Potential Impacts of Reduced Vessel Traffic on Wake, Erosion and Sensitive Marine Areas in the St. Lawrence Seaway: A Literature and Data Review

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1 Introduction

The St. Lawrence Seaway is a 3,700 km long waterway stretching from Lake Superior in the Great Lakes to the Atlantic Ocean at the mouth of the St. Lawrence River . The Seaway is open to year-round navigation, and large and vital ports exist along the route from the Great Lakes to the ocean. Off the coast of Quebec is St. Lawrence Seaway where vessels travel along the St. Lawrence River as it meets the Atlantic Ocean in the the world's largest estuary (Government of Quebec; Transport Canada, 2019). Nearly 80% of the population of Quebec lives near the St. Lawrence River, which has played a significant role both culturally and economically for centuries (Government of Quebec; Transport Canada, 2019). An example of an industry that spans both culture and economy is fishing. Fishing for both fish and crustaceans is a large economy dependant on the river, and the commercial fishery in Quebec is estimated to be worth $200 million annually (Agriculture, Pecheries et Alimentation Quebec: Fishing, 2019).

The St. Lawrence Seaway consists of 5 canals connected by 15 locks. Each lock serves to connect sections of the waterway with differing water levels (The St. Lawrence Seaway Management Corporation, 2019). Seven of these locks are along the St. Lawrence River, from the outlet of Lake Ontario near Kingston to the mouth of the Atlantic Ocean near Gaspe (FIG) (Government of Quebec; Transport Canada, 2019), and are within the domain of this analysis.

Nova Scotia Community College's (NSCC) Applied Geomatics Research Group (AGRG) was tasked by Global Spatial Technology Solutions (GSTS) to conduct a literature and data review related to the potential environmental impacts of reduced vessel traffic in the St. Lawrence Seaway. Potential effects to consider include impacts of reduced vessel traffic on wake, erosion along sensitive shorelines, and intrusions into sensitive marine areas.

2 Literature Review

Erosion along the coasts in the upper St. Lawrence River, the St. Lawrence Estuary, was shown to vary from 0.5 and 2.0 metres per year. Wave action from storm surges and significant high tides were identified as a major cause of erosion along sandy cliffs, while the erosion of silt and clay-based cliffs in the St. Lawrence Delta was due more to cryogenic and hydrogeological processes (Bernatchez & Dubois, 2004). The same study published a map of problematic coastal erosion zones for the shoreline along the St. Lawrence River and Gulf of St. Lawrence (Figure 1).

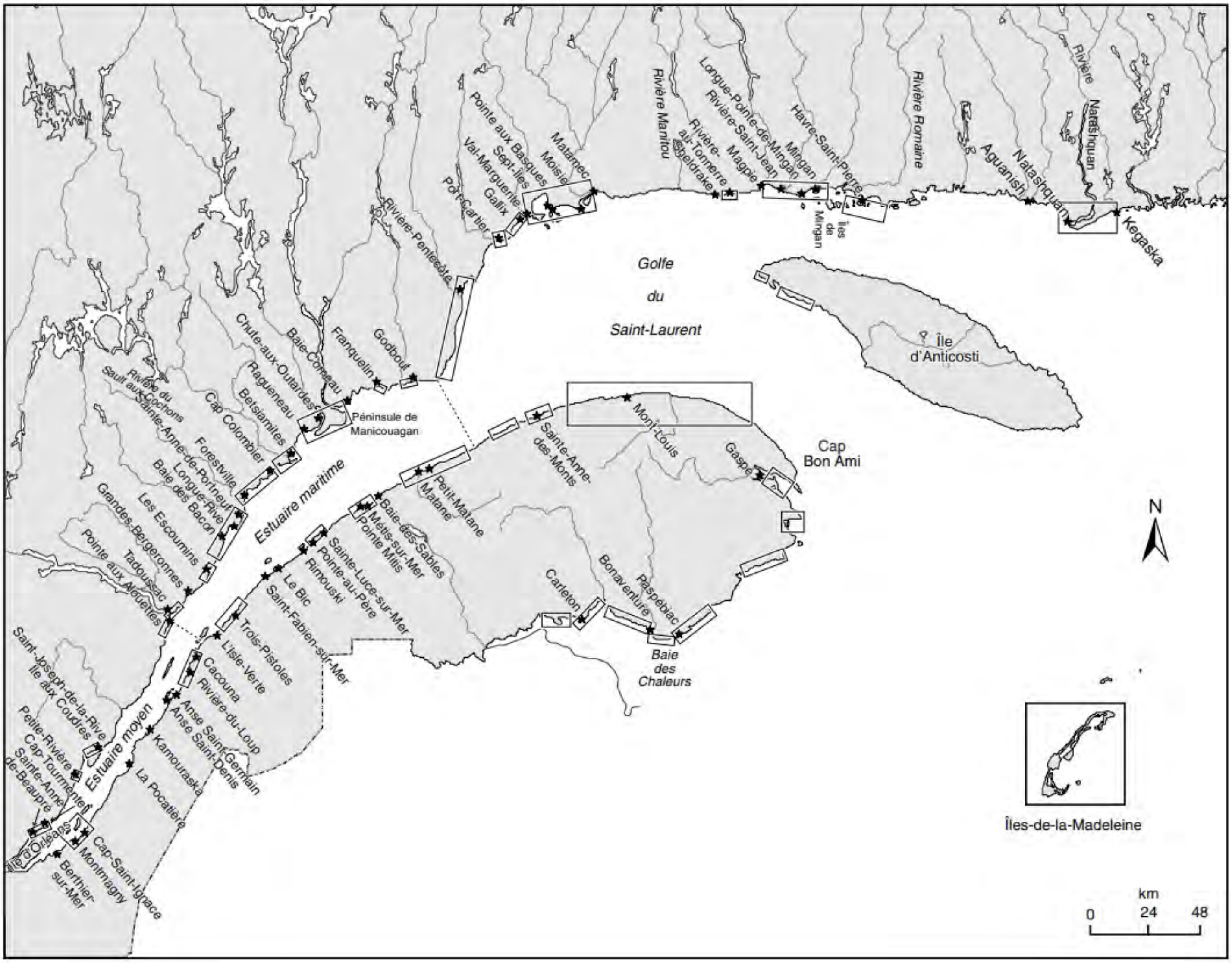

Figure 1. A distribution of problematic coastal erosion zones (in boxed areas) for the shoreline along the St. Lawrence River and Gulf of St. Lawrence as published in 2004 by Bernatchez & Dubois.

Extensive research has been done into the processes and factors impacting shoreline erosion. Water level fluctuations such as wave energy reaching the coast and sea level rise are known to contribute to shoreline erosion (Amin & Davidson-Arnott, 1997). The susceptibility of a shoreline to erosion depends largely on the geomorphic sediment composition of the bank (W. F. Baird & Associates Ltd., 2010; Amin & Davidson-Arnott, 1997), where bedrock shoreline is not sensitive to water level fluctuations, but beaches and cohesive bluff shorelines are sensitive to fluctuations in the water level (W. F. Baird & Associates Ltd., 2010), as are sandy coastlines (King, 1972). Factors such as sediment supply, beach-sediment budget, and sea ice cover are known to impact erosion rates (Amin & Davidson-Arnott, 1997; Lemmen & Warren, 2016). Shoreline reinforcement (also known as armouring), has been studied with respect to water level increase such as sea level rise (Davies, MacDonald, & Wiebe, 2011), and various studies have been done regarding the impacts of wave action along a coastline, discussed later in more detail.

The effects of marine vessel wakes on shorelines is well documented, but results are conflicting. In New Zealand, large vehicle and passenger-carrying fast ferries resulted in wake influences on very low energy sandy beaches as much as 7 km from the vessel path, while gravel beaches along the route exhibited almost immediate changes once wake was introduced, though these areas have shown stability more recently except in areas with geologic instability (Parnell, McDonald, & Burke, 2007).

A tanker wave study, completed to support the design of a Kitimat LNG Export Terminal, determined the size of vessels wake wave heights based on channel depth and vessel speed, and compared these wave heights to ambient waves in Douglas Channel, BC. The report determined that the calculated wake wave heights resulting from the added tanker traffic would be inconsequential compared to average ambient wave conditions in the areaand were concluded to be insignificant in terms of their potential for increased shoreline erosion or impact on other vessel traffic (Moffatt & Nichol, 2011). Alternatively, a St. Lawrence Action Plan 2010 publication reports that nearshore current velocity increases from 20 cm/s to almost 100 cm/s shortly after ships pass, when combined with the wake produced by the vessel these factors are considered as a primary cause of shoreline erosion (Government of Quebec; Transport Canada, 2010). Another study in 2010 (Gharbi, et al., 2010) confirmed that wave height resulting from a ship's passage did increase by between 10 – 20 cm several minutes after the vessel passed the study site. The same study concluded that longer vessels do not necessarily produce larger wake waves, but that longer vessels do produce a higher number of wake waves reffered to as a wake train. Finally, the report claimed that the number of waves in the wake train is a more significant factor for riverbank erosion than maximum wake wave height and that longer container ships would cause more erosion as a result of a longer wake train as more overall energy is hitting the coast.

Various coastline reinforcement measures have been studied to mitigate erosion caused caused by ship wakes and natural waves. Two of the most common methods for coastal reinforcement are engineered structures designed to deflect wave energy away from sensitive sites, and living shorelines designed to absorb energy before it is able to impact sensitive coastal areas. Engineered structures, such as concrete seawalls, are known to be effective at displacing wave energy, but they are expensive, short-lived, and tend to result in seaward scour and prevent natural upslope vegetation migration in estuarine environments (Herbert, et al., 2018). The same study determined that vertical breakwaters were effective in wave energy mitigation, but results vary according to the porosity of the breakwater, which was found to be site-specific. A study in the Sacramento-San Joaquin River Delta in California found that wave breaks could be created using bundles of brush set into the intertidal seabed parallel to the shoreline. These wave breaks were found to reduce wave energy caused by boats by 60% at specific water depths and were deemed an effective method for reducing shoreline erosion (Ellis, Sherman, Bauer, & Hart, 2002). A Wake Mitigation study in New Jersey disagreed, and found that a significant amount of wave energy passed through breakwaters with even very low porosity. The study recommends only solid vertical breakwaters be used according to local wave energy conditions, after finding 90% of wave energy was attenuated by solid, zero porosity structures (Herrington, 2010). The living shoreline approach to erosion management has shown equally positive results. A 2010 literature review on wetlands and shoreline protection found that coastal vegetation plays a critical role in wave attenuation by decreasing wave heights, and that even small wetlands provide substantial shoreline protection (Gedan, Kirwan, Wolanski, Barbier, & Silliman, 2010). A 2014 wave tank study assessed wave attenuation in new and 1-year old installations of *Crassostrea virginica* (eastern oyster) and *Spartina alterniflora* (smooth cordgrass), and found that 1-year old installations reduced 67% of the wave energy created by a single boat wake (Manis, Garvis, Jachec, & Walters, 2014).

Studies have also been done on optimizing vessel operations to mitigate wake effects. It is well established that increased vessel speed results in larger wake waves (Moffatt & Nichol, 2011; Brebner, Helwig, & Carruthers, 1966), and a 2018 study found that during vessel acceleration both the height and period of the maximum wake wave were significantly increased compared to that of a steady vessel speed (Macfarlane & Graham-Parker, 2018). Gharbi et al. (2010) states that longer vessels produce longer wake trains that result in more energy being transferred to the coast compared to shorter vessels with a shorter wake trains. Macfarlane et al. (2014) developed a complex wave wake predictor tool to predict wave height, wave period, wave decay rate, and wave angle based on several input parameters (Macfarlane, Bose, & Duffy, 2014). Vessel metrics included the hull type, length, speed, and displacement, while environmental parameters included the water depth, water density, and the lateral distance from the vessel to the coastline or other point of interest. This white paper was based on Macfarlane (2012), a doctorate thesis from the University of Tasmania, which gives much more extensive and indepth information on wave wakes at various vessel speeds and wave wake regulations. The thesis also demonstrates that the generally accepted practice of using a single wake wave to determine potential damage from a watercraft is inadequate, and recommends at least three waves be considered, which include the leading divergent wave, the next most significant wave, and the highest wave within a wake train.

Commercial and recreational marine vessels can also impact marine life, and it is well established that ships are a source of underwater noise. Research into underwater noise emissions in the Baltic Sea found that container ships were the most significant source of underwater noise (Jalkanen, et al., 2018). Another 2018 study into a method for modeling the acoustic footprint of marine vessels in shallow areas found that most of the low frequency (<1 kHz) sound fluctuations in shallow marine environments were associated with shipping noise (Bagočius, Narščius, & Anne, 2018). Various research studies have been done to assess the effects of marine vessels on marine life. A 2007 study found that human-generated sound impacted the sound-mediated behavior of marine animals in areas where shipping overlaps with marine animal areas or pathways (Hallers-Tjabbes, 2007). Empirical measurements from a 2002 study demonstrate that large acoustic shadows, or ‘quieter zones’, exist directly in front of approaching ships, which may have a deleterious effect on the whales’ ability to detect and locate the approaching ship as the whales swim to the quieter zone in front of the vessel seeking refuge (Gerstein, Blue, & Forsythe, 2002). A recent study has directly addressed the welfare of sensitive marine areas in the presence of marine vessel traffic. A 2019 underwater acoustics study on the impact of recreational boat traffic on fish call rates in the Western Mediterranean found that motorboat noise negatively impacted the complexity of fish assemblages (González-Correa, et al., 2019). Another study into animal behavior in marine protected areas in British Columbia stated that *Orcinus orca* (killer whales) are more vulnerable to ship disturbances while feeding (Ashe, Noren, & Williams, 2010).

3 Data

The area of interest within the St. Lawrence Seaway can be defined as the St. Lawrence River, from where it meets Lake Ontario to where it flows into the Gulf of St. Lawrence (Figure 2). A dataset retrieved from the Department of Fisheries and Oceans of Canada's Marine Protected Areas (MPA) shows that no MPAs are present within the study area, with the closest one being close to shore along the eastern tip of the Gaspe Peninsula (Figure 1). According to the literature review, shoreline erosion sensitivity is based on several factors, such as winter sea ice cover, shoreline sediment supply, and the beach-sediment budget. However, the biggest factor was consistently defined as the geomorphic shoreline composition.

The Geological Survey of Canada is imminently releasing a new dataset (which NSCC-AGRG was provided pre-release) which describes the sensitivity of Canada's marine coasts to a changing climate (Manson, Couture, & James, 2019). The dataset uses the CanCoast Marine Shoreline Version 2.0 as a basemap vector of the shoreline, which was derived from 1:50,000 scale topographic maps (NRCan, 2011) and covers the St. Lawrence River as far as Quebec, defined as the western extent of the marine (tidal) influence of the St. Lawrence Estuary (Manson, Couture, & James, 2019) (Figure 2). While the study assesses a larger 'climate change' susceptibility of the coastline, the dataset contains several metrics relevant to assessing shoreline erosion only, most importantly the geomorphic coastal material. The CanCoast Material dataset contains integral data to erosion analysis including the geomorphic classification of the shoreline along the upper St. Lawrence Seaway (Figure 3) as well as an 'erodability scale' of 1 – 5 based on coastal materials, with 1 being resistant to erosion and 5 being susceptible to erosion (Figure 4).

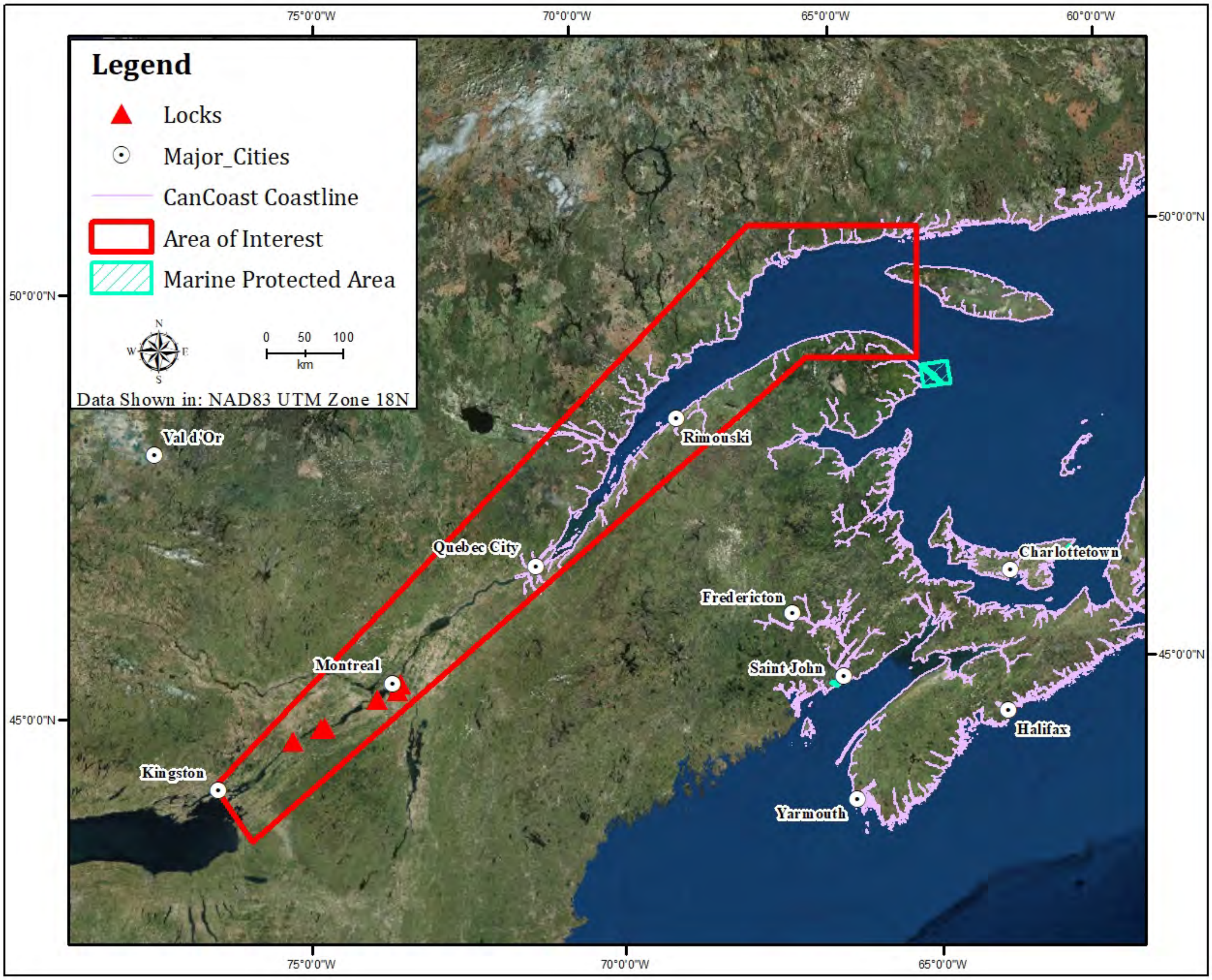

Figure 2. The defined area of interest (red polygon) contains several canal locks along the St. Lawrence River (red triangles) while a marine protected area (in teal) is just outside the boundary. The extent of the CanCoast Version 2.0 coastline is shown in purple.

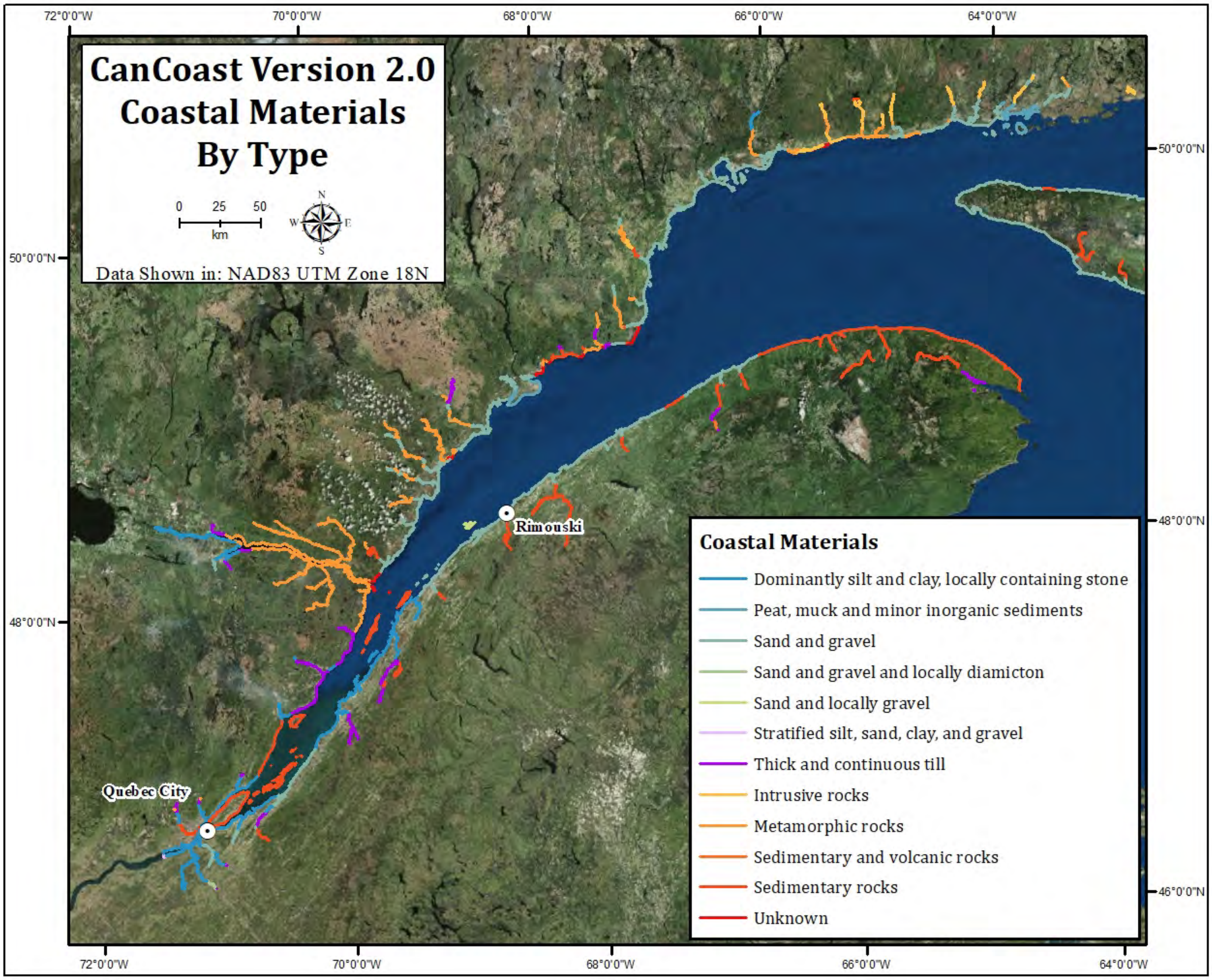

Figure 3. The Coastal Materials dataset of the CanCoast Version 2.0 study shows the classification of 11 geomorphically different coastlines along the St. Lawrence River from just west of Quebec to the Gulf of St. Lawrence.

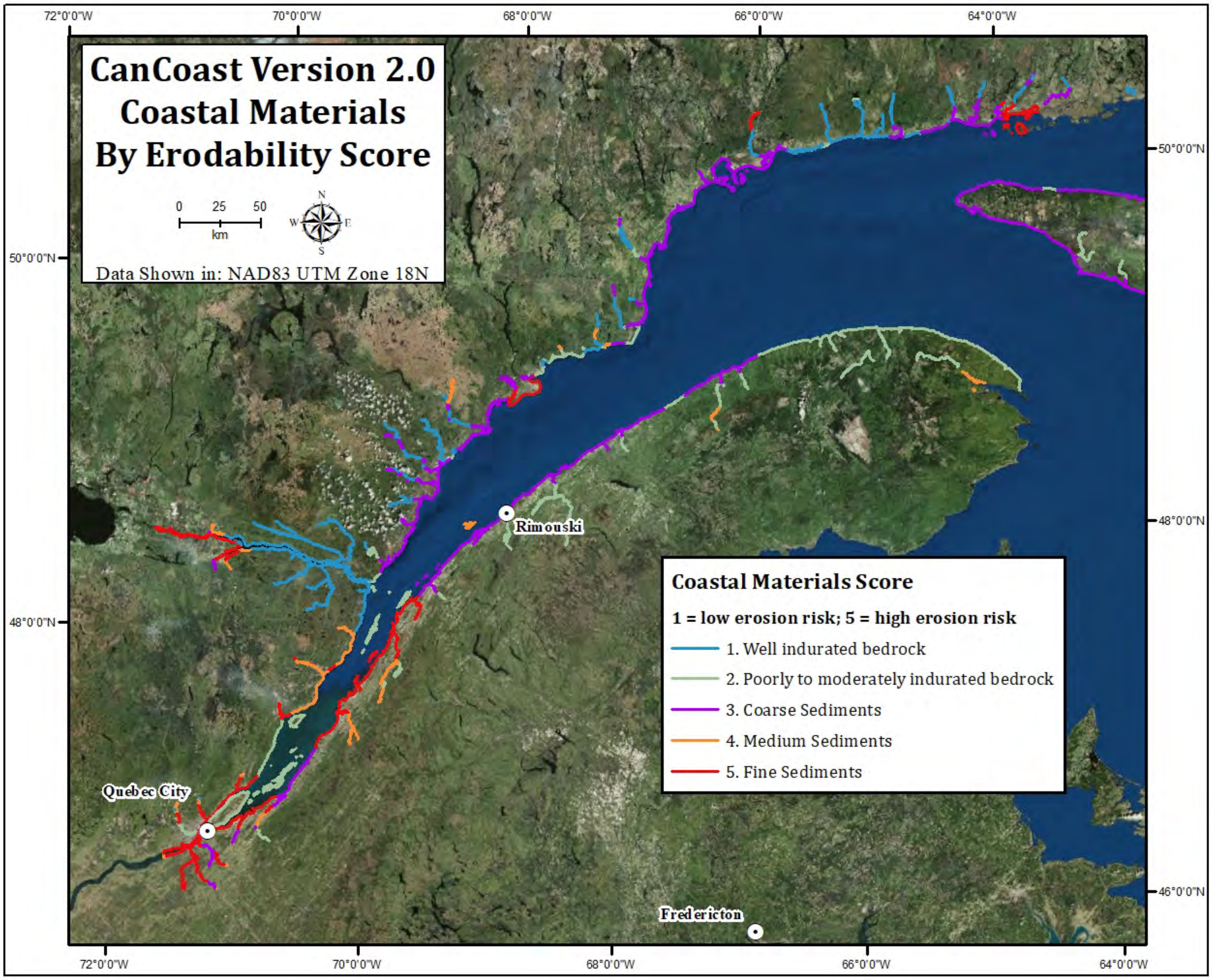

Figure 4. The CanCoast Version 2.0 study assigned an 'erodability' score of between 1 and 5 to each geomorphic shoreline classification, with 1 being shorelines composed of well indurated bedrock, which is the most geomorphically resistant to erosion, and 5 being shorelines composed of fine sediments, which are the most geomorphically susceptible to erosion.

Additional CanCoast Version 2.0 data layers contain important metrics including sea level change from 2006 – 2020, sea level change from 2006 – 2099, mean wave height with sea ice from 1996 – 2005, and mean wave height with sea ice projected for 2090-2099. These datasets, shown with their various metrics in Figure 5, may help determine how sea level rise and wave energy would impact erosion in the upper St. Lawrence Seaway. For these areas, the

'Score' attributed to them is relative to the rest of Canada, thus not relevant to assessing one smaller section of the coastline such as the Seaway alone (Manson, Couture, & James, 2019).

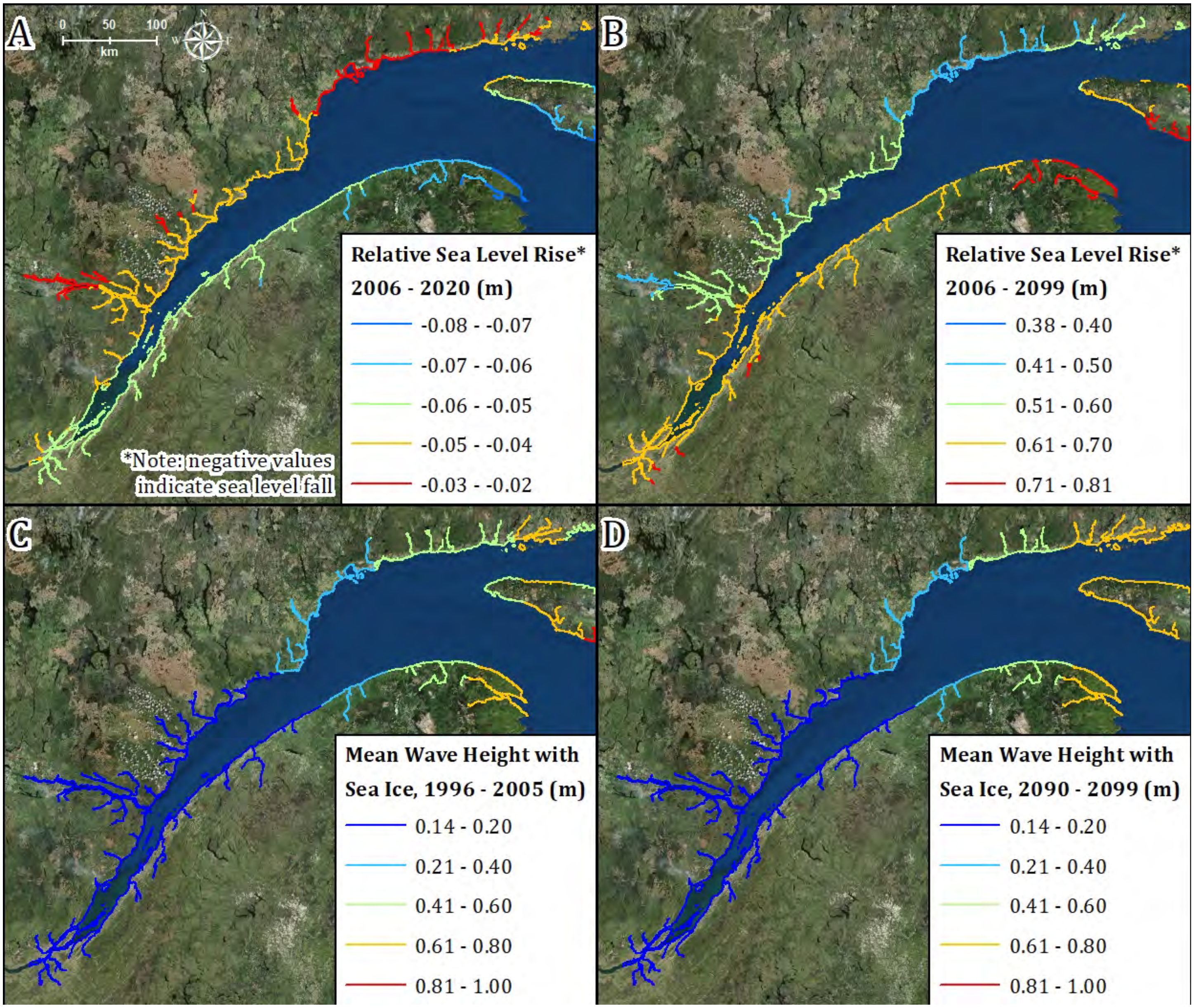

Figure 5. Additional CanCoast Version 2.0 layers available are (A) Relative Sea Level Rise from 2006 – 2020, where negative values indicate sea level falling, (B) Relative Sea Level Rise from 2006 – 2099, (C) Mean Wave Height with Sea Ice from 1996 – 2005, and (D) Mean Wave Height with Sea Ice projected for 2090-2099.

Unfortunately, the CanCoast Version 2.0 data only spans half of the desired study area, and is absent along the section of the St. Lawrence River that spans from Quebec City to Kingston, Ontario and into the United States (on the south side of the river). Several dataset have been published by local and regional organizations such as the Governments of Quebec and Ontario, NOAA, Department of Fisheries and Oceans, and Canadian Hydrographic Service, but no data on coastline geomorphology nor local marine protected areas were found. Data provided on the Government of Quebec website[1] for free spatial data are provided in French only. The Natural Resources Canada website[2] hosts a multitide of various open source datasets, but has a broken link for one dataset of interest, Protected Areas in Canada (though there may be no relevant marine protected areas in this dataset). The NRCan website provided the CanVec 1:50,000 scale waterbodies layer seen in Figure 6, which could be used as a river vector for any future research into classifying the geomorphology of the shoreline along the river from Quebec City to Kingston.

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[1] https://www.donneesquebec.ca/fr/

[2] https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/download-directory-documentation/17215

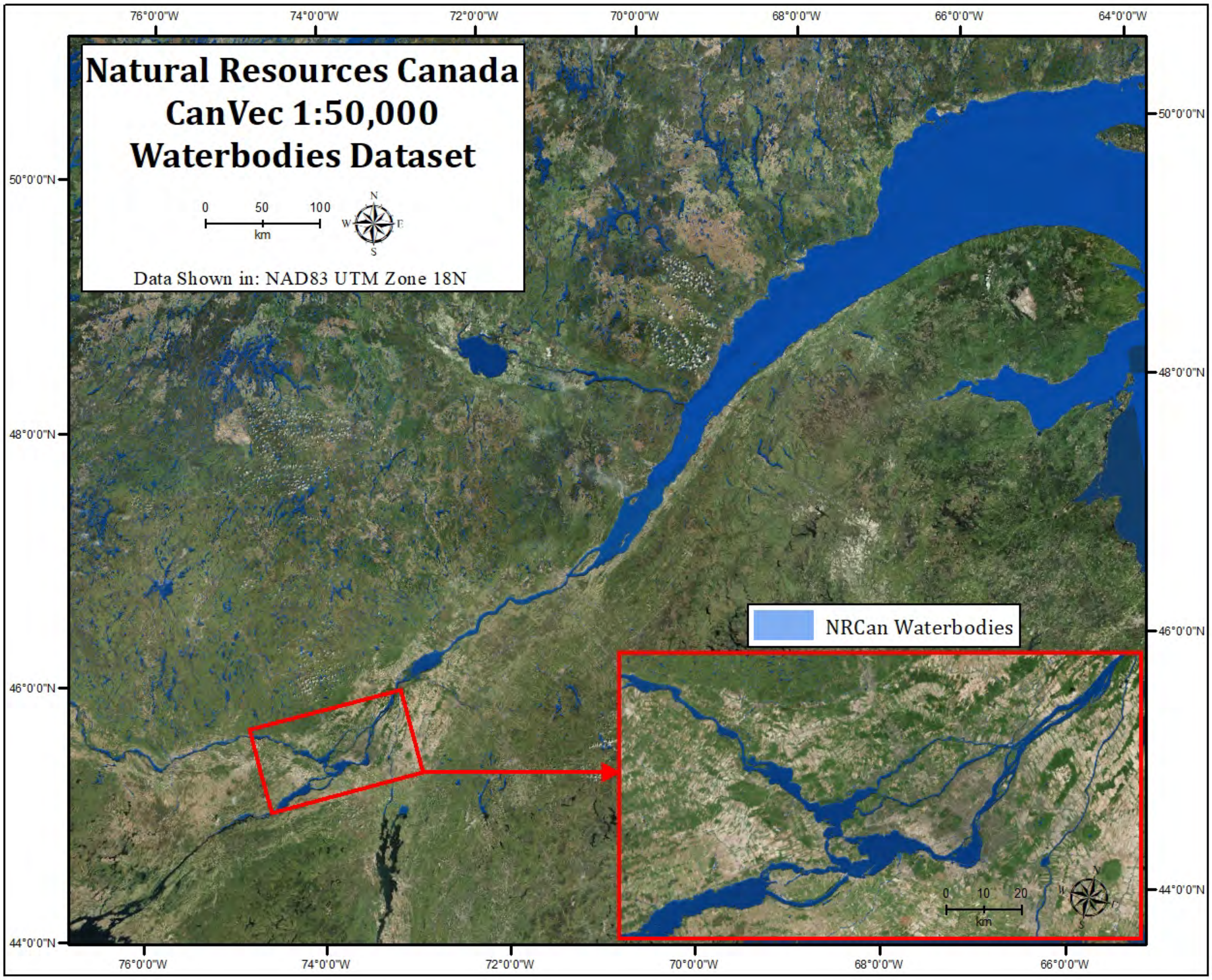

Figure 6. The CanVec 1:50,000 scale waterbodies layer (in blue) might be used as a baseline vector for adding geomorphic shoreline classification during a future erosion study.

4 Conclusion

It is well established that the geomorphic nature of a shoreline strongly influences its susceptibility to erosion. It is also well known that wave energy acting on erosion-susceptible shorelines contributes to erosion along that shoreline (W. F. Baird & Associates Ltd., 2010). The passage of vessels along a shoreline results in a series of waves with varying heights that hit the shoreline shortly after the vessel has passed, contributing to the overall wave energy that hits the coast (Gharbi, et al., 2010; Government of Quebec; Transport Canada, 2010), thus contributing to erosion along that shoreline. While no studies could be found on the impacts of less vessel traffic on shoreline erosion, it can logically be concluded from the other studies that fewer vessels passing a shoreline would remove the wake that would have been caused by those vessels, thus less overall wave energy hitting the shoreline and result in less erosion in susceptible areas.

No MPAs exist within the study area. However, any amount of vessel traffic, either commercial or recreational, produces underwater acoustics that have been known to impact the feeding and pathways of marine fish and mammals (Ashe, Noren, & Williams, 2010; González-Correa, et al., 2019; Jalkanen, et al., 2018), and in some cases can directly contribute to ship strikes (Gerstein, Blue, & Forsythe, 2002). Thus, fewer commercial vessels would have an immediate and direct effect by removing the underwater noise that would otherwise have been made by these vessels.

The CanCoast Version 2.0 data, particularly the Erodability Score from the Coastal Materials, are incredibly useful datasets. Vector shoreline data of a fairly high resolution (> 1:50,000) for the St. Lawrence River was retrieved from Natural Resources Canada and should be used as a vector to append shoreline geomorphology for future assessments.

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