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CLIMATE CHANGE AND THE COASTS OF MARITIME CANADA: EXPECT THE PREVIOUSLY UNEXPECTED

JEFF OLLERHEAD[1]

[1]Department of Geography and Environment
Mount Allison University, Sackville, NB E4L 1E4

Hurricane Fiona battered the Canadian Maritime provinces (New Brunswick – NB, Nova Scotia – NS, and Prince Edward Island – PEI) on 24 September 2022. It was a record-breaking storm in several regards. At St. Peters, PEI (Climate ID 8300562), the barometric pressure dropped to 95.23 kPa and wind gusts of up to 140 km/hr from the north were recorded. The storm surge was at least 2 m (Mulligan *et al.* 2023) and news media reported on widespread damage to coastal infrastructure and significant coastal erosion. In the following weeks, I visited several sites in PEI National Park and NB (the Shediac and Bouctouche areas) to survey the damage. The impacts of Hurricane Fiona were readily apparent at all north-facing coastal sites visited (Fig 1). So, was Fiona 'unprecedented'? Do the impacts of Fiona represent the future for the coasts of Maritime Canada? As it turns out, this is a difficult question to answer, primarily because by the time we have sufficient data from major storms to draw statistically significant conclusions, it will be too late to adopt some solutions/responses. We must therefore rely on computer models, data from other regions, and on our own observations to judge what we might expect in the coming decades at our Maritime coasts.

Just as Fiona battered PEI in 2022, Hurricane #5 battered PEI in 1923 (MacEachern 2022, Mathew *et al.* 2010). Damage from Hurricane #5 was widely reported at the time in the newspapers of the day. Wharves were damaged, bridges and rail lines washed away, barns flattened, and so on. To the best of my knowledge, the storm surge associated with Hurricane #5 produced catastrophic overwash along the whole length of what is now the Greenwich Dunes section of PEI National Park, which is about 10 km west of St. Peters (Mathew *et al.* 2010). The 1936 aerial photos show complete destruction of all

* Author to whom correspondence should be addressed: jollerhead@mta.ca

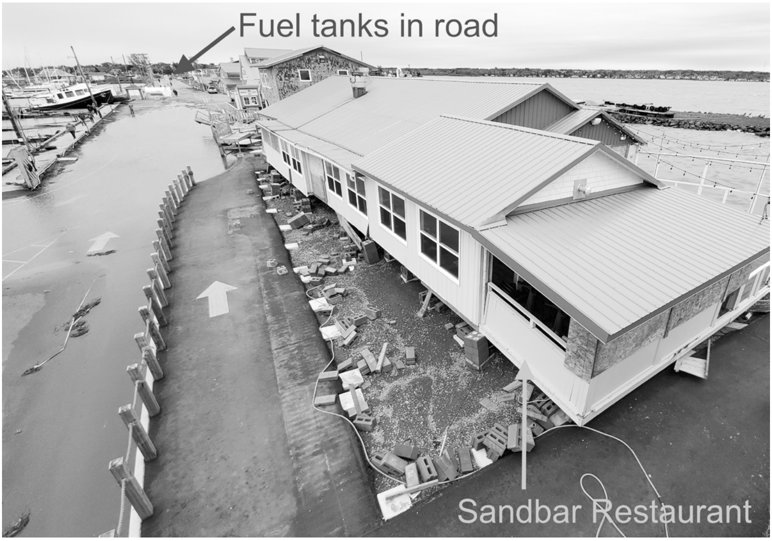

Fig 1 **The Pointe-du-Chêne Wharf, NB, on 24 September 2022, a few hours after the passage of Fiona. Note the Sandbar Restaurant that was pushed off its foundation (which also happened during Hurricane Dorian in 2019) and the wharf's fuel tanks that were pushed into the road. Photo credit: Andrew Ollerhead.**

foredunes. It took nearly 40 years for a continuous foredune system to become re-established at Greenwich, and a further 30 years before the inland dunes stabilized. Details of the recovery process can be found in Mathew *et al.* (2010).

Given that Fiona was at least as powerful as Hurricane #5, why was there not more coastal erosion and damage? Why did Hurricanes Dorian (7-8 September 2019) or Juan (29 September 2003) not cause as much coastal erosion and damage? Over the course of our research (e.g., Ollerhead *et al.* 2013) it has become clear that storms of similar magnitude do not result in a similar amount of geomorphic work being done nor, apparently, the same amount of damage to infrastructure. Some of the reasons for this can be explained by advances in technology. Bridges built in recent decades are constructed with concrete and/or steel and placed well above the highest expected water level. Most bridges built 100 years ago in PEI were constructed of wood and were likely not well above the highest expected water level (A. MacEachern, personal communication). Buildings are now engineered to higher standards and constructed with certified materials.

Thus, less infrastructure damage today cannot be viewed as evidence of a less intense storm. This is not, however, the case for our natural coasts, which unless armoured, have much the same geomorphology today as 100+ years ago.

Determining whether our Maritime coastal geomorphology is now being impacted to a greater degree by climate change is difficult and may well be impossible. Controlling parameters that operate on a decadal-to-century scale, like bedrock geology and rate of relative sea level rise (RSL – the combination of rising global sea level and any rise or fall of land level), can be predicted and/or measured with relatively high confidence. Likewise, controlling parameters that operate on an annual-to-decadal scale, like sediment budget or vegetation cover, can be predicted and/or measured with relatively high confidence. What is difficult or impossible to predict, more than a few days or weeks in advance of a storm, are those controlling variables that operate on a weekly to monthly scale, such as presence/absence of embryo dunes in front of a foredune system, amount of sea ice that can offer storm protection, and time in the tidal cycle. As an example, a storm of a given magnitude will have different impacts on the coast if it passes coincident with neap low tide after a period of relative 'calm' than if it passes coincident with spring high tide during a particularly active storm season. Put another way, antecedent environmental conditions and storm timing matter a great deal in terms of how a coastal system responds to a given storm.

From a management perspective, the importance of the storm frequency and magnitude question lies in understanding both the impacts of human actions on coastal systems and on predicting how those systems are likely to respond to natural events, particularly as our climate changes. For example, Naylor *et al.* (2017) present evidence demonstrating how antecedent geomorphic and climate parameters can "alter the risk and magnitude of landscape change caused by extreme events" (p. 166). They argue that "adopting geomorphologically-grounded adaptation strategies will enable society to develop more resilient, less vulnerable socio-geomorphological systems fit for an age of climate extremes" (p. 166).

A significant challenge to influencing public policy is that by the time we are confident that climate change is affecting our coastal systems, it will be too late to take some actions. As an example, sea ice coverage data for the Gulf of St. Lawrence over the past 50 years are highly variable (Fig 2). Maximum ice coverage has decreased by about 0.20% per year over the period of record and the trend is statistically significant. However, the highest value since 1968/69 was in 2002/03 (58%) and the lowest value was in 2009/10 (12%) – both within the past 20 years. Thus, the amount of sea ice, which can protect the coast from erosion during winter storms (Manson *et al.* 2016), is highly variable from year to year. Recent work by Keefe and Wang (2023) illustrates the same point. To develop a comprehensive understanding of winter ice formation around PEI, historic ice coverage data from 1981 to 2023 for 50 locations around the Island were analyzed. They also found high variability from year to year but demonstrated that at every site, there was decreasing ice coverage over the study period, with a loss rate of approximately 1.1 weeks of ice coverage per decade (Keefe and Wang 2023). These results agree with those of Senneville *et al.* (2014) who found that average annual sea-ice cover on the east coast of Canada has decreased by 0.27% per year since the Canadian Ice Service began collecting data in 1968/69. Senneville *et al.* (2014) also found that for the period 1998–2013, the average decrease was 1.53% per year and they projected that sea ice will be almost completely absent in most of the Gulf of St. Lawrence

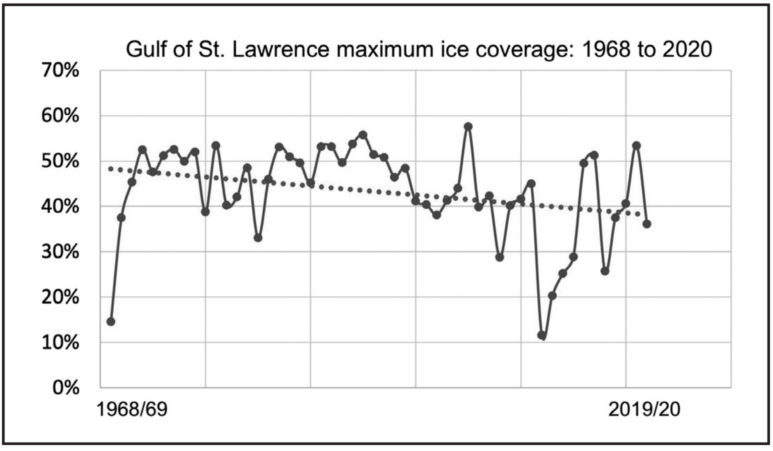

Fig 2 **Gulf of St. Lawrence maximum ice coverage plot (% of total area) for 52 seasons (1968 to 2020). The linear regression line is significant *($p < 0.05$)* and the slope is approximately -0.20% per year. Data are from: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/climatology/gulf-st-lawrence-graph-1968-2016.html**

by 2100. The challenge is that by the time a clear trend for annual winter sea ice coverage in the Gulf emerges in the public and/or decision makers' minds, it will be too late!

Likewise, having looked at storm data for PEI for the past 100 years, it would be challenging to prove that major storms are becoming more frequent and/or severe in the Maritimes. In my time living in New Brunswick (since 1994), Pointe-du-Chêne has been flooded by significant storm surges in 2000, 2010, 2019 and 2022. Is this a trend of increasing major storms? I don't know. Thus, I turn to the Intergovernmental Panel on Climate Change (IPCC) for the best guidance available – specifically the IPCC's 6th assessment report or AR6 (IPCC 2023) which summarises the latest state of knowledge on climate change, its widespread impacts and risks, and climate change mitigation and adaptation options. A key question is whether our observations over the past 2-3 decades appear to fit with what has been predicted by the IPCC (2023)?

The longer synthesis report of AR6 was released in March 2023 (IPCC 2023). It states upfront that "The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years." (p. 11). It presents data showing that "The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr^{1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr^{1} between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr^{1} between 2006 and 2018 (high confidence)." (p. 11). It asserts that "Human-caused climate change is already affecting many weather and climate extremes in every region across the globe" and that "It is likely that the global proportion of major (Category 3-5) tropical cyclone occurrence has increased over the last four decades." (p. 12). A striking aspect of AR6 is that the predictions are, in many cases, more dire than those of AR5 from 2014. As time passes, the risks and consequences to human infrastructure and our ecosystems are increasing.

Sadly, AR6 makes it clear that there are gaps between stated global ambitions to tackle climate change and the sum of declared national ambitions to do so. Modelled pathways "consistent with the continuation of policies implemented by the end of 2020 lead to global warming of 3.2 [2.2 to 3.5] °C (5-95% range) by 2100 (medium confidence)." (p. 33). Regardless of what we do, "Global warming will continue to increase in the near term in nearly all considered scenarios and modelled pathways." (p. 33). Specific to coasts, it points out that "Sea level rise poses a distinctive and severe adaptation challenge as it implies both dealing with slow onset changes and increases in the frequency and magnitude of extreme sea level events (high confidence)." (p. 44).

Put simply, if one accepts the findings of the IPCC's AR6, one must accept that our Maritime coasts and coastal communities will face accelerating relative sea level rise, the loss of protective sea ice where applicable, and an increase in the frequency and magnitude of major storms over the balance of this century and beyond. Recent observations in Maritime Canada appear to fit the IPCC (2023) predictions. We cannot wait until we have enough data of our own to test these conclusions. Comparing Fiona and Hurricane #5 is insufficient to draw conclusions. Thus, our communities and governments need to plan now for the expected realities. Simply adding shoreline armouring or raising buildings by 50 cm will not be sufficient, despite the fact that in some locations, hardening the shoreline and raising infrastructure may be necessary as the only 'feasible' short-term choice. In many other locations, however, we should be open to alternatives such as relocating infrastructure and leaving accommodation space into which mobile coastal features can migrate (e.g., salt marshes, barrier islands, sandy beach and dune systems, and so on). Rebuilding or re-establishing salt marshes and sand dune systems helps to mitigate impacts.

As Lane (2020) argued, action on climate change is needed now. Lane (2020) suggests several ways to do this, including a call for "increased investments … to be directed to communities so that they can take more responsibility and be more prepared to live with climate change impacts" (p. 237). Lane (2020) also suggests that encouraging action requires "science-based information and education whereby climate action is clearly defined along with the consequences of actions (or inaction)" (p. 237). I am skeptical of this latter argument for our coasts, however, as I don't view lack of "information and education" as part of the problem. Lemmen *et al.* (2016) edited "Canada's Marine Coasts in a Changing Climate" which has detailed information on climate change, its consequences, and suggested actions for all of Canada's coasts. It is a worthwhile read for anyone interested in the subject. Put plainly – there is no shortage of information available.

In the case of our Maritime coastal communities, informed planning is now needed to prepare for the future that is coming. Even though we cannot confidently attribute any given extreme weather event specifically to climate change, we will likely have to leverage the damage done by such events to amplify calls for action. It takes time to build relationships within communities and with local governments, and to assist them in assessing options. The time to plan is not during or immediately after a major storm like Fiona. The tendency then is to put things back the way they were. Communities should think carefully about how they build or rebuild in hazardous locations. At Pointe-du-Chêne Wharf (Fig 1) the fuel tanks displaced by Fiona have been returned to their pre-Fiona locations, apparently with better anchoring, but at the same locations nevertheless.

As noted in the IPCC's (2023) AR6, our responses to climate change will be "more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and underpinned by inclusive community engagement processes (high confidence)." (p. 44). Communities should be encouraged to consider how nature-based solutions as a response provide co-benefits (Bridges *et al.* 2021). As an example, if a salt marsh is restored or created in front of a new dyke, not only are the ecosystem benefits of a salt marsh gained, but organic carbon compounds are sequestered too, and natural protection in front of that dyke develops which has the potential to grow vertically and keep up with relative sea level rise without the need for expensive maintenance (Sutton-Grier *et al.* 2015). Likewise, a healthy coastal dune system provides natural protection from coastal flooding during major storms.

Climate change and how to respond and adapt to it is arguably one of the greatest challenges to face humanity – ever. The impacts will, of course, vary with location. In some places relative sea level (RSL) is falling (*e.g.,* parts of Newfoundland and Labrador) so the strategies employed by coastal communities in those locations to prepare for climate change will not necessarily be the same as in most of the Maritimes, where RSL is rising. Regardless of local differences, if we continue to develop and build along our coasts in the same manner as in previous decades, we should expect ever increasing damage to our infrastructure and financial losses over the coming decades. Put simply, we must now expect the previously unexpected, and start to prepare and respond creatively and effectively. Our coasts and coastal communities deserve nothing less.

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