Gulf of Maine Council on the Marine Environment
Climate Change Network

Identifying Coastal Habitats at Risk from Climate Change Impacts in the Gulf of Maine

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Introduction

The Gulf of Maine Council on the Marine Environment (GoMC) 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.[1] The Council consists of committees falling under the headings of habitats, maritime activities, services, and cross-cutting. Under these general headings there are several sub-committees, such as habitat monitoring and IT and mapping initiatives.

The two cross-cutting committees consist of the Ecosystem Indicator Partnership (ESIP) and the Climate Change Network (CCN). ESIP's activities focus on convening regional practitioners in six indicator areas: coastal development, contaminants and pathogens, eutrophication, aquatic habitat, fisheries and aquaculture, and climate change. ESIP is developing indicators for the Gulf of Maine (GoM) and integrating regional data for a new web-based reporting system for marine ecosystem monitoring. The CCN strives to bring the latest climate change science, impacts, and adaptation information to the Gulf of Maine community.[2]

The Climate Change Network is currently working toward completion of three sections of the 2007-2012 Action Plan under Goal 1. These include:

- 1.6 Compile and disseminate information on coastal habitats and watersheds at risk due to climate change;
- 1.17 Conduct risk analysis and prioritize the vectors of invasive species and understand the effects of climate change; and
- 1.18 Convene stakeholder workshops to identify and promote mitigative and adaptive strategies for dealing with sea-level rise and changes in water quality related to climate change.

This is the first of three documents addressing the background of the information available on climate change. This paper specifically targets identification of coastal habitats at risk due to climate change and builds on a discussion paper titled "Climate Change Impacts on Habitat restoration in The Gulf of Maine" (Cullen and Lines, 2008) The purpose of this document is to identify what research has been carried out in relation to climate change and its effects on the GoM coast. The research primarily includes studies on habitats and climate change and includes information on geology, topography, and watersheds. The focus is to bring together the available information in publications and maps and to begin to identify where gaps may exist. Ultimately this information may be used to help construct a comprehensive GIS (geographic

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[1] http://www.gulfofmaine.org/

[2] http://www.gulfofmaine.org/council/committees/

information system) map with links to publications and relevant information that can be used by the various GoMC groups.

The Gulf of Maine Overview

The Gulf of Maine (Figure 1), with an approximate area covering 93 000 km^2 (36 000 mi^2) of ocean, 12 000 km (7 500 mi) of coastline, and a watershed of 179 000 km^2 (69 000 mi^2) is of significant importance to many species of marine, estuarine, and terrestrial nature. Many of the habitats found in this region are sensitive to environmental change and are constantly under threat from human activities both direct, such as point source pollution (e.g. sewage effluent) and human development; and indirect, such as non-point source pollution (e.g. acid rain) and sea level rise. Of particular sensitivity are the coastal ecosystems. These areas are the interface between the terrestrial and marine environments and are influenced by the abiotic factors in both. Therefore, as specialized habitats they can be subject to a synergistic effect of detrimental changes in the two ecosystems.

Historically, due to the transport links and plentiful food source, coastal regions have been areas of the greatest development and highest population densities. This development has rarely taken the natural environment into great consideration, as human need and economic growth have taken precedence. In particular, in the last 30 years, scientists have found objective data to prove what anecdotal evidence has been finding: that damage to the coasts is increasing at an alarming rate.

Figure 1: the Gulf of Maine[4].

Governments, as well as scientists, are now considering the possible impacts climate change may have in the immediate and distant future. The Intergovernmental Panel on Climate Change (IPCC) was created by the World Meteorological Organization and United Nations Environmental Program to give policy makers an objective source “of information about the causes of climate change, its potential environmental and socio-economic consequences and the adaptation and mitigation options to respond to it”.[3] The GoMC is now trying to identify and incorporate thes risks of climate change into decisions made regarding the GoM.

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[3] http://www.ipcc.ch/about/index.htm retrieved 9th Feb 2009

[4] http://www.gulfofmaine.org/knowledgebase/aboutthegulf/aseabesidethesea.php

Geology and the Evolution of the GoM Ecosystems

The geologic history of the Gulf of Maine's surrounding states and provinces can be traced back 650 million years to the Precambrian Period. Various orogenic events and other tectonic activities have shaped the mountain ranges, especially the major orogeny episode in the Devonian Period 360-417 MA (million years ago). This saw the final development of the northern Appalachian Mountains.[5] Geologic maps show the bedrock geology resulting from these major tectonic events.

The Gulf of Maine as we know it today was shaped more by the processes of glaciation. The geologic record for Maine shows that approximately 120 million years passed between the formation of the youngest bedrock and the Pleistocene Epoch (1.5 MA - 8 000 BC), popularly known as the ‘Ice Age’.[6] See Figure 2.[7] In that interval there was little weathering and erosion. During the Pleistocene there were many ice sheets, which advanced, covered, and retreated numerous times carving out the bedrock and depositing glacial sediments. Around 35 000 MA the Laurentide Ice Sheet covered the eastern seaboard of North America. The extensive weight of the glaciers pushed the land down hundreds of feet. The ice margin began to recede from the Gulf of Maine 21 000 MA (Borns et al., 2004). As the glacier retreated, the sea flooded southern Maine because the Earth's crust was still depressed by the weight of the ice.[8] “Isostatic rebound of the crust occurred simultaneously with thinning and retreat of the glacier margin. Rapid rebound caused a fall in local relative sea-level to 60 m below present sea-level approximately 10 000 years ago, when a short-term equilibrium was reached between eustatic sea-level

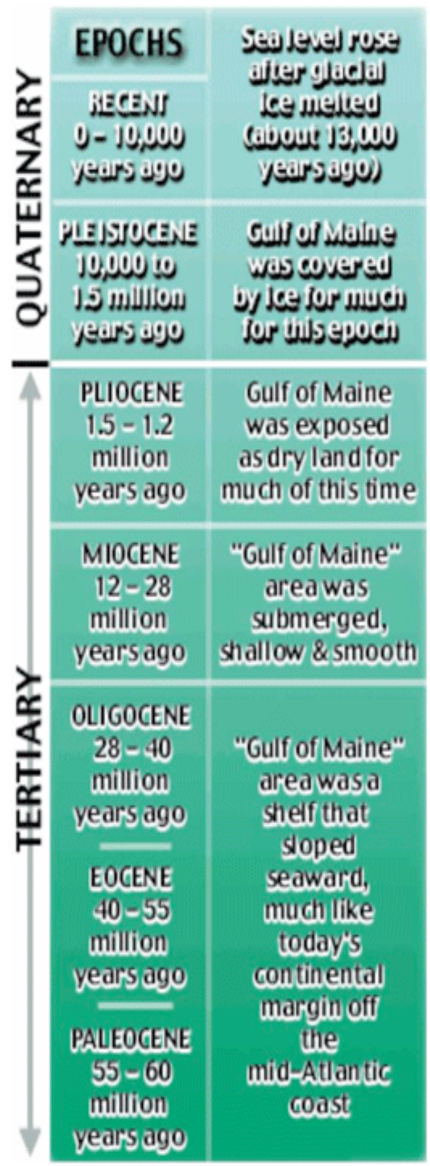

Figure 2: "Geologic timeline for the Cenozoic Era, describing the development of the Gulf of Maine."[7]

[5] http://www.maine.gov/doc/nrimc/mgs/explore/bedrock/facts/geol-hist.htm retrieved 6-02-09

[6] http://www.maine.gov/doc/nrimc/mgs/explore/surficial/facts/surficial.htm 6-02-09

[7] http://www.bigelow.org/virtual/bath_sub3.html

[8] http://www.maine.gov/doc/nrimc/mgs/explore/surficial/facts/surficial.htm 6-02-09

rise and rate of isostatic rebound".[9]

The seawater extended far up the Kennebec and Penobscot valleys of Maine. During this time sediment washed out of the melting ice and into the sea. Deltas were formed from accumulated sand and gravel while the finer silt and clay dispersed across the ocean floor.[10] From these geologic events has arisen a multitude of substrate types. Granite and basalt are found on the western shores of the Bay of Fundy and into Maine, New Hampshire, and Massachusetts. Cape Cod has glacial deposits of sand and gravel, and sandstone and mudflats are found at the head of the Bay of Fundy (Tyrrell, 2005).

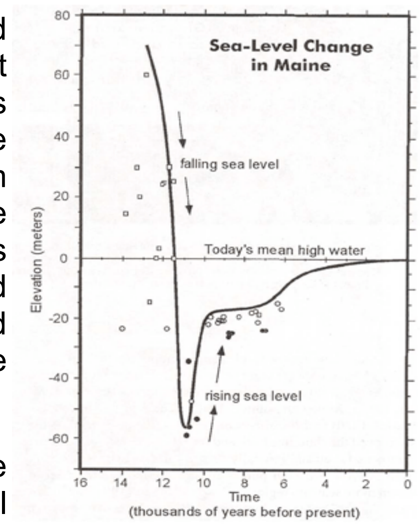

Figure 3: history of sea level change in Maine[11]

Today much of New Brunswick, Maine, New Hampshire and Massachusetts are still rebounding from the glacial depression, while Nova Scotia is still subsiding. Coastal habitats in the subsidence areas may therefore experience a greater degree of total sea-level rise than those where relative sea-level rise is less. Areas undergoing rebound will experience less total sea-level rise, as the rising land will compensate for some of the climate change-driven sea-level rise.

The massive size of the Laurentide Ice Sheet and the time taken for advancement and retreat meant that a large volume of sediment was created and deposited. This can be seen as the unconsolidated material that makes up the vast coastal margins. The movement of water has further shaped these sediments and given rise to the highest tides in the world found in the Bay of Fundy and created an area rich in biodiversity. The areas of the coast that are primarily glacial deposits are also more vulnerable to erosion than coastlines of hard bedrock.

The Watershed

"The Gulf of Maine watershed encompasses much of Nova Scotia, New Brunswick, Maine, New Hampshire and Massachusetts, and a small portion of Quebec. The total land area of this watershed is 69,115 square miles, or 179,008 square kilometres."[12] Figure 4 shows the Gulf of Maine Watershed including major river basins. There are

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[9] http://research.usm.maine.edu/gulfofmaine-census/about-the-gulf/physical-characteristics/geology/geologic-history retrieved 6-02-09

[10] http://www.maine.gov/doc/nrimc/mgs/explore/surficial/facts/surficial.htm retrieved 6-02-09

[11] http://www.maine.gov/doc/nrimc/mgs/explore/marine/seafloor/images/fig06.htm

[12] http://www.gulfofmaine.org/knowledgebase/aboutthegulf/aseabesidethesea.php

several significant rivers that drain into the Gulf. The St. John (NB) and Penobscot (ME) have the greatest discharge. Others include, counter clockwise from Nova Scotia to Massachusetts, the Annapolis (NS), Shubenacadie (NS), Salmon (NS), Petitcodiac (NB), Magaguadavic (NB), St. Croix (NB/ME), Kennebec (ME), Saco (ME), Piscataqua (NH), and Merrimack (MA) rivers. The State or province listed is where each river enters the Gulf of Maine, but as rivers cross political boundaries freely there may be more than one jurisdiction in each watershed[13,14]. This is by no means an exhaustive list. There are many watershed groups working toward the betterment of their particular areas. One list of watershed groups can be found on The Gulf of Maine Summit report site[15]. These projects include many of the major river systems and estuaries.

Figure 4: watershed of the Gulf of Maine and its major tributaries.[16]

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[13] http://www.nationmaster.com/encyclopedia/Gulf-of-Maine
[14] http://en.wikipedia.org/wiki/Gulf_of_maine
[15] http://www.gulfofmainesummit.org/grouplist.html
[16] http://www.gulfofmaine.org/knowledgebase/aboutthegulf/maps/mapsandphotos.php

In New Brunswick and Nova Scotia important estuaries have been studied by Hildebrand and Eaton (1990) using parameters such as surficial geology, physical oceanography, land use, and resources. These are available in hard copy from Environment Canada (Hildebrand and Eaton, 1990).

Protected Areas and Designations

One method of protection for an environmentally sensitive area is through the use of designations. In countries that have a highly modified environment though a long human history and/or high population densities, environmental designations are extremely important. There are very few such designations in North America and they seem to be at multiple political levels. One international designation used however is the Ramsar Convention[17].

> Ramsar is a global intergovernmental treaty on the conservation and sustainable use of natural resources, The mission of the Ramsar Convention, as adopted by the Parties in 1999 and refined in 2002, is ***the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution toward achieving sustainable development throughout the world.***[18]

The Ramsar Convention takes a broad approach in determining which wetlands are worthy of their designation and what it defines as a wetland:

> areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres...may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands.

Five major wetland types are generally recognized by Ramsar. These are:

- **marine** (coastal wetlands including coastal lagoons, rocky shores, and coral reefs);
- **estuarine** (including deltas, tidal marshes, and mangrove swamps);
- **lacustrine** (wetlands associated with lakes);
- **riverine** (wetlands along rivers and streams); and
- **palustrine** (meaning “marshy” - marshes, swamps and bogs).[19]

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[17] http://www.ramsar.org/about/info2007-01-e.pdf
[18] http://www.ramsar.org/about/info2007-02-e.pdf
[19] http://www.ramsar.org/about/info2007-02-e.pdf

For the purposes of this document the coastal wetlands of marine and estuarine are the main focus.

Ramsar Sites in Canada

The Convention on Wetlands came into force for Canada on 15 May 1981. Canada presently has 37 sites designated as Wetlands of International Importance, with a surface area of 13 066 675 hectares. Four of these are found within the Gulf of Maine boundaries[20].

New Brunswick:

- Mary's Point - A peninsula of various terrestrial habitats bordered by gravel beaches and extensive intertidal mudflats.
- Shepody Bay - A tidal embayment of saltmarsh, eroding coastline with sand and gravel beaches and extensive intertidal mudflats.

Nova Scotia:

- Chignecto - Half the site consists of **Spartina**-dominated saltmarsh dissected by numerous tidal creeks and channels. The freshwater wetlands range from sink-hole ponds, small lakes and bogs to reed marsh.
- Southern Bight-Minas Basin - An estuarine embayment surrounded by uplands interspersed with salt marshes. High tidal amplitudes expose extensive intertidal sand and mud flats.

All sites have important habitats for waterfowl and many for crustaceans. These are by no means unique in the Gulf of Maine.

Ramsar Sites in the United States

As of Spring 2008 there were 24 Ramsar sites in the United States with two opening later in the year. However there are no Ramsar sites in the Gulf of Maine. The closest site is the Connecticut River, which starts in Québec, flows through Massachusetts and empties at Connecticut.[21]

Climate Change

Much work has been done to understand how the world's climate may change over the next century. Although well known efforts such as the Intergovernmental Panel on Climate Change's assessments (e.g. IPCC, 2007) have traditionally focussed on understanding the science and impacts of climate change at global and continental

[20] http://atlas.nrcan.gc.ca/site/english/learningresources/theme_modules/wetlands/index.html#risk
[21] http://www.ramsarcommittee.us/Ramsar_Sites_Brochure.pdf

levels, each subsequent assessment has provided more detail of regional value. Christensen et al. (2007) looked at future climate projections from a number of models and emission scenarios. For the east coast of North America they concluded that over the remainder of the century average annual temperature could rise 2°C to 3°C and average annual precipitation is expected to increase, particularly in the fall and winter. Nicholls et al., (2007) concluded that sea surface temperature may increase 1.5-2.6°C on average globally by the end of the century. This may result in changes to circulation, increased stratification, and increased dissolved CO_2. The latter may lead to increased ocean acidity (Nicholls et al., 2007).

A major impact of climate change on the marine environment is sea-level rise. Nicholls et al. (2007) estimated average, global sea-level rise by the end of the century, based on a moderate scenario of greenhouse gas emissions, to be 0.35 m. The Gulf of Maine may experience additional sea-level-rise over the same period, possibly 0.05-0.1 m, resulting from changes in ocean salinity, density, and circulation (Meehl et al., 2007).

Generally speaking, climate change may lead to more storms in the marine environment, resulting in increased strength and frequency of waves, and an increase in coastal erosion and deposition. Increased water temperatures can lead to lower dissolved oxygen levels. Sea-level rise may drive salt wedges upstream and infiltrate fresh water aquifers with salt-water.

National and sub-national studies have attempted to determine more regional impacts of climate change and can offer more detailed information of use to the Gulf of Maine region. Some recent examples include work by the Union of Concerned Scientists (2006), Environment Canada (Daigle et al., 2006), and Natural Resources Canada (Lemmen et al., 2008). Individual researchers also conduct smaller relevant studies, although their results may not always be published in sources easily accessible by the non-academic community.

Indicators of Past and Future Climate Change

Understanding climate change is not limited to computer-based and other scientific models. Many of the impacts can be readily detected over time, through deliberate observations of current events or data mining of past records. Making such observations and understanding their relationship to climate change can result in the development of climate change indicators. Once identified, these indicators can tell us which aspects of a local system are sensitive to climate change and thus should be monitored into the future to better understand how climate change is driving changes in the local ecosystems.

In the Gulf of Maine region several efforts to develop climate change indicators have taken place in recent years. Clean Air - Cool Planet and Wake (2005) looked at indicators in the North-eastern U.S., and Wake et al. (2006) built upon that effort by expanding the area to include the Maritime Provinces. The mostly terrestrial indicators included timing and magnitude of meteorological, hydrological, and phenological events over the last 100 years and generally indicated a trend toward a warmer, wetter climate for the region. Both sea-level rise and sea surface temperature, the two marine-specific indicators chosen, showed upward trends.

Subsequent climate change indicator work for the Gulf of Maine is underway by ESIP [22] (McKenzie et al., 2008). Using a pressure-state response framework, the committee has chosen four initial priority climate change indicators: air temperature change, precipitation anomalies, sea-level rise, and sea surface temperature change.[23]

Coastal Sensitivity to Climate Change

Coastal areas are particularly sensitive to changes in climate. CCNS[24] laid out a set of criteria that describe the attributes that make the specialized environments susceptible:

- Many coastlines have low elevations, and are made up of unconsolidated materials (sand, shale, gravel) that are highly susceptible to erosion
- Coasts receive fresh water discharge from upland areas, as well as tidal influx and storm surges from the sea, so they are already at risk of flooding
- Coastal areas are home, habitat, and feeding grounds for many birds, plants and other species at risk whose populations are already in decline
- Coastal areas are experiencing increasing development pressure that affects the coast's natural adaptability and resiliency[25]

Sea-level rise is a major driver of these climate change impacts. Titus and Richmond (2001) attempted to map the sensitivity of coastlines in several regions of the US to sea-level-rise, resulting from elevation based computer flood models. Figure 5 shows the result for New England. They caution that:

> This map is based on modeled elevations, not actual surveys or the precise data necessary to estimate elevations at specific locations. The map is a fair graphical representation of the total amount of land below the 1.5- and 3.5-meter contours; but the elevations indicated at particular locations may be wrong. Those interested in the elevations of specific locations should consult a topographic map. Although the map illustrates elevations, it does not necessarily show the location of future shorelines. Coastal protection efforts may prevent some low-lying areas from being flooded as sea level rises; and shoreline erosion and the

[22] http://www.gulfofmaine.org/esip/

[23] G. Lines, personal communication, 2009

[24] http://ccns.chebucto.org/publications.htm

[25] http://ccns.chebucto.org/publications.htm

accretion of sediment may cause the actual shoreline to differ from what one would expect based solely on the inundation of low land. This map illustrates the land within 1.5 and 3.5 meters of the National Geodetic Vertical Datum of 1929, a benchmark that was roughly mean sea level in the year 1929 but approximately 20 cm … below today's sea level.

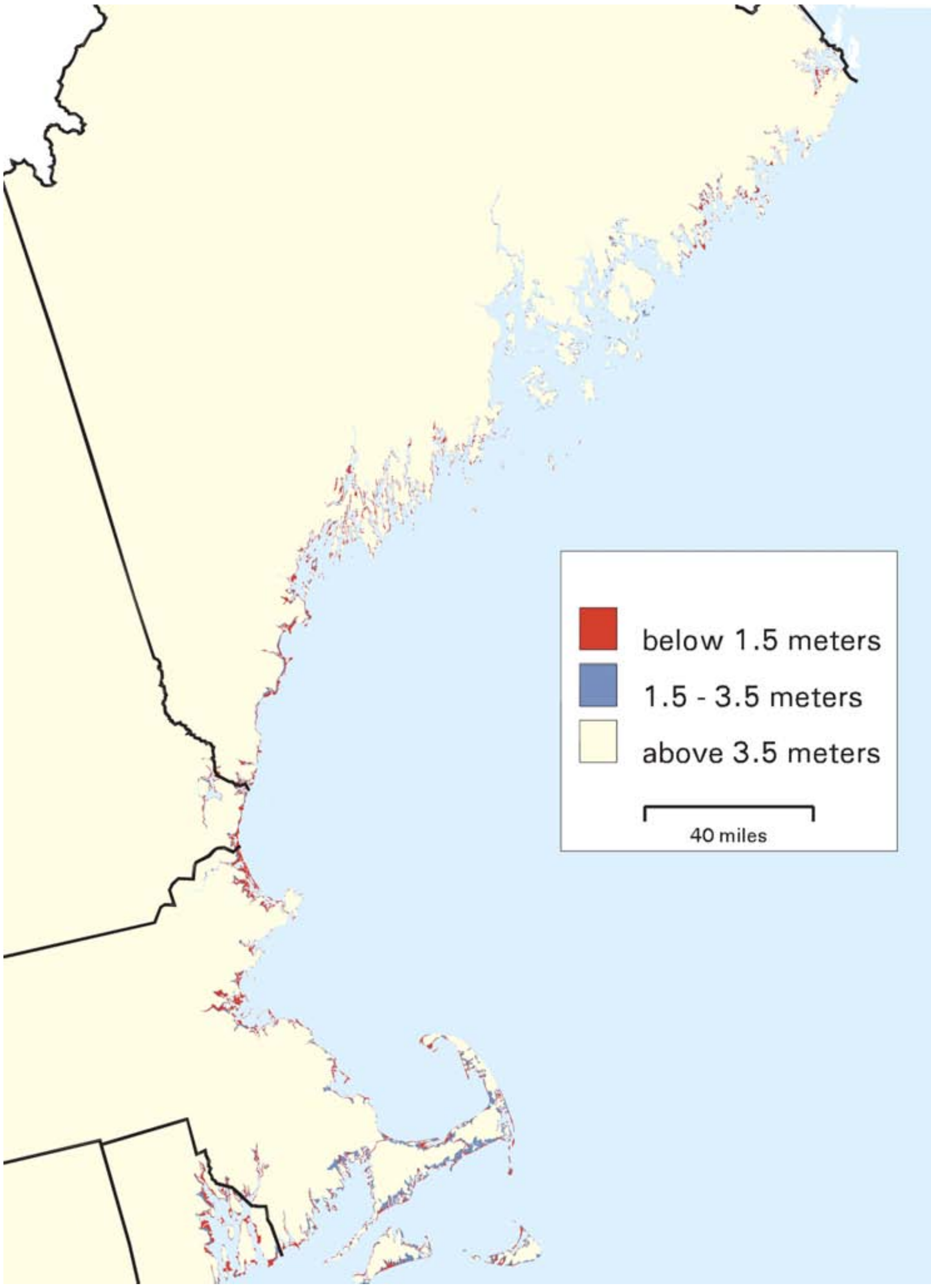

Figure 5: sensitivity of the New England coastline to sea-level rise (after Titus and Richman, 2001).

In Canada, Shaw et al. (1998) undertook an earlier, but coarser, analysis of the entire coastline of the country. Their criteria for sensitivity included “relief, geology, coastal land form, coastal retreat rate, sea-level trend, wave energy, and tidal range”. Figure 6 shows the Maritime portion of that effort. Both maps show that there are some areas in the Gulf of Maine that are much more sensitive to sea-level rise than others.

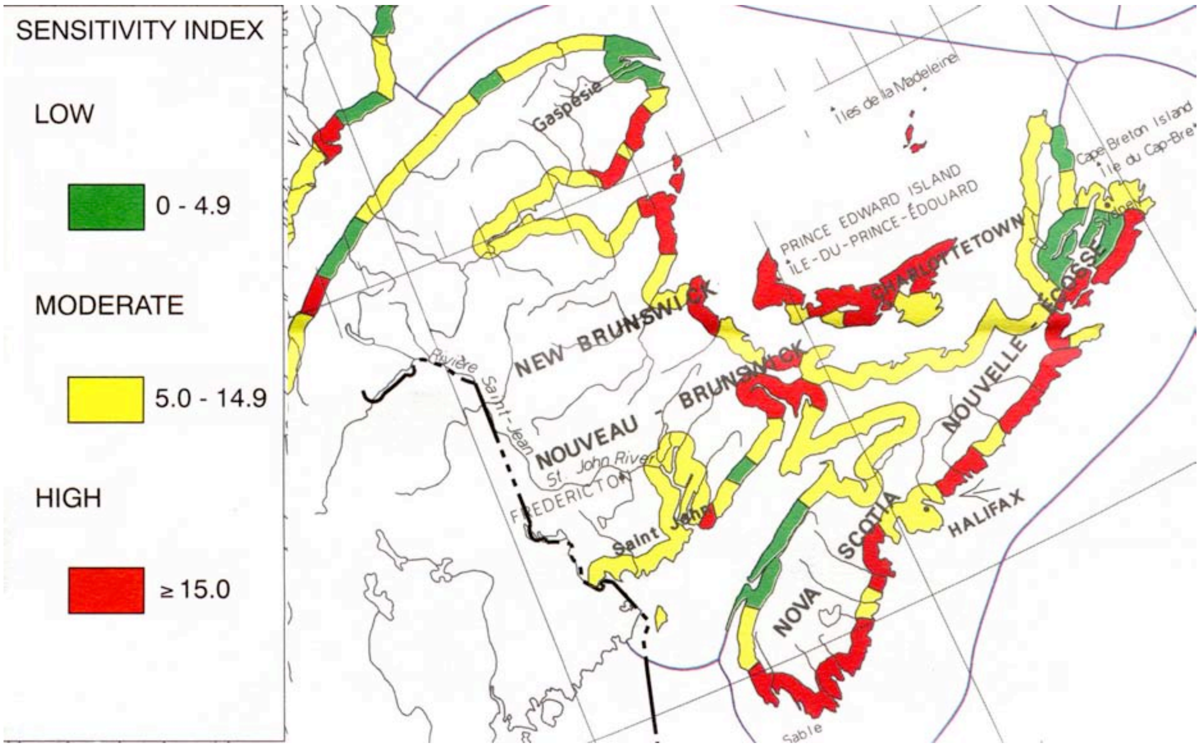

Figure 6: coastal sensitivity to sea-level rise in the Maritime Provinces (after Shaw et al., 1998)

Wetlands can also be categorized by a colour-ed sensitivity scale. Coastal wetlands around the Bay of Fundy (Figure 7) exhibit moderate to high risk characteris-tics.

Figure 7: wetlands at risk of climate change[26]

[26] http://atlas.nrcan.gc.ca/site/english/learningresources/theme_modules/wetlands/index.html#risk retrieved 8-02-09

Ecosystems in the Gulf of Maine

The nutrient-rich waters, diverse bottom habitats and lengthy coastlines make the Gulf of Maine an area of rich biodiversity. In a 2006 study it was found to be home to some 3317 species.[27] The marine habitats of the Gulf of Maine support a productive fishing industry as well as carrying out functions such as nutrient cycling, sediment trapping, pollutant filtering, carbon storage, and protection of upland and inland areas from storm damage.[28]

The coastal zone extends three miles from land and is the site of harvests of lobsters, sea urchins, clams, scallops, shrimp, and mussels. "Maine and Nova Scotia have the greatest density of marine organisms, the highest productivity, and the largest number of people dependent on marine resources for their livelihood."[29]

Much restorative work has been done to counteract damage already caused to coasts, and many organizations are also working to protect areas that are still relatively untouched. Most of the restoration work carried out has been in the areas of greater population densities, i.e. the eastern seaboard of the United States. The majority of this work has been on coastal wetlands. Primarily, this has taken the form of salt marsh restoration, barrier removal, and environmental monitoring programmes. Traditionally the focus of conservation work has been to restore an area to its original state or to preserve the status quo. However, as the planet faces new threats such as those from climate change, new methods of conservation that take these threats into account are becoming increasingly common.

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27 http://allthingsmaine.blogspot.com/2006/01/biodiversity-in-gulf-of-maine.html
28 http://www.gulfofmaine.org/habitatprimer/introduction.pdf
29 http://www.gulfofmaine.org/knowledgebase/aboutthegulf/habitats/coastalhabitats.php

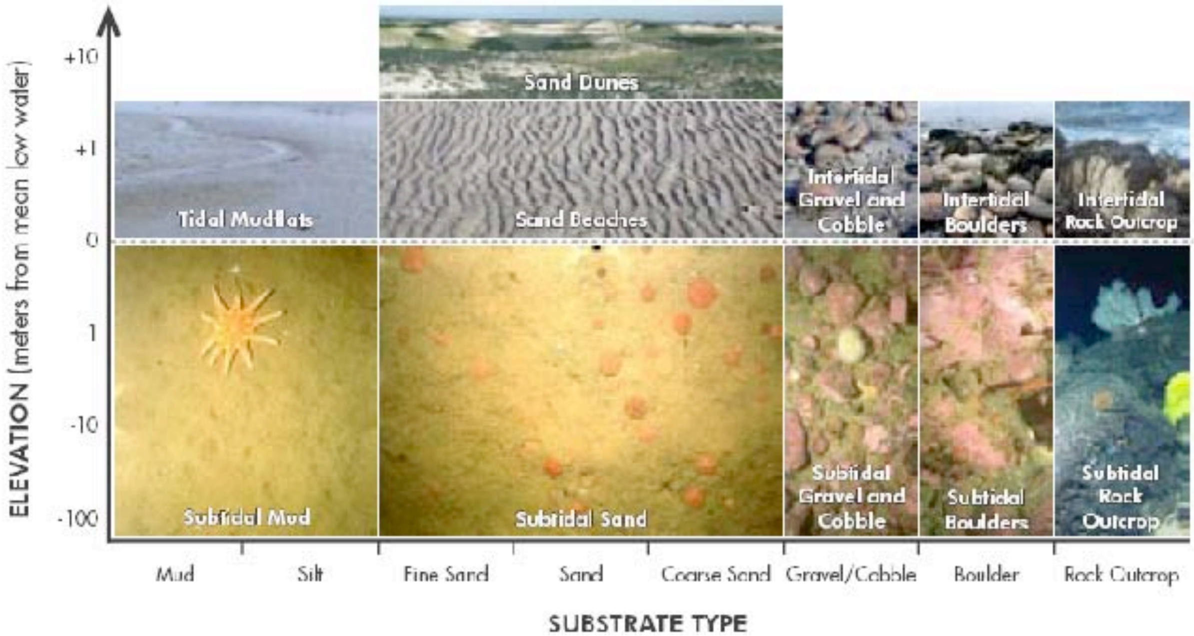

Figure 8: "The distribution of physically defined habitats according to substrate type and elevation from mean low water. Sand dunes are formed primarily by wind and therefore extend above the intertidal zone into the supralittoral zone" (Tyrrell, 2005).

Habitats and Climate Change

There are several habitat types as set out in the GoMC Habitat Primer[30] and the Discussion paper for Climate Change Impacts on Habitat Restoration in the GoM (Cullen and Lines, 2008). This section is an overview of each habitat and the possible impacts of climate change on each.

The Habitat Primer (Tyrrell, 2005) categorizes habitats based on "substrate type and sediment grain size, water depth, and presence of structure-forming plants and animals that create biogenic habitat."

Each habitat has its own response to the threats posed by changing climates. It is impossible to make predictions based on generalizations but the table in the Appendix speculates on possible threats to ecosystems of various impacts of climate change.

[30] http://www.gulfofmaine.org/knowledgebase/aboutthegulf/habitats/coastalhabitats.php

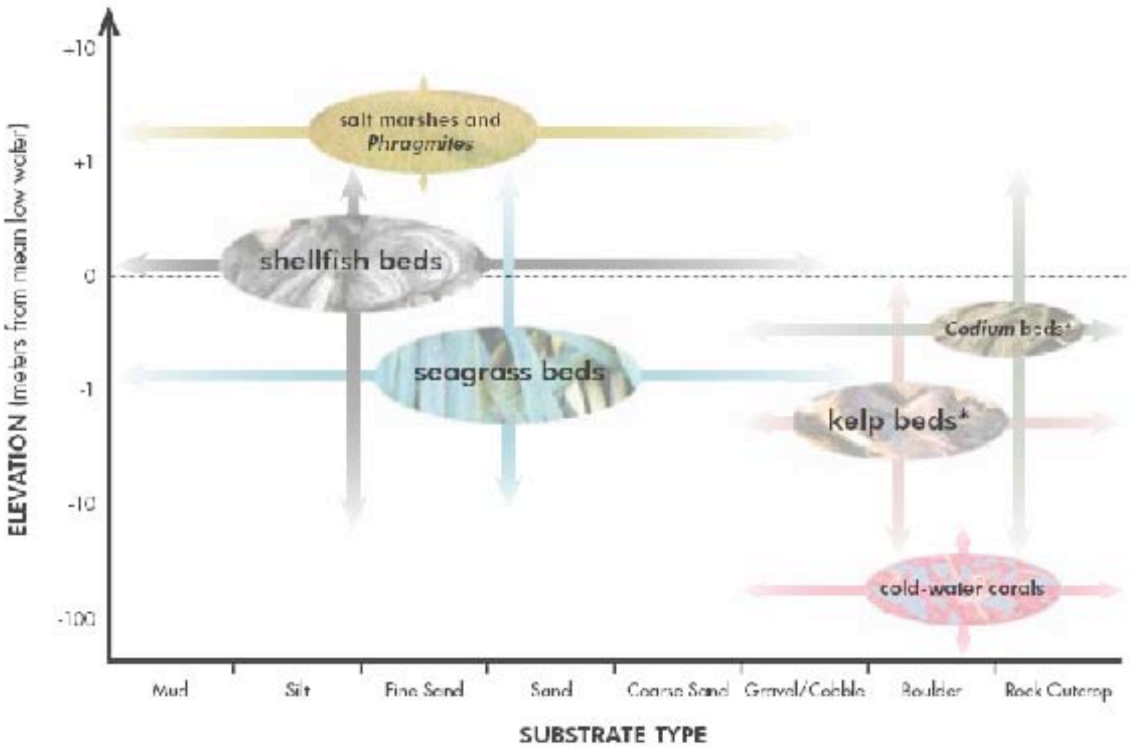

*Figure 9: "The distribution of biogenic habitats according to substrate type and elevation from mean low water. Depth distributions, particularly for lower depth limits, are approximate. *Codium and kelp can attach to a wide variety of substrates, including shellfish that occur in soft sediments, but neither algal species forms beds in soft sediments" (Tyrrell, 2005).*

Habitat Types

Rocky Shore (Littoral Zones)

Much of the Gulf of Maine has a distinctive shoreline of hard multi-sized boulders, where rock outcrops dominate in areas with heavy wave action. Rocky shores are areas of bedrock that are exposed between high and low tide. They are areas of interface between marine and terrestrial ecosystems.[31]

Rocky habitats provide a hard substrate for many marine species. However, this also puts this ecosystem at high risk as the intertidal (eulittoral) zone shifts with sea-level rise. Organisms that are slow growing or are essentially sessile, such as the limpet during maturity, may not adapt quickly enough to the pace of a shifting intertidal zone and subsequently reduce in number.

This is a complex ecosystem with a multitude of ecological tiers ranging from the rock

[31] http://museum.gov.ns.ca/mnh/nature/nhns/h2/h2-1.htm retrieved 13-02-09

base, to the seaweed canopy in high tide, to the protective layer the algae creates on shore at low tide. Species are distributed on the shore primarily according to tolerance of water immersion and emersion.

Diversity of species increases with the stability of an ecosystem. Rock and gravel areas that are stable have higher biodiversity than those that shift regularly with wave action (Schoch et Dethier, 1996). An increase in storm activity resulting from climate change could therefore create an unstable environment where sheltered habitats are lost. This would affect breeding grounds as hiding places for juvenile fish are moved before they have a chance to grow to maturity, and small invertebrates may be washed away. Increased wind and wave action could also strip the shore of photosynthesizing organisms and therefore affect the entire food web dependent on these.

Figure 10: rocky shore, Maine coastline[32]

Dunes and Beaches

There is a variety of beaches, dunes, and sandy sublittoral bottoms. The nature of sandy habitats is one of movement. Over time there is a dynamic shift of particles, which means less diversity of species than that of other habitats. This makes these ecosystems vulnerable to change caused by movement. Climate change effects such as increased wind, rain, and waves can destroy the cohesion of particles that make up sandy environments. Species that rely on sheltered stable conditions will be at a disadvantage and those tolerant of wind through burial (or avoidance of) may be favoured. Increased water runoff removes sediment and increases erosion. The reduction of snow and ice cover in winter means greater exposure to destructive influences, as ice protects sand from winter storms.

[32] http://www.comestiblog.com/

Sea-level rise may also destroy beaches as the rate of sand migration may not keep pace with the rise in water level. This leads to flooding of the beach and reduction of the habitat. Beaches and dunes also act as buffers to inland habitats. The loss of these could mean greater risk of storm damage inland and salt-water intrusion into terrestrial habitats.

Figure 11: piping plover on sandy beach (courtesy Mary Scott, Birding America[33])

Tidal Mudflats

Extensive tidal mudflats are to be found in the Bay of Fundy region of the Gulf of Maine. Sediments in the upper areas of the Bay are derived from the erosion and deposition of the soft surrounding sedimentary rocks. The Minas Basin has sediments moved from the head of the Bay of Fundy. The combination of tidal movement and geology have created some of the world's largest mudflats.

Sediments in mudflats tend to stick together because of the small size and shape of particles, presence of diatoms, and large quantities of water. These are low oxygen environments. Increased sedimentation from increased precipitation and runoff may further reduce oxygen levels and preclude some species from surviving. Redistributed sediment can change the composition of mudflat substrates. Rapid sedimentation can also bury bottom dwelling species.

An increase in average precipitation or freshwater input from extreme events can reduce salinity rapidly. Freshwater does not run off near horizontal mudflats like a steep sloped rocky shore but rather infiltrates the sediment. This can cause great stress to saline-dependent organisms.

[33] http://www.birdingamerica.com/

Temperature also affects the physical nature of the mudflat. In extreme conditions, high temperatures can affect those organisms living in the mud by disrupting reproduction, feeding, and metabolic activities. High temperatures can also desiccate the upper mud layer and lead to wind-blown erosion. If there is also an increase in wind then the combined effect may not allow a recovery of species and irreversibly alter the physical characteristics of the mudflat[34].

Figure 12: Tidal mudflats in the Bay of Fundy
Photo: Sherman Bleakney

Salt Marshes

Salt marshes are habitats often associated with tidal mudflats that are dominated by halophytic grasses. They range from the lower intertidal zones to the upper high tide mark. Salt marshes are one of the most biologically productive ecosystems on the planet, with twice-daily submersion and regular input of nutrients and accretion of sediments.

> As seas rise, coastal habitats are subject to inundation, storm surges, salt-water intrusion, and erosion. If less sediment is available, marshes that are seaward of such structures may have difficulty maintaining appropriate elevations in the face of rising seas. Wetlands that are unable to accrete sufficient substrate as sea level rises will gradually convert to open water, even if there is space available for them to migrate inland, thereby eliminating critical habitat for many coastal species. In addition, landward migration of wetlands may replace current upland habitats that are blocked from migration … Habitat changes in response to sea-level rise and related processes may include structural changes (such as shifts in vegetation zones or loss of vegetated area) and functional changes (such as altered nutrient cycling). In turn, degraded ecosystem processes and habitat fragmentation and loss may not only alter species distributions and relative

[34] http://www.glf.dfo-mpo.gc.ca/os/bysea-enmer/mudflats-vasiere-e.php#physical_characteristics

> abundances, but may ultimately reduce local populations of the species that depend on coastal habitats for feeding, nesting, spawning, nursery areas, protection from predators, and other activities that affect growth, survival, and reproductive success. (Titus et al., 2009)

The problem of blockage of inland migration of salt marshes is particularly relevant to the areas in the Bay of Fundy that have been dyked. It is thought that 85% of salt marshes in the Bay have been lost to dyking, infilling, and tidal restrictions (Singh et al., 2007). If marshes are not able to move past a structural barrier the marsh may be lost to 'coastal squeeze'. The IPCC (Christensen et al., 2007) defines coastal squeeze as "The squeeze of coastal ecosystems (e.g., salt marshes, mangroves and mud and sand flats) between rising sea levels and naturally or artificially fixed shorelines, including hard engineering defences".

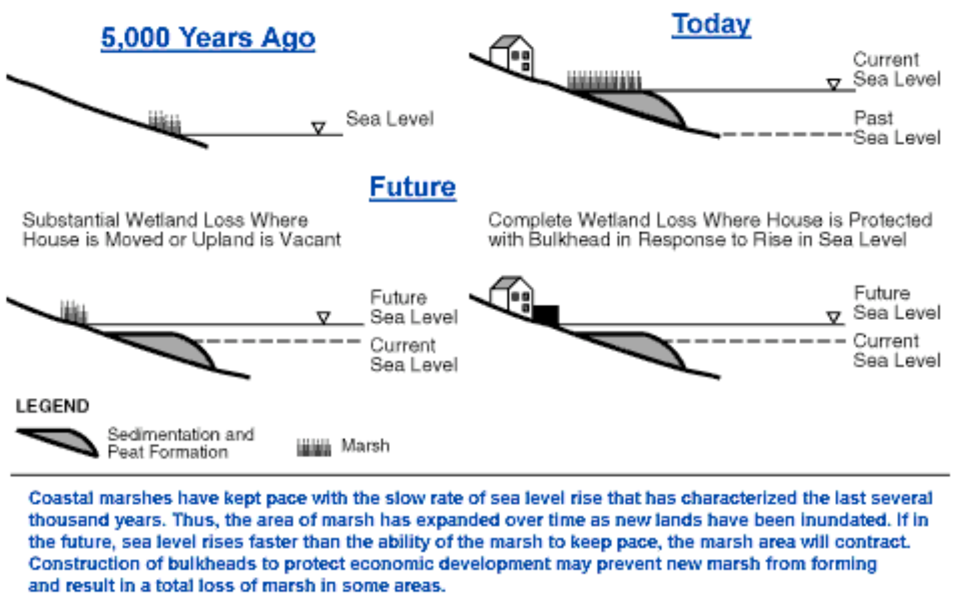

Figure 13: evolution of a coastal marsh under rising sea-level (Titus, 1991)

Figure 14: Sherman Marsh

Seagrass – Eelgrass

There are many submerged aquatic vegetation types throughout the GoM. The dominant species, Eelgrass (*Zostera marina)* lives in the low intertidal and subtidal environments. Eelgrass roots its rhizomes in substrates that range from pebbles, through coarse sand, to mud. Eelgrass is a valuable part of estuarine ecosystems because it traps sediments and nutrients, produces oxygen, stabilizes bottom sediments, and reduces wave energy. An increase in strength or frequency of waves could potentially dislodge the grasses from the seabed and leave the area vulnerable to an increased rate of erosion. Increased storm activity or precipitation will disturb sedimentation and increase turbidity. As eelgrass is sensitive to light limitation it will lose photosynthesizing ability.

It has been estimated that a 50 cm increase in water depth as a result of sea-level rise could reduce light penetration by 50 percent. This would result in a 30 to 40 percent reduction in seagrass growth in those areas due to decreased photosynthesis[35]. This would also lead to a loss of the species dependent on this specialised habitat.

Temperature increase also places eelgrass at a disadvantage to competing species. Although the tolerance range for eelgrass is large (0-30°C), prolonged high temperatures may favour more tropical plants and increase the number of pathogens. Slime mould can be a particularly destructive disease for *Z. Marina* and has in the past killed up to 90% of the species. High temperatures also lower the amount of dissolved oxygen in water and would be harmful to oxygen sensitive species living in this habitat.

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[35] CCSP 4.1 January 15, 2009 pg257 of 790 Final Report

Figure 15: eelgrass

Estuaries

*"*An estuary is a semi-enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea." (Pritchard, 1967). These are areas with marine and freshwater inundation. This provides a mixing of the water column and a constant influx of nutrients. Nutrients along with an abundance of sunlight make estuaries habitats with high primary productivity. Tomczak[36] categorizes estuaries as:

- **Salt wedge**. River output greatly exceeds marine input; there is little mixing, and thus a sharp contrast between fresh surface water and saline bottom water.

- **Highly stratified**. River output and marine input are more even, with river flow still dominant; turbulence induces more mixing of salt water upward than the reverse.

- **Slightly stratified**. River output is less than the marine input. Here, turbulence causes mixing of the whole water column, such that salinity varies more longitudinally rather than vertically.

- **Vertically mixed**. River output is much less than marine input, such that the freshwater contribution is negligible; longitudinal salinity variation only.

- **Inverse estuary**. Located in regions with high evaporation, there is no freshwater input and in fact salinity increases inland; overall flow is inward at the surface, downwells at the inland terminus, and flows outward subsurface.

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[36] http://www.es.flinders.edu.au/~mattom/IntroOc/notes/lecture12.html

- **Intermittent estuary**. Estuary type varies dramatically depending on freshwater input, and is capable of changing from a wholly marine embayment to any of the other estuary types.

Estuary types may change from one to another depending on the effects of climate change. The species that have evolved to each particular estuary type may not be able to adapt.

Sea-level rise will have an important impact on the nesting and feeding sites of birds. As sea-levels rise, coastal erosion may increase. Flooding will lead to salt water intrusion into rivers that have low salinity levels. Productivity of estuaries depends on the vertical mixing of water; therefore changes in the water column affect changes in the flora and fauna.

Figure 16: estuary under protection of U.S. Environmental Protection Agency

Kelp Beds

Although identification of coastal habitats at risk focuses on the low water mark and inland, kelp beds are worthy of mention. The ability of kelp, such as *Laminaria digitata,* to dissipate wave energy and provide ecological niches make kelp beds a valuable resource.

“Kelp beds form a distinct type of underwater habitat. While many different seaweeds live on rocky substrates in the Gulf of Maine, kelps ... create underwater forests with physical structure and layering similar to that of a terrestrial forest.”[37]

Kelp requires clear water, which means an increase in sedimentation due to surface run off from precipitation, or churning from storm wave action will affect photosynthesis and nutrient intake. Kelp attaches to solid structures so movement of substrate may dislodge

[37] http://www.gulfofmaine.org/habitatprimer/introduction.pdf

the holdfasts. Any increase in seawater temperature will adversely affect these algae as they are primarily found north of Cape Cod where the Labrador Current keeps the water temperature low.

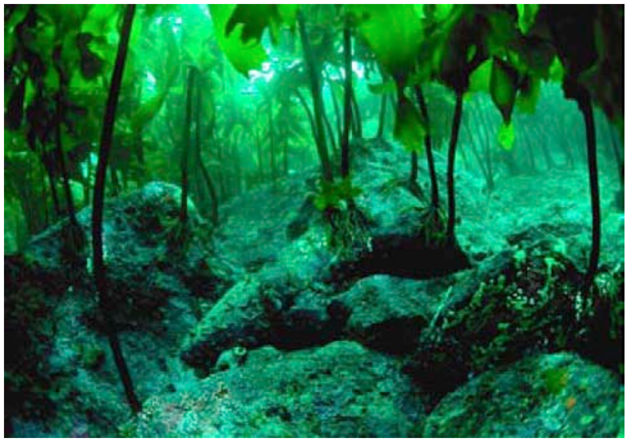

Figure 17: canopy of kelp: holdfasts shown on rocky substrate (Tyrrell, 2005)

Gap Analysis

During the research of this document a number of barriers to the free flow of information became apparent. Many members of the Gulf of Maine community have specific knowledge of their area but do not necessarily have knowledge of the relationship to or location of further information. Therefore it is pertinent to facilitate the sharing of knowledge in a standardized and user-friendly format. Below are issues relating to the categorization of authorities, standardization of terminology, knowledge gaps, and availability or accessibility of information.

1. Categorization of Authority and Responsibility

The GoMC transcends provincial, state, and national boundaries. The users and providers of information have a variety of backgrounds and there are many levels of responsibility for the physical and living environments. The multiple layers of governmental organisations and non-governmental organisations is very difficult for the average person to untangle. At times there are several sections or even departments carrying out work related to an area and holding responsibility for the ecosystems within. This does not appear to always be the most efficient way of conducting research or protecting resources. There is not even a standard between provinces or states in the naming of the same type of government department. Adding to the confusion when dealing with the GoM, is the issue of two federal governments, each with its own relevant agencies. Responsible authorities are not always located in analogous agencies on each side of the border. This makes it challenging to identify who is the equivalent person in each jurisdiction.

2. Definition Confusion

Occasionally the very definitions used are subject to interpretation. There is no single definition for terms used such as 'coast' or 'watershed'. For example, the Cambridge Dictionary of American English[38] defines coast as: "the land next to or close to the sea". Nelson[39] states that "coastal zones are continually changing because of the dynamic interaction between the oceans and the land". Therefore some ideas of coastal habitats, in particular to areas needed for protection, may be interpreted differently. How far from the land/sea boundary does a coast extend? There is a reference to varying coastal zones in the recommendations on the GoMC site. It states "Restore the four coastal marine habitat types: 1. riverine, 2. intertidal, 3. subtidal, including nearshore and offshore waters, and 4. beaches, sand dunes, and islands, using a regional strategy to prioritize projects."[40] This gives some guidelines for the purpose of standardization.

This is also true of the term watershed. However, there is a greater consensus in the North American community that the watershed includes the drainage basin and not just the division between basins. In this case the GoMC watershed includes all the feeder tributaries and incorporates terrestrial areas reaching into Québec (2 700 mi^2 or 7 000 km^2) (Cullen and Lines, 2008). On the GoMC website there is occasionally an option to link to a dictionary. This may be the first step in creating a glossary of terms agreed to by the GoM members.

Measurement systems also differ. Canada primarily uses the SI units of measurement but material from the United States may be exclusively Imperial. This can create difficulties in comparisons and understanding.

3. Scientific Study: Fragmentation of Information

Although there is a plethora of information, it is very fragmented with diverse levels of detail. Some work is so broad as to be ineffective except as comparison of the GoM to other biomes (e.g. Commission for Environmental Cooperation watershed map[41]); some work is extremely detailed and specific to a limited area only (e.g. Government of Canada sea-level rise studies for sections of Prince Edward Island [McCulloch et al., 2002] and New Brunswick [Daigle et al., 2006]). Generally, there has been a great deal of study done in relation to climate change worldwide. Recently there has been an increase in interest in how climate change is affecting coasts. The EPA has recently released a study titled 'Coastal Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region' (Titus et al., 2009). Although this

[38] http://dictionary.cambridge.org/Default.asp?dict=A

[39] http://www.tulane.edu/~sanelson/geol204/coastalzones.htm retrieved 3-02-09

[40] www.gulfofmaine.org/council/internal/documents/gom_synthesis_rec_meet_doc_process.doc

[41] http://www.cec.org/trio/stories/index.cfm?ed=17&ID=185&varlan=english retrieved 14-02-09

document is focussed on the mid to lower latitudes of the United States, there is a lot of information that can be extracted and applied in general terms to the Gulf of Maine. This, however, points to a gap in the knowledge base on the GoM itself. There are very few completed studies looking specifically at the impact of climate change on the GoM coasts. There have been a few papers published relating to habitat restoration projects but none is comprehensive for the GoM. The studies that have been carried out have shown predictions of the impacts of climate change varying greatly depending on a number of factors: coastal geomorphology, hydrology, habitat type, land use, etc. Because of the complexity of variables, the predictions of impacts are difficult to generalize and more work needs to be done to study common features so as to be more useful to users in understanding possible effects. There are now private companies and charities setting up their own prediction software and vulnerability indices (eg. Natureserve) in order to fulfil the demand by decision makers on the future of areas in relation to climate change. Again this is a disjointed approach and would be better served if the groups doing this work were able to pool their resources.

4. Map Varieties

Maps specific to the Gulf are mostly found on the GoMC website. In general there are serious problems with standardizations in maps. This appears to be a legacy of the evolution of maps, from various authorities, to the modern more global versions using GIS. Maps are to be found in municipal, provincial, state, and federal libraries as well as on-line. Most maps are now being converted to an electronic format and are available on the Internet. However, there are still a large number that can only be accessed in hard copy in the libraries (or personal bookshelves) concerned. Even with access, the maps are not always comprehensive. There are different scales (cross-over of mapped areas is especially difficult to merge if the scales are different); voids in mapped areas (where, to overcome this, GIS scientists need to manipulate the data using educated guesses but not always maintaining integrity despite best efforts); for GIS scientists, difficulty in finding equivalent levels in Metadata out of which to create maps; out of date publications (this is especially true of habitat type maps where human development has occurred faster than the updating of the maps); and, as mentioned, access problems.

5. Access to Information

The Gulf of Maine website is the most comprehensive site on issues relating to the GoM. The organisations that associate with the GoMC and provide links together are as comprehensive a collective as possible. There are references to this site in documents written on many related subjects. This is the easiest method to get up to date information on work related to the GoM. However, availability of studies done by non-GoMC related scientists is limited. The GoMC Knowledgebase portal[42] is the

[42] http://references.pearl.maine.edu/kb/search.asp

closest search engine for this information but the material is extremely limited. There are a number of journals referenced when using meta-search engines and it would be useful if the average user had access to these. For research purposes the Knowledgebase assumes the individual has access to all written information. This is a problem when journals require subscription, and access is limited to the physical presence of the researcher in the particular library that has such subscription. It is unclear even which institutes have access to which journals and whether the average user would be allowed, either freely or through payment, to have access to their libraries. This may mean that duplicate studies are being conducted and each party is unaware of the other.

Further Work

In order to address these issues there are several steps that may be taken:

1. **Categorization of Authority and Responsibility**

- To better comprehend the vastness and complication of the multiple organisations involved in the GoM, an organisational chart would be useful. If possible it could show tiers and identify counterparts in each jurisdiction.

2. **Definition Confusion**

- Create a glossary of terms agreed upon by all members of the communications group. Glossaries are available in major works such as the CCPS (EPA) Final Report or on intergovernmental websites such as IPCC.
- Include a thesaurus, which acknowledges the different terminology which is standardised to some extent within different regions. This could be structured similar to taxonomy used in science with an agreed term and common usages.

3. **Scientific Study: Fragmentation of Information**

- Initially, further study could be done on the specifics of each habitat. This background paper only gives an overview of possible impacts of climate change but this could be expanded. Input from habitat experts in each field could be solicited. They could give account of the effects they may have already witnessed (or have historical knowledge of) and give a more detailed explanation of the possible consequences of each climate indicator. Case studies could be included. Further research could also identify further sources of information.
- More detailed scientific study of the coast, such as that conducted by Environment Canada (using LiDAR) and the detailed analysis found in the CCPS Final Report. Use of these advanced technologies would be the most comprehensive way to get an overview of the entire area. This of course is an expensive and time consuming option and one to be taken over the long term.

- A systematic approach of information gathering. Research of availability of information for each segment of the coastline and watershed. Using a grid system of reasonable size (to be determined by experts in spatial disciplines), conduct a search of each segment using terms and key words. Define a set of criteria as search parameters (e.g. habitat types, surficial geology, flooding risk etc.) and have a comprehensive and comparable guide to the entire area. This should help highlight any outstanding omissions.

4. Map Varieties

- Although the legacy of maps and the difficulties with metadata is essentially out of the control of the users, the creation of an interactive map (through GOMMI) would be extremely useful for helping predict, given various situations and worst-case scenarios (such as those seen during the Saxby Gale[43]), what may occur in the future. Identification of the main threats to an area would be a starting point for decision makers. The map could use parameters such as geology, topography, hydrology, habitat type etc. against common climate change indicators. Attempts have been made to create such maps but as can be seen there is no standardisation of methods so it is difficult to make comparisons.

5. Access to Information

- Create a portal for Climate Change where information is in a user-friendly form, perhaps specific to area or habitat type, with links to relevant information. Within this there could be:
  - standardized factsheets on biotic and abiotic factors of specific areas;
  - a practical guide for decision makers and concerned individuals;
  - the interactive maps; and
  - a communication section (forum) where people could post what they are working on, share information on topics, and identify areas that, with their local knowledge, they know may be at risk or show signs of damage from climate change now.
- The GoMC could become part of a consortium such as those some universities have begun to set up. An example is the Novanet system in Nova Scotia. Libraries at universities and other higher education institutions have opened intranet access to students across the province. This has increased the availability of journals by thousands. Dalhousie University had subscriptions to approximately 5 000 journals, but now has a database of about 25 000. Perhaps

[43] http://www.atl.ec.gc.ca/weather/hurricane/hurricanes5.html#1869

an accredited member of the Gulf of Maine community could have access to information in libraries across borders if the main providers would agree to a shared extra cost.

- Further detailed scientific study such as that conducted by Environment Canada (using LiDAR) and the Environmental Protection Agency.

Conclusion

This report represents a starting point for those interested in understanding the possible impacts of climate change on the various coastal habitats in the Gulf of Maine Region. Although it is not an explicit guide on how to incorporate climate change considerations into coastal habitat decisions, it can help such decision makers start to know what questions they need to ask regarding climate change and their particular habitats of interest. The authors hope that it will be built upon in the future and grow to become a sought out source of information for all those concerned about the impacts of climate change on coastal habitats around the Gulf of Maine.

Many sources of general climate change information were identified, but much more work needs to be done on the impacts of climate change on the specific habitats of the Gulf of Maine. As knowledge of these issues expands, various auspices of the GoMC (web site, Knowledgebase, GOMMI, etc.) could become the repositories of such information, allowing researchers, decision-makers, and other interested parties to access the latest knowledge on this subject from one credible source.

References

Borns, H.W. Jr., L.A. Doner, C.C. Dorion, G.L. Jacobson, Jr., M.R. Kaplan, K.J. Kreutz, T.V. Lowell, W.B. Thompson, and T.K. Weddle, (2004). The deglaciation of Maine, U.S.A. 89-109

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, (2007). “Regional Climate Projections.” In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA, pp. 847-940.

Clean Air - Cool Planet and C. Wake (2005). *Indicators of Climate Change in the Northeast 2005*. 32 pp. http://cleanair-coolplanet.org/information/pdf/indicators.pdf.

Cullen and Lines (2008). “Discussion Paper for Climate Change Impacts and Habitat Restoration on the Gulf of Maine”. Climate Change Network, Gulf of Maine Council on the Marine Environment, 29 p.

Daigle, R., D. Forbes, G. Parkes, H. Ritchie, T. Webster, D. Bérubé, A. Hanson, L. DeBaie, S. Nichols, and L. Vasseur [eds.] (2006). *Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick*. Environment Canada, 611 p.

Hildebrand, L. and P. Eaton (1990). “A Profile of Important Estuaries in Atlantic Canada” Environmental Quality Division, Conservation and Protection, Environment Canada, Atlantic Division Map and associated information

IPCC (2007). *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA, 996 p.

Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush (eds.) (2008). *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Government of Canada, Ottawa, ON, 448 p.

McCulloch, M.M., D.L. Forbes, and R.D. Shaw (2002). *Coastal Impacts of Climate Change and Sea-Level Rise on Prince Edward Island*. Geological Survey of Canada, Open File 4261.

McKenzie, K., C. Tilburg, and L. Vescovi (2008). "Understanding ecosystem changes in the Gulf of Maine marine environment through climate change indicators." Gulf of Maine Council on the Marine Environment.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao (2007). "Global Climate Projections." In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)], Cambridge University Press, Cambridge, UK and New York, USA, pp. 747-845.

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe (2007). In: "Coastal systems and low-lying areas." *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, and New York, USA, pp. 315-356.

Pritchard, D.W. (1967). "What is an estuary: physical viewpoint" A.A.A.S. Publ. 3-5

Schoch, C.G. and M.N. Dethier (1996). "Scaling up: the statistical linkage between organismal abundance and geomorphology on rocky intertidal shorelines". *Journal of Experimental Marine Biology and Ecology*, 201:37-72.

Shaw, J. R.B Taylor, D.L. Forbes, M.H. Ruz, and S. Solomon (1998). *Sensitivity of the coasts of Canada to sea-level rise* Geological Survey of Canada Bulletin 505

Singh, K., B.B. Walters, and J. Ollerhead (2007). "Climate Change, Sea-Level Rise and the Case for Salt Marsh Restoration in the Bay of Fundy, Canada" *Environments Journal* 35

Titus, J.G. and C. Richman (2001). "Maps of Lands Vulnerable to Sea Level Rise: Modeled Elevations along the U.S. Atlantic and Gulf Coasts". *Climate Research*.

Titus, J.G., K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (2009). *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. Climate Change Science Program and the Subcommittee on Global Change Research, U.S. Environmental Protection Agency, Washington D.C., USA. 242 p.

Tyrrell, M.C. (2005). *Gulf of Maine Marine Habitat Primer*. Gulf of Maine Council on the Marine Environment, www.gulfofmaine.org. 54 p.

Wake, C., L. Burakowski, G. Lines, K. McKenzie, and T. Huntington (2006). *Cross Border Indicators of Climate Change over the Past Century: Northeastern United States and Canadian Maritime Region*. 31 p. http://www.gulfofmaine.org/council/publications/cross-border-indicators-of-climate-change.pdf

Union of Concerned Scientists (2006). *Climate Change in the U.S. Northeast* A report of the Northeast Climate Impacts Assessment, Cambridge, MA, 52 p.

Appendix: Summary of climate change impacts on key coastal habitats in the Gulf of Maine

	Climate Change Impacts			
Habitat Type	*Temperature*	*Precipitation*	*Storms*	*Sea-Level Rise*
Rocky – Intertidal and Subtidal	• increase in atmospheric temperature • loss of coastal terrestrial species as part of the food web • increase in sea surface temperature • loss of mobile species from area to colder climates • loss of sessile species from habitat • increased competition from warmer marine species	• increased precipitation can cause washout of pollutants from river systems and non-point sources • bioaccumulation of toxins in marine organisms and biomagnification in higher trophic levels • increased sediments deposited in areas surrounding estuaries • change in habitat substrate – mobile species move and immobile die • increased flow of fresh water causing dilution of saline water in shallow coastal areas and estuaries	• intense storms can cause kelp beds and other algaes to become dislodged • loss of seaweed species and loss of habitat type and species dependent on this • frequency of storms cause disturbance in the ecosystem which does not allow recovery time • species unable to survive recovery period move or die out	• water level rises faster than species can adapt • mobile species move up shore and immobile species numbers decline • increased flooding inland • loss of rocky habitat • loss of species from rocky intertidal zones • loss of habitat due to contact with coastal development • change in patterns of currents • change in nutrient availability • sedimentation due to movement of unconsolidated material from other coastal locations

	Climate Change Impacts			
Habitat Type	*Temperature*	*Precipitation*	*Storms*	*Sea-Level Rise*
		• loss of esturine and marine organisms • increased erosion • loss of habitat		• increased erosion • loss of habitat
Dunes and Beaches	• increased temperature • loss of protective winter ice cover • increased winter erosion	• increased runoff across beaches and dunes • washing away of dune structures and loss of beach sediment	• increased wind and storms cause increased erosion - sand destabilised and lost • beachgrass has difficulty establishing or is torn away, thus loss of habitat	• loss of beach zone due to flooding • areas for nesting birds lost
Tidal Mudflats	• increased sea surface temp • change in composition of species • favourable conditions for invasive species	• increased precipitation in the form of rain • washing away of detritus • extreme precipitation events • rapid dilution of minerals • increased and redistributed sediments • disruption to bottom dwelling organisms, particularly	• increased wave action • alteration of small ripples and disruption to burrowing animals • washing away of detritus • Increased sedimentation • difficulty for burrowing organisms to obtain oxygen • suspension and filter feeders have	• low water mark moves inland • loss of nesting and feeding grounds for shorebirds • mobile species migrate in land or die if flooding occurs too rapidly • sessile species decline or die out • redistribution of sediments • disruption to bottom dwellers

	Climate Change Impacts			
Habitat Type	*Temperature*	*Precipitation*	*Storms*	*Sea-Level Rise*
		invertebrates	difficulty obtaining nutrients	• loss of mudflat if inland migration halted at a barrier
Salt Marshes	• increased atmospheric and sea surface temp • change in composition of species – may provide more ideal conditions for invasive species	• faster channel flow • sediment not able to settle in marsh • decreased salinity	• erosion of seaward edge • loss of marsh at a faster rate than replacement • reduction of species • increased wind • salt marsh meadows erode rapidly	• erosion of outer boundary • problem if marsh is not able to move horizontally due to a barrier causing 'coastal squeeze' • loss of species of fish, birds, and invertebrates • flooding occurs faster than accretion rates • loss of protection for land from storm surges
Seagrass – Eelgrass	• increased water temperature • disadvantage from competing aquatic organisms native and invasive • dissolved oxygen deficits enhanced • increased pathogen	• increased sedimentation (and turbidity) • reduction of sunlight penetration in shallow waters • reduced photo-synthesis • reduction of ability to	• increased turbidity • reduction of sunlight in shallow waters • reduced photo-synthesis • storms dislodge substrates • create 'patches' of grass with less	• flooding inland • due to slow growth rate, eelgrass unable to adapt • loss of habitat and dependent species • reduction in water quality in area

Identifying Coastal Habitats at Risk from Climate Change Impacts in the Gulf of Maine

	Climate Change Impacts			
Habitat Type	*Temperature*	*Precipitation*	*Storms*	*Sea-Level Rise*
	exposure • reduction in reproduction	absorb nutrients • increased runoff rich in nitrogen • decreased productivity • loss of habitat	ecological value	
Kelp Beds	• increase in invasive and competing species • increased vulnerability of kelp to dislodging	• increased sediment and turbidity • reduction in photo-synthesis	• storms rip kelp from beds • reduction of primary productivity of food web for the area	• low water mark moves vertically or inland • decreased availability of sunlight • reduced grow rate
Estuaries	• reduction of vertical mixing of water column • reduction of availability of nutrients to estuarine producers • decrease in dissolved oxygen in deeper water • loss of higher trophic species	• freshwater runoff containing NPK • increased eutrophication and decreased water quality • increased sedimentation • reduction of light • reduced photo-synthesis and productivity	• frequent storms • increased erosion	• increased height of tides • flooded nesting and feeding sites • salt water intrusion • reduction of species with low tolerance to salinity