**Supplemental Material**

**Projected Changes to Temperature, Sea Level Rise and Storms for the Gulf of Maine region in 2050**

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**Table S-1. Short list of potential climate change impacts in the Gulf of Maine due to changing air temperatures (*Dupigny-Giroux et al., 2018; Lemmen et al., 2014; Savard et al., 2016; Zhang et al., 2019)***

|  |  |
| --- | --- |
| **Climate Element** | **Impact** |
| **Higher average temperatures** | More frequent drought conditions due to increased rates of surface evaporation and loss of water from plants caused by higher temperatures |
| Earlier and longer fire seasons due to hotter and drier conditions |
| Increased weed and pest pressure due to a longer growing season and warmer winters |
| Decline in freshwater quality due to more frequent algal blooms in warmer surface waters of large lakes |
| Earlier river ice breakup and freshet flow in spring due to earlier peaks in spring snowmelt |
| Changes to hydrological power production due to changes in timing of spring streamflow |
| Impacts to winter recreation industries due to warmer (and shorter) winter conditions |
| Impacts to rural industries such as logging and maple syrup production due to warmer winter conditions |
| Possible changed patterns of infectious and vector-borne diseases due to warmer conditions |
| **More frequent and severe heat events** | Increases in associated health-related impacts, such as heat stroke and exhaustion and costs associated with more frequent and severe heat-related events |

**Table S-2. Short list of potential climate change impacts in the Gulf of Maine due to changing sea level (*Atkinson et al., 2016; Savard et al., 2016; Greenan et al., 2018; Bush et al., 2014; Sweet et al., 2017a)***

|  |  |
| --- | --- |
| **Climate Element** | **Impact** |
| **Higher average water levels** | More frequent and severe flooding events |
| Loss of areas providing physical protection (e.g., wetlands and dykes) |
| Increased permanent inundation due to higher average water levels |
| Increased saltwater intrusion within coastal rivers and aquifers |
| Flooding of wetlands and ecosystem changes that will affect the flora and fauna, causing the loss of habitat for fish, birds, plants and many other species |
| **More frequent and severe coastal flooding** | Flooding of highways causing isolation of coastal communities |
| Accelerated erosion of coastal farmland, housing or recreation areas |
| Damage to coastal infrastructure used for fisheries, such as ports, wharves, piers and fish plants |
| Damage to tourism infrastructure (e.g., wharves and coastal properties) and cultural resources |
| Impacts to existing and proposed coastal export terminals |

**Table S-3. Short list of potential climate change impacts in the Gulf of Maine due to changing storm factors (*Oppenheimer et al., 2019*; *Savard et al., 2016; Forbes et al., 2004; Shackell et al., 2013; Rapaport et al., 2017; Federal Emergency Management Agency, 2013*)**

|  |  |
| --- | --- |
| **Climate Element** | **Impact** |
| **Increase wave action and storm surge** | Dangerous conditions for ocean transport and coastal infrastructure becoming less usable due to increased wave action |
| Increased damage to coastal infrastructure including the potential for coastal communities to become inaccessible |
| Increased demand for emergency response and search and rescue services due to increase in storm-driven winds and wave action |
| Potential for increased severe storm surge and wind-driven damage due to more intense tropical cyclones and winter storms |
| More intense tropical cyclones may threaten human health and safety and cause damage to infrastructure, in turn elevating insurance costs and having effects on the tourism industry |
| Loss of productivity to the transportation sector with a consequential economic impact due to storm-related disruptions |
| Destabilization of the coast within small dunes |
| **Precipitation** | Extreme precipitation events can cause flooding, erosion and damage to infrastructure such as roads and buildings |
| Potential for less snow occurrence and a shorter snow season leads to possible effects on water resources, ecosystems and the economy |
| More winter season rain could increase rain-on-snow events which can have an impact on snow loads resulting in compromised infrastructures like rooftops and cause damage to roadways including extensive washouts |

# **Text S-1. Initiatives with a focus on addressing climate change resilience, adaptation and education within the Gulf of Maine**

With the increased concern regarding the potential impacts associated with rising sea levels and intensifying weather events caused by climate change, federal governments have begun supporting provincial/state level projects in coastal regions that focus on reducing the impact of natural disasters, such as coastal flooding:

* In early 2019, the province of Nova Scotia and the Canadian Federal government (through the Disaster Mitigation and Adaptation Fund) announced funding for two projects in Nova Scotia to reduce the impact of coastal flooding along the Bay of Fundy and Minas Basin. In the face of rising tides and storm surge events, these projects will mitigate damage to the region’s ecosystems and municipal infrastructure and provide flood protection for residents and businesses, historical and world heritage sites, Indigenous communities and thousands of hectares of farmland.
* The Canadian Department of Fisheries and Oceans (DFO) developed the **Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT)**. This information is intended to provide advice to DFO Small Craft Harbours (SCH) sectors but can also be utilized more broadly by coastal planners. Projections of sea level allowances, or vertical change to infrastructure necessary to accommodate for changing sea levels due to climate change, are calculated (*Zhai et al., 2014; 2015*). The output is given in 10-year intervals (including 2050) over the 21st century period and available through an online interface (CAN-EWLAT) for tide gauge sites along the east coast of Canada and parts of the northeast US (<http://www.bio.gc.ca/science/data-donnees/can-ewlat/index-en.php>).
* In the Northeastern United States, the federal government (through the Federal Highway Administrations "Green Infrastructure Techniques for Coastal Highway Resilience" project) funded a pilot project in which the Maine and New Hampshire Departments of Transportation partnered to study future sea-level rise and storm surge impacts on portions of state coastal highways and to develop nature-based solutions that address vulnerabilities. The final report is available at <https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/northeastern/>).
* The **New Hampshire Coastal Risk and Hazards Commission** (<https://www.nhcrhc.org/>) was established in 2013 to assist the state and coastal municipalities prepare for climate change and the associated coastal flooding risks. The commission is comprised primarily of representatives from all three levels of government and includes science and technical advisory panel members. An extensive report overseen by the Commission (*NH Coastal Risk and Hazards Commission, 2016*) along with the recent scientific foundation report published by Wake et al. (2019), provide guidance and recommendations that will help New Hampshire enhance coastal community and watershed resilience to the effects of storm surge, sea-level rise, and extreme precipitation.
* At the international level, the **International Joint Commission (IJC)** was formed between Canada and the US under the 1909 Boundary Water Treaty to prevent and resolve disputes along boundary or transboundary waters. The Climate Adaptation Working Group (CAWG) within the IJC developed a Climate Change Guidance Framework Pilot Project in 2017 to recommend an approach to addressing climate change for the Boards within the IJC (*Bernstein et al., 2017*). The St. Croix River, which forms the boundary water between New Brunswick and Maine, was used in the pilot. An analysis was conducted to estimate how climate change may alter the flows and levels within the watershed, and particularly how these changes may affect compliance with IJC Orders of Approval for structures (i.e. dams) along the river. The results showed a generally warmer and wetter climate for the 2036-2065 period with the possibility of the river flows and levels exceeding the tolerances of the current parameters. With these projections, the International St. Croix River Watershed Board has recognized the need to develop and implement a plan in response to climate change. This is an example of science informed decision-making, resulting in action.
* In 1989, the Gulf of Maine Council on the Marine Environment (<https://gulfofmaine.org/public/gulf-of-maine-council-on-the-marine-environment>) was created by the governments of Maine, Massachusetts, New Brunswick, New Hampshire and Nova Scotia as a Canadian-American regional partnership to engage governmental and nongovernmental representatives in an effort to foster environmental health and community well-being throughout the GOM. A Climate Change Network Task Force within the Gulf of Maine Council Working Group spearheaded a 2006 report “Cross Border Indicators of Climate Change” (<https://www.gulfofmaine.org/council/publications/cross-border-indicators-of-climate-change.pdf>), intended for use as an advisory tool for the Council and the public for determining the appropriate emphasis to place on the impacts of climate change. Since that time, the Climate Change Network Task Force has continued to use this international partnership to move forward climate change issues important to the GOM.

There are also many other initiatives at the municipal and provincial/state levels that have a common goal to investigate local sea level rise impacts and to educate and engage the public on adaptation and mitigation efforts. Although such climate change adaptation initiatives in a few of the larger metropolitan areas discussed above have received funding and are well advanced, for much of the GOM region such initiatives remain at the grass-roots level and tend to be underfunded or in their infancy stage.

The following is a sampling of some of the municipal and provincial/state level initiatives currently taking place throughout the GOM region:

* In the larger metropolitan areas within the GOM, climate change resilience studies and programs can be well funded and are well advanced. For example, **Climate Ready Boston** (<https://www.boston.gov/departments/environment/climate-ready-boston>) is an initiative, led by the City of Boston, to work with the community and other partners with the goal of helping Boston and its metro region plan for the impacts of climate change and build a resilient future. This well-funded and leading-edge initiative features four components including updated climate projections, vulnerability assessments, focus areas and climate resilience initiatives. As Boston moves towards developing a city adaptation plan, the city worked with the Boston Research Advisory Group (BRAG) team, overseen by the University of Massachusetts-Boston, to produce a Climate Projections Consensus Report (*Douglas et al., 2016*). City-wide and neighborhood-scale vulnerability assessments have also been conducted and various neighborhood resilience plans have been put in place, all of which are publicly available.
* The provincial governments of Newfoundland and Labrador, Nova Scotia, Prince Edward Island, and New Brunswick, along with regional stakeholders including nonprofits, tribal governments, and industry are working together to address regional climate change impacts through the **Atlantic Climate Adaptation Solutions (ACASA) Project**. The ASCASA website (<https://atlanticadaptation.ca/>) provides information and access to projects, publications, toolkits and other research outputs that aim to help Atlantic Canadians better prepare for, and adapt to, climate change.
* The **Ecology Action Centre (EAC)** is a member-based environmental charity in Nova Scotia which takes leadership on critical environmental issues from biodiversity protection to climate change to environmental justice.  The EAC and their Coastal Adaptations branch have been working alongside government in support of legislation for coastal protection. In addition, EAC has an Educating Coastal Communities About Sea-level Rise (ECoAS) Project which is designed to make useful climate change information available to coastal communities in Atlantic Canada and to provide education on the need for planning for future sea-level rise impacts. As part of this initiative, EAC has teamed up with Fisheries and Oceans Canada to create an informative website – [www.sealevelrise.ca](http://www.sealevelrise.ca) – with sea-level rise resources for coastal residents, fishers, and municipalities that are specific to Atlantic Canada and British Columbia.
* Relative sea-level rise projections for Atlantic Canada are expected to be higher than the global average (*Greenan et al., 2018*). The Halifax Regional Municipality within Nova Scotia, being the largest urban centre within Atlantic Canada, has formed a group “**HalifACT 2050 – Acting on Climate Together**” to develop a plan to reduce emissions and adapt to climate change. The group aims to engage the public as well as stakeholders to raise awareness about climate change and help develop and support climate actions to reduce emissions and to ensure communities and individuals are more resilient to the impacts of climate change. Community involvement to date includes an interactive map where locals can highlight changes they have observed due to climate change, for example changes and damages due to coastal erosion, storm surge, wind and flooding (<https://www.shapeyourcityhalifax.ca/haliFACT2050/maps/map-hazards-in-your-community>).

**References**

Atkinson, D.E., Forbes, D.L. and James, T.S. (2016): Dynamic coasts in a changing climate; *in* Canada’s

Marine Coasts in a Changing Climate, (ed.) D.S. Lemmen, F.J. Warren, T.S. James and C.S.L. Mercer

Clarke; Government of Canada, Ottawa, ON, p. 27-68.

Bernstein, A., Brown, C., Taner, M.U., and Werick, B. International Joint Commission (2017) Climate Change Guidance Framework Pilot Project (p. 53).

Bush, E.J., Loder, J.W., James, T.S., Mortsch, L.D. and Cohen, S.J. (2014): An Overview of Canada’s

Changing Climate; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation,

(ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON, p. 23-64.

Douglas, E., Kirshen, P., Hannigan, R., Herst, R., Palardy, A., DeConto, R., … Ruth, M. ( 2016). Climate Change and Sea Level Rise Projections for Boston: the Boston Research Advisory Group Report (p. 54). Boston, MA: Climate Ready Boston.

Dupigny-Giroux, L.A., E.L. Mecray, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills,

E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell, 2018: Northeast. In *Impacts, Risks, and Adaptation in the United States: Fourth*

*National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program,

Washington, DC, USA, pp. 669–742. doi: 10.7930/NCA4.2018.CH18

Federal Emergency Management Agency. Snow Load Safety Guide. FEMA P-957, January 2013. P. 2-6.

Forbes, D. L., Parkes, G. S., Manson, G. K., & Ketch, L. A. (2004). Storms and shoreline retreat in the

southern Gulf of St. Lawrence. *Marine Geology*, 210(1-4), 169-204. doi:10.1016/j.margeo.2004.05.009.

Greenan, B.J.W., James, T.S., Loder, J.W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R.C., Gilbert, D., Tremblay, J-E., Wang, X.L. and Perrie, W. (2018): Changes in oceans surrounding Canada; Chapter 7 *in* (eds.) Bush and Lemmen, Canada’s Changing Climate Report; Government of Canada, Ottawa, Ontario, p. 343–423.

Lemmen, D.S., Johnston, M., Ste-Marie, C. and Pearce, T. (2014): Natural Resources; *in* Canada in a

Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen;

Government of Canada, Ottawa, ON, p. 65-98.

NH Coastal Risk and Hazards Commission, 2016. “Preparing New Hampshire for Projected Storm Surge, Sea-Level Rise and Extreme Precipitation.” <http://www.nhcrhc.org/wp-content/uploads/2016-CRHC-final-report.pdf>.

Oppenheimer, M., Glavovic, B.C., Hinkel, J., van de Wal, R., Magnan, A.K., Abd-Elgawad, A., Cai, R.,

Cifuentes-Jara, M., DeConto, R.M., Ghosh, T., Hay, J., Isla, F.,Marzeion, B., Meyssignac, B., and

Sebesvari, Z. (2019): Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities.

*in: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C.

Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M.

Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Rapaport, E., Starkman, S., and Towns, W. (2017). Atlantic Canada. *In* K. Palko and D.S. Lemmen

(Eds.), Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 218-262).

Ottawa, ON: Government of Canada

Savard, J.-P., van Proosdij, D. and O’Carroll, S. (2016): Perspectives on Canada’s East Coast region; *in*

Canada’s Marine Coasts in a Changing Climate, (ed.) D.S. Lemmen, F.J. Warren, T.S. James and C.S.L.

Mercer Clarke; Government of Canada, Ottawa, ON, p. 99-152.

Shackell, N. L., Greenan, B. J. W., Pepin, P., Chabot, D., Warburton, A., & Canada. Department of

Fisheries and Oceans. (2013). *Climate change impacts, vulnerabilities and opportunities analysis of the marine Atlantic Basin.* Ottawa: Fisheries and Oceans Canada.

Sweet, W.V., R. Horton, R.E. Kopp, A.N. LeGrande, and A. Romanou (2017a). Sea level rise. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I [*Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 333-363, doi: 10.7930/J0VM49F2

Wake, C., Knott, J., Lippmann, T., Stampone, M., Ballestero, T., Bjerklie, D., Burakowski, E., Glidden, S., Hosseini-Shakib, I., Jacobs, J. (2019). New Hampshire Coastal Flood Risk Summary – Part I: Science. Prepared for the New Hampshire Coastal Flood Risk Science and Technical Advisory Panel. Report published by the University of New Hampshire, Durham, NH.

Zhai, L., Greenan, B., Hunter, J., James, T., Han, G., Thomson, R., . . . Bedford Institute of Oceanography. (2014). *Estimating sea-level allowances for the coasts of Canada and the adjacent united states using the Fifth Assessment Report of the IPCC*. Dartmouth, NS: Bedford Institute of Oceanography.

Zhai, L., Greenan, B. J. W., Hunter, J., James, T. S., Han, G., MacAulay, P., & Henton, J. A. (2015). Estimating sea-level allowances for Atlantic Canada using the Fifth Assessment Report of the IPCC. *Atmosphere-Ocean*, 53(5), 476-490. doi:10.1080/07055900.2015.1106401

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G.,

Kharin, V.V. (2019): Changes in Temperature and Precipitation Across Canada; Chapter 4 *in* Bush, E. and Lemmen, D.S. (Eds.) Canada’s Changing Climate Report. Government of Canada, Ottawa, Ontario,

pp 112-193.