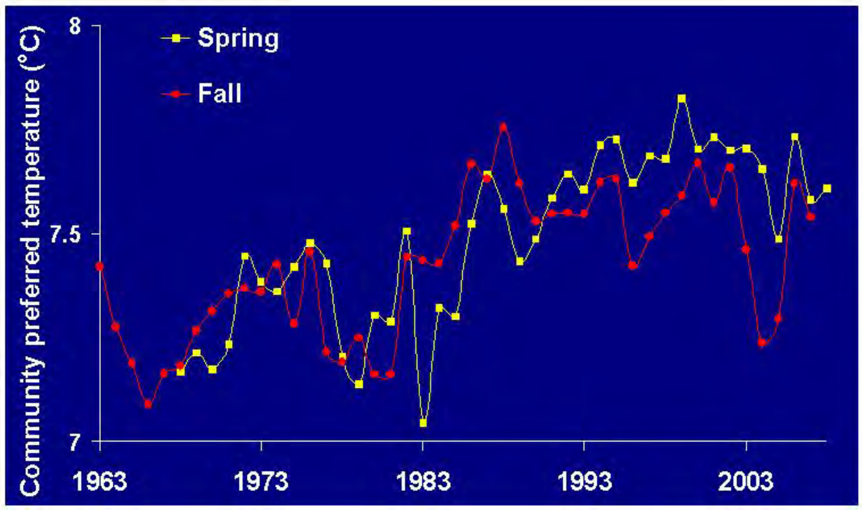


Figure 9: Preferred temperature of the fish community in the Gulf of Maine calculated using NMFS multispecies bottom trawl surveys that occur in the spring and fall. Higher values indicate a higher abundance of warm-water species in relation to cold-water species as well as a shift of warm-water species into the Gulf of Maine.
Modified from Ecosystem Assessment Program Report 2009

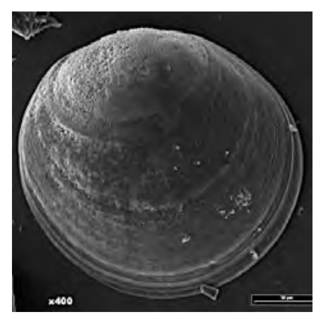
4.3 Changes in Timing of Ecosystems Events

As water temperatures warm at a large spatial and temporal scale, the timing of ecological events or phenology may change. Specifically, spring may arrive earlier and fall may arrive later. Many organisms time their migrations and spawning to changes in temperature and photoperiod. As temperature, salinity, and hydrography changes, organisms will likely shift the timing of the spawning and migration. There is concern that species may shift these events so that they are out of phase with other elements of the ecosystem such as the prey upon which they rely. If species change the timing of spawning and migrations in unison then the effects on the ecosystem will be minor. However, if species do not change in unison, reproductive success for many organisms may be dramatically reduced. Even subtle changes will lead to changes in the structure and function of the Gulf of Maine ecosystem. For instance, if the hatching of fish species happens significantly before or after its dominant prey increases in abundance, the predator populations may rapidly decline. Additionally, the rate at which temperature increases in the fall and spring may be much different than what organisms are adapted to. Globally, studies of changes in phenology have shown that the bloom times of many plants and the arrival of migratory species has occurred earlier in recent time periods (Parmesan and Yohe 2003). Locally, studies have detected changes in the arrival of some bird species in Maine (Wilson Jr. 2007, 2009) and that Northeast US apples and grapes bloom earlier on average in the time period from 1965-2001 (Wolfe et al. 2004). In the northern shrimp, egg development and hatching times are tightly correlated with local bottom water temperatures such that young shrimp hatch at times when food is available (Koeller et al. 2009). While there appears to be a match between bottom temperature, hatching times, and food availability that enhances the survival of young shrimp, surface water temperatures are increasing more rapidly than bottom water temperatures. If this trend continues, there may be a mismatch between hatching time of shrimp (dependent on bottom temperature) and their prey (dependent on sea surface temperature), creating a mismatch that would lead to poor shrimp recruitment. This would have negative effects for the predators that rely on shrimp for food and to commercial fishing of this species.

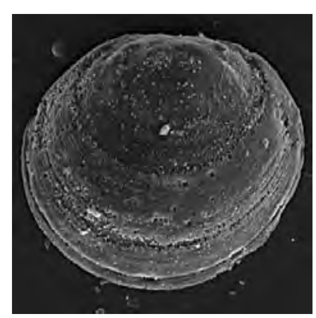
4.4 Ocean Acidification

Few time series exist to document the change in ocean pH over time and much controversy surrounds those time series of pH measurements that do exist. There are several possible responses of organisms to ocean acidification, but the most direct threat would be that marine "calcifiers" or "animals with shells" may not be able to make the hard calcified shells to protect them from predators. Secondly, a change in pH may have metabolic costs such that growth decreases. A decrease in growth of marine calcifiers like American lobster, ocean quahog, and scallops mean less shell meat to sell and to eat. Several recent studies have started to elucidate the ways in which ocean acidification may affect organisms and ecosystems. An analysis of eighteen marine calcifiers showed that the response to acidic waters is different for each species (Ries et al. 2009). In fact, some species like the blue crab and American lobster may respond favourably to acidification. However, most organisms responded unfavourably with increasing acidity, particularly bivalve species that constitute important commercial fisheries such as American oyster, soft shell clams, and ocean quahog. Studies have documented a decrease in calcification (or a softening) of shells, decreases in growth, and increases in mortality in marine species (Green et al. 2009; Findlay et al. 2010). The pictures at right (Figure 10) show the dissolution of the shells of juvenile hard clams (*Merceneria mercenaria*) after 7 days in sediments just slightly more acidic than their typical environment today (Green et al. 2009).

Day 0



Day 4



Day 7

Figure 10: Dissolution of hard clam shells (*Merceneria merceneria*) after 7 days in water just slightly more acidic than "average" sediment pH. Note jagged surfaces and pitting in the shell at Day 4 and 7 as compared to Day 0. Modified from Green et al. 2009

4.5 Impacts on Coastal Ecosystems

Increases in temperature, change in salinity regime, and increased precipitation and storm events also affect coastal areas. Many coastal organisms are already exposed to a wide range of temperatures and salinity because these physical variables are naturally more variable due to large tidal cycles and freshwater runoff from land. Therefore, additional pressures from climate change such as sea level rise and increased storm events will drive changes to an already stressed environment. Possible impacts from sea level rise and increased storm events are summarised in Table 1.

Declines in sea grass habitats have been observed due to increases in temperature, losses from changes in bird migration patterns, and changes in storm patterns (Figure 11). However, there may be some positive effects of climate change on aquatic plants. Sea level rise will increase leaf size with greater water depth and there may be increases in production with an increase in CO_2. By far, the greatest impact on seagrass habitat are from anthropogenic effects other than climate change such as deforestation, sedimentation, nutrient pollution, shoreline hardening, dredging, boating, and fishing (Short and Neckles 1999).

Shifts in community structure have been observed in nearshore benthic communities by the synergistic effects of climate change and overfishing (Collie et

Table 1: Summary of qualitative impacts of increased sea level rise and storm events on coastal ecosystems. Adapted from Leys 2009

COASTAL ELEMENT	IMPACTS
Beaches	• Large-scale morphologic adjustments to absorb the wave energy, including: a. Overwashing and increased erosion b. Potential formation of new beaches downdrift of erosion areas c. Landward migration of barrier beaches
Unconsolidated cliffs	• Accelerated erosion
Estuaries and tidal rivers	• Increase in tidal volume and exchange • Further saltwater penetration
Freshwater marshes	• Gradually become salt marshes or migrate landward
Salt marshes	• More frequent tidal flooding • Sedimentation and possible landward migration at a rate commensurate with sea level rise depending on sediment and organic matter supply
Small islands	• Submergence
Species and ecosystems	• Modification of coastal habitat • Threatened viability from changes in numerous factors including, but not limited to, water temperature, salinity, sea ice patterns (e.g. seals), runoff and water quality

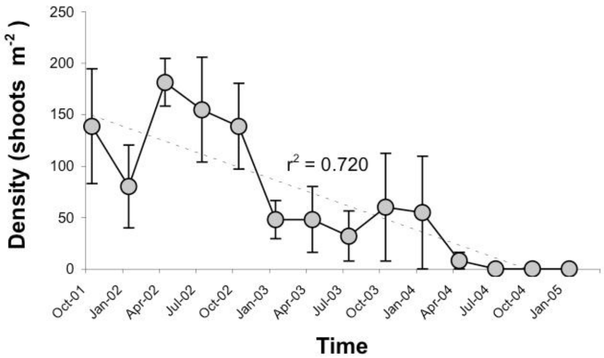


Figure 11: Changes in density of shoots in a New Hampshire seagrass habitat.
Source: Frederick Short, University of New Hampshire, pers. comm., 2010

al. 2008). Species invasions by opportunistic species are more common when overfishing occurs in a warming environment (Harris and Tyrell 2001; see theme paper on *Invasive Species*).

4.6 Changes in Fisheries Productivity

Global climate models predict overall declines in catch potential of marine fisheries in the Gulf of Maine region. Projections in the year 2055 range from decreases as low as 5% if 2000 level emissions were maintained to as high as 30% in high emissions scenarios (Cheung et al. 2009). The relative abundance of Atlantic cod is expected to decrease in the Gulf of Maine (Cheung et al. 2008). Warmer temperatures in the Gulf of Maine will positively influence the growth of adult cod, but will negatively impact survival of cod in early life stages (Fogarty et al. 2007b). These temperature-mediated effects will result in a loss of yield for this species.

5. Actions and Responses

Responses to climate change can either be proactive or reactive. Proactive responses are those that attempt to manage the problem at its source by alleviating pressures on the environment, while reactive responses are those that manage or mitigate the impacts. The inherent complexity of ecosystems makes it difficult to mitigate most of the impacts and, thus, effective responses must be proactive. These include policy responses, as well as research and monitoring of the marine and coastal ecosystems in the Gulf of Maine.

5.1 Government Policy and Action Plans

In the Gulf of Maine watershed area, there is a commitment to address global warming through emission control. The Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP) has committed to a Climate Change Action Plan (August 28, 2001; NEG/ECP 2001) that identifies steps to address those aspects of global warming that are within the region's control to influence. The Plan requires the development of a comprehensive and coordinated regional plan for reducing greenhouse gases (GHGs), and a commitment by each jurisdiction to reach specified reduction targets for the region as a whole. In particular, the mid-term goal is to reduce regional GHG emissions by 10% below 1990 emissions by 2020. More detail on policy responses to climate change from jurisdictions in the Gulf of Maine is provided in the theme paper *Climate Change and its Effects on Humans*.

While reducing emissions addresses the root cause of climate change, the effects of climate change are already being observed in the Gulf of Maine area. Thus, several states and city governments have developed adaptation plans that attempt to prepare their jurisdictions for the impacts of climate change. Adaptation plans to protect ecosystems and habitats include: upgrading sewage treatment and stormwater runoff systems; protecting habitats such as existing and future wetlands, and protecting migration routes. For example, an adaptation plan exists for Keene, NH (City of Keene 2004), and Massachusetts will present a report to the governor in spring 2010 (http://www.mass.gov/dep/public/committee/ccaac.htm). An extensive report has been developed in Maine that advocates "developing policies and regulations to restore, maintain, and improve the resilience of natural systems" and maintaining and developing monitoring programs to assess changes in the status of diadromous fish, invasive species, harmful algal blooms and other coastal marine resources (Maine DEP 2010). Adaptation strategies are included in many state and provincial action plans. These mitigation and adaptation policies are important first steps in reducing the impact of climate change on marine ecosystem and the people who rely on them.

5.2 Monitoring and Research

To detect changes in the ecosystem at the large temporal and spatial scale at which global climate change is occurring, monitoring must be coordinated between local, state, and national organizations in the region. The Gulf of Maine is monitored and managed by the states of Maine, New Hampshire, and Massachusetts and by both US and Canadian federal agencies. While there are many sources of data to detect changes in temperature, salinity, and precipitation, few time series exist to detect changes in acidity or changes in timing of ecological events. Many fish stocks have been assessed and managed by the US and Canada jointly since 1998 (http://www.mar.dfo-mpo.gc.ca/science/TRAC/TRAC.HTML).

Data on oceanography, the abundance and distribution of phytoplankton, zooplankton, macroinvertebrates, fish, and marine mammals are collected by Fisheries and Oceans Canada (DFO) and the US National Marine Fisheries Service (NMFS). However, the timing of these surveys and the methods used to collect biological samples are different, making it difficult to combine data collected in different survey programs within the Gulf of Maine. Efforts to combine data from Canadian DFO surveys with US NMFS surveys are ongoing (Nye et al. 2010; Shackell et al. in review). These efforts to compare data amongst surveys will be important to detect changes in spatial distribution of marine species and to predict the rate of species invasions into adjacent areas (Blanchard et al. 2007). These data can then be used in ecosystem level models to predict the effects of climate change on marine and coastal habitats and potentially to evaluate the effects of different management scenarios.

The Gulf of Maine Council on the Marine Environment established the Climate Change Network Task Force in 2003 to develop climate change indicators for the Gulf of Maine. This task force identified key indicators for the Gulf of Maine and surrounding areas (Wake et al. 2006). Similar efforts are in place to monitor changes in the marine ecosystem using US data (http://www.nefsc.noaa.gov/omes/OMES/) and a joint effort between the US and Canada to develop Integrated Ecosystem Assessments (IEA) began in April 2010 with the initiation of a Working Group on the Northwest Atlantic Regional Sea. Part of the IEA process will include risk analysis of the effects of climate change (and other factors) and provide multiple potential management scenarios.

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	TREND*	ASSESSMENT
Global mean air temperature	Global warming	Driving Force	–	Fair
Population density	Increase in greenhouse gas emission and demand for natural resources	Driving Force	–	Fair
Water temperature	Increase in water temperature	Pressure	–	Fair
Precipitation	Increase in precipitation, river flow, and storm events	Pressure	–	Poor
Salinity	Decreasing salinity in the ocean	Pressure	–	Fair
Sea level in the Gulf of Maine	Inundation of coastal ecosystems	Pressure	–	Poor
Ocean acidification	Low growth and high mortality in some species	Pressure	?	Unknown
Thermal habitat	Decreases in thermal habitat of native organisms,	Impact	/	Fair
Shifts in species distribution	Fishers increase effort to utilize traditional fishery resources	Impact	/	Fair
Ecological timing	Declines in some species including endangered right whales	Impact	/	Fair
Community assemblage	Changing community assemblages	Impact	/	Fair
Ecosystem productivity	Reduced ecosystem services including tourism and fishery yield	Impact	/	Fair

* KEY:
– Negative trend
/ Unclear or neutral trend
\+ Positive trend
? No assessment due to lack of data

Data Confidence

- Numerous monitoring stations indicate increasing temperature, precipitation, and severe storm events for most areas within the Gulf of Maine and its watershed.
- Global climate models all predict an increase in air and water temperature for the Gulf of Maine region.
- Global climate models predict higher salinity, but salinity may decrease or be buffered by the effect of melting sea ice and glaciers.
- Projected global sea level rise has been modelled in several ways. All predict sea level rise, but predictions for the next century range from 50 cm to 190 cm, an order of magnitude difference.
- Regional land subsidence estimates are also modelled to determine current subsidence levels. However, these have been verified through values from local sea level gauges.

Data Gaps

- Considerable uncertainty surrounds how broadscale hydrography will change in the next 50-100 years.
- Information on the impacts from climate change on ecosystems is growing. However, there has been little analysis on the cost of these changes.
- Little to no data are available to assess the status of ocean acidification in the Gulf of Maine. Data are accumulating on the effects on organisms in laboratory experiments, but no data exist on acidification in nearshore or ocean ecosystems for the Gulf of Maine.
- Little analysis is available on synergistic effects of climate change and natural thermal variation.

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