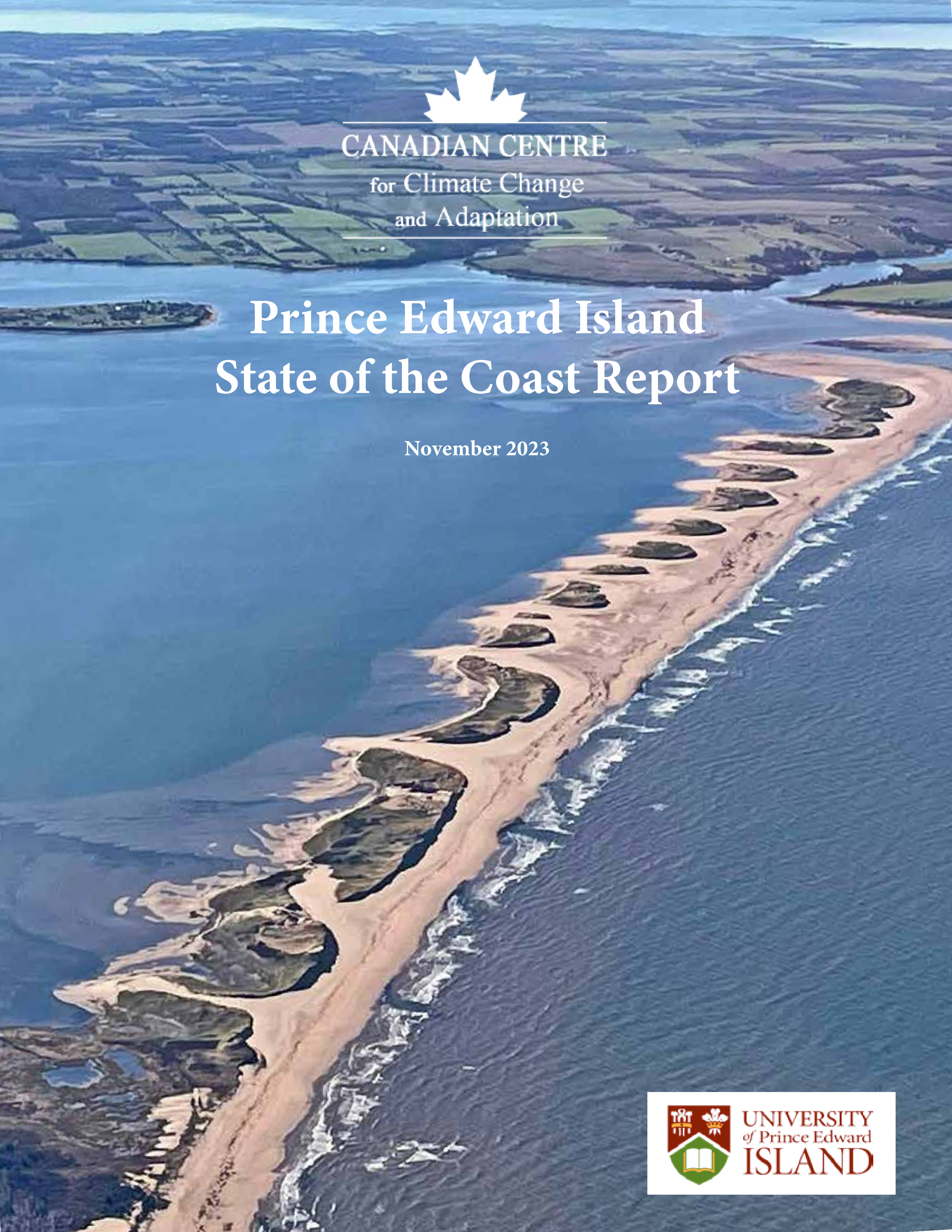

CANADIAN CENTRE
for Climate Change
and Adaptation

Prince Edward Island State of the Coast Report

November 2023

UNIVERSITY of Prince Edward ISLAND

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Contents

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Introduction

Figure 1. Georgetown, Three Rivers (H. Parnham, 2023)

PEI's Dynamic Coastline

The First Nation Mi'kmaq peoples who have lived on and have been stewards of this land and its surrounding waters since time immemorial call it *Epekwitk*, roughly translated as "land cradled in the waves". For a small island (5,660 km^2), the province of Prince Edward Island (PEI) has a relatively long coastline with over 3,000 km of beaches, sand dunes, sandstone cliffs, salt marshes, large bays, and many estuaries. Today, residents and visitors alike remain uniquely tied to the coastal landscape, as all aspects of Island-life including the climate, economy, and recreational attractions are intrinsically linked to the coast.

The natural features of PEI's coastline are dynamic; they are continually changing over time. The Island, as it is commonly referred to, only became an island approximately 6,000 years ago. As glaciers melted, sea level rose, and the water flooded the land bridge that once connected this area to the mainland. Since then, the Island's coast has continued to evolve under the influence of winds, waves, currents, and changes in sea-level. These changes have been observed over time and are well known in local communities. Islanders fondly remember where lighthouses once stood, where cottage goers once played, and where unique landforms have been photographed.

PEI may be the smallest province in Canada, but it is also the most densely populated. Waterfront homes line the coast from tip to tip, in cities, coastal communities, on rural farms and seasonal cottage lots. But on the coast, there are also fishing harbours, agricultural lands, tourist destinations, and transportation infrastructure including roads and bridges, shipping ports and ferry terminals. And while residents and visitors continue to be drawn to the water's edge, waterfront properties and coastal infrastructure are increasingly vulnerable to the processes that have long shaped the coastline, now intensified by climate change.

Fortunately, the dynamic nature of the coast provides a natural ability for the landscape to adapt to a changing climate. However, these natural processes and the critical habitats they support are vulnerable to the impacts of coastal development, especially where shorelines have been armoured, seawalls erected, and saltmarshes infilled. While often called coastal protection, these structures are specifically designed to protect property and infrastructure – not the coast, and their installation comes at a cost of altering coastal processes and eliminating habitat. As a result, in some areas the coastline has lost its natural ability to adapt and can no longer act as the protective barrier to Island communities as it once did.

PEI State of the Coast Report

The **PEI State of the Coast Report 2023 (PEI SCR)** provides an overview of the current conditions of PEI's coastline, highlighting the state of both natural and human systems. The report provides background information on the environmental processes that have shaped the coastline over time and the projected impacts of climate change on these processes. The purpose of the PEI SCR is to identify the conditions under which natural coastal processes and coastal development intersect, where ecosystems are vulnerable, and where built systems are at risk.

The PEI SCR will serve as a tool for communicating with the public, government agencies, non-governmental organizations, and industry on issues relating to coastal processes, coastal environmental protection, and coastal development. It is intended to promote transparency in decisions relating to coastal matters, and to foster greater awareness and understanding of the complexity of coastal zone issues. It will also provide the necessary background information to develop policies for enhanced coastal zone management.

The PEI SCR 2023 functions primarily as a summary and compilation of past research within western science and dominant worldviews, ways of knowing and knowledge systems. The scope did not include the opportunity to engage or collaborate with First Nations, Indigenous communities or rightholders.

The report was prepared using the most up-to-date data available to the research team. Data presented has been previously collected or developed by others and either published or directly shared with the research team for inclusion in this report. The only field work and research completed as part of this project was an aerial survey of the coast completed in May 2023 to update the shoreline structure inventory previously completed in 2018.

Note that while this report is dated 2023, the provincial government's current geospatial datasets are primarily based on the 2020 province-wide LiDAR and orthophotography datasets. Demographic information is based on the 2021 Canadian Census, unless otherwise specified. Whenever possible, additional data and information has been provided to account for the recent impacts of Post-Tropical Storm Fiona which occurred in September 2022.

Figure 2. (left) East Point lighthouse with remnants of the previous foundation location at the edge of the bank (D. Jardine, 2023)

Figure 3. (right) Cottages once lined the shore off of Rte 12, in what is now Jacques Cartier Province Park (Gov PEI, 1974)

Figure 4. (page 7) "The Teacup" coastal formation at Darnley (D. Jardine, 2019)

The PEI SCR includes the following four sections:

1. The Natural Environment

This section provides a description of PEI's different shore types, coastal habitats, and the vulnerable species that live in the coastal zone. The section also describes the dynamic coastal processes that have shaped the coastline over time, including shifting sands and changing water levels, and how these processes will change in the future due to climate change.

The information in this section is important to help readers understand how different coastal processes are connected, how changes to these processes in one location can alter the coastline in another, and the importance of these processes to the health of the Island's coastal ecosystems and the natural resources that we depend on. This information may also be used to help identify the areas of the coastline that require active conservation management, restoration, and protection from future development.

2. Coastal Communities and the Built Environment

This section provides a summary of land use and coastal development under 3 general categories: coastal settlement patterns, coastal infrastructure, rural coastal development.

This section also describes the results of 3 shoreline structure inventories conducted in 2010, 2017/18 and 2023 which provide context for how coastal development in vulnerable locations leads to shoreline alterations and armouring.

This information is necessary to identify the communities and built infrastructure that are at risk to coastal hazards now and in the future, and to identify the types of development that are having the greatest impact on the environment of the coast.

3. PEI's Coastline by the Numbers

This section summarizes the data collected as part of this project and is intended as a quick reference on the issues discussed throughout the other sections of the report. The data in this section may be used as a baseline for comparison in future studies.

4. Research Recommendations

The final section in the report provides recommendations for future research and ongoing data collection based on gaps identified in the present study. Ongoing monitoring of the physical environment and development trends will be necessary to evaluate the effectiveness of new coastal zone management policies, plans and programs, and to measure progress towards the established targets. Given the dynamic nature of the coast, it will also be important that the PEI SCR be updated as new data becomes available and to address new and emerging issues in coastal zone management.

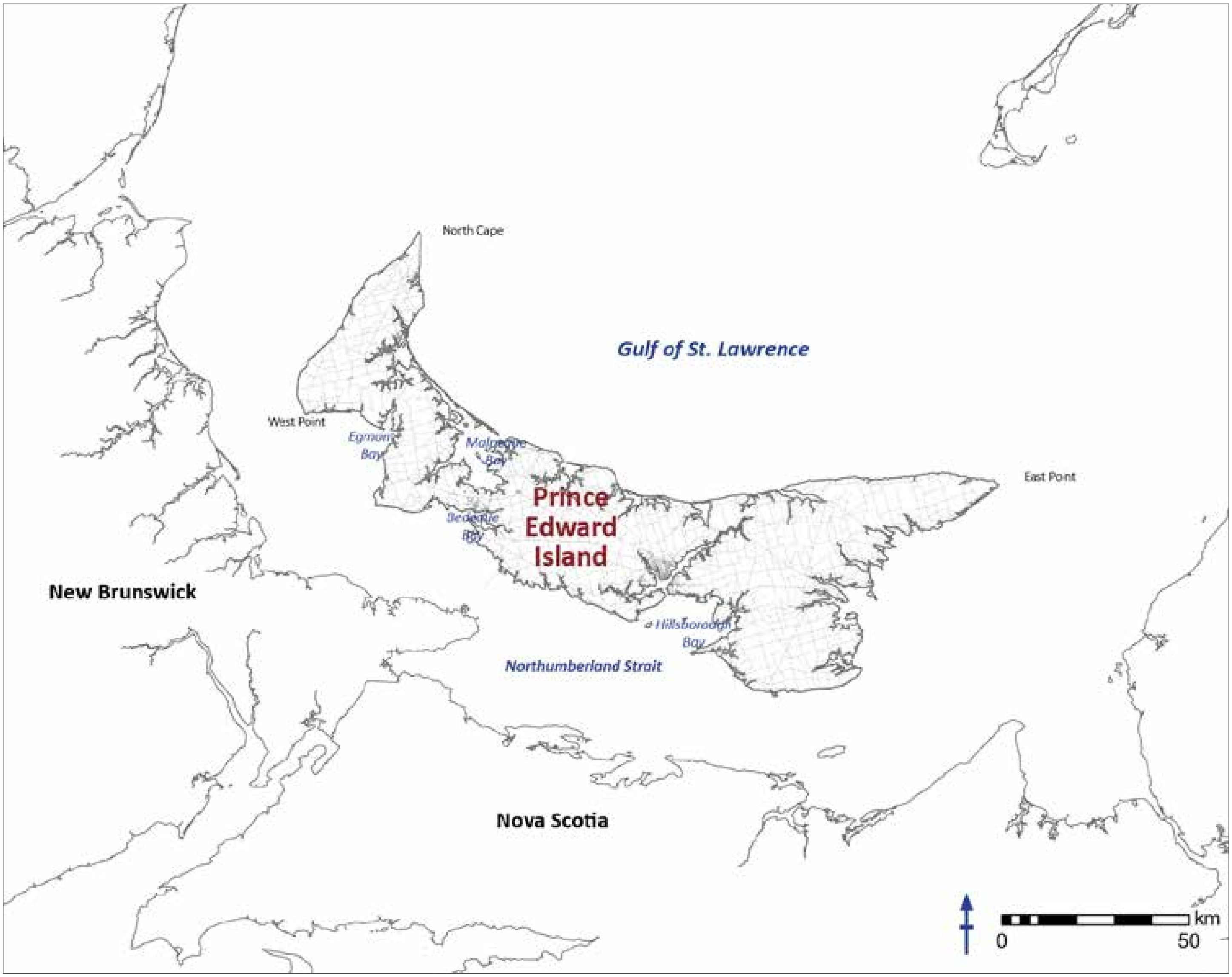


Figure 5. PEI Context Map

The Natural Environment

Figure 6. Pitaweikek, Hog Island (D. Jardine, 2023)

THIS SECTION INCLUDES:

- **Shore Types and Habitat**
- **Water Levels and Coastal Flooding**
- **Ocean and Marine Conditions**
- **Coastal Erosion**

Shore Types and Habitat

PEI is located on the East Coast of Canada in the southern part of the Gulf of St. Lawrence. The Island is 5,660 km^2 in size, has a crescent shape that is approximately 230 km long, and ranges between 6.5 and 64 km wide. It is separated from New Brunswick and Nova Scotia by the Northumberland Strait, which ranges between 13 and 50 km wide. The topography of PEI is described as gently rolling hills with the elevation in the south-central portion rising to a height of 142 m above sea level.

The Island owes its irregular shape and long (approximately 3,280 km) coastline to its many bays and estuaries. These features represent former river valleys that were submerged when sea level rose forming the Northumberland Strait and separating PEI from the other Maritime provinces (Shaw, 2005).

The coastline provides a rich and diverse habitat for many bird and plant species due to a mix of saltmarshes, sandy beaches, sand spits, offshore islands, and cliffs. Plants that grow on the coast are uniquely adapted to the seasonal variability and harsh conditions of being regularly exposed to salt spray and coastal flooding.

The different shore types provide critical nesting, feeding and resting areas for many shorebirds, gulls, waterfowl and small animals. Additionally, many migratory birds such as the Canada Goose, plovers, sandpipers, dunlins and others stop on PEI's coast to rest on their seasonal journey to and from their breeding and nesting grounds in other regions.

A province-wide shore type (i.e., geomorphic) coastal classification was completed in 2012 by Coldwater Consulting. Every 1m segment of the coastline was categorized as either coastal (exposed) or estuary (inshore/sheltered), to distinguish between coastlines that are subject to different conditions, processes and geomorphology.

PEI has approximately 802 km of coastal and 2,477 km of estuary shorelines.

The coastal classification study further described the nearshore, foreshore and backshore conditions of each shoreline segment (*See* definitions below). The backshore classification categories, commonly referred to as the shore type (i.e., cliffs, bluffs, low plains, dunes, and wetlands) were identified based on the specific elevations and slope conditions. PEI's different shore types (i.e., backshore) are further described in the following sections.

Shore Type Exposure	Total Length	Percentage
Coastal	**802 km**	**24%**
Cliffs and Bluffs	421 km	53%
Low Plains	89 km	11%
Saltmarsh	42 km	5%
Dunes	250 km	31%
Estuary	**2,477 km**	**76%**
Cliffs and Bluffs	602 km	24%
Low Plains	303 km	12%
Saltmarsh	1,341 km	54%
Dunes	231 km	9%

Table 1. Summary of PEI Coastline Classification and Shore Types (Adapted from Coldwater Consulting, 2012)

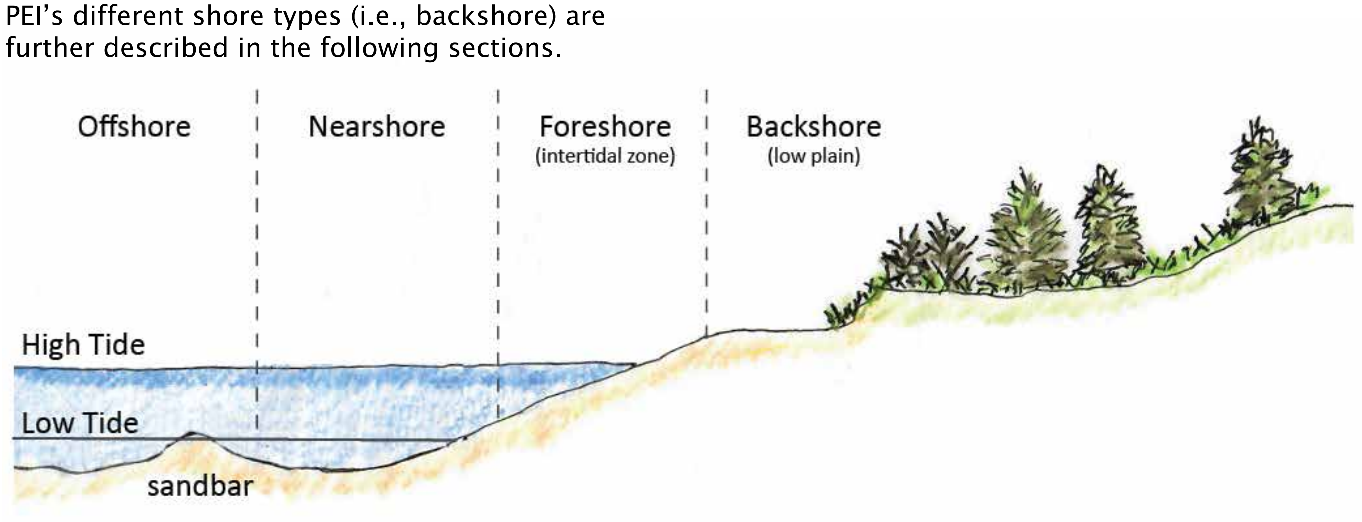


Figure 7. Coastline cross-section with a low plain backshore shore type.

Nearshore - The seabed extending seaward from the beach at mean sea level offshore to the limit of influence of wave action (the area below mean sea level). In PEI the nearshore is describes as sandstone bedrock frequently overlain by sand which varies in thickness from several meters down to patchy, non-existent cover.

Foreshore - Extends from the beach at mean sea level up to the ordinary limit of wave action during high tides. The landward limit can often be identified by the wrack line or upper limit of kelp, driftwood and other debris. The area between mean sea level and the area under water during high tide. Either sand, sandstone cobble or sandstone bedrock

Backshore - Extends from the ordinary limit of wave action at high tides landward to the limit of influence of coastal processes. The area above high tide.

Coldwater Consulting, 2012

Cliffs, Bluffs and Low Plains

PEI is famous for its iron-rich soil and red sandstone cliffs. The bedrock that is exposed in PEI's cliffs and bluffs is called sedimentary redbeds, which were created when lime, clay, silt, and sand eroded from the Appalachian Mountain Range and were deposited into a valley about 285 million years ago (van de Poll, 1983). Given their size and composition, PEI's cliffs and bluffs are susceptible to coastal erosion due to exposure to winds, tides, wave action, and ice. They are also vulnerable to frost wedging, the splitting and breaking up of rock caused by water freezing in the cracks.

In many areas the bedrock is overlain by other deposits consisting mainly of loose sediments such as sand, gravel, peat, and other organic materials. Where these unconsolidated materials are exposed to freeze-thaw cycles and wave action they can become unstable and are susceptible to decomposition and breakdown.

PEI bluffs are coastlines with an elevation higher than 3m, but less than 8m. Cliffs have an elevation higher than 8m or a near vertical slope greater than 80%. (Coldwater Consulting, 2012)

PEI's cliffs are found in all regions around the Island but vary in height and steepness. About 47% of the Island's exposed (coastal) shoreline and 19% of the estuary shoreline are classified as cliffs or bluffs. The coastline with the highest percentage of cliffs and bluffs is on the west end of the Island, between West Point and North Cape. The Island's highest cliffs, which reach about 35m in elevation, are found on the south shore in Orwell Bay.

Low plains have an elevation less than 3m, and account for approximately 12% of the Island's total coastline (Coldwater Consulting, 2012). Low plains are predominantly found in the estuaries and on the south shore, more specifically in the Egmont Bay area.

Low plains are normally dry land and offer easy access to the water's edge. As such, they have historically been the ideal location for community settlements, fishing harbours and a variety of other land uses. However, these coastlines are particularly vulnerable to coastal flooding which will be discussed further in later sections in this report.

NESTS IN ERODIBLE CLIFFS

The Island's cliffs and bluffs support large nesting colonies of birds including double-crested cormorant, great cormorant, and peregrine falcon which build their nests on cliff ledges. In contrast, the Bank Swallow burrows into the eroding cliffs to create its nests. Factors that influence whether a cliff area will be the site of a nesting colony include the steepness of the slope - with preference given to near-vertical conditions - as well as the ocean currents and availability of nutrient sources in adjacent waters (Butler, 1996). The Bank Swallow was identified as a threatened species in Canada in 2013 because it had lost more than 98% of its population since the 1970s (COSEWIC, 2017). Loss of breeding and foraging habitat due to coastal development and erosion control projects (i.e., shoreline armouring), have been identified among the primary human activities which contributed to the decline of this species.

Figure 8. Sandstone cliffs in Orwell Bay (H. Parnham, 2023)

Figure 9. Bank swallow nests, Wood Islands (D. Jardine, 2020)

Estuaries and Saltmarshes

Estuaries are the transitional zones that form where rivers and streams meet the open sea. The water within an estuary is called brackish, which means it is a mix of fresh and saltwater, and fluctuations in salinity levels due to the tides. Estuaries are very productive ecosystems that are home to many plants, animals, fish, and birds. Species that inhabit estuaries adapt to daily and seasonal salinity variability. Commercial and recreational fishing and aquaculture occur in the estuaries.

Coastal wetlands, referred to as saltmarshes, are found extensively within the inner estuaries. Saltmarshes develop on sheltered coastlines in the upper intertidal zone between mean sea level and high tide. where coastal flooding of the land happens during high and extreme high tides. Over 1,300 km (54%) of PEI's estuary coastlines are classified as wetlands, in contrast to only 5% of the exposed coastline (Coldwater Consulting, 2012). Saltmarshes are generally found on the Island's more-sheltered south shore and in the protected bays and estuaries on the north shore. The largest saltmarshes in PEI are as much as 7 km^2 are found in the Percival River (MacQuarrie, 2022).

Saltmarshes provide important ecosystem services including carbon sequestration, water quality and quantity maintenance, habitat, recreational activities and protection against coastal storms and flooding (Rabinowitz and Andrews, 2022). In fact, in the United States a recent study found that the coastal wetlands avoided $625M in flood damages during Hurricane Sandy in 2012 (Narayan, et al. 2017). Saltmarsh vegetation stabilizes shorelines against coastal erosion and provide a natural adaptive capacity to sea level rise due to their ability to grow in elevation over time by trapping sediments (Fagherazzi et al. 2020).

Where saltmarshes have been damaged or destroyed through infilling by human activities there can be serious consequences for the waterfowl, wildlife, plants, and people who live in or near these areas (US EPA, 2023).

LIFE IN A SALTMARSH

Saltmarshes are considered one of the most productive coastal ecosystems because they represent areas of high biological productivity, contain important nutrients, improve water quality, and provide key habitat for fish, and aquatic and terrestrial animals including mink, muskrat, coyote, red fox, and raccoon (MacQuarrie, 2022). As tides move in and out over the saltmarsh, nutrients are carried out and deposited into other areas in the estuary, increasing the health and productivity of the estuarine and marine food chain (Butler, 1996).

Figure 10. Coastal saltmarsh (H. Parnham, 2017)

Salt marshes have three distinct zones based on how the vegetation relates to the tidal range (Webster, 2013). In the low marsh zone, the vegetation is dominated by Smooth Cordgrass, a species that can withstand constant flooding and high concentrations of salinity. In the middle marsh zone, Saltmeadow Cordgrass is the dominant vegetation. It can withstand flooding during storm tides but cannot be submerged for long periods of time. The highest and driest marsh zone consists of vegetation such as Rough Cordgrass, which can withstand infrequent flooding of salt water during the spring tide cycle or during severe storms.

Collectively these grasses are known as 'marsh hay' which was a highly valued resource of the Mi'kmaq and the Island's early European settlers (MacQuarrie, 2022).

Sand Dunes, Sand Spits and Barrier Islands

Sandy coastal systems are highly dynamic. Under normal, calm weather conditions, the sand that has accumulated in the nearshore zone appears as sand bars and offshore ridges. Small waves and tidal action gradually and continually transport this sand landward and deposit it on the sandy foreshore of the beach.

During a storm event, increased wave action erodes the sand on the beach and carries it back out to sea. As the wave energy dies off after the storm the sand settles out of the water and starts to build up in the nearshore zone again.

This cycle is continuous and while sand may appear to be lost during significant storm events, given enough time the sand will gradually accumulate on the beach again.

I think of sand dunes like a bank account: there are continual deposits and withdrawals throughout the year. Some happen on a seasonal cycle, others because of weather events.

Fiona has just made a huge withdrawal, but – fortunately – our shores still have a steady and reliable income stream (offshore sand), which will be added back to the bank account over time.

(K. MacQuarrie, 2022)

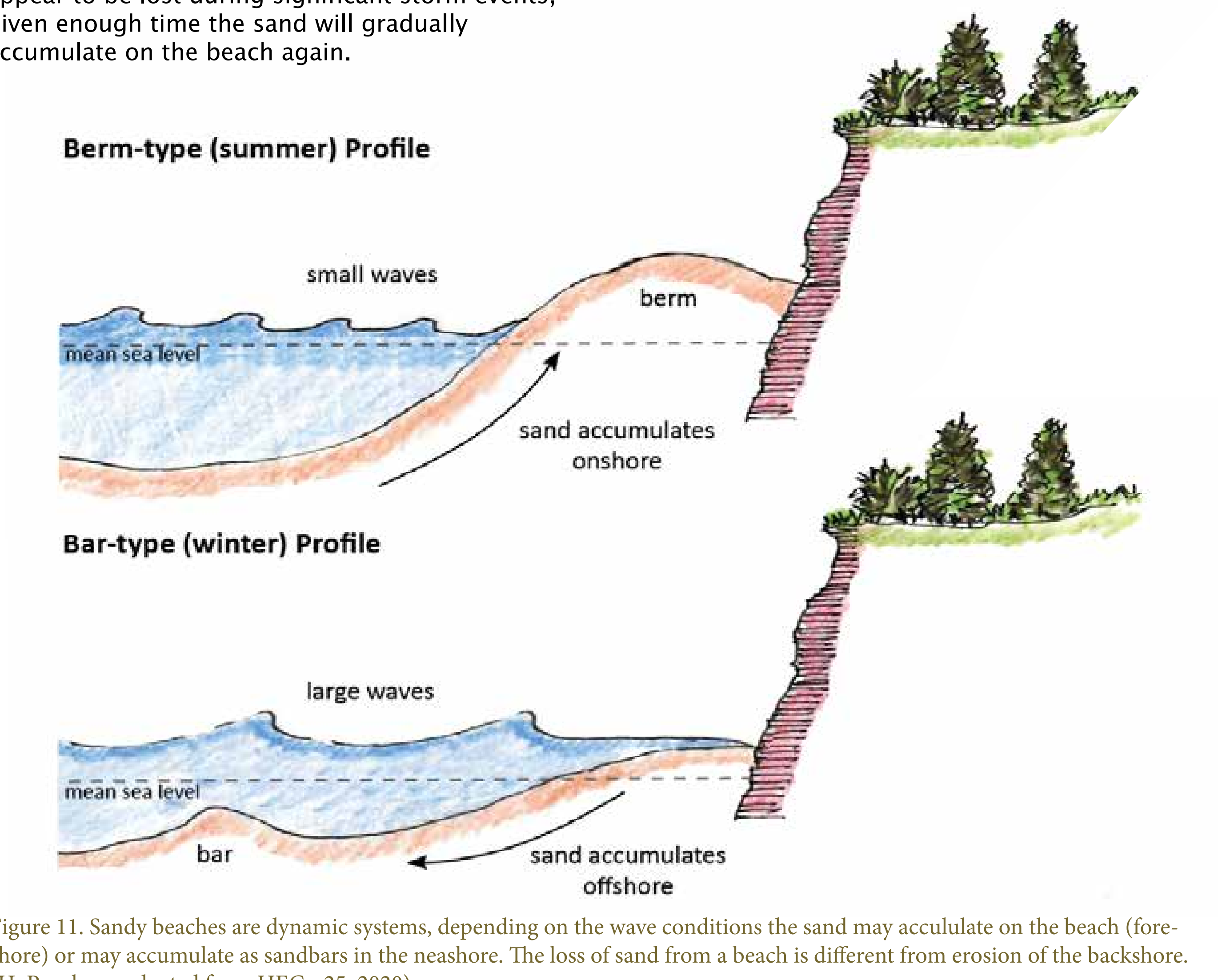


Figure 11. Sandy beaches are dynamic systems, depending on the wave conditions the sand may acculULATE on the beach (fore-shore) or may accumulate as sandbars in the neashore. The loss of sand from a beach is different from erosion of the backshore. (H. Parnham; adapted from HEC - 25, 2020)

Coastal sand dunes are formed from the wind, as sand from the beach is blown and accumulates in the backshore. Dunes have a higher elevation than the foreshore with a relatively steeper slope. PEI's north shore features a mobile parabolic sand dune system which is relatively rare in North America. To be sustained, this system must have a large supply of sand from nearby offshore sandbars or from the erosion of cliffs or bluffs. These large dune systems migrate inland over time, shifting under the influence of the prevailing winds.

Sand dunes are stabilized by vegetation, including marram grass, bayberry, and white spruce (Butler, 1996). The presence of this vegetation helps protect the sand from blowing away during storms.

Sand spits and barrier islands are long chains of sand dunes that form when wind and wave action erode a beach and deposit the sand offshore, ultimately forming a sand spit which extends into a waterbody but remains connected to the main beach.

When a spit breaks off from the main beach it becomes a barrier island. As the name suggests, these islands form a barrier between the open ocean and the estuary behind it by breaking the force of wind and waves (Butler, 1996).

PEI has over 481 km of sand dune shorelines, which accounts for approximately 15% of the total coastline (Coldwater Consulting, 2012). Sand dunes are more prevalent on the exposed coast than in the estuaries (i.e., 31% of the exposed coast is sand dunes compared to only 9% in the estuaries).

On PEI's north shore, the Malpeque barrier chain is a 43 km long sand dune system comprised of three separate barrier islands extending from Malpeque Bay to the Alberton area. These islands are estimated to be between 1,500 and 3,000 years old (Arman, 1975).

Figure 12. Parabolic dunes at Greenwich, PEI National Park (D. Jardine, 2023)

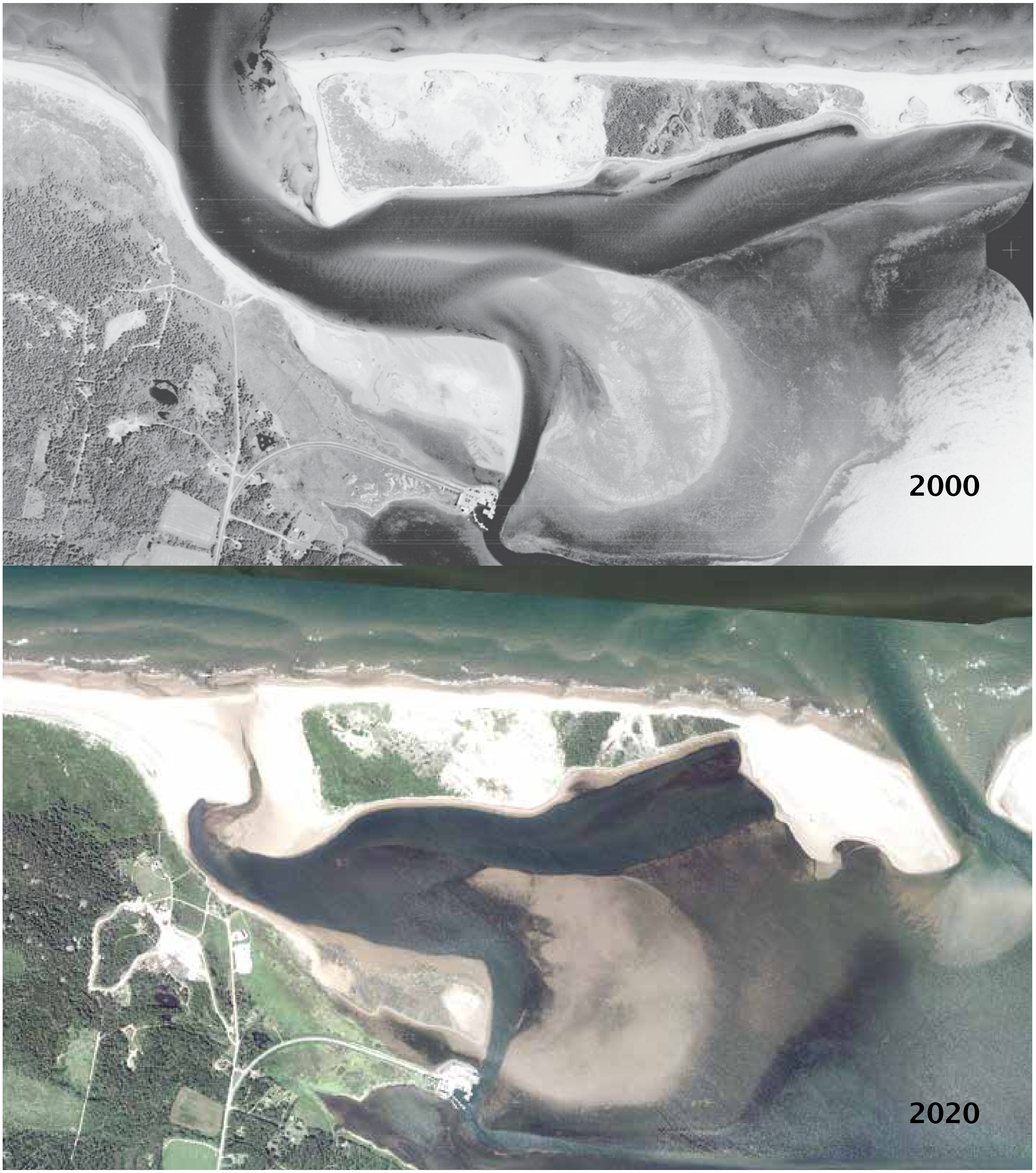


Figure 13. Sandspit and barrier island evolution at Tracadie Bay, 2000 and 2020 comparison. (Gov of PEI, 2000 and 2020)

LIFE ON BEACHES AND SAND DUNES

Behind the open beaches, marram grass forms a living net which helps hold sand dunes in place as the dune develops. It is a hardy species that thrives with little freshwater, frequent exposure to salt spray and extreme seasonal temperature variations (MacQuarrie, 2022). Once marram grass has established itself on the dune a variety of other plants and animals will move in.

The Piping Plover is an endangered small shorebird that is only found in North America. Piping Plover nest on wide sandy beaches with little vegetation and a mix of substrates such as pebbles, gravel, shells and sticks, typical of PEI's sandy beaches and barrier islands. Their habitat in PEI has been significantly impacted by development, recreation, and other human activities (COSEWIC, 2003).

High tides and winds from increased storm intensity due to a changing climate puts increased pressure on Piping plovers as their nesting area is under additional threat due to sea level rise. While vulnerable to these processes, storm events that breach dune systems and create overwash areas also provide new nesting opportunities. The cover photo for this report shows the extent to which the storm surge caused by Post-tropical storm Fiona created overwash areas on the Cavendish Sandspit.

Heavily vegetated dunes generally represent dunes that are more stable, however even stable dunes are fragile and easily damaged by human activity and storm events. Walking on dunes eliminates the protective plant cover. It can take as few as ten footsteps to destroy a marram grass colony (Parks Canada, 2023). Once the grass is gone, the wind blows away the exposed sand and turns relatively stable dunes into constantly shifting hills, unable to support vegetation or wildlife.

Most sand dunes in PEI are called primary dunes and they appear yellowish colour. However, in a few locations the dunes have turned a grey colour. These dunes are much older and over time have been covered in lichens and thin layers of soil.

Grey dunes are most common in Eastern PEI (South Lake, Basin Head and Black Pond). Grey dunes provide unique conditions for such plants as the Common Juniper, Reindeer lichens, Earthstart fungi, Bearberry and Woolly Beach-heath (MacQuarrie, 2022).

Figure 14. South Shore Watershed Association place signage encouraging people to stay off the dunes (D. Jardine, 2016)

Other Unique Habitats

KRUMMHOLZ FORESTS

A krummholz forest is a landscape of stunted and windblown trees. It is not restricted to any one shore type, but rather forms under harsh conditions of coastal winds and salt spray and results in stunted, twisted, and dense conifers. The word krummholz is German for crooked wood. Species common to PEI's krummholz areas include White Spruce, Black Spruce, Balsam Fir, Eastern Larch, and Juniper. Under these unique conditions these plants grow more horizontally than vertically forming dense mats of vegetation (McRae, 2022) which protects the coastline from erosion and can provide a haven for birds and other animals during major storm events.

The Island's exposed shorelines would have been predominantly krummholz prior to European colonization in the 1700s but most were cleared for agricultural lands and coastal developments. Today, krummholz forests are found in undisturbed locations along the North Shore, from North Cape to East Point, as well as in exposed locations on the south shore, including Cameron Island and North Enmore (McRae, 2022).

Research on the importance of coastal krummholz forests has been recently conducted by the MacPhail Woods Ecological Forestry Project. More information on this project can be found on their website (MacPhail Woods, 2023).

BLACK MARSH AND PEAT BOGS

The Black Marsh on the top of the cliffs at North Cape was first formed as an inland pond when the coastline was much farther offshore than it is today. Over time as sea level rose and the shoreline retreated the pond became exposed to the extreme winds and salt spray of the coast, leading to the creation of this unique habitat which supports species more commonly found in subalpine and alpine areas, including Twisted Whitlow Grass, Loose-flowered Alpine Sedge, and Bakeapple (MacQuarrie, 2022)

Peat Bogs, such as the one found at Ellerslie, formed when glaciers retreated and left unique conditions that supported Sphagnum moss growth on a low-lying bedrock formation. Over thousands of years the Sphagnum moss continued to build up over older decomposing layers called peat. This process is very slow, growing at a rate of about 1mm per year (MacQuarrie, 2022). Unique vegetation found in Island peat bogs includes Small Cranberries, Labrador Tea, Black Spruce, Eastern Larch, Pitcher Plant and Round-leaved Sundew. The Black Banks in the Foxley River area is a black peat bog which yields a black shoreline exposure which is susceptible to coastal erosion and flooding as it is very low in elevation.

Figure 15. Krummholz shoreline. Savage Harbour. (D. Jardine, 2016)

Protected Areas and Species at Risk

PEI has the least amount of land protected for conservation of any province or territory in Canada at 254 km^2 and by percent at only 4.89%. Most of the areas currently protected are coastal properties and include approximately 15km^2 of marine areas. The protected coastal properties are adjacent to approximately 450 km (or 12.8%) of the coastline, with approximately 23% within the National Park on the North Shore.

The federal government, through the federal *Species at Risk Act* (SARA) is responsible for the designation, protection, and recovery of species on federal lands. Similarly, the *Migratory Birds Convention Act* (MBCA) protects migratory birds and their habitat. While SARA is only enforceable on Federal Lands, the MBCA is enforceable everywhere. It is the responsibility of the provincial government to take the necessary actions to ensure the conservation of species at risk.

The provincial *Natural Areas Protection Act* and its Regulations, and the *Wildlife Conservation Act* and its Regulations are intended to provide the necessary protection for natural areas, species at risk and their habitats. The *Environmental Protection Act* also provides a legislative mechanism for protection for critical habitat.

There are five federally designated species that have coastal habitat or habitat adjacent to the coast in PEI, including the Bank Swallow (bird, threatened), Piping Plover (bird, endangered, Little Brown Myotis (mammal, endangered), Northern Myotis (mammal, endangered), and Gulf of St. Lawrence Aster (plant, threatened). As part of the National Recovery plans for these designated species, the Federal government has mapped the critical habitat areas for each. Only the Bank Swallow and Piping Plover habitat are mapped outside of the National Park.

39% (1,265 km) of the total length of PEI's coastline is included in areas identified as critical habitat.

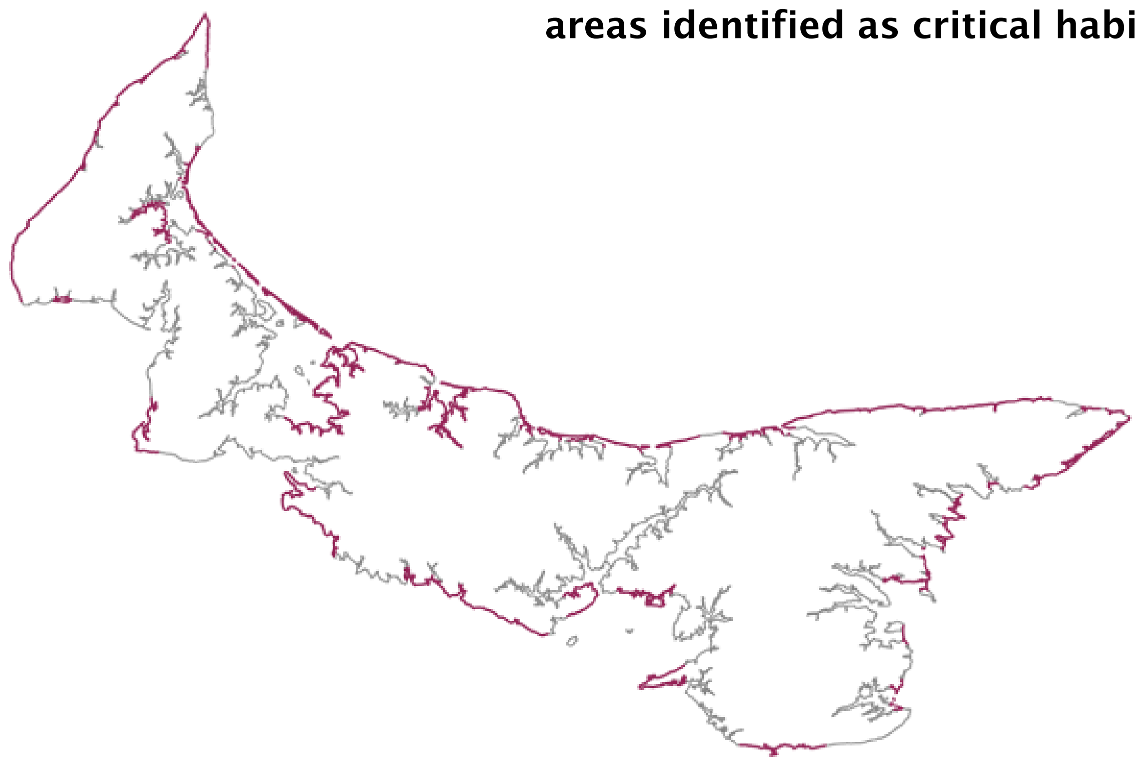


Figure 16. Coastlines within critical habitat as defined by the Federal Government under the Species at Risk Act and Migratory Birds Convention Act. (Critical Habitat of Species at Risk, DFO, 2023)

Water Levels and Coastal Flooding

Tides

The water level on PEI's coastline fluctuates with two high tides and two low tides each day. The average water level (in between the high tide and low tide) is called the mean sea level (MSL). The tidal range (i.e., the difference between high tide and low tide) changes from day to day based on the time of year and phase of the moon. An extreme tidal range occurs when different lunar phases align at the same time (Coldwater Consulting, 2021).

In addition to astronomical factors, local geography, bathymetry (water depths), and oceanographic conditions influence the height and timing of tides at specific locations. As such, the timing of the tides and the tidal range are not consistent around PEI's coastline.

During the rising tide (flood tide) the ocean water builds in the Gulf of St. Lawrence (high tide on the north shore) causing the water to wrap around the Island from both directions filling the Northumberland Strait, until the two surges meet in the middle near Hillsborough Bay (Coldwater Consulting, 2021). Consequently, the tidal range on the south shore is almost three times that of the tidal range on the north shore. When the south shore is experiencing a high tide, the north shore is experiencing a low tide, and vice versa.

Spring Tide - a larger than average tidal range, occurring twice each month.

Lunar Perigee - when the moon is closest to the earth in its orbit creating a higher tidal range, occurring every 27.5 days.

King tide - when the lunar perigee occurs at the same time as when the earth is also closest to the sun creating the highest tide of the year, occurring in late December or early January shortly after the winter solstice.

Figure 17. Low and high tide comparisons. The tidal range on the south shore at Victoria (top) can be over 2.8 m, where as the tidal range on the north shore near North Rustico is only about 1.1 m (bottom). (D. Jardine, 2023)

Sea Level Rise

Sea level rise refers to the increase in mean sea level relative to the land as measured at the coastline. As global air temperature increases due to climate change the temperature of the ocean water also increases, and when water gets warmer it expands causing sea level to rise.

Global warming is also causing ice sheets to melt in Antarctica, the Arctic and Greenland, which increases the amount of water entering oceans and causes the sea level to rise further.

In Atlantic Canada the relative sea level has been rising for thousands of years due a process called land subsidence. During the last ice age, the continent of North America had been pushed down under the weight of the glaciers. Since the glaciers melted and retreated the centre part of North America has been slowly rising back up which is causing the land on the edges of the continent in the Atlantic region to sink (or subside) back down.

With the 'sinking' of the land and rising of sea level due to climate change, the region is subject to cumulative impacts.

The sea level around PEI is expected to rise by approximately 30-35 cm by 2050; and by 75-80 cm by 2100. *

The impacts of sea level rise on our coastline will be experienced in several ways, including:

1. Permanent inundation (flooding) of low-lying coastal land.

2. More frequent flooding and storm damage due to waves and storm action reaching higher elevations than before.

3. Saltmarsh loss and/or change, due to changes to sediment supply, and storm wave action.

4. Erosion, due to wave action reaching higher elevations, which also causes changes to sediment supply.

5. Saltwater intrusion of surface and ground waters.

The impact of sea level rise on coastal properties and infrastructure on the Island will depend on the slope and topography of the land in the coastal zone. In areas with steep terrain (i.e., cliffs and bluffs), the shoreline may appear to be relatively unchanged. In low-lying areas, a small rise in sea level can cause permanent coastal flooding and shift the shoreline a significant distance inland.

* The rise in sea level is measured relative to 2006 water elevations, Climatedata.ca, 2023

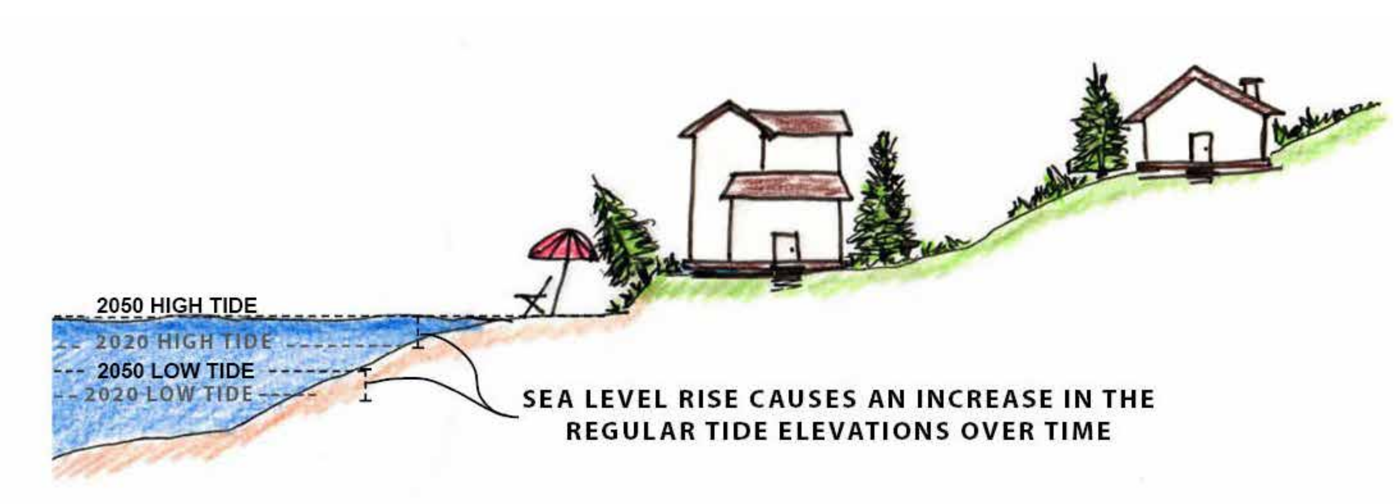


Figure 18. Gradual impacts of sea level rise on the coastal tidal range over time, 2020-2050, shown in still water conditions. (Government of PEI, 2021)

Saltmarsh Migration due to Sea Level Rise

As sea level rises, there are three potential responses that a saltmarsh may experience:

1. A saltmarsh can drown if the rate of sea level rise is greater than the ability of the marsh adapt.

2. A saltmarsh can remain stable if the rate of sea level rise equals the rate of sediment deposition, which allows the salt marsh to grow vertically and the surface elevation to be maintained.

3. A saltmarsh can expand or migrate horizontally if the rate of sediment deposition is greater than the rate of sea level rise, assuming it has room to move and is not restricted by any barriers.

(Orson, et al., 1985)

The horizontal expansion of a saltmarsh is referred to as saltmarsh migration. As the saltmarsh migrates, the vegetation shifts inland relative to the changes in water elevation. When a saltmarsh migrates, the land that is encroached upon hasn't experienced coastal erosion but rather has been inundated by salt-tolerant marsh plant species. As such, adaptation measures that are designed to mitigate or reduce coastal erosion are not appropriate for shorelines subject to coastal flooding and saltmarsh migration as they can result in "coastal squeeze".

Coastal squeeze is the term used to describe where shoreline development or infrastructure, including sea walls or shore parallel roadways, have reduced the space a saltmarsh has to migrate landward within the coastal zone. These structures prevent the ecosystem from adapting to climate change naturally (Chávez, 2021). A saltmarsh under stress due to coastal squeeze will be more vulnerable to storm events and will eventually drown as sea level rises.

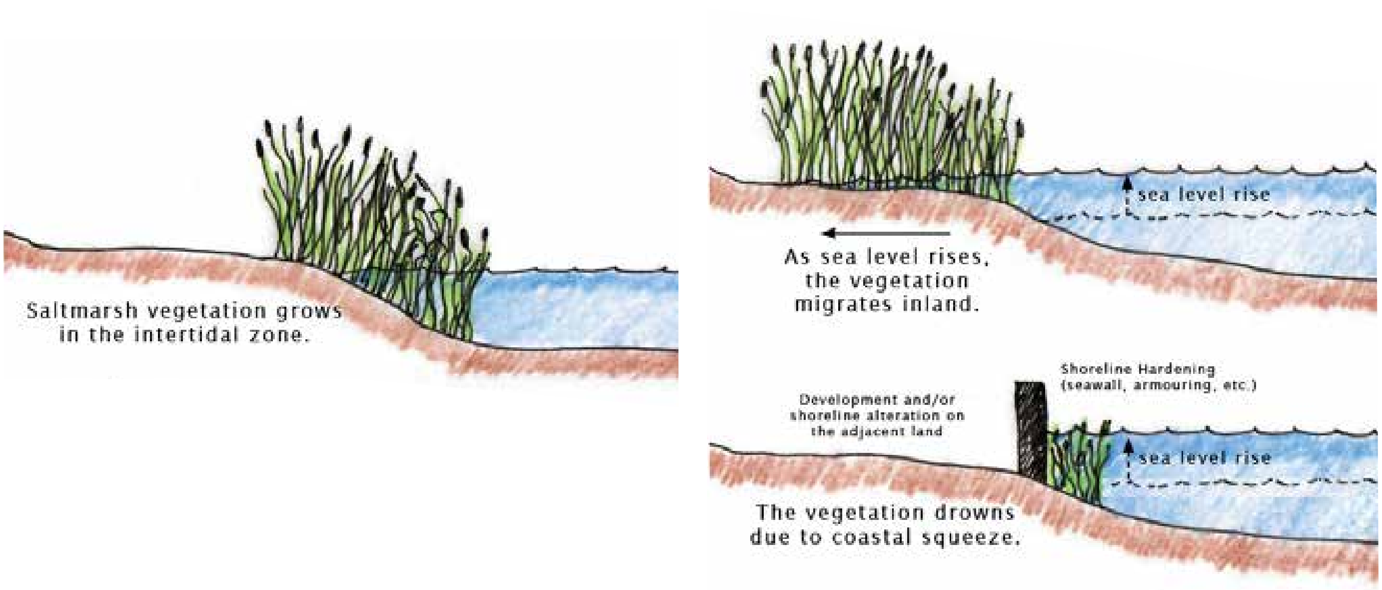


Figure 19. Sea level rise causes saltmarshes to migrate landward. If development or shoreline hardening prevents migration of the salt marsh and the vegetation will eventually drown. (H. Parnham; Adapted from VIMS, 2009)

Storm Surge and Coastal Flooding

WHAT IS A STORM SURGE?

Coastal flooding occurs when seawater flows temporarily over low-lying but ordinarily dry coastal land. In PEI, coastal flooding is commonly caused by storm surge events which occur during a weather event that creates a drop in atmospheric pressure. A decrease in atmospheric pressure of 1 milibars (mb) will produce an increase in sea level of approximately 1 cm (Gornitz, 2005). For context, a pressure of 932.7 mbar was unofficially measured on Hart Island during Post-tropical storm Fiona, setting the all-time low-pressure record for a storm making landfall in Canada (Forgarty et al., 2022)

Storm surge events can happen on relatively calm days and when they occur at low tide it can go unnoticed by local observers. However, when an extreme weather event coincides with a high tide, and strong winds and large waves contribute to pushing water towards the shore, the storm surge can be damaging to coastal properties and infrastructure.

A "worst case scenario" event could occur if a powerful storm happens at high tide during the king tide lunar alignment.

In PEI, because the timing of the high tide alternates between the north and south shores, it is rare for both the north and south shores to be impacted by coastal flooding during the same extreme weather event.

The probability of a storm surge of a specific elevation occurring in any given year is called the Annual Exceedance Probability (AEP). A storm surge water level that occurs frequently, at least once every year, has an AEP of 100%. A storm surge with a higher flood water level may occur less frequently but can have a greater impact on coastal properties.

The coastal floodplain is the area of land adjacent to the shoreline flooded by a 1% AEP storm surge.

A storm surge with a 1% chance of happening each year (1% AEP) is commonly referred to as a 1-in-100-year storm or flood event. Note this does not mean it can only happen once in 100 years. In fact, based on the probabilities of storm occurrence, a property located within the coastal floodplain has at least a 22.2% chance of flooding over the course of a 25-year mortgage (Government of PEI, 2021).

Storm intensity for the North Atlantic region is expected to increase by the 2080s under multiple climate change models. This means that PEI is likely to experience more intense and more frequent tropical cyclones causing storm surge flooding in the future.

Figure 20. The coastline floodplain as defined by the extent of coastal flood waters during a storm surge with a 1% AEP = Annual Exceedance Probability (Government of PEI, 2021)

Mapping Coastal Flood Hazards

The total land area that falls within the coastal floodplain is approximately 194 km^2, equivalent to about 3% of the land area within the province.

As one would expect, the coastal areas with low elevations adjacent to saltmarsh, low plain and sand dune shore types are most susceptible to coastal flooding.

While understanding the potential reach and likelihood of coastal flooding in the floodplain is useful for decision-making, the floodplain does not define the limits of potential flooding. Rare, extreme events, such as Post-tropical storm Fiona in September 2022, can cause a storm surge that exceeds that of the coastal floodplain. Over time, as sea level rises, and storm surge waters reach higher elevations the limits of the coastal floodplain will shift inland.

Figure 21. The high (red), moderate-high (orange) and moderate-low hazard zones are mapped for McEwens Island, commonly known as the Hebrides. (Gov of PEI, CHIP, 2023)

To account for the range in possible flood exposure, the provincial government has classified flood hazard zones as follows:

High Flood Hazard Zone - the area within the current coastal floodplain. This low-lying area is likely to experience flooding during extreme storm events and will be impacted more frequently as sea level rises and storm surge water levels reach higher elevations. Eventually, as sea level continues to rise, a portion of this area will be regularly under water during high tides.

Moderate-High Flood Hazard Zone - the area within the 2050 coastal floodplain. This area is less likely to experience flooding today; however, the likelihood of flooding during an extreme storm event will increase over time as sea level rises.

Moderate-Low Hazard Zone - the area within the 2100 coastal floodplain. This area is unlikely to experience coastal flooding now; however, the likelihood of flooding during an extreme storm event will increase over time.

Minimal Flood Hazard Zone - the area above the 2100 coastal floodplain. This area may be susceptible to flooding over time as storms reach higher elevations.

A worst-case scenario flood water elevation has also been delineated to account for an additional 0.65m of sea level rise due to melting of the Greenland Ice Sheet. Under the worst-case scenario for 2100, the total land area that could be within the coastal flood hazard zones (i.e., subject to flooding during storm surge events) is equivalent to about 7% of the land area of the province.

The good news is that even in a worst-case scenario, 93% of PEI is relatively safe from a coastal flood hazard for the next 80 years and we can plan accordingly.

To view the map of coastal flood hazard zones see the provincial government's Coastal Hazards Information Platform (CHIP).

Coastal Flood Elevation Monitoring

The federal government provides information on the predicted water levels of the tides for 24 different locations around the Island (Gov of Canada, 2023a). The predicted tide water levels assume normal sunny day conditions, however the actual water level can differ significantly due to the weather.

Tide gauges are used to measure the actual water level that occurs. The Island has a historic tidal record for the Charlottetown area that dates to the early 1900s. In recent years, twelve (12) additional tide gauges have been added around the coastline by UPEI, Mi'kmaq Confederacy of PEI, and PEI Emergency Management Office. The actual water level at each of these tide gauges is available online - in real time - on the UPEI PEI Storm Surge Early Warning System (PSSEWS) (UPEI, 2023).

Based on the tide gauge record for Charlottetown, the highest water level ever recorded for the south shore (Charlottetown) occurred on January 20, 2000 at 2.22 m (CGVD2013) or 2.4 m above MSL (Government of Canada, 2023b).

POST-TROPICAL STORM FIONA HIGH WATER MARK ELEVATIONS

On September 24, 2022, Post-Tropical Storm Fiona was the strongest storm in Canadian history as gauged by barometric pressure (932.7 mb). When the centre of the storm front passed over the Eastern Kings area of PEI it coincided with a high tide on the north shore creating an unprecedented storm surge. Unfortunately, where the highest storm surge was experienced the tide gauges were damaged and the maximum water level was not recorded.

As an alternative to tide gauge measurements, high water marks (HWM) were surveyed on the ground following the event. Based on the HWM data, it is estimated the flood water in North Rustico reached an elevation of at least 2.4 m (CGVD2013), approximately 2.8 m above mean sea level (Jardine, 2023a). The storm surge water level exceeded the coastal floodplain elevation for the area, and more closely aligns with that of a 1-in-150-year event, with a 0.6% AEP (Jardine, 2023a).

For more information on the HWM flood levels for different areas of the coastline, see the full report by D. Jardine (2023a) here.

Figure 22. Storm surge flooding during Post-Tropical Storm Fiona, McEwan's Island, the Hebrides (shared with permission)

Figure 23. Building flooded by storm surge during Post-Tropical Storm Fiona. Malpeque Harbour PE (C. Wall, 2022)

Figure 24. Top: Coastal floodplain (red) for North Rustico (Gov PEI, CHIP 2023). Bottom: Actual coastal flood extent (blue) following post-tropical storm Fiona based on high water mark survey elevations (Jardine, 2023a)

Ocean and Marine Conditions

The Gulf of St. Lawrence presents a unique set of physical oceanographic conditions. The body of water is characterized by its circulation patterns, temperature variations, and salinity levels, all of which are influenced by the Atlantic Ocean and the St. Lawrence River.

The circulation within the Gulf is primarily driven by the tides, wind, and the density differences caused by temperature and salinity variations. The currents are generally towards the east or west, depending on the depth and time of year. These currents play a crucial role in distributing heat, nutrients, and marine life throughout the Gulf. The sea-surface temperatures in the Gulf fluctuate throughout the year. These temperature variations influence the density of the seawater, which in turn affects the circulation patterns and the distribution of marine species.

Salinity, the concentration of salts in the water, is influenced by the freshwater input from the St. Lawrence River and the saltwater from the Atlantic Ocean. This mix of fresh and saltwater creates a unique environment that supports a diverse range of marine life (Galbraith, et al., 2022).

Climate change will affect the conditions in the Gulf in many ways, including:

· Increased global air temperature will increase the temperature of the ocean.

· Warmer waters will attract different marine species and existing species already at their upper limits of habitable temperature range.

· Coastal waters will become less saline due to melting sea ice and increased rainfall at high latitudes.

· Warmer water will hold less oxygen, significantly shifting living conditions for many marine species.

· Increased ocean acidification could lead to increased seaweed growth.

Changes in Sea Surface Temperature

The temperature of the water surrounding PEI is warming due to climate change. Sea surface temperature measurements in this region have been increasing at an average rate of 0.347 ˚C per decade since 1982 (Merchant et al., 2019). Due to the heat capacity of water, this is slower than the observed increase in air temperature over the same period which was 0.468 ˚C per decade (ECCC, 2023) because water takes longer to adjust to changing climate conditions. However, given time, the temperature of the sea surface will continue to increase to meet that of the air. To date the observed warming rates in this region are higher than the average global rates (air temperature change: 0.18 ˚C per decade, sea surface temperature change: 0.12 ˚C per decade) (Huang et al., 2017).

Ocean Acidification

Climate change will impact the chemical composition of the ocean, including salinity and acidity. Greenhouse gas emissions cause increased CO_2 concentrations in the atmosphere and the oceans, which reacts with water to form carbonic acid in a process called ocean acidification. Evidence of ocean acidification has already been detected in the Gulf of Saint Lawrence (Nesbitt and Mucci, 2021), and further acidification is projected to accelerate in the near to mid-future (Wanninkhof et al., 2015). In the waters around PEI, this change will primarily affect molluscs and crustacean development and other species that rely on them as a food source (Siedlecki et al., 2021).

Sea Ice Coverage

The Gulf of St. Lawrence and the Northumberland Strait have traditionally experienced seasonal sea ice coverage from December to April, with the maximum extent in late February or early March. As sea surface temperatures rise, ice coverage in the region is trending downward.

Historic ice coverage data at 50 sites around the province were analyzed from 1981 through 2023 (ECCC, 2021). The seasonal ice index (SII) is analogous to the number of weeks of ice coverage per year. The mean SII across all 50 sites was 11.3 weeks and every site showed decreasing ice coverage over the study period. The PEI sites with the highest SII values had average ice seasons of up to 16 weeks, more than twice as long as the shortest. Longer ice seasons occurred in the more sheltered areas, particularly in large bays and coves. The sites with the shortest SII were situated along the eastern shore of the Island. Generally, ice coverage increased east to west, with Kings County demonstrating significantly fewer ice weeks than Queens or Prince Counties. Sites along the more exposed north shore experienced more extensive ice loss compared to those in the south.

Reduced ice coverage is expected to have negative impacts on marine benthic species in shallow waters such as lobster, which relies on the ice above to provide stability in the marine environment during winter storms (Stantec, 2023). Shorelines, previously protected from winter storm wave action will be further exposed with reduced ice coverage in the future, which could further increase the susceptibility to erosion.

Ice Rafting

Ice rafting can occur when sea ice is carried by coastal flood water onto the adjacent low-lying coastline by strong winds blowing on shore during a storm surge and high tide event. Exposed coastlines with deeper water near the shoreline are more susceptible to ice rafting. Shallow waters with sandbars would otherwise catch the ice blocks before they reach the shoreline.

Ice rafting is most likely to occur when the high tide is at its highest, which occurs in January. However, in recent years, the presence of ice in early January has been less common due to the warming of coastal waters caused by climate change.

Ice rafting of the magnitude shown in the photos below is a relatively rare phenomenon, however it can result in significant damage to coastal structures located near the edge of the bank. In January 2018, Charlottetown recorded one of its highest water levels on record and ice blocks were rafted to a height of over 8 to 9 m in some areas on the south shore causing ice to be deposited on the top of cliffs.

Figure 25. Ice Rafting, Cape Traverse (D. Jardine, 2018)

Figure 26. Ice Rafting, Maximeville (D. Forbes, 2004)

Coastal Erosion

Coastal erosion is the natural breakdown and removal of bedrock, glacial material, sand, and soil from the backshore of the coastline. Coastal erosion of the Island's cliffs and bluffs is the primary source of sand needed to recharge the Island's sandy beaches and sand dunes. It is also critical for habitat opportunities for species at risk, such as the Bank Swallow.

Coastal erosion is not a new phenomenon on PEI. Sea levels have been rising around PEI for the past 10,000 years (Shaw, 2005) and consequently all areas of the coast have been eroding since that time (Coldwater Consulting, 2012). Erosion can be a slow and gradual process over time; however, the most evident coastal erosion takes place during a storm event when strong waves and elevated water levels reach further inland, and higher on the backshore cliffs and bluffs.

During Post-Tropical Storm Fiona, storm surge water levels and wave action reached unprecedented elevations resulting in significant coastal erosion in some areas. At one property in Ebbsfleet in Western PEI, the horizontal loss of land due to erosion which left a V-shaped notch into the property was measured at approximately 26 m deep (*pers. comm.*, Jardine, 2023).

Figure 27. Coastal erosion and property damage at Savage Harbour, Pigots Point (UPEI, 2022)

Figure 28. Coastal erosion at East Point where an old foundation is located at the top of the cliff (H. Parnham, 2023)

Causes of Coastal Erosion

There are many factors that can contribute to the susceptibility of a coastline to erosion, including the shore type, geology or soil composition, shore orientation, exposure, and fetch (i.e., the width of the open water in front of the shore) as well as coastal processes including the annual freeze–thaw cycle, wave action, ice rafting, and stormwater runoff. Human activity and development (e.g., removing vegetation, excavating near the top of the bank, installing hard structures that deflect wave energy) can also accelerate the otherwise natural processes of erosion by increasing the shoreline's vulnerability.

FROST WEDGING

Frost wedging is the dominant process responsible for breaking down and eroding the Island's cliffs (Spooner, 2012; Catto et al, 2002).

Like the creation of potholes in Island roads, frost wedging is caused by water seeping into cracks, freezing and expanding. The expansion cracks allow more water to enter, and the process continues until the rock breaks apart completely.

UNDERCUTTING

Erosion that starts at the bottom of a slope or at the toe of the bank is generally caused by direct wave action hitting the base causing undercutting, and gradually weakening the stability of the slope. Where PEI's sandstone cliffs form sea stacks, caves and sandstone headlands, these areas may appear stable from above, but the top portion of the slope will eventually collapse into the water below. Wave action is also responsible for periodically removing the frost-displaced debris from the base of cliffs (Catto et al., 2002).

Well known PEI coastline features, including 'Elephant Rock' in North Cape and 'the Teacup' in Thunder Cove, were formed because of slow gradual erosion at the base of a sandstone cliff, and eventually collapsed during extreme weather events.

Figure 29. Cliff undercutting at Lower Darnley (D. Jardine, 2011)

STORMWATER RUNOFF

Stormwater runoff during heavy rain or snowmelt conditions or other freshwater sources originating inland can also cause coastal erosion. This is particularly evident in urban or developed areas where stormwater does not have an opportunity to infiltrate the ground and instead is directed towards the shoreline. Cleared agricultural land can also cause stormwater runoff induced erosion, especially when the land has a steep slope and there is no vegetation to buffer the impacts of the runoff as it reaches the edge of the bank. Erosion caused by runoff can often be visually identified by a gully that is created over time at the top of a cliff or bluff, and by the vertical striations (tiny parallel grooves) that are apparent on the sides of the bank.

Figure 30. Stormwater gully on cliff at West Point (H. Parnham, 2023)

SLOPE FAILURE

Some coastlines in PEI experience erosion due to slope failure. When soil loses its stability, it is less able to support the weight of itself and any structures or vegetation above. Signs of recent slope failure are where large tuffs of grass or other vegetation are visible on the material that has slid down the bank. Soil saturation can also result in relatively large slope failure which appears as a coastal slump or landslide.

Figure 31. Soil slumping at Victoria Provincial Park (D. Jardine, 2011)

OVERTOPPING / OVERWASH

Wave overtopping typically occurs during extreme weather events when waves driven by intense storm winds reach elevations well beyond average or ordinary levels. Overtopping by waves can cause destruction and flattening of the coastal system. In Greenwich, a significant storm with catastrophic overwash occurred in 1923, after which it took approximately 70 years for the dune system to become reestablished and stabilized. (Mathew et al., 2009)

When erosion mitigation structures (e.g., seawalls, dykes, rock revetments, rip rap) are installed in low lying areas, they are also susceptible to damage due to overtopping. Wave action can still result in the soil behind a structure being eroded, even if the structure holds during the storm event. Many armoured properties on PEI's north shore experienced damage due to overtopping during Post-Tropical Storm Fiona in 2022.

HUMAN ACTIVITY

Human activity, including coastal development, removal or clearing of vegetation, excavation for in-ground services and other disturbances on the land immediately adjacent to the shoreline can increase the vulnerability of the shore to erosion.

Ironically, attempts to mitigate coastal erosion through shoreline armouring can also lead to unintended consequences, including the loss of the sandy beach on the foreshore side of the armouring and increased rates of erosion on the ends of the structure, called end-scouring.

CLIMATE CHANGE

Climate change could lead to an increase in the average rate of erosion experienced on PEI's coastlines (Forbes et al., 2004). As sea level rises, intense storms will occur frequently at higher elevations. During the winter months there is less sea ice coverage, and the frost is not as deep in the soil which would otherwise help to stabilize the banks.

It is very important to understand the underlying cause of coastal erosion on a site prior to implementing an erosion mitigation strategy.

Figure 32. Sea wall overtopping at North Rustico (D. Jardine, 2019)

Figure 33. End-scouring on Langley Sea Wall at West Point (D. Jardine, 2019)

Shoreline armouring and seawalls installed at the toe of a bank are intended to address coastal erosion caused by wave action by reducing the vulnerability of the bank to undercutting. However, the coastal geomorphology and fracture patterns of cliffs in PEI indicate that land-based erosional processes (frost wedging) play a more significant role in coastal cliff failures than that of marine processes like wave action (Spooner et al., 2012). In many instances, mitigation of coastal erosion could be more effectively addressed through on-site stormwater management strategies, runoff diversion structures, or the restoration of vegetation in the area adjacent to the top of the bank.

Measuring Coastal Change

The Government of PEI commissioned a study on historic coastal change rates in 2012. This study used geospatial data (i.e., computer models) to measure the difference in coastline locations between air photos taken in 1968, 2000 and 2010. The study produced a historic coastal change rate for each metre of PEI's coastline (Webster, 2012). The study found that the average rate of coastline change measured for the entire island between 1968 to 2010 was 28 cm/year (with a 127 cm/yearr standard deviation), and the average rate of change between 2000 to 2010 was 40 cm/year (with a standards deviation of 119cm/year).

The results of this study have been used to interpret the historic rates of coastal erosion and the Provincial government has classified the erosion hazard for individual coastal properties accordingly (Government of PEI, 2021), as follows:

High Erosion Hazard: more than 90 cm/yr

Moderate Erosion Hazard: 30-90 cm/yr

Low Erosion Hazard: less than 30 cm/yr

While the results of the 2012 study appear to indicate that the rate of change (erosion) is increasing over time it is recognized that coastlines can also change due to accretion (the buildup on new sediment), saltmarsh migration, sediment transport, dynamic sand systems (dunes, spits, barrier islands), and human activities and coastal development. While the 2012 study has been very useful for assessing change on a local (property) scale, the Island-wide average does not capture the high variability between different shorelines or the cause behind the observed effect, for which the standard deviation of the dataset should be given more attention. When interpreting coastal change data, it is extremely important to consider the local context, more specifically the geomorphology, shore type and exposure, as well as any changes to land use and development on the adjacent lands.

For example, the installation of new shoreline armouring (riprap, seawall, etc.) can reduce the rate of change in one location while accelerating the rate of change on adjacent properties or properties down shore if the beach is narrowed due to a reduced sand supply. Furthermore, extreme weather events, such as Post-tropical storm Fiona, can cause significant erosion in a particular area in a single day. The episodic nature of coastal erosion is not captured in average rates of change that imply a gradual, annual progression.

Figure 34. A comparison of the coastline location between 1968 (yellow), 2000 (light orange), 2010 (dark orange) and 2020 (red). Cavendish National Park Campground (Air photo: Gov PEI, 2020)

The Province has recently completed the delineation of the 2020 coastline and a late-2022 coastline which captures data associated with impacts of Post-tropical storm Fiona. A preliminary analysis of this new (currently unpublished) dataset provides an update on the average coastal change rates on the Island. There are 4 key messages that can be drawn from the preliminary analysis of the new data:

1. As noted earlier in this report (pg. 10) 76% of the Island's coastline is classified as an estuary exposure. These coastlines which are subject to different coastal processes and conditions, appear to be significantly more resilient to coastal change than coastlines with a coastal exposure, regardless of shore type. The estuary and coastal datasets should not be combined into a single average calculation because the rate of change for coastal exposure shore types is higher but represents a much smaller length of coastline.

2. The increase in the average rate of change that was observed in the measurements for 2000-2010 (Webster 2012) was not maintained as a 'new normal' in the following decade (2010-2020). In fact, between 2010-2020 the average rate of change for cliffs and bluffs was less than that which was measured between 1968-2010.

3. An extreme weather event can have a significant impact on coastal change (note the difference between 2010-2020 and 2010-2022). The episodic nature of this sudden change should not be interpreted as an accelerated or potential annual rate of change. If a storm of a specified magnitude has a 1% chance of occurring annually, the extent of erosion caused by such an event is equally improbable, although still possible.

4. Saltmarshes and sand dunes, both of which are dynamic environments subject to change unrelated to coastal erosion. These shore types present anomalous datasets when compared or combined with the trends associated with gradual rates of change for cliffs, bluffs, and low plains. These shore types need to be analyzed in isolation and with a methodology that accounts for the unique processes that shape these areas.

Average annual erosion rates that do not distinguish between shore exposure and shore types, or between gradual and storm-induced changes oversimplify coastal erosion processes and can be misleading.

Exposure/Shore Type	Average Rate of Coastal Change (m/yr) for Selected Time Periods				
Coastal (802 km)	**1968-2010**	**2000-2010**	**2010-2020**	**2010-2022**	**2020-2022**
Cliffs	0.24	0.40	0.17	0.30	0.86
Bluffs	0.35	0.50	0.21	0.38	1.09
Low Plains	0.10	-0.05	0.25	0.45	1.37
Saltmarsh	0.03	0.38	0.45	0.80	2.29
Dunes	0.19	0.39	0.24	0.14	-0.31
Estuary (2,477 km)	**1968-2010**	**2000-2010**	**2010-2020**	**2010-2022**	**2020-2022**
Cliffs	0.05	0.18	0.05	0.09	0.26
Bluffs	0.06	0.15	0.03	0.08	0.30
Low Plains	0.03	-0.08	0.09	0.22	0.75
Saltmarsh	-0.01	-0.24	0.09	0.28	1.03
Dunes	0.09	0.50	0.03	0.02	0.07

Table 2. Summary of the average rate of coastal change for PEI's coastline by exposure and shore types. A negative coastal change rate means that the shoreline experienced accretion (Adapted from Webster, 2012; and Gov. PEI 2023)

UPEI Erosion Field Monitoring Program

The University of Prince Edward Island conducts an Erosion Field Monitoring Program each summer measuring the coastline at 120 locations around the Island each year. The data is collected using both drone technology and manual peg-line measurements.

The average annual rate of coastal change ranged from 16 cm/year (2015) to 54 cm/year (2016), with a total average of 33 cm/year over the past 7 years.

In 2021, the data collected in the UPEI Erosion Monitoring Program was compared with the provincial government's historic rate of change datasets (1968-2010) (Webster, 2012). The results of the comparison found that the field measurements documented higher rates of annual change than that of the historic rates. It is assumed that the rate is overestimated because the monitoring network was established at sites that are more vulnerable to erosion. The older datasets also do not account for recent extreme events, such as Hurricane Dorian in 2019.

In the 2022 field season, 8 sites recorded a change of over 1m, including sites in Savage Harbour, Conway Sandhills and Seaview. These 3 sites had experienced high annual rates of change in at least 3 other years during the coastal monitoring program.

The 2022 summer field season captured the rate of change between 2021 and 2022, however measurements were taken prior to Post-Tropical Storm Fiona (September 2022). In November new measurements were taken at eight of the sites based on the observed impacts of the storm. Of these sites remeasured, the post-Fiona data from Cape Gage Road showed the highest single point of loss of any site over the entire monitoring programs records, at 17.56m, an increase of over three times from the previous highest recorded loss at just over 5m. With the post-Fiona results for these eight sites included in the overall analysis for 2021-2022, the annual average rate of change doubles from 0.33 cm/yr to about 87 cm/yr for the season (UPEI, 2023).

Figure 35. Drone imagery captured at Cape Gage (UPEI, 2023)

Figure 36. Drone orthomosiac for 2022 with coastlines comparing change over one year (purple is 2021, yellow is 2022) at Cape Gage showing a single point loss of about 17.5 m in a single year (UPEI, 2023)

Coastal Communities and the Built Environment

Figure 37. City of Charlottetown's working waterfront includes: inport/export port, cruise terminal, private marinas, tourist destinations, a conference center, entertainment, commercial activity and residential development (D. Jardine, 2023)

THIS SECTION INCLUDES:

Coastal Settlement Patterns

Epekwitk (PEI) is located on Mi'kma'ki, the unsurrendered contemporary and ancestral lands of the Mi'kmaq people. The Epekwitnewaq Mi'kmaq have stewarded the lands and waters of Epekwitk since time immemorial. The earliest physical evidence of the presence of people found on the Island dates to about 11,000 years ago, during a time when the land was still connected to the mainland and sea level was rising rapidly.

The coastline, rich in marine resources, offered the Mi'kmaq a wealth of shellfish, finfish, and waterfowl, while salt marshes provided marsh hay (MacQuarrie, 2022). Evidence of early campsites have been discovered in coastal areas on the east end of the Island, between Souris and East Point, and on the North shore in the Malpeque and Rustico Bay areas (Baldwin, 1998). Unfortunately, much of the evidence of the earliest Mi'kmaq people has been lost as their original settlements were likely on the coast which was much farther offshore than it is today.

The arrival of Europeans in the late 1400s marked a significant shift in the Island's history. The first permanent European settlements, established in the 1700s, were strategically located in sheltered coastal areas and near salt marshes. In the 1760s, Captain Samuel Holland surveyed the Island and divided the land into 67 lots of approximately 20,000 acres each. The lots were distributed to landlords in Britain with the intent that each would promote settlement within their lot. The land disbursement led to widespread clearing for agriculture and settlements across each of the lots over the next century. Newcomers remained clustered on the coast with each new farm needing access to saltwater resources (Bolger, 1973).

Significant forest cover and coastal habitat was lost during this time. The remnant boundaries of the 67 lots and coastal settlement patterns within each remains evident on the Island's coastline today.

Captain Samuel Holland's survey provides the earliest comprehensive mapping of colonial settlement patterns on the Island. The Illustrated Historical Atlas of the Province of Prince Edward Island (1880), more commonly referred to as the Meacham's Atlas, provides another snapshot in time about early colonial settlement patterns across the Island and in the developing cities and towns. The Meacham Atlas includes details of wharfs and seawalls indicating that the Island's coastline was altered in the earliest days of settlement.

Beyond their historical significance, these maps continue to serve as a reference for measuring natural and human constructed change in the Island's coastline over the past 250 years.

Figure 38. A comparison of the City of Summerside, Meacham's Atlas (1880) to 2020. Red line indicates location of railline (1880) and Confederation Trail (2020). (Air photo: Gov PEI, 2020)

Figure 39. Town of Souris. (D. Jardine, 2023)

POPULATION DISTRIBUTION

Today, PEI has many small rural communities dispersed across the Island and along the shoreline. As of April 1, 2023, the population was estimated to be 176,113 and growing with a yearly increase of about 4.6% (PEI Gov, 2023). This growth is the largest year-over-year population increase for PEI on record since 1951 and the highest year-over-year growth rate among provinces and territories. While cities remain relatively small, the population density of the province is at 23.9 people/sq km, the highest among all Canadian provinces, contrasting sharply with the national average of only 3.2 people/sq km (Statistics Canada, 2021).

PEI's population distribution and coastal development trends are heavily influenced by the influx of seasonal residents and tourists. In 2020, there were approximately 3,500 seasonal residents who come to PEI each year, including about 2,300 Canadians, 1,150 from the United States and 50 from other parts of the world. These residents own PEI property but do not live here year-round (CBC, 2020).

COASTAL COMMUNITIES AND VULNERABILITIES

Coastal communities and infrastructure built near the coast are vulnerable to coastal processes and hazards associated with climate change.

Coastal communities may also be vulnerable to saltwater intrusion - when salt water from the ocean mixes with the groundwater supply. Saltwater intrusion has already been documented in several areas in PEI and is particularly a problem in small-lot subdivisions where each property is serviced by a private on-site well. Increasing pressure for coastal development in areas without access to municipal services suggests this problem will only increase in the future (Linzey 2011).

As more coastal communities and property owners are faced with decisions about how to respond to coastal vulnerability it is important that they have accurate data on projected hazards and risks to inform their decisions.

First Nations Lands and Communities

The *Indian Act* established four reserves on the Island. Two additional reserves were added at a later date. The Lennox Island First Nation (L'nui Mnikuk), with a total population of about 950, has about 308 people living in Lennox Island First Nation Reserve (#1) (MCPEI, 2023). The Lennox Island First Nation also has land in East Bideford (#5) and Fernwood (#6) however these properties currently have no infrastructure or residents. The Abegweit First Nation (Epekwitk), which has a total population of about 400, has about 300 residents living across 3 communities in Morell #2, Rocky Point #3 and Scotchfort #4 Reserves (MCPEI, 2023).

The Lennox Island First Nation, Abegweit First Nation, and the Mi'kmaq Confederacy of Prince Edward Island (MCPEI) have worked closely with UPEI's School of Climate Change and Adaptation on research relating to coastal vulnerability and adaptation over the past 10 years.

The following sections provide a brief description of the current and future coastal vulnerability of building infrastructure to coastal flooding in these areas. Note that Morell #2 Reserve and the Lennox Island East Bideford #5 have been excluded because they are not located on the coast. It is recognized that Indigenous knowledge and values may differ from that which is reflected in the following data. Hazards associated with cultural assets and natural features within these communities was beyond the scope of the present study but is identified as a gap that should be addressed in future research.

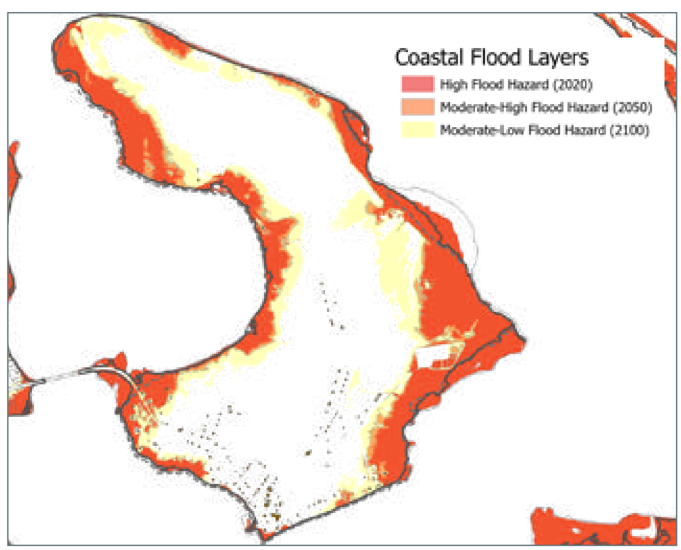
Figure 40. Lennox Island First Nation. (D. Jardine, 2023)

LENNOX ISLAND FIRST NATION

Pop. 308

Coastline Length (km)	16.4
Coastline designated as Critical Habitat (km)	0
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	8
Buildings (#) wtihin Moderate-low Hazard Area (future floodplain)	24
Length of Shoreline Armouring (km)	0.8

Table 3. Lennox Island First Nation. Coastline Statistics

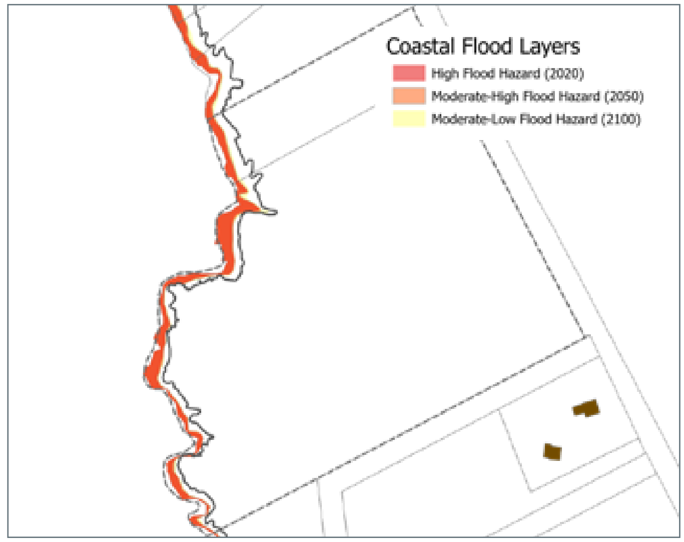


LENNOX ISLAND - FERNWOOD

Pop. 0

Coastline Length (km)	0.63
Coastline designated as Critical Habitat (km)	0.63
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	0
Buildings (#) wtihin Moderate-low Hazard Area (future floodplain)	0
Length of Shoreline Armouring (km)	0

Table 4. Lennox Island - Fernwood. Coastline Statistics

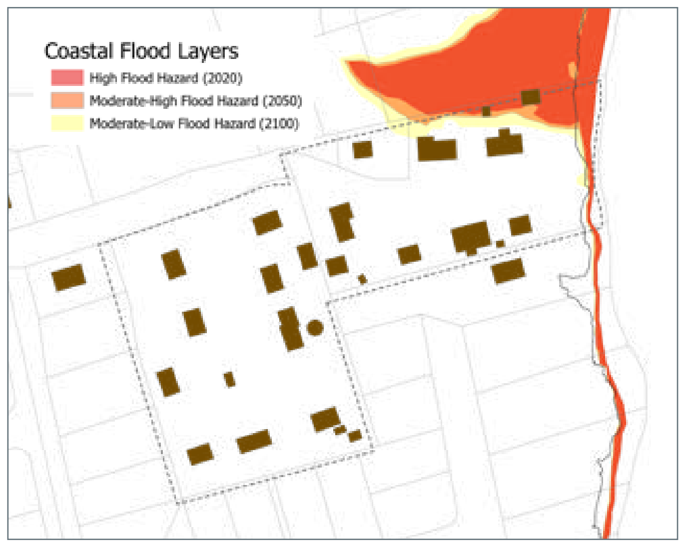


ROCKY POINT

Pop. 47

Coastline Length (km)	0.81
Coastline designated as Critical Habitat (km)	0.81
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	2
Buildings (#) wtihin Moderate-low Hazard Area (future floodplain)	2
Length of Shoreline Armouring (km)	0.81

Table 5. Rocky Point. Coastline Statistics

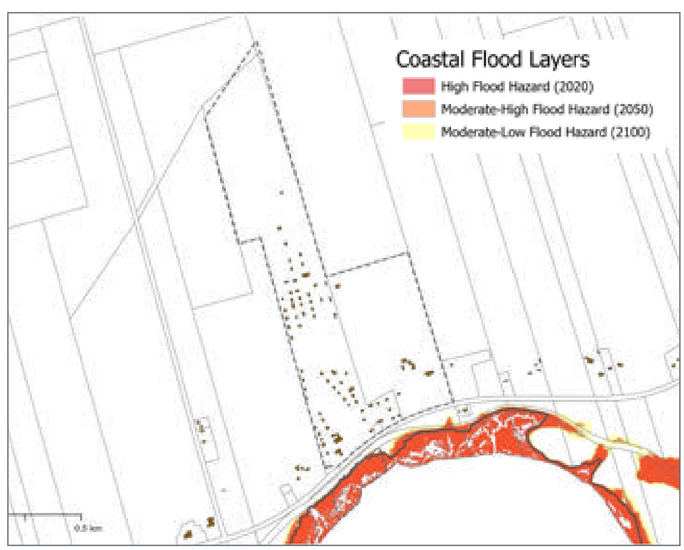


SCOTCHFORT

Pop. 230

Coastline Length (km)	0.26
Coastline designated as Critical Habitat (km)	0
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	0
Buildings (#) wtihin Moderate-low Hazard Area (future floodplain)	0
Length of Shoreline Armouring (km)	n/a

Table 6. Scotchfort. Coastline Statistics



Coastal Municipalities

There are 58 municipalities in PEI that cover about 32% of the province's land area. Forty-four (44) of the municipalities are located on the coast, with about 42% of the coastline falling within their boundaries. Municipalities provide local government services to their residents. Under the *Municipal Government Act* they are required at a minimum to provide fire protection, emergency measures planning, and municipal planning services (by 2025).

To date only 29 municipalities (of which 20 are coastal municipalities) provide municipal land use planning. The remaining land area (65% of the Island; and 78% of the coastline) is unincorporated, or is within a municipality that does not yet offer planning services, and falls within provincial jurisdiction for land use, subdivision, and development regulations. The Province currently does not have a land use plan for this area.

For coastal municipalities, the length of coastline varies considerably between each, as does the amount and type of coastal infrastructure and buildings that are vulnerable to coastal hazards. A brief description of the current and future coastal vulnerability for waterfront properties and building infrastructure within each of PEI's coastal municipalities with land use planning authority is summarized in the following sections.

Coastal municipalities with planning authority have a responsibility for the "protection, conservation, and management of coastal areas", in accordance with the Statements of Provincial Interest identified in the *Planning Act*.

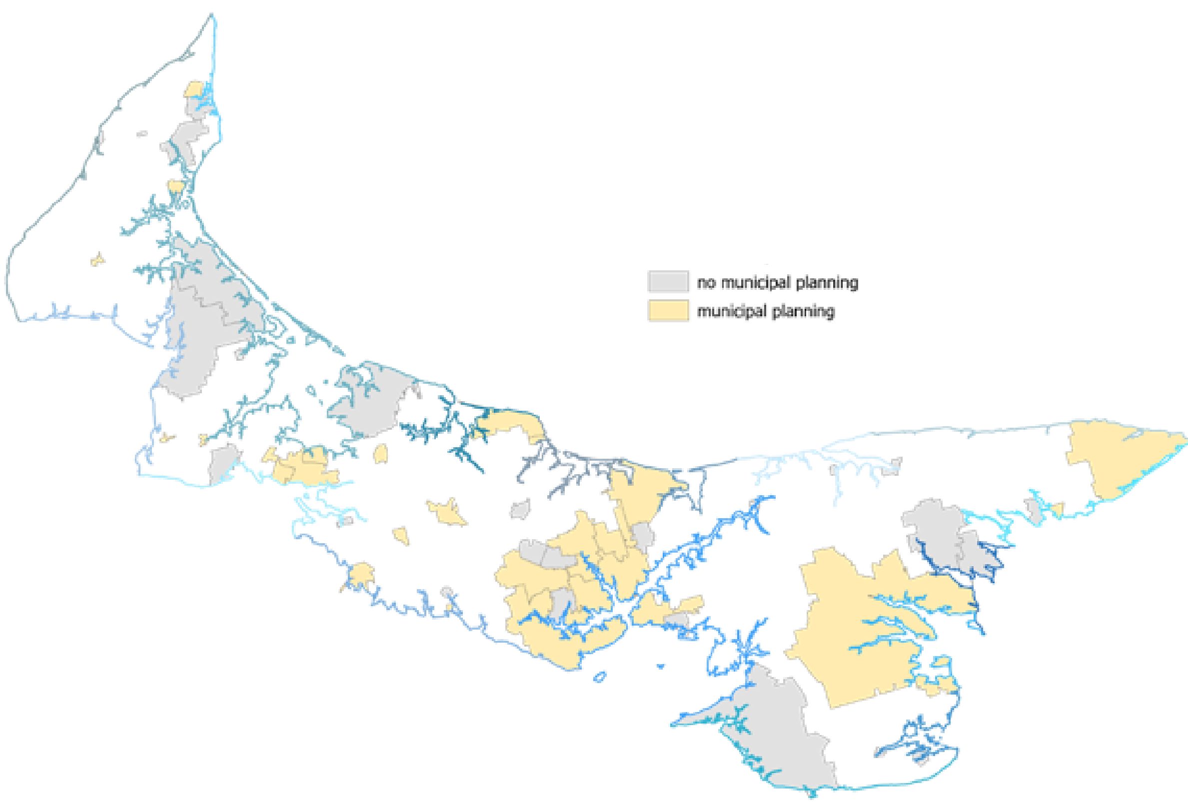


Figure 40. PEI Municipalities. Municipalities that have adopted Official Plans and Bylaws relating to land use planning (yellow); municipalities still under provincial planning authority (grey).

CITY OF CHARLOTTETOWN

Pop. 38,809

Coastline Length (km)	27.3
Waterfront Properties (#)	1481
Developed Lot (has a civic #)	1066
Vacant (no civic #)	415
Shoreline Stabilization (% of coastline)	41%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	142
Buildings wtihin Moderate-low Hazard Area (future floodplain)	381

Table 7. City of Charlottetown. Coastline Statistics

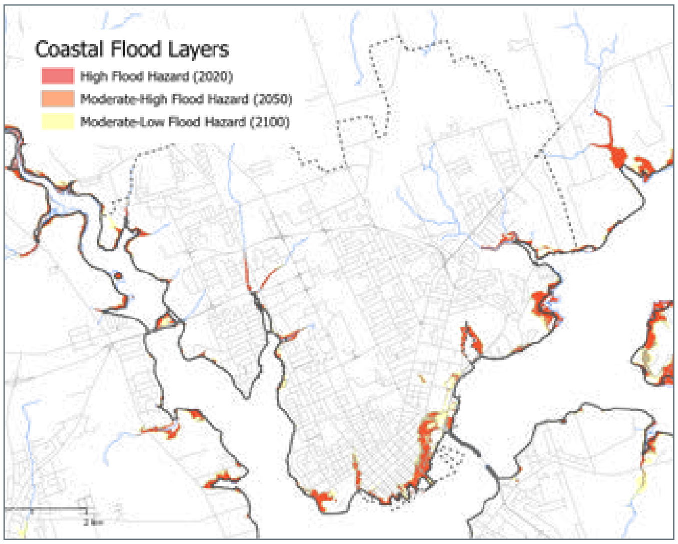


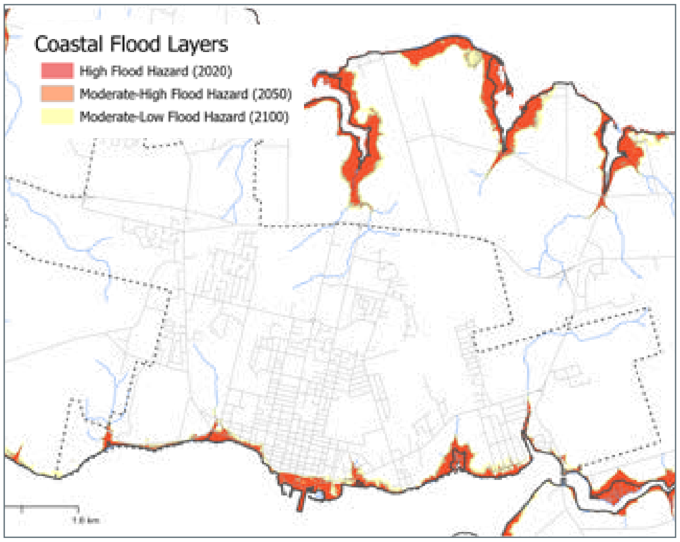
Figure 41. Ellen's Creek discharges into the North River, Charlottetown. (D. Jardine, 2023)

CITY OF SUMMERSIDE

Pop. 16,001

Coastline Length (km)	13.13
Waterfront Properties (#)	768
Developed Lot (has a civic #)	515
Vacant (no civic #)	253
Shoreline Stabilization (% of coastline)	54%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	55
Buildings wtihin Moderate-low Hazard Area (future floodplain)	156

Table 8. City of Summerside. Coastline Statistics

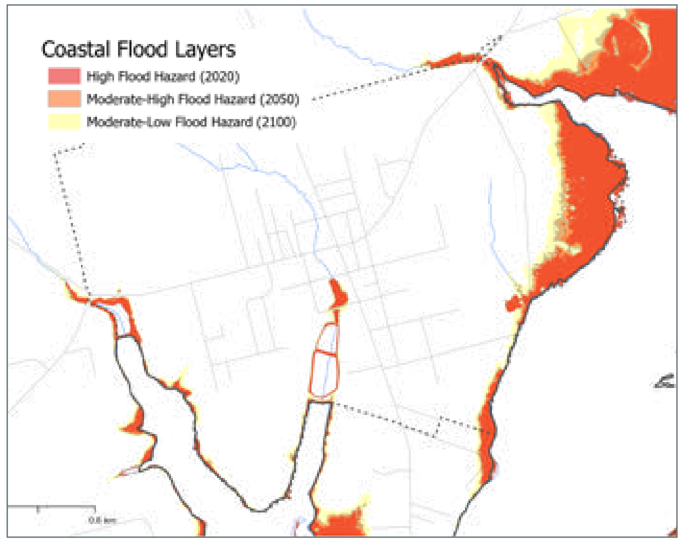


TOWN OF ALBERTON

Pop. 1,301

Coastline Length (km)	4.51
Waterfront Properties (#)	99
Developed Lot (has a civic #)	36
Vacant (no civic #)	63
Shoreline Stabilization (% of coastline)	4%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	1
Buildings wtihin Moderate-low Hazard Area (future floodplain)	4

Table 9. Town of Alberton. Coastline Statistics

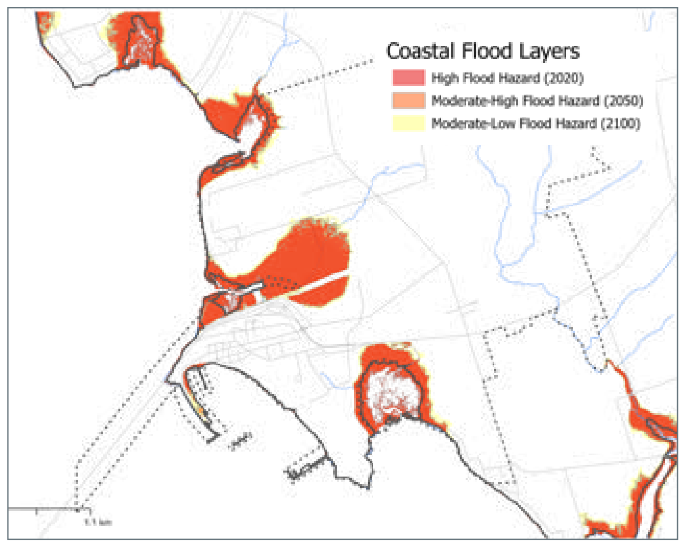


TOWN OF BORDEN-CARLETON

Pop. 788

Coastline Length (km)	14.66
Waterfront Properties (#)	183
Developed Lot (has a civic #)	73
Vacant (no civic #)	110
Shoreline Stabilization (% of coastline)	39%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	5
Buildings wtihin Moderate-low Hazard Area (future floodplain)	10

Table 10. Town of Borden-Carleton. Coastline Statistics

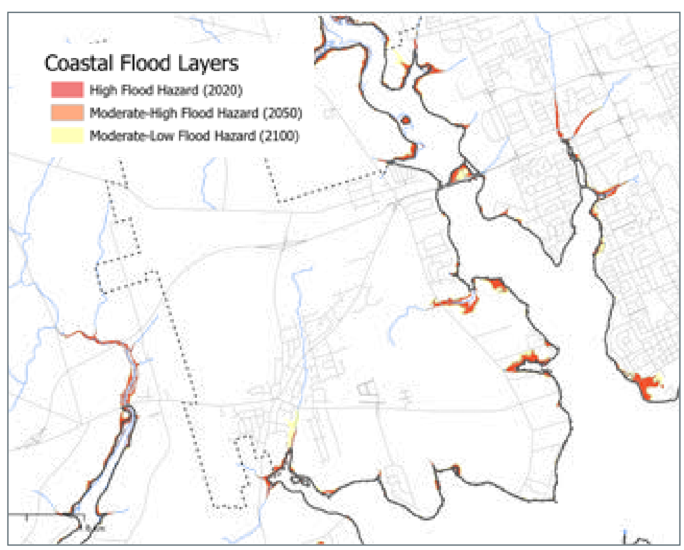


TOWN OF CORNWALL

Pop. 6,574

Coastline Length (km)	17.48
Waterfront Properties (#)	309
Developed Lot (has a civic #)	152
Vacant (no civic #)	157
Shoreline Stabilization (% of coastline)	23%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	3
Buildings wtihin Moderate-low Hazard Area (future floodplain)	6

Table 11. Town of Cornwall. Coastline Statistics

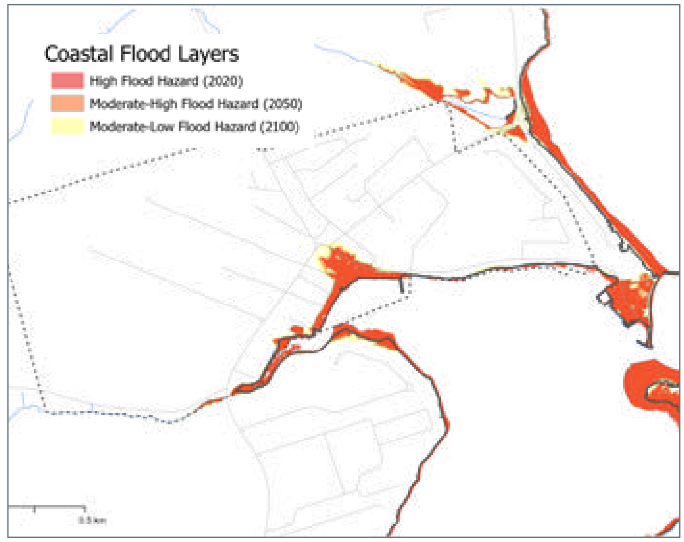


TOWN OF NORTH RUSTICO

Pop. 648

Coastline Length (km)	2.28
Waterfront Properties (#)	127
Developed Lot (has a civic #)	92
Vacant (no civic #)	35
Shoreline Stabilization (% of coastline)	61%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	35
Buildings wtihin Moderate-low Hazard Area (future floodplain)	46

Table 12. Town of North Rustico. Coastline Statistics

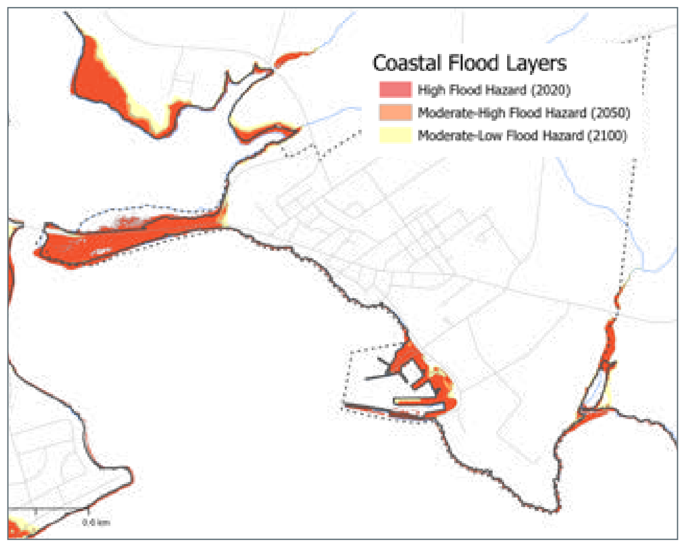


TOWN OF SOURIS

Pop. 1,079

Coastline Length (km)	9.89
Waterfront Properties (#)	142
Developed Lot (has a civic #)	86
Vacant (no civic #)	56
Shoreline Stabilization (% of coastline)	49%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	32
Buildings wtihin Moderate-low Hazard Area (future floodplain)	35

Table 13. Town of Souris. Coastline Statistics



TOWN OF STRATFORD

Pop. 10,927

Coastline Length (km)	22.46
Waterfront Properties (#)	549
Developed Lot (has a civic #)	368
Vacant (no civic #)	181
Shoreline Stabilization (% of coastline)	38%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	1
Buildings wtihin Moderate-low Hazard Area (future floodplain)	22

Table 14. Town of Stratford. Coastline Statistics

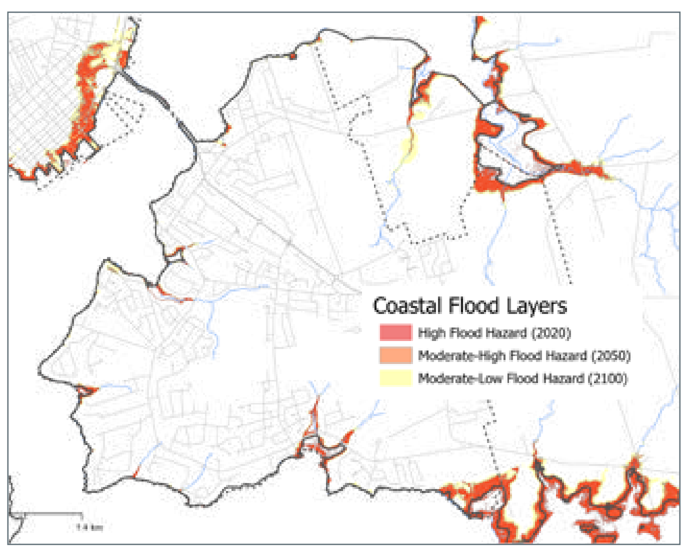


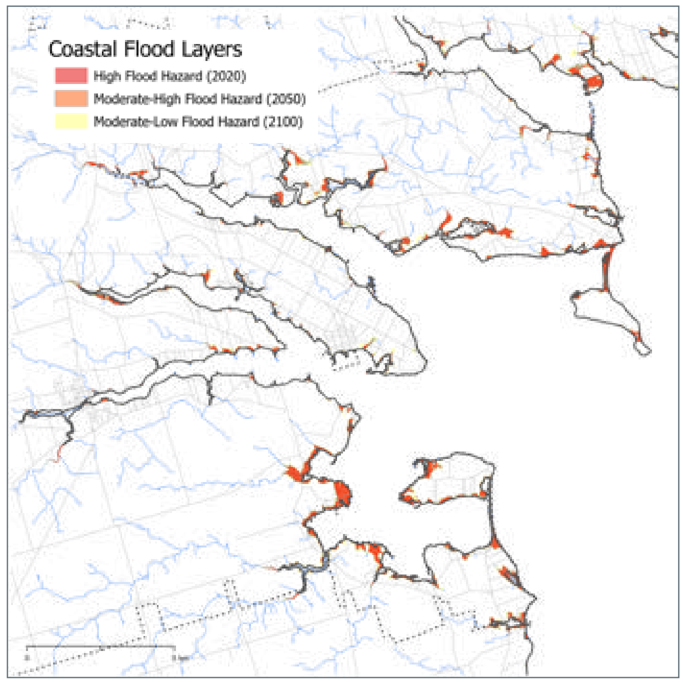
Figure 42. Montague, Town of Three Rivers (D. Jardine, 2023)

TOWN OF THREE RIVERS

Pop. 7,883

Coastline Length (km)	214.56
Waterfront Properties (#)	2566
Developed Lot (has a civic #)	1073
Vacant (no civic #)	1493
Shoreline Stabilization (% of coastline)	13%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	149
Buildings wtihin Moderate-low Hazard Area (future floodplain)	271

Table 15. Town of Three Rivers. Coastline Statistics

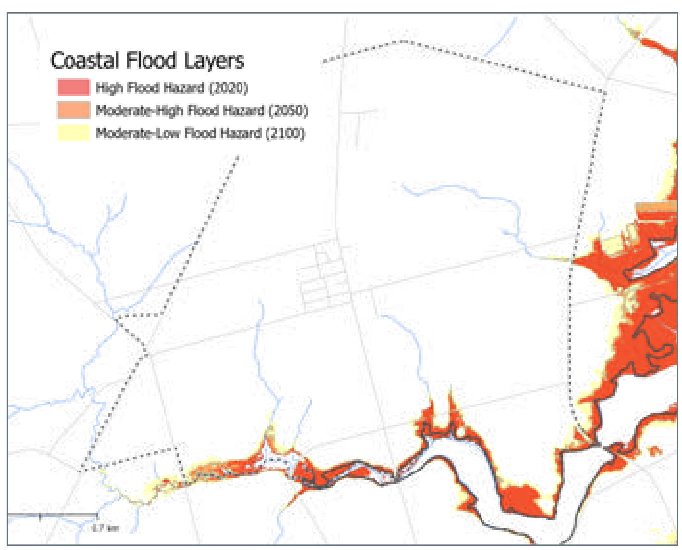


TOWN OF TIGNISH

Pop. 744

Coastline Length (km)	3.05
Waterfront Properties (#)	44
Developed Lot (has a civic #)	22
Vacant (no civic #)	22
Shoreline Stabilization (% of coastline)	5%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	1
Buildings wtihin Moderate-low Hazard Area (future floodplain)	1

Table 16. Town of Tignish. Coastline Statistics



RURAL MUNICIPALITY OF EASTERN KINGS

Pop. 687

Coastline Length (km)	108.30
Waterfront Properties (#)	631
Developed Lot (has a civic #)	198
Vacant (no civic #)	433
Shoreline Stabilization (% of coastline)	3%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	98
Buildings wtihin Moderate-low Hazard Area (future floodplain)	108

Table 17. RM of Eastern Kings Coastline Statistics

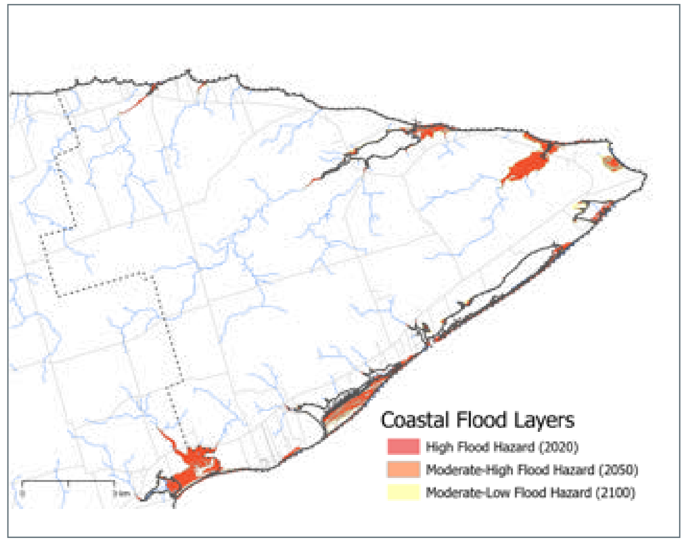


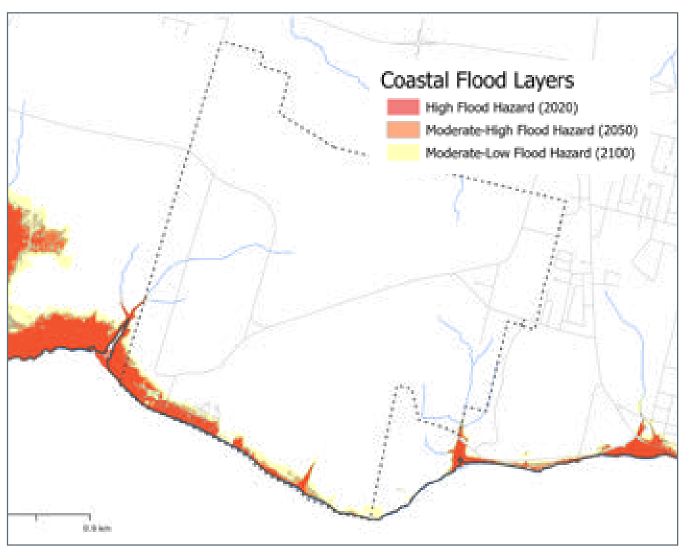
Figure 43. Linkletter Provincial Park (H. Parnham, 2023)

RURAL MUNICIPALITY OF LINKLETTER

Pop. 315

Coastline Length (km)	3.12
Waterfront Properties (#)	35
Developed Lot (has a civic #)	16
Vacant (no civic #)	19
Shoreline Stabilization (% of coastline)	10%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	4
Buildings wtihin Moderate-low Hazard Area (future floodplain)	10

Table 18. RM of Linkletter. Coastline Statistics

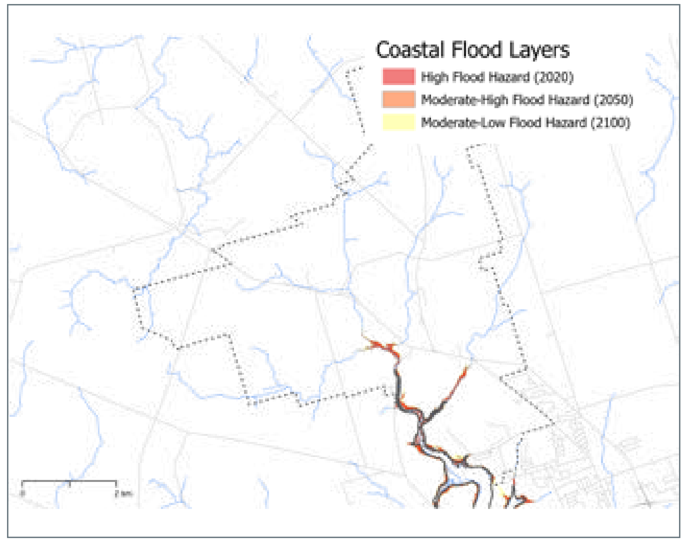


RURAL MUNICIPALITY OF MILTONVALE PARK

Pop. 1,196

Coastline Length (km)	6.48
Waterfront Properties (#)	59
Developed Lot (has a civic #)	24
Vacant (no civic #)	35
Shoreline Stabilization (% of coastline)	0%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	0
Buildings wtihin Moderate-low Hazard Area (future floodplain)	0

Table 19. RM of Miltonvale Park. Coastline Statistics

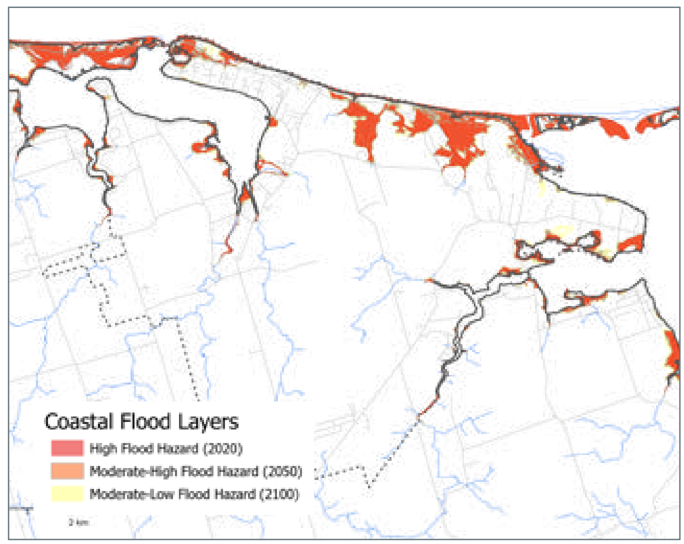


RURAL MUNICIPALITY OF NORTH SHORE

Pop. 2,500

Coastline Length (km)	54.16
Waterfront Properties (#)	815
Developed Lot (has a civic #)	357
Vacant (no civic #)	458
Shoreline Stabilization (% of coastline)	9%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	20
Buildings wtihin Moderate-low Hazard Area (future floodplain)	68

Table 20. RM of North Shore. Coastline Statistics

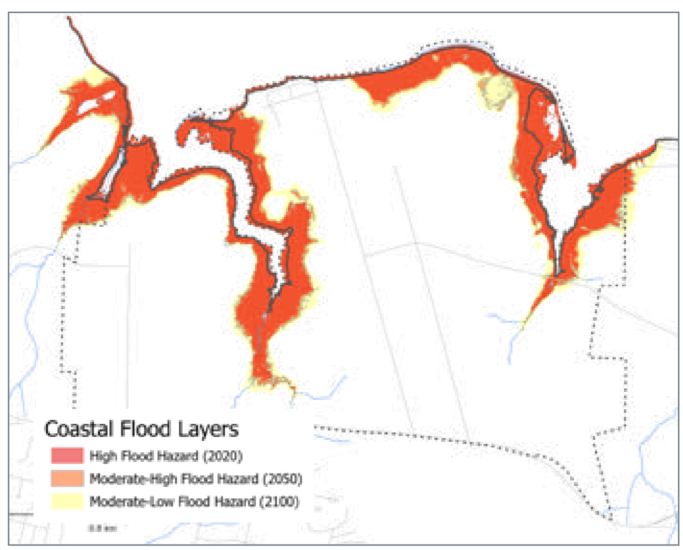


RURAL MUNICIPALITY OF SHERBROOKE

Pop. 178

Coastline Length (km)	13.63
Waterfront Properties (#)	77
Developed Lot (has a civic #)	36
Vacant (no civic #)	41
Shoreline Stabilization (% of coastline)	6%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	0
Buildings wtihin Moderate-low Hazard Area (future floodplain)	2

Table 21. RM of Sherbrooke. Coastline Statistics



RURAL MUNICIPALITY OF VICTORIA

Pop. 139

Coastline Length (km)	6.07
Waterfront Properties (#)	118
Developed Lot (has a civic #)	43
Vacant (no civic #)	75
Shoreline Stabilization (% of coastline)	31%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	9
Buildings wtihin Moderate-low Hazard Area (future floodplain)	20

Table 22. RM of Victoria. Coastline Statistics

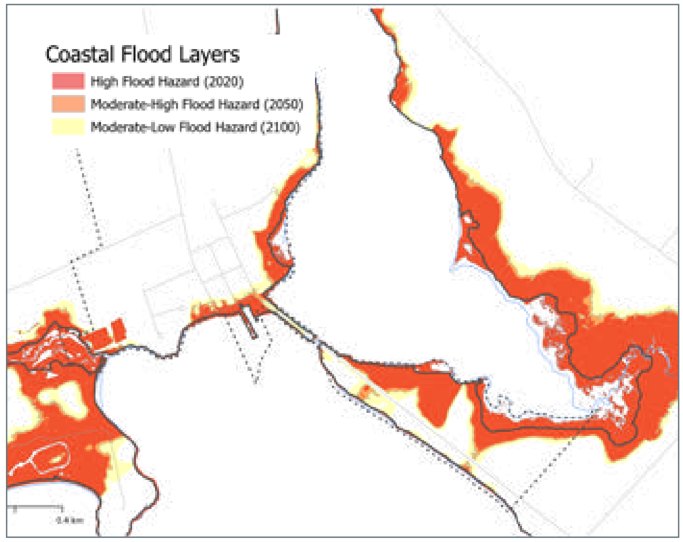


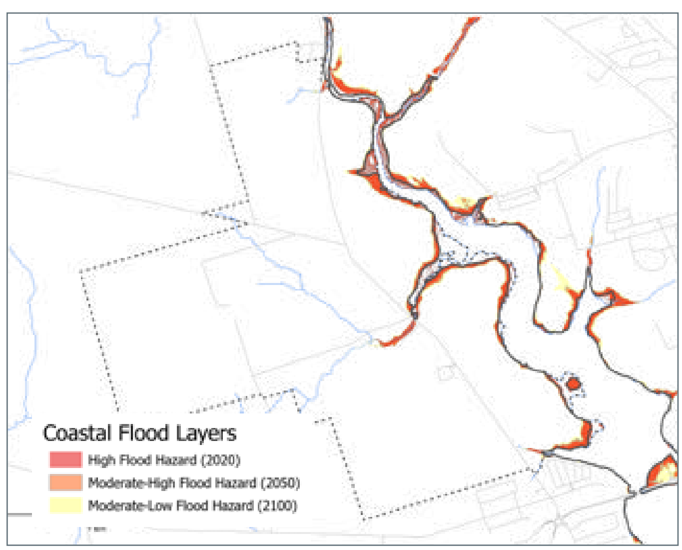
Figure 44. Rural Municipality of Victoria (H. Parnham, 2023)

RURAL MUNICIPALITY OF WARREN GROVE

Pop. 374

Coastline Length (km)	7.95
Waterfront Properties (#)	44
Developed Lot (has a civic #)	21
Vacant (no civic #)	23
Shoreline Stabilization (% of coastline)	0%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	0
Buildings wtihin Moderate-low Hazard Area (future floodplain)	0

Table 23. RM of Warren Grove. Coastline Statistics

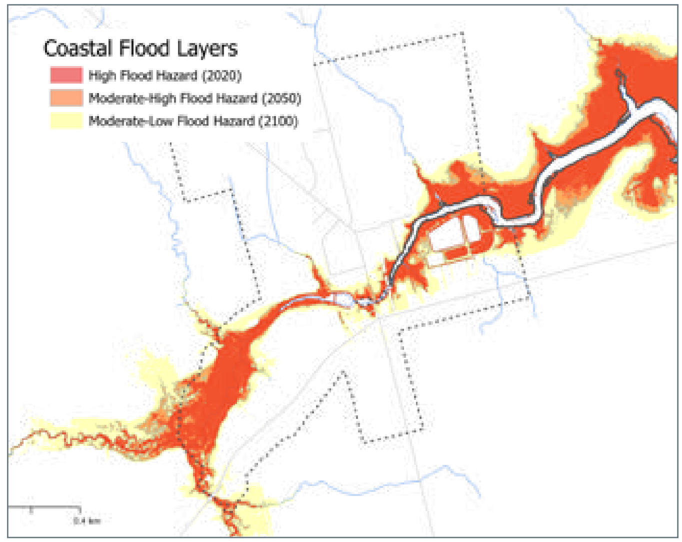


RURAL MUNICIPALITY OF WELLINGTON

Pop. 414

Coastline Length (km)	1.04
Waterfront Properties (#)	137
Developed Lot (has a civic #)	71
Vacant (no civic #)	66
Shoreline Stabilization (% of coastline)	0%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	3
Buildings wtihin Moderate-low Hazard Area (future floodplain)	11

Table 24. RM of Wellington. Coastline Statistics

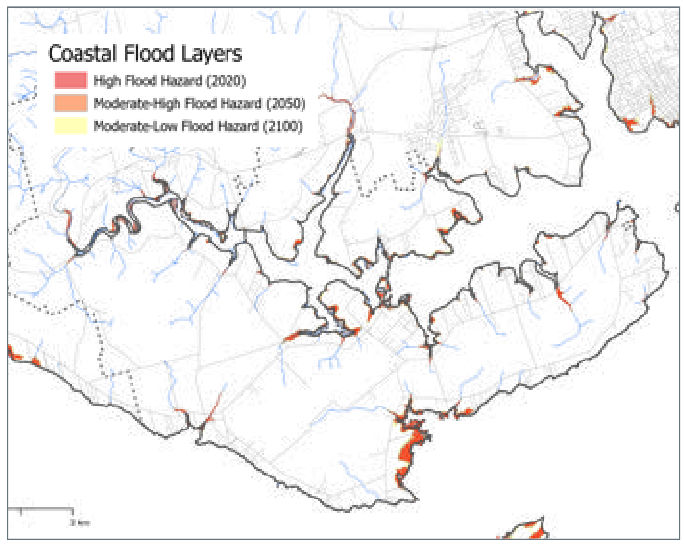


RURAL MUNICIPALITY OF WEST RIVER

Pop. 3,473

Coastline Length (km)	117.81
Waterfront Properties (#)	1267
Developed Lot (has a civic #)	582
Vacant (no civic #)	685
Shoreline Stabilization (% of coastline)	5%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	29
Buildings wtihin Moderate-low Hazard Area (future floodplain)	73

Table 25. RM of West River. Coastline Statistics

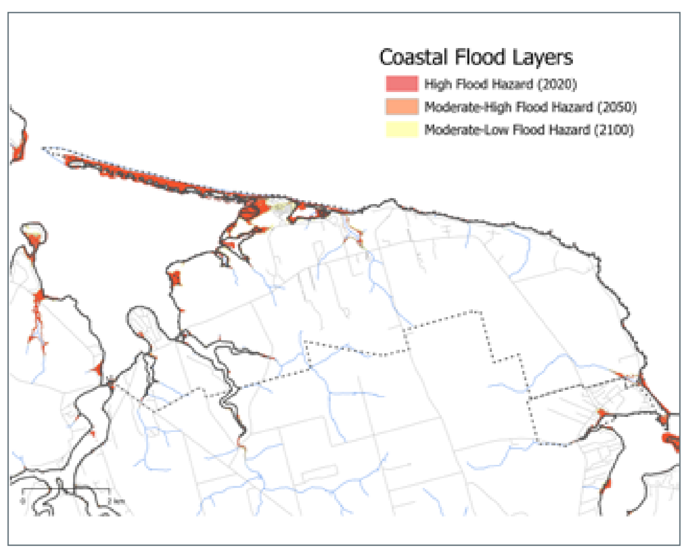


RESORT MUN. OF STANLEY BRIDGE, HOPE RIVER, BAYVIEW, CAVENDISH, AND NORTH RUSTICO

Pop. 359

Coastline Length (km)	47.21
Waterfront Properties (#)	244
Developed Lot (has a civic #)	111
Vacant (no civic #)	133
Shoreline Stabilization (% of coastline)	9%
Buildings (#) within High Flood Hazard Area (current coastal floodplain)	7
Buildings wtihin Moderate-low Hazard Area (future floodplain)	13

Table 26. Resort Municipality. Coastline Statistics



North Rustico and Rustico Harbour: Resilience & Adaptation

The Town of North Rustico and adjacent community of Rustico Harbour have both experienced severe impacts from coastal hazards over the past few decades. The Town has a year-round population of about 648 residents whereas the Rustico Harbour area has a year-round population of less than 50 people.

With direct exposure to the Gulf of St. Lawrence, the Rustico Harbour area is vulnerable to storm surges and high waves during extreme weather events. The severity of the storms and waves reached a new level when Hurricane Fiona struck on September 24, 2022, culminating wind damage and flooding to buildings including the North Rustico Fire Hall, wharf storage buildings, restaurants, commercial buildings, and roads. Damages are estimated to have been in the millions of dollars.

This was not the first-time storm surge water has impacted the Town. On December 21, 2010, storm surge water flooded the former wastewater treatment plant on Harbourview Drive. The Province completed a vulnerability assessment with the community in 2011 which helped the municipality identify its vulnerabilities and adaptation options. In 2014 the plant was relocated at a cost of over $3,000,000. The Town also opened a new access road on Simon Drive to Route 6 to provide a second exit for residents of the Lantern Hill area as Harbourview Drive is impassable due to floodwaters during storm events.

In anticipation of the projected storm surge ahead of Post-tropical storm Fiona, the fire trucks from the North Rustico Fire Department were relocated to higher ground for the duration of the storm while the inside of the building was under water. The Town is now seeking a new site for the Fire Hall on higher ground.

The owner of Seagulls Nest Gift Shop in Rustico Harbour opposite the lighthouse has been tracking storm surge water levels on the wall inside the building. The waves in the photo show the elevation of the waves inside the building during Fiona (2.92m CGVD2013). The owner reports that this was the worst storm surge since he started his business at this location in 1984. At least 6 storm surges have entered his building. During Fiona almost all giftware was ruined with no insurance coverage to date.

Residents and businesses in the two communities are adapting to the impacts of more intense storms driven by climatic forces. They want to know how to construct or modify buildings, roads, and other structures to withstand storms for the next 50 to 100 years. Improved access to information and adaptation tools and resources would help them in this process.

Figure 45. Town of North Rustico and Community of Rustico Harbour (D. Jardine, 2023)

Figure 46. Storm Surge water levels marked on the Blue Wall in Sea Gulls Nest Giftshop. Rustico Harbour (D. Jardine, 2023)

Coastal Infrastructure

Critical Infrastructure

Public Safety Canada defines critical infrastructure (CI) as “processes, systems, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government.” In PEI, coastal CI mainly includes transportation (coastal roads, bridges, marinas, ferry terminals and wharfs), fisheries and tourism-related infrastructure.

In addition to the coastal CI, there are a wide range of other types of CI (i.e., hospitals, schools, emergency response facilities, fuel storage etc.) that are currently located on the coast but that are not coastal in the nature by which they function or the service they provide. Rather, these properties are located adjacent to the coast due to desirability, market demand, and/or historic development patterns. These properties and structures may be in locations which were once considered safe and appropriate but have over time become increasingly exposed to coastal hazards. The difference between coastal CI and other infrastructure located on the coast is an essential distinction for developing coastal management strategies and adaptation purposes. Small craft harbours and wharves cannot be relocated out of a flood risk area, but other infrastructure like fire departments and sewage treatment facilities can.

Figure 47. Carrefour De L’Isle-Saint-Jean (H. Parnham, 2023)

The provincial government conducted Critical Infrastructure Vulnerability Assessments (CIVA) in 2022 on 700 public and private properties containing infrastructure with respect to coastal flooding and coastal erosion hazards (GPEI, 2022). The types of infrastructure included in the study were: health-care facilities (e.g., hospitals, manors, community care facilities), education (e.g., schools), emergency services (e.g., ambulance services, emergency reception centres, fire departments), energy (propane storage facilities), social housing, telecommunications (e.g., radio facilities), cultural (museum and heritage buildings), and economic (e.g., tourism buildings, fish, and seafood processing facilities) assets.

Of the 700 properties studied, forty-six properties (<7%) were found to be in the current (24) or future (22) coastal floodplains. A quarter of these properties were identified as coastal infrastructure, that is fisheries, aquaculture and/or seafood industry-related and their proximity to the coast is necessary to their function. (GPEI, 2022)

Properties containing other types of CI located within the high-hazard zone (coastal floodplain) include the:

- North Rustico Fire Hall;
- Carrefour De L’Isle-Saint-Jean;
- 13 heritage designated properties including properties in Charlottetown, Summerside, Murray Harbour, Northport, Victoria, and Montague; and
- 3 social housing properties located in Charlottetown (Dorchester Street).

Properties containing CI found within the future (2100) coastal floodplain included a community care facility, EMS, propane storage, and radio station. While it is unlikely that this area will experience coastal flooding due to a storm event now, the likelihood of flooding will increase over time.

Of the 700 properties assessed, no properties had a high hazard classification for coastal erosion other than a few provincial parks, which are discussed in a following section of this report.

Fisheries and Aquaculture

The fisheries and aquaculture industry in PEI is a significant contributor to the province's economy and are deeply connected to the rural coastal communities. The fisheries industry is characterized by a diverse range of species, with lobster being the most valuable, landing over 47 million pounds of lobster in 2021 (GPEI, 2021). The aquaculture sector is dominated by the cultivation of blue mussels which accounted for approximately 80% of the total aquaculture production (GPEI, 2021), and for which PEI is the leading producer in North America. Oyster aquaculture has also experienced increases in the landings and value over the past several years.

The fisheries and aquaculture industries are vulnerable to the impacts of climate change, which can affect both the marine species the industries depend upon, and the infrastructure that supports these industries. A study on climate-related risks to the aquaculture sector (DFO, 2012) identified several issues including increased water temperatures, changes in ocean acidity, and extreme weather events as primary concerns. These changes can affect the growth and survival of fish and shellfish, potentially leading to decreased productivity and economic losses. Another study (Stantec, 2023) on the impact climate change will have on lobster habitat on the lobster fishing areas off PEI found that the primary risks to lobsters were related to decreased sea ice presence and increased frequency of storms. Lobster food sources will be primarily impacted by climate related stresses including increasing temperature, ocean acidification, and changes in sea ice coverage. And lobster competitors and predators were also found to be impacted by changes in temperature and ocean acidification.

Figure 48. Miminegash Harbour (H. Parnham, 2017)

Coastal infrastructure that supports the fisheries and aquaculture industries is also at risk. The following types of infrastructure are used or are of strategic importance to the sectors:

- Wharves and other moorings or landing areas for vessels
- Fishery-related plants, dry-docks, lobster pounds and storage facilities
- In-water and on-shore fish farms and other aquaculture facilities (including oyster floats and bags, and mussel socks)
- Marine slips and boat launches (commercial / large)
- Shipyards
- Marine navigational aids
- Causeways, roads and other access routes to fisheries and aquaculture infrastructure
- Water supply, electrical supply, sewage, and communication services to fisheries infrastructure

(CBCL Ltd, 2012)

Natural coastal features, including estuary channels, headlands, barrier islands and sand bars also serve an important role in the protection of other relevant infrastructure. Due to the large number of sandy and shallow bays on PEI and influences of the tides on sediment transport along the coast, regular maintenance and dredging is necessary to keep vessel channels navigable. Changes in the channel locations over time can result in changes to the water quality and the vulnerability of built infrastructure.

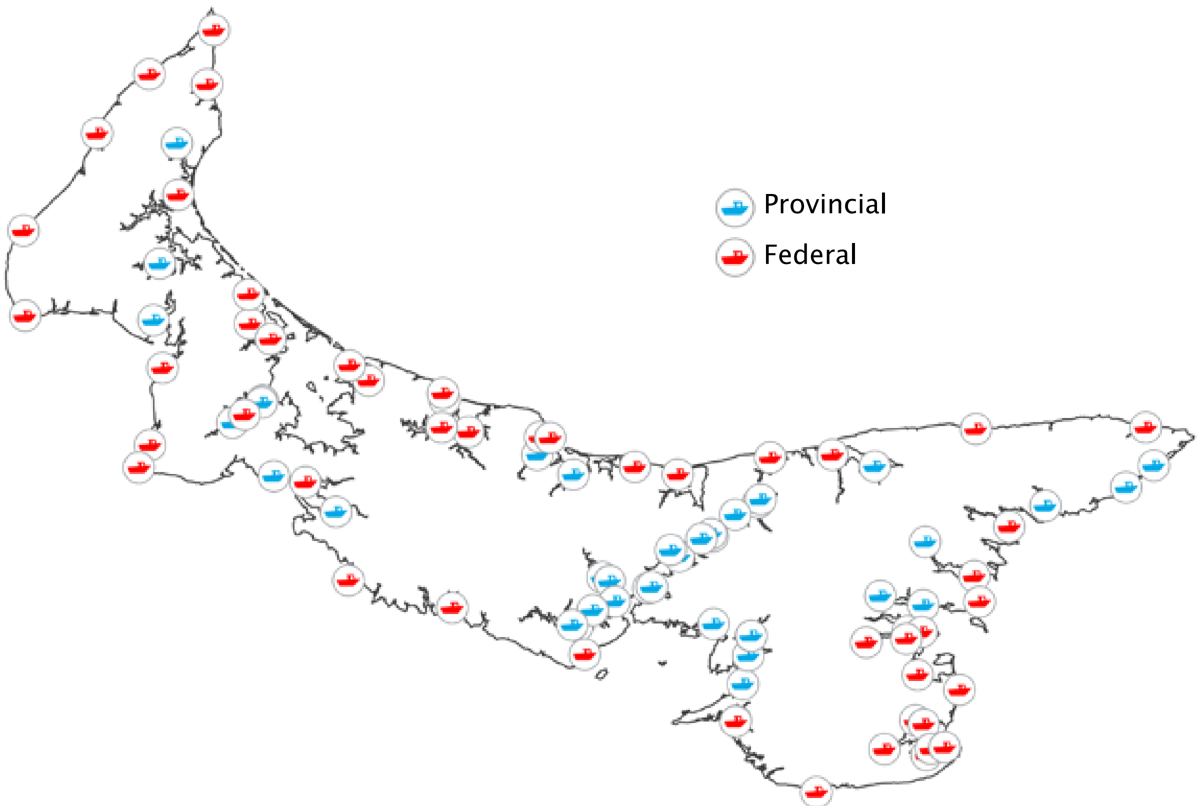


Figure 49. PEI provincial and federal fisheries instructure (small craft harbours, wharfs and road accesses)

With regards to coastal zone infrastructure, small craft harbours, wharfs and road access points are the primary locations of interest on the coast. There are approximately 50 federal, 40 provincial and 72 private sites or locations on PEI's coast. Private sites are primarily road access boat launches and small wharfs. These numbers are subject to change as responsibility regularly changes hands.

The infrastructure supporting the aquaculture industry is designed to withstand the impacts of regular coastal processes. However, the industry faces vulnerabilities due to rising sea levels, increasing storm intensity, high wave energy and erosion. These factors could potentially damage the infrastructure and disrupt operations, posing significant risks to the industry (DFO, 2012; CBCL, 2012).

Aquaculture infrastructure within the waterway consists of leased lots categorized into three types:

Bottom (BOT) culture lease: for conducting aquaculture on the seabed; leases range from 1 to 5 acres in size. There are approximately 5,300 acres of bottom leases in PEI's waterways.

Off-Bottom (OB) lease: for conducting aquaculture in the water column for oyster aquaculture; leases range from 1 to 100 acres in size. There are approximately 2,700 acres of off-bottom leases in PEI's waterways.

Surface (SUR) lease: to conduct aquaculture in the water column; leases range from 1 to 100 acres in size. There are approximately 11,200 acres of surface leases in PEI's waterways.

(DFO, 2023a)

Leased lots are almost exclusively located within the estuaries and adjacent to sheltered coastlines.

The Prince Edward Island Shellfish Aquaculture Leasing Policy (DFO, 2023) includes regulatory and policy restrictions to help define areas where shellfish aquaculture may or may not occur. The system considers several factors, including Canadian Shellfish Sanitation Program growing area classifications, migratory bird interactions, considerations for species listed under the Species at Risk Act (SARA), and policies such as no lease within 100 feet of the high tide mark, with exceptions for clam leases (DFO, 2023a). The site assessment criteria for lease applications consider navigation considerations, fishing activity, and other water users, the location of navigation channels, vessel types and quantity that frequent the area, riparian rights of adjacent landowners, and the presence of existing moorings or floating docks.

It is noted that the land use, or existing and future development potential of coastal properties is not included in these considerations. In most cases, this information would not be readily available as the unincorporated areas currently do not have land use planning designations. It is also noted that there are no known examples of where the province or a municipal planning jurisdiction have considered the location of leased lots in their land use planning policies and development regulations. However, the potential impacts of land use and development on aquaculture lease lots within adjacent watercourses is significant.

An incident that involved the unlawful clearing of trees from the shoreline of a residential property in 2022, resulted in significant runoff causing damage to eight years' worth of oyster crops in the adjacent 100-year-old leased lots (CBC, 2022). In a separate incident, in 2010 when the North Rustico wastewater treatment plant was flooded due to storm surge fishers were concerned about the impact of untreated sewage being released into Rustico Bay.

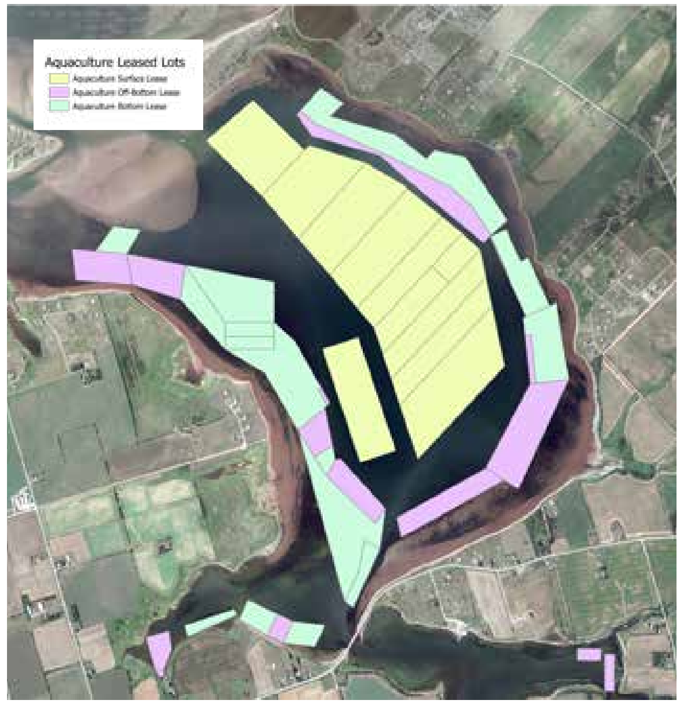


Figure 50. Aquaculture leases. Darnley, PE

For more information on the location of leased lots and other aquaculture related infrastructure, including buoy locations and spat collection sites, see DFO's PEI Aquaculture map, here (DFO, 2023b).

Figure 51. Aquaculture leases. Rusticoville, PE (D. Jardine, 2023)

Maritime Infrastructure

PORTS

Transport Canada considers Summerside to be the main commercial port for PEI due to the increase in passenger (cruise) ship traffic and recreational vessels in Charlottetown. Summerside's port receives imports of fertilizer, aggregate and lime, and exports produce such as soybeans, potatoes, and grain. The main wharf in Summerside is currently undergoing a major refit and the wharf deck will be raised to accommodate rising sea levels. Ports in Souris and Georgetown also receive smaller shipments of armour rock and gravel for jobs required in the local area.

Figure 52. Port Summerside. (D. Jardine, 2017)

FERRY TERMINALS

There are two ferry terminals operating in PEI, both are owned by Transport Canada. The ferry terminals and their services were described by CBCL Ltd (2020a and 2020b) in the Transportation Assets Risk Assessments (TARA) to Climate Change, as follows:

The Souris Terminal is privately operated by Coopérative de Transport Maritime et Aérien (CTMA) Traversier. The ferry terminal facilitates year-round travel between Souris, PEI and Cap aux Meules, Quebec on the Îles de la Madeleine and accommodates a total of more than 100,000 passengers each year. The ferry provides between 3 and 7 crossings every week depending on the weather conditions and season. The cross provincial journey is serviced by the MV Madeleine, Voyageur and Vacancier. (CBCL, 2020a)

Figure 53. Wood Islands Ferry Terminal. (H Parnham, 2017)

The Wood Islands Ferry Terminal is operated by Northumberland Ferries Limited. The ferry terminal facilitates travel from May to December between Wood Islands, PEI and Caribou, NS. The ferry terminal facilitates up to 9 departures per day from each port during peak season. The cross-provincial journey is serviced by the MV Confederation a roll on/roll off passenger ferry vessel. [The MV Holiday Island went out of service in 2022 and the federal government announced recently that they have found a temporary replacement]. (CBCL, 2020b)

The risk assessments concluded that winds represent the greatest risk in terms of operational impacts to both ferry services, and that in the long-term, extreme sea levels represent the prevailing climate risk for infrastructure. However, the existing assets will exceed their estimated remaining service life and will require significant rehabilitation or replacement before sea level rise poses a direct threat.

At the Wood Islands Terminal, a breach in the west barrier beach is expected to cause gradually increasing wave action and could lead to an increase in dredging requirements. While erosion risks will increase along the barrier beaches connected to the entrance breakwaters, most of this shoreline has already been armoured. A decrease in ice coverage in Northumberland Strait due to a warming climate could possibly lead to an extended shipping season at Wood Islands which may help contribute to the local economy.

Figure 54. Port Charlottetown (H Parnham, 2017)

CRUISE TERMINAL

Most cruise ships visiting PEI dock at Charlottetown while smaller passenger vessels alternatively stop in Summerside. The season runs from early-May through early-November. The cruise industry was initiated in 2005 and by 2019, the season saw 87 ship calls and 183,000 visitors (passengers and crew), with 11 ships canceled due to weather. Based on 2019 figures, the cruise ship industry contributes $42.2M to the PEI economy, through employment, spending, and taxation. In 2021, a 3-year $12M berth expansion project was completed so that the Port can now accommodate two large vessels at berths. Following the 2-year pause in cruise shipping in Canada due to the COVID pandemic, the 2022 season had a total of 74 ships scheduled, of which 55 landed bringing 96,000 tourists. In 2023, Port Charlottetown was expected to receive 91 ships with approximately 150,000 passengers, exceeding pre-pandemic numbers. (Port Charlottetown, 2023).

Following Hurricane Fiona, the Port paused cruise traffic for 2 weeks to support local community recovery efforts. There was no report of significant damage to the port infrastructure. Storms like Fiona have a major impact on the industry as navigation can be shut down for several days or even weeks and power outages on land can contribute to more lost time for ships coming to port.

Water and Wastewater Facilities

FRESH WATER SUPPLY

PEI is fully dependent on groundwater for its source of potable water. This includes all First Nations, cities, towns, municipalities, subdivisions, cottages, and rural areas. There have been numerous occasions where communities have experienced difficulty procuring fresh water or had existing wells contaminated with saltwater including two municipal water supply wells in Summerside turned salty, the Hebrides Cottage Subdivision in New London had to go far inland to locate a fresh water well, and homes and cottages at Hampton had to drill a central water supply well inland to obtain fresh water. On-site wells can also be impacted when infiltrated by saline storm surge water causing temporary water quality issues. These problems are expected to increase due to encroachment of the saltwater interface into aquifers underlying the province. The problem is exasperated by intensification of development on undersized and unserviced lots on the coast in rural areas. There are also some conflicting uses of groundwater when processing plants, factories, and fish rearing facilities which are located near the coast and require large quantities of water for their production. This can lead to induction of saline water into the aquifer by drawdown of the water table below sea level.

WASTEWATER TREATMENT AND DISPOSAL

Municipal wastewater treatment facilities, and municipal or privately owned treatment ponds, have traditionally been constructed adjacent to the coast for the benefits of a gravity fed system and because they require a discharge pipe. Discharge of effluent can lead to conflicts between fishers, tourism operators, general public and nearby landowners due to the smells or impact on water quality in the receiving surface water body.

This was a prevalent issue in Charlottetown as shellfish closures had to be enacted in Hillsborough Bay. The recent separation of the storm water and wastewater systems has alleviated the issue, enabling the Wastewater Treatment Plant on Riverside Drive to maintain its capacity during heavy rainstorms and snowmelt periods.

Due to their location adjacent to the coast, many facilities are in locations vulnerable to the accelerating impacts of climate change and higher storm surge event, and some have been upgraded or relocated accordingly in recent years.

In many rural subdivisions with small lots (<1 acre) malfunctioning or overloaded septic systems have caused contamination of private water supply wells due to the density of housing overloading the adsorption capacity of the local soil. This problem is compounded by the increase in water requiring disposal due to increased demands from larger cottages and more year-round homes being constructed on small lots. Inland and coastal flooding of septic tile beds can result in overloading of these systems especially those constructed over 10 years ago.

Figure 55. City of Charlottetown, Wastewater Treatment Plant, (D. Jardine, 2023)

Souris Causeway - Intertidal Artificial Reefs

The Souris causeway was constructed on a sandspit, connecting the Town of Souris to Rte 2 and the primary route connecting the Town to the rest of the Island. The causeway also contains a popular beach for residents and tourists.

Most of the southern beaches and dunes are low-lying and at an increasing risk of erosion. An analysis of historic photos shows that there has been significant erosion on the causeway over the last 86 years, especially along the southern shore. The eastern end of the beach has been eroding at 1,300 m^3 per year, except immediately behind the breakwaters, there has been an annual net loss of 800 m^3 of sand. The low-lying road has a 50% likelihood of flooding at least once in the next 20 years (UPEI, 2023).

Two artificial reefs were installed in the water in front of the causeway to baffle wave energy, protect the causeway, and capture sand. The reefs are considered a nature-based solution as they provide an opportunity for benthic (on the bottom of a body of water) and intertidal habitat and are constructed with PEI's local sandstone rock.

Using local material helps the structure maintain its natural appearance and contributes to the sand of the beach as the rock erodes over time. The artificial reefs have shown early success in capturing sand and rebuilding the beach behind them.

Figure 56. Intertidal reefs at low tide, Souris PEI (V. Leys, 2018)

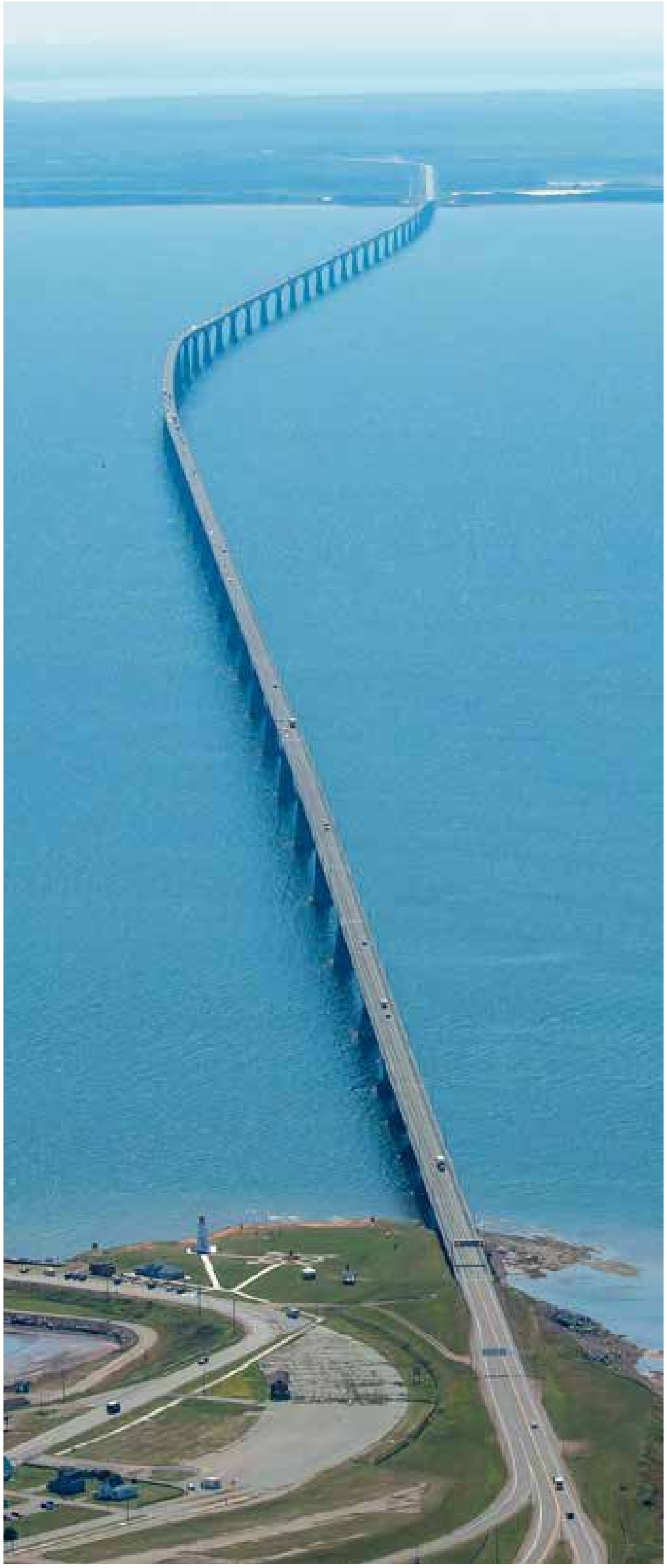


Figure 57. Confederation Bridge, Borden-Carleton (D. Jardine, 2017)

Transportation Infrastructure

The Department of Transportation and Infrastructure (DTI) maintains essential transportation systems for the public and for the transport of goods, ensuring that Island roads, bridges and causeways are safe. The DTI is regularly involved in the maintenance, restoration, and reconstruction of vulnerable coastal infrastructure. Traditional coastal adaptation projects include raising bridges, reinforcement of bridge embankments and installing shoreline armouring adjacent to shore-parallel roadways and public properties. In recent years, the DTI has been instrumental in supporting new innovative approaches to coastal adaptation projects. Buried revetments and offshore artificial reefs have been used to achieve goals of infrastructure protection through nature-based or hybrid strategies.

During Hurricane Fiona (Sept 2022), several federal, provincial, and private roadways, including causeways and bridges, experienced unprecedented flooding, and damage. Based on the provincial floodplain maps the service on approximately 1135 roads (591 paved and 543 unpaved) is vulnerable to coastal flood hazards, with over 42 km of paved roads and almost 60 km of unpaved roadways located within the floodplain. While the full length of a roadway may not be inundated, flooded roads prevent access from one end to another which is particularly dangeous on dead-end roads and creates a public safety risk when individuals attempt to drive through and across the flooded areas.

The Confederation Bridge connects PEI to New Brunswick at the Town of Borden-Carleton. The 12.9 km (8 mile) long bridge is the longest in the world crossing ice-covered water. The bridge is operated and maintained by Strait Crossing Bridge Limited (SCBL). The bridge opened in 1997 and it was designed to accommodate a 1m rise in sea levels. At the time this issue caused some debate over the amount of sea level rise that could be expected in the future. The bridge structure was specially designed for a 100-year life span which required unique specifications of the components and concrete composition. Today, it is a frequently cited example of incorporating adaptation into infrastructure design. (Gregg, 2010)

Recreation and Heritage

Parks and Recreation

PEI is home to a rich array of parks and recreational sites, many of which are located along the coastline and provide access to the beach and/or view of the water, which also makes them particularly vulnerable to coastal processes and climate change. These sites are not only popular destinations for outdoor activities, but many also hold significant cultural value and are environmentally sensitive landscapes.

PEI NATIONAL PARK

PEI National Park has over 65 km of shoreline. The park includes beaches, red sandstone cliffs, and rolling sand dunes on the North Shore. It offers extensive walking trails, boardwalks, and a 20 km paved multi-use trail for cyclists. The National Park natural features and attractions are susceptible to the impacts of coastal hazards. In recent years, boardwalks and beach access stairs, and infrastructure in the Cavendish National Park Campground have been significantly damaged due to severe weather events. Efforts are currently underway to recover from the damage caused by Post-Tropical Storm Fiona, which includes dune restoration, repairing damaged structures and the managed retreat of Robinson's Island which will no longer be accessible by vehicles due to the road being washed out by the storm surge overwash.

PROVINCIAL PARKS AND GOLF COURSES

The province boasts numerous provincial parks, many of which are located on or near the coast, or along other rivers influenced by tidal waters.

The provincial Coastal Infrastructure Vulnerability Assessment (CIVA) found that Cedar Dunes Provincial Park (at West Point) and Jacques Cartier Provincial Park Campground (Kildare) are within high hazard areas for both coastal flooding and coastal erosion (GPEI, 2022). West Point, at Cedar Dunes has lost approximately 20m due to erosion since 1999, and it is projected that the problem will only increase in the future (Jardine, 2023). Recent efforts to stabilize the shoreline at West Point involved the installation of offshore reefs. While the reefs are not designed to prevent coastal flooding, it appears they have been successful in capturing sand on the foreshore of the beach which will help reduce the impacts of wave action that causes erosion. PEI sandstone armour rock was installed along the full length of Jacques Cartier Provincial Park in 2015.

The Linkletter and Panmure Island Provincial Parks were also found to be within high flood hazard areas. A rock revetment system and artificial dune was installed at the Panmure Island Park in 2004 after being damaged by a large storm surge. The dune has been washed away by subsequent storm surges on at least three occasions. Although classified as a minimal flood hazard, high water marks surveyed after Fiona indicated that water levels inundated the lower portion of the Bloomfield Day-Use Park. No structural damage was

Figure 58. PEI National Park at Greenwich (D. Jardine, 2023)

Figure 59. Northumberland Provincial Park (D. Jardine, 2023)

Figure 60. Jacques Cartier Provincial Park (H. Parnham, 2017)

reported. Despite these instances, in comparison to residential properties, recreational sites which have limited hard infrastructure and buildings, and which are generally vacant during extreme weather events, may be more suitable land uses for flood prone areas.

PEI is also home to three provincial golf courses: Brudenell, Dundarave, and the Links at Crowbush Cove. Crowbush has been impacted by several storm surge events in the past. A severe winter storm in 2004 washed away large portions of the dune system protecting holes 16 and 8. Since then, various measures have been taken to protect the course, including the installation of a buried revetment and dune restoration projects. These early hybrid adaptation strategies have since been damaged by storm events, including Hurricane Fiona. In the past year, a large armour stone barrier was constructed in its place.

PUBLIC BEACHES

The beaches across the Island are plentiful and diverse. While the National Park and Provincial Parks provide accessible access (at some locations), bathroom services and supervised swimming areas for those visiting the beach, the entire coastline of PEI is a beach to be explored.

Provincial Park	Coastal Flood Hazard Classification	Coastal Erosion Hazard Classification
Argyle Shore Provincial Park	Minimal	Moderate
Belmont Day Use Park	Minimal	Moderate
Bloomfield Day Use Park	Minimal	Low
Brudenell River Provincial Park	Minimal	Low
Cabot Beach Provincial Park	Minimal	Low
Cedar Dunes Provincial Park	High	High
Chelton Beach Provincial Park	Minimal	Low
Green Park Provincial Park	Minimal	NA
Jacques Cartier Provincial Park	High	High
Kings Castle Provincial Park	High	High
Northumberland Provincial Park	Minimal	Moderate
Panmure Island Provincial Park	High	Low
Pinette Provincial Park	Minimal	Low
Red Point Park	Minimal	Moderate
Strathgartney Provincial Park	Minimal	NA

Table 27. Provincial Park Coastal Vulnerability Assessment (Adapted from GPEI, 2022)

The federal government oversees coastal waters from the ordinary low-water mark seaward to 200 nautical miles. But the provincial government is responsible for coastal lands including everything above the ordinary low-water mark. The intertidal zone, between the low and high-water marks is deemed provincial Crown land and is publicly accessible.

Some of the more popular publicly accessible beaches have been developed with parking facilities to support the growing number of visitors. Most, however remain a local community's best kept secret. Beaches such as Tracadie, Thunder Cove, Lakeside, Wood Islands, Blooming Point and Canoe Cove are frequented year-round by beach enthusiasts.

Figure 61. Thunder Cove Beach (D. Jardine, 2017)

Figure 62. Beach access at Blooming Point (D. Jardine, 2017)

Lighthouses

PEI has 61 lighthouses and range lights. Historically, lighthouses were strategically located along sandy beaches and atop Island cliffs, to guide mariners away from dangerous reefs and into safe harbours. Due to high maintenance costs and the development of modern aids for navigation, the Federal Department of Fisheries and Oceans (DFO) declared virtually all its lighthouses as surplus. These structures, once vital for navigation, now serve as important cultural and tourism landmarks. Nine of the remaining PEI lighthouses are protected under the Heritage Lighthouse Protection Act, seven of which are seasonally open to the public.

As with other infrastructure located near the coast, lighthouses are vulnerable to coastal hazards. Efforts to mitigate these risks have included relocation (i.e., East Point, Cape Bear, Rustico, and Cape Egmont), repeated attempts to install shoreline armouring (i.e., Point Prim, Beach Pt, Souris and West Point) and most recently the construction of offshore reefs at West Point. While many of the structures are located at high elevations, damage due to storm surge flooding has occurred at locations including the Brighton Beach Front Range Lighthouse, Beach Point Range Light in Murray Harbour, and the West Point Lighthouse.

Figure 63. East Point Lighthouse. (D. Jardine, 2017)

Rural Coastal Development

In comparison to other Canadian jurisdictions, PEI is considered Canada's most rural province, with one of the highest percentages of people living in rural and small-town areas. The two largest municipalities, the City of Charlottetown and City of Summerside, have populations of 38,809 and 16,001 respectively (Statistics Canada, 2021). And together approximately one-third of the provincial population lives within these cities - which in other jurisdictions, would be considered small towns.

Generally speaking, in PEI rural areas refer to the unincorporated land areas that have no local government or municipal services and those rural municipalities that do not have commercial or employment service centres to support their residents. In contrast to the Island's cities and towns, the economy in these areas is uniquely dominated by seasonal employment sectors, including farming, fishing, and tourism. The coastlines of these areas are predominantly agricultural and residential land uses, and isolated coastal infrastructure.

Residential development in rural areas was traditionally associated with a large farm property and the buildings were located in close proximity to the road rather than on the backside of the property by the coastline. The traditional farmhouses still present are relatively safe from direct impacts of coastal hazards.

The opposite pattern is found with rural residential subdivisions and cottage developments, where clusters or strips of lots have been subdivided to maximize water frontage. These rural coastal subdivisions evolved in an ad hoc manner, driven by the market value rather than land use planning policies, and have resulted in a disproportionate number of waterfront properties being subdivided from farm properties for large estate-style homes and/or cottages (seasonal dwelling).

Although PEI's subdivision regulations currently require a minimum lot size for new unserviced properties, a vast majority of coastal properties were subdivided prior to the adoption of these regulations and are non-conforming to the current requirements. These lots continue to be approved for development with on-site water and sewerage services today.

The majority of PEI's vulnerable properties fall into this category of non-conforming, waterfront properties in rural areas. Not only are these residential properties vulnerable to coastal hazards due to their small size and coastal proximity, but they also create land use conflicts. Many residential users are bothered by the noise, smell and spraying of agricultural lands behind them, even though the agricultural use was present before the development. Furthermore, the desire for a clear view of the water and access for personal recreational uses (staircases and docks) results in a high demand for clearing of vegetation in the environmentally sensitive buffer zone and saltmarsh environments, which can impact the health of the watercourse and further increase the vulnerability of the property to the coastal hazards.

Figure 64. Seasonal residential development off the waterfront edge of an agricultural field (H. Parnham, 2017)

Shoreline Structure Inventory

A PEI Shoreline Structure Inventory (SSI) has been conducted in 2010, 2018 (data collected in 2017 and 2018) and 2023. The inventory involved the identification of shoreline erosion mitigation structures including riprap, armour stone, sea walls and gabion baskets. To date, only the 2010 dataset has been previously published.

The 2010 SSI was completed by Coldwater Consulting (2012) as a desktop study based on permit records and the 2010 provincial orthophotos. The study identified segments of the coast as either structures or natural segments. Due to the nature of the desktop study, many of the rivers and estuaries were excluded because tree cover blocked visual identification of the structures in orthophotos. The 2010 SSI found 161 km of structures but recognized that this was likely a low estimate of the total length that existed at the time.

For the 2018 SSI the research team conducted an aerial survey and collected over 20,000 high-resolution aerial oblique photos of the coastline which provided detailed qualitative information that was not otherwise visible in the 2010 orthophotos. The pictures covered over two-thirds of the Island's coastline, including 98% (784 km) of the Island's exposed coast; and at least 50% (1,270 km) of the Island's sheltered estuary shoreline. Once the location of the structures was identified in the photos, a field team visited the accessible shorelines to survey the length and collect additional information (i.e. type, material, and condition).

This study found a total of 202 km of erosion mitigation structures, an increase of about 41 km (UPEI, unpublished). Because the 2010 study was an underestimate of the actual conditions, it can be inferred that the rate of installation prior to 2018 was no greater than 5.1 km/year during the period between the two studies (UPEI, unpublished).

Of the structures measured in the field, 88% were described as 'riprap', 9% were vertical or near vertical seawalls, and the remaining 3% varied

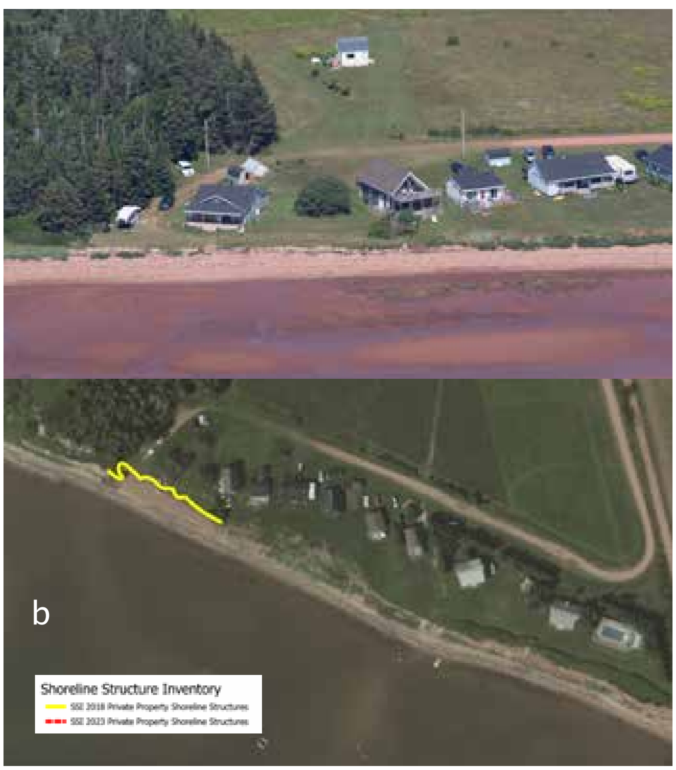


Figure 65. (a) Aerial survey photo of shoreline structures (D. Jardine, 2017); (b) corresponding SSI 2018 map over 2010 orthophoto. Argyle Shore, PE

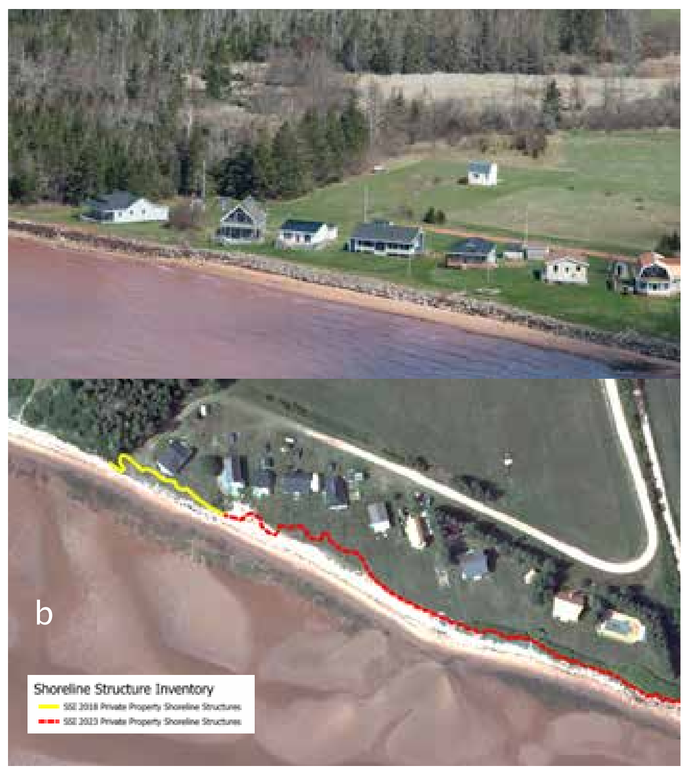


Figure 66. (a) Aerial survey photo of shoreline structures (D. Jardine, 2023); (b) corresponding SSI 2023 map over 2020 orthophoto. Argyle Shore, PE.

Shoreline Structure Type	2010	2018	2023	Rate of Installation (2010-2018)	Rate of Installation (2018-2023)
Transportation Infrastructure (m)	-	38,282	38,767	-	97 m/yr
Marine Infrastructure (Small craft harbours, wharfs, ports, ferry terminals) (m)	-	57,953	58,171	-	43 m/yr
Erosion mitigation structures on private properties (m)	-	105,340	140,653	-	7,063 m/yr
Total Length (m)	161,083	201,576	237,590	5,062 m/yr	7,203 m/yr

Table 28. Summary of Shoreline Structure Inventories 2010, 2018, and 2023 (Coldwater, 2012; UPEI, unpublished)

including gabion baskets, vegetation/living shorelines, and slab/block formations. Of the riprap variety: 39% were primarily made of concrete (including demolition debris with protruding rebar); 27% primarily sandstone; 24% primarily conglomerates; and only 5% were identified as granite. Note that 30% of the riprap structures contained secondary material type(s), which were either installed with the primary material or installed in separate attempts to address erosion over time (UPEI, unpublished).

A similar methodology was used in 2023, excluding the ground-survey work. This year an additional 36 km of new shoreline structures were identified. This indicates that in recent years, shoreline erosion mitigation structures have been installed at an accelerated rate of 7.2 km/year.

Both the 2018 and 2023 SSIs distinguished between the types of land use associated with the structures, including transportation infrastructure (bridge embankments and shore parallel roads), marine infrastructure (small craft harbours, wharfs, ports, and ferry terminals), and shoreline parallel structures on private properties (mainly residential). When the rate of change is assessed by land use type, it is evident that there has been minimal changes in the length of structures associated with transportation and marine infrastructure over the past 5 years. Private property installations accounted for 98% of the new structures.

Figure 67. Beach access reinforced with poured concrete, concrete slabs and gabion baskets (H. Parnham, 2018)

Figure 68. Typical residential shoreline armouring with old concrete/construction debris (H. Parnham, 2018)

Over the past 5 years, shoreline erosion mitigation structures, such as seawalls and armour stone, have been installed at an accelerated rate of over 7.2 km/year, 98% of which was on private properties.

PEI's Coastline by the Numbers

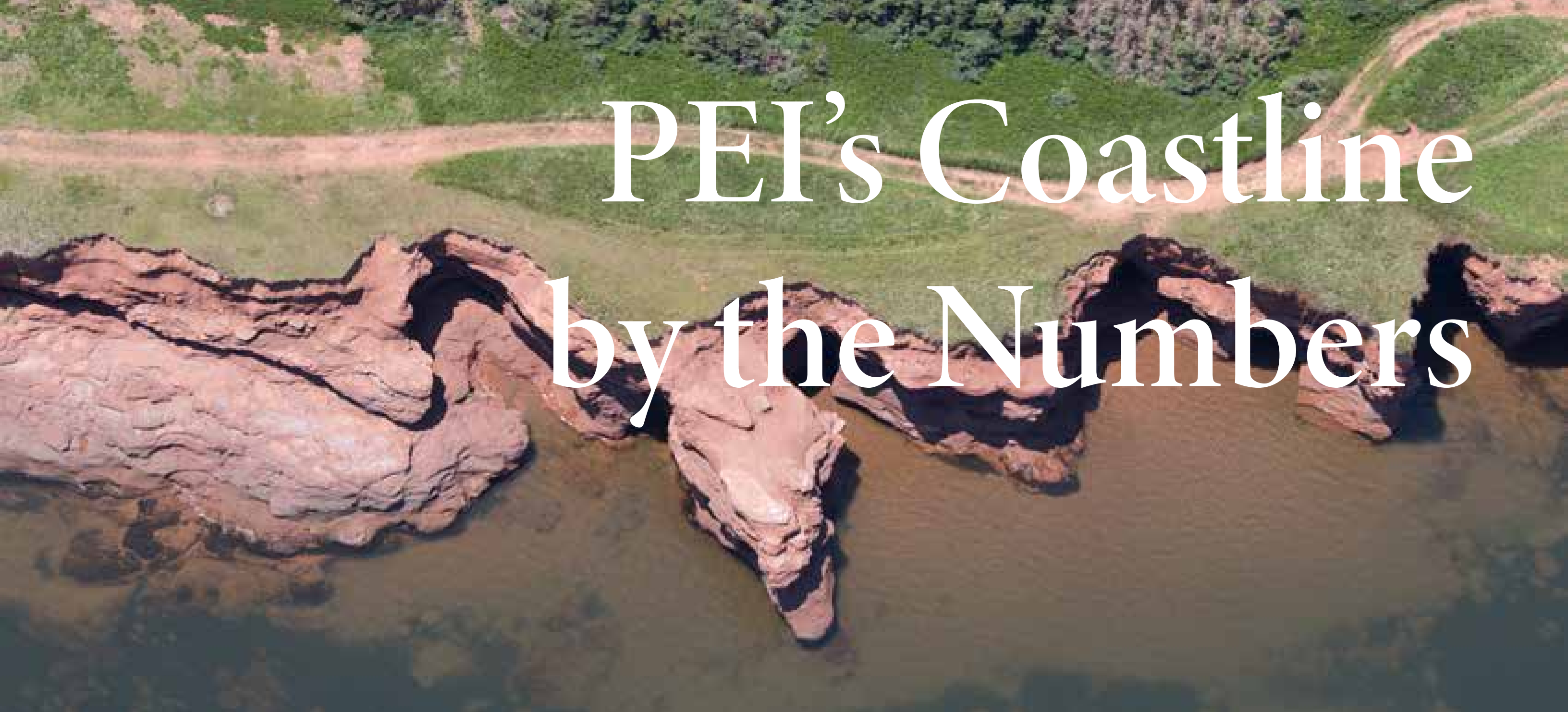


Figure 69. Kildare Capes (D. Jardine, 2017)

The previous sections of this report have described the range of natural and built conditions that contribute to the variations in PEI's coastline. This section summarizes the data associated with those variables and is intended as a quick reference for comparing different areas with one another and as a baseline for monitoring change over time in future studies.

While the data in this section provides a broad overview of PEI's coastal landscape, province-wide and regional statistics should be used with caution as it can mask the significance of the variability present in specific areas, communities and between individual properties. For example, while the average rate of erosion for the province at 30cm/yr may seem alarming, it means very little in terms of understanding the actual degree of risk to any specific property. The average does not provide information on how much erosion can occur in areas that are eroding at a much faster pace, or on how much of the total coastline is relatively resilient and where minimal changes have been observed over time. Furthermore, it provides no information on the factors contributing to the erosion, such as the shore type, land cover (lawn versus vegetated buffer zone), soil conditions or the geology or disturbances such as a storm or new development.

Relying solely on provincial or regional statistics can lead to misconceptions about hazards and risks, and consequently can also lead to inadequate policy decisions. It will be necessary to delve deeper, examining the nuances and local variabilities that shape PEI's coastline to support long-term coastal management.

Littoral Cells

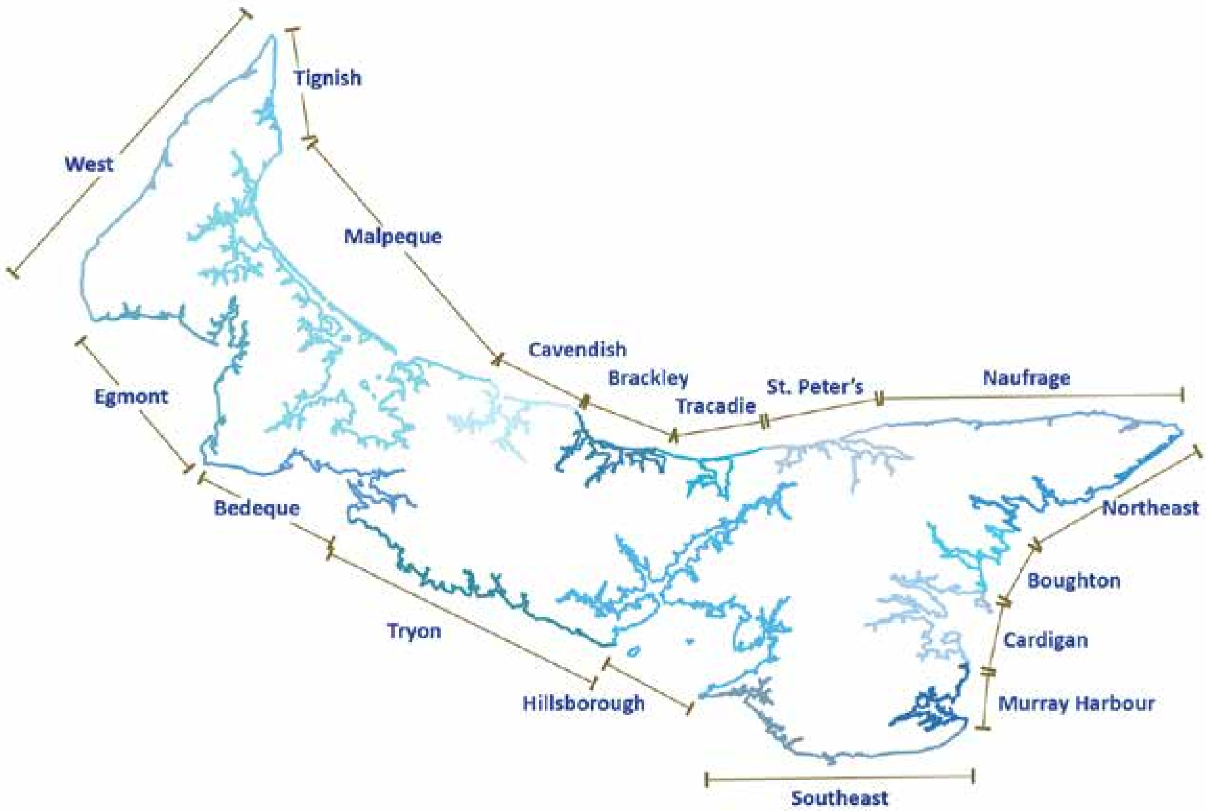


Figure 70. PEI Littoral Cells (Adapted from Coldwater Consulting, 2012)

Sediment (sand and soil) is constantly being moved by tidal and wave action, and the predominant net movement runs parallel to the shoreline by longshore currents. These currents are caused by the combination of waves, tides, and wind, and vary seasonally in strength and direction.

A study of the longshore and nearshore wave conditions on PEI's coastline facilitated the identification of the Island's 17 littoral cells (Coldwater Consulting, 2012).

Littoral cells are segments of the coastline within which sediment (sand) transport processes are either partially or completely contained.

The cells vary in length, and each contains a combination of both exposed (coastal) and sheltered (estuary) coastlines with different backshore shore types.

Defining the boundaries of the littoral cells is important because best practice in the development of a shoreline management plans is to conduct a system-based assessment at the scale of the littoral cell (DEFRA, 2016) or littoralshed when referring to integrated land/water systems (Gov. Canada, 2023c). A littoralshed consists of one or more drainage basins (watersheds) and one or more littoral cells (Zuzek Inc, 2017).

This practice ensures that the potential impacts of development or the implementation of shoreline management strategies at one location within the cell are understood across the entirety of the system.

The statistics provided in this section are broken down to the scale of the littoral cell, which helps identify the unique challenges and opportunities each segment (cell) of the coastline presents.

Savage Harbour Breakwater

An example of how actions in one location can impact other areas within the littoral cell can be seen on the north shore near Savage Harbour. The Savage Harbour Breakwater was installed in 1954. The structure extends perpendicular to the shore to provide shelter for the small craft harbour and channel.

As a result of the construction, sand movement along the length of the shore has been impeded. As sand accumulates on the east side of the structure, the beach and dune system on the west side have gradually narrowed due to the reduced sand supply.

The loss of beach width and dunes in this area has increased the vulnerability of the backshore to erosion caused by wave action which further increases the vulnerability of adjacent land uses and properties which would have otherwise been protected by the natural adaptive capacity of the sandy beach and the natural sediment transport processes of the system.

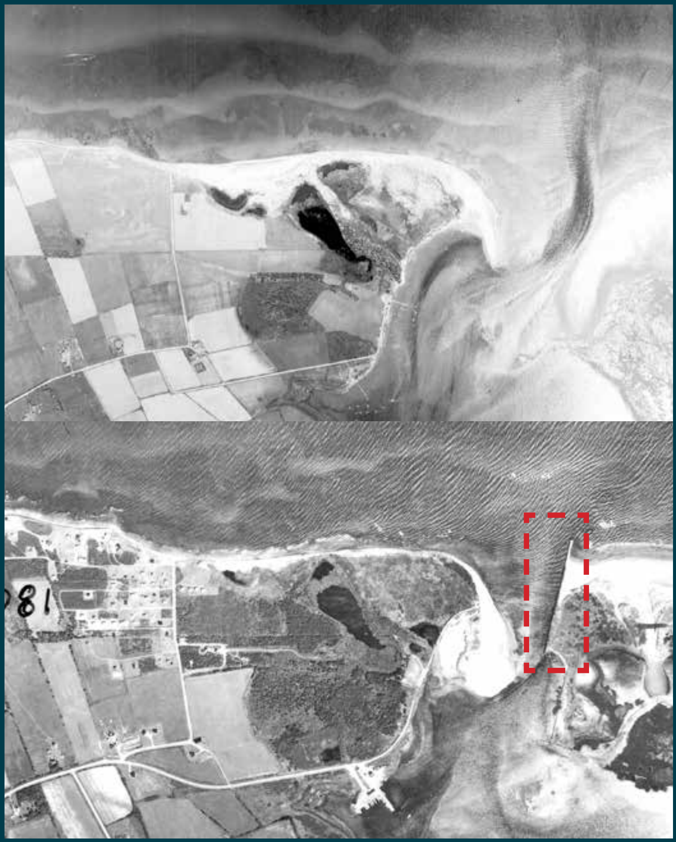


Figure 71. Comparison of the sandy beach conditions at Savage Harbour 1936 (before the breakwater) and 1990 (after). Breakwater outlined in red..

Shore Types

The Malpeque and Hillsborough littoral cells are significantly larger by coastal length than the other cells due to their large bays and long estuarine rivers. On the north shore in the Malpeque cell, sand dunes are the dominant shore type due to the presence of long barrier spits and islands. In contrast, on the south shore the shoreline of the Hillsborough cell contains a mix of cliffs, wetlands, low plains, and bluffs.

The four points of the Island are the locations where ocean and longshore currents from different cells collide. They are influenced by the processes of the West and Tignish cells (North Cape), West and Egmont cells (West Point), Naufrage and Northeast cells (East Point), and the Southeast cell (Cape Bear). Except for the Egmont and Northeast cells, these cells are characterized by their primarily exposed (coastal) shorelines with a high percentage of cliffs and bluffs.

The eastern side of the Island has predominantly sheltered shorelines with the presence of multiple river systems and well-defined points between each of the Northeast, Boughton, Cardigan and Murray Harbour cells. These cells have a high variability in shore type in comparison to the other areas.

The south shoreline (Tryon, Bedeque and Egmont cells) is characterized by relatively small coves and harbours inundating long stretches of exposed coast. The boundary between each of the cells is defined by well-developed headlands and points.

The Malpeque, Cavendish, Brackley, Tracadie and St. Peter’s cells span the central portion of the north shore. Each is predominantly sheltered (estuary) shorelines and sand dunes are the dominant shore type on the exposed coast creating a long system of barrier spits and islands along much of the length.

Littoral Cell	Length of Shoreline by Shore Type (km)					Total Length
	Bluff	Cliff	Low Plain	Sand Dune	Wetland	
Coast	**47.60**	**373.90**	**89.34**	**249.49**	**42.10**	**802.44**
Bedeque	7.27	13.90	13.32	4.41	9.06	47.96
Boughton	0.42	15.59	0.81	10.34	1.05	28.21
Brackley	0.62	4.94	0.05	18.23	0.00	23.84
Cardigan	3.75	12.73	3.71	9.51	5.61	35.30
Cavendish	0.00	10.81	0.00	12.03	0.00	22.84
Egmont	3.18	12.05	34.28	11.94	0.88	62.32
Hillsborough	7.39	44.93	11.69	4.99	17.68	86.69
Malpeque	1.46	14.59	1.47	52.10	0.37	70.00
Murray Harbour	1.98	7.11	2.08	5.24	1.66	18.06
Naufrage	4.75	45.84	0.25	13.31	2.66	66.81
Northeast	1.80	25.69	2.62	24.13	0.87	55.12
Southeast	3.65	43.36	5.13	12.16	1.21	65.50
St. Peter's	0.87	0.56	0.37	23.93	0.00	25.73
Tignish	1.49	18.90	1.26	5.31	0.08	27.04
Tracadie	0.12	0.61	0.06	22.29	0.35	23.44
Tryon	6.30	49.74	11.28	2.86	0.27	70.47
West	2.54	52.55	0.96	16.70	0.37	73.12
Estuary	**129.53**	**472.52**	**302.79**	**231.20**	**1,340.63**	**2,476.68**
Bedeque	10.77	11.03	19.07	2.95	43.07	86.89
Boughton	5.42	30.38	5.60	6.06	23.74	71.20
Brackley	2.59	33.89	6.35	7.67	73.95	124.46
Cardigan	13.55	55.31	14.58	28.98	52.53	164.95
Cavendish	4.20	54.27	4.83	8.03	64.79	136.12
Egmont	3.79	1.63	49.66	10.52	62.89	128.50
Hillsborough	13.13	80.00	19.29	1.54	307.86	421.83
Malpeque	41.57	89.73	107.97	82.71	380.97	702.95
Murray Harbour	5.39	25.54	8.41	15.60	49.47	104.41
Naufrage	0.29	1.48	0.86	0.93	13.35	16.90
Northeast	4.96	29.08	5.02	27.78	47.67	114.51
Southeast	2.65	12.09	15.50	6.77	59.23	96.24
St. Peter's	8.89	22.73	9.71	16.54	59.95	117.81
Tignish	1.05	1.02	2.75	1.14	33.30	39.25
Tracadie	2.65	9.45	1.65	7.64	33.57	54.96
Tryon	6.62	11.92	27.17	3.19	21.50	70.40
West	2.02	2.98	4.37	3.15	12.80	25.32
Total	**177.13**	**846.42**	**392.14**	**480.70**	**1,382.73**	**3,279.12**

Table 29. Comparison of PEI littoral cells by length of shore exposure and shore types (km). (Based on Coldwater Consulting, 2012 shore types, updated with data from the 2020 coastline delineation)

Species at Risk Habitat and Protected Coastal Areas

Littoral Cell	Coastline within/adjacent to critical habitat (km) by species: Bank Swallow	Piping Plover	Northern Myotis	Little Brown Myotis	Gulf of St. Lawrence Aster	Combined Critical Habitat (km)	Protected Area (km)
Bedeque	34.45		NA	NA	NA	34	3
Boughton	37.14	15.45	NA	NA	NA	39	13
Brackley	36.05	42.35			2.28	54	40
Cardigan	14.46	13.70	NA	NA	NA	25	17
Cavendish	33.46	25.89	100.18	100.18		120	35
Egmont	32.41	10.26	NA	NA	NA	42	48
Hillsborough	89.99		NA	NA	NA	90	43
Malpeque	189.92	163.37	NA	NA	NA	336	63
Murray Harbour		14.93	NA	NA	NA	15	16
Naufrage	61.39	28.27	NA	NA	NA	76	5
Northeast	56.70	76.20	NA	NA	NA	96	67
Southeast	52.89	2.87	NA	NA	NA	52	6
St. Peter's	36.08	43.35	NA	NA	NA	45	41
Tignish	14.94		NA	NA	NA	15	9
Tracadie	30.22	33.59			6.85	33	31
Tryon	91.95		NA	NA	NA	91	1
West	98.44	7.01	NA	NA	NA	103	13
Total	**915.65**	**477.25**	**100.18**	**100.18**	**9.13**	**1,265**	**452**

Table 30. Length of coastline within or adjacent to critical habitat (Critical Habitat for Species at Risk National Dataset - Canada, ECCC, 2023). The habitat identified for each species may overlap and the combined critical habitat is not the sum of each of the species. Only Bank Swallow and Piping Plover habitat has been mapped outside of the National Park on the North Shore.

Critical habitat for bank swallows is found in 16 of the 17 littoral cells. The Murray Harbour cell is the only area without cliffs or bluffs suitable for their nesting sites. Whereas the entire length of the West cell has been identified as potential habitat.

Habitat for piping plovers, characterized as low-lying sandy beaches, has been identified in all but 4 of the littoral cells.

Habitat delineation for other species at risk has been limited to the land area within the National Park. The Northern and Little Brown Myotis is a small, endangered mammal for which habitat has been identified in the Cavendish area. The Gulf of St. Lawrence Aster has been identified in the Brackley and Tracadie cells.

Protected lands located on or adjacent to the coastline account for 452 km (13%) of the coast.

Most of the Protected Areas on the coast are provincially owned natural areas (31%), are within the National Park (23%) or are designated as Provincial Wildlife Management Areas (15%). Other than the National Park area, protected lands are not necessarily areas that contain critical habitat.

Privately owned conservation and natural areas account for 22% of the protected areas on the coast, of which the Island Nature Trust and Nature Conservancy of Canada are the largest lands holders.

Coastal Flood Hazards

Littoral Cell	Coastal Floodplain (km²)	Ratio of floodplain area to coastline length (km)	Future (2050) Floodplain (km²)	Future (2100) Floodplain (km²)	% of future floodplain already at risk of flooding today
Bedeque	14.72	0.11	16.63	21.72	68%
Boughton	2.50	0.03	2.83	4.06	61%
Brackley	6.16	0.04	6.78	8.35	74%
Cardigan	6.19	0.03	7.08	9.84	63%
Cavendish	4.17	0.03	4.57	5.68	73%
Egmont	25.14	0.13	28.15	35.88	70%
Hillsborough	27.92	0.05	30.91	38.97	72%
Malpeque	53.71	0.07	59.92	77.42	69%
Murray Harbour	4.46	0.04	5.34	7.73	58%
Naufrage	3.01	0.04	3.37	4.24	71%
Northeast	6.58	0.04	7.33	9.76	67%
Southeast	6.86	0.04	7.78	10.42	66%
St. Peter's	8.63	0.06	9.77	13.20	65%
Tignish	3.87	0.06	4.35	5.89	66%
Tracadie	9.22	0.12	10.48	13.13	70%
Tryon	7.18	0.05	8.00	10.03	72%
West	4.01	0.04	4.38	5.62	71%
Total	**194.32**	**0.06**	**217.68**	**281.96**	**69%**

Table 31. The area occupied by the coastal floodplain and future floodplains (2050 and 2100) in each littoral cell. The ratio of floodplain area to coastline length represents the average extent of floodplain inundation for each km of coastline.

The total area of the coastal floodplain is approximately 194 km², equivalent to about 3% of the total land area of the province. The littoral cells with the greatest amount of land area vulnerable to coastal flooding relative to the length of their coastline are Egmont, Bedeque and Tracadie.

As sea level continues to rise, low lying coastal lands and salt marshes will be permanently inundated by sea water at high tides, and storm surge flood waters will reach further inland, expanding the floodplain. By 2100, the land area within the coastal floodplain will be approximately 282 km² (5% of the province).

Note that the future floodplain projections do not account for the potential for increased frequency of a storm surge event that currently has a 1% annual exceedance probability (1% AEP). The storm surge caused by Hurricane Fiona in September 2022, reached peak water elevations higher than that of the coastal floodplain and more closely aligned with that of a 0.6% AEP, or the 2050 future floodplain for coastal areas on the North Shore.

As extreme weather events become more frequent the projected floodplains for PEI will need to be redrawn to more accurately reflect the increased probability that flood water levels will reach higher elevations.

While vulnerability to coastal flooding will increase in the future, 69% of the future floodplain is already at risk of flooding today.

Coastal Erosion Hazards

Coastal erosion (coastal change) rates are highly variable and when data over large areas is overly simplified the significance of the locally specific factors that contribute to the variability can be lost. It is more accurate to assess trends in average coastal change rates by comparing coastlines with similar exposure and shore type.

The following tables provide the annual rate of change for cliffs, bluffs, and low plain shore types, in both coastal and estuary exposures for each of the littoral cells.

Wetlands (saltmarshes) and sand dunes have been excluded from the tables because the methodology used to measure coastal change does not accurately reflect the dynamic nature of saltmarshes which are influenced by inland migration and coastal squeeze. Furthermore, the processes that influence sand dunes, including erosion, migration and other sediment transport processes are not accurately represented by a single horizontal measurement of change over time. In some cases, sand dunes may migrate landward, but the volume of the dune may remain the same.

The average rate of change in cliff shore types follow the Island-wide trends, whereas the time period between 2000-2010 experienced an accelerated rate of change in comparison to the 1968-2010 period, followed a decade of significantly lower rates of change. This pattern was consistent between cliffs with coastal and estuary exposures.

Average Rate of Coastal Change (m/yr) for Cliff Shore Types						
Littoral Cell	**Coastal Exposure**			**Estuary Exposure**		
	1968-2010	**2000-2010**	**2010-2020**	**1968-2010**	**2000-2010**	**2010-2020**
Bedeque	0.30	0.64	0.09	0.13	0.29	0.14
Boughton	0.18	0.28	0.18	0.04	0.16	0.09
Brackley	0.35	0.50	0.22	0.03	0.07	0.07
Cardigan	0.10	0.25	0.10	0.06	0.33	0.04
Cavendish	0.23	0.38	0.05	0.04	0.21	0.08
Egmont	0.32	0.65	0.20	0.09	0.13	0.00
Hillsborough	0.16	0.34	0.10	0.06	0.26	0.05
Malpeque	0.20	0.32	-0.02	0.04	0.03	0.01
Murray Harbour	0.20	0.33	0.17	0.05	0.31	0.09
Naufrage	0.16	0.20	0.19	0.06	-0.03	0.02
Northeast	0.13	0.25	0.09	0.05	0.37	0.03
Southeast	0.16	0.26	0.08	0.07	0.14	0.08
St. Peter's	0.38	0.55	0.38	0.01	0.16	0.04
Tignish	0.37	0.46	0.31	0.05	0.12	0.00
Tracadie	0.30	0.63	0.37	0.06	0.19	0.07
Tryon	0.19	0.27	0.11	0.05	0.13	0.08
West	0.30	0.54	0.21	0.01	0.13	0.04

Table 32. The average rate of coastal change (m/yr) for cliff coastlines with coastal and estuary exposures for the time periods 1968-2010, 2000-2010 and 2010-2020.

Average Rate of Coastal Change (m/yr) for Bluff Shore Types						
Littoral Cell	Coastal Exposure			Estuary Exposure		
	1968-2010	2000-2010	2010-2020	1968-2010	2000-2010	2010-2020
Bedeque	0.58	0.87	0.08	0.17	0.33	0.17
Boughton	-0.04	0.39	0.07	0.04	0.27	0.03
Brackley	0.00	-0.15	0.27	0.02	0.16	0.02
Cardigan	0.23	0.49	0.22	0.05	0.24	0.06
Cavendish	NA	NA	NA	0.07	0.36	0.09
Egmont	0.38	0.58	0.23	0.05	0.29	0.01
Hillsborough	0.18	0.44	0.08	0.09	0.25	0.06
Malpeque	0.96	0.81	-0.23	0.07	0.07	0.06
Murray Harbour	0.10	0.40	0.40	0.13	0.38	0.07
Naufrage	0.26	0.52	0.11	NA	NA	0.02
Northeast	0.08	0.50	0.27	0.02	0.29	0.02
Southeast	0.36	0.56	0.35	0.10	0.22	0.06
St. Peter's	0.89	0.56	0.22	0.09	0.30	0.08
Tignish	0.33	0.72	0.52	-0.04	0.16	0.08
Tracadie	0.61	0.16	0.00	0.01	0.06	0.07
Tryon	0.31	0.46	0.22	0.08	0.26	0.09
West	0.42	0.76	0.50	-0.06	-1.31	-0.49

Table 33. The average rate of coastal change (m/yr) for bluff coastlines with coastal and estuary exposures for the time periods 1968-2010, 2000-2010 and 2010-2020.

The average rate of change in bluff shore types is less consistent than that of the cliff trends. While most littoral cells experienced an accelerated rate of change in the period between 2000-2010 in comparison to the 1968-2010 period, there were a number of cells that experienced the opposite, including Brackley, Malpeque, St. Peter's, and Tracadie.

Similarly, the bluff shore types in most cells experienced a decade of lower rates of change from 2010-2020, but not in all cells. And the average rate of change in low plain shore types was even less consistent between littoral cells than that of the cliff and bluff shore types.

Overall, the highest rates of change were observed along the southwest coastlines in the Egmont and Bedeque cells, which are characterized by exposed low plain coastlines. These areas were also noted as having the highest vulnerability to coastal flooding. The north shore along the Brackley, Tracadie, and St. Peter's cells which are characterized by sand dune shorelines also have a higher rate of change than that of the provincial average.

The east end of the Island (Naufrage, Northeast, Boughton, Cardigan, Murray Harbour, and Southeast cells) has consistently had a lower average rate of erosion than that of other cells.

When comparing the rate of change from 1968-to-2010, and the rate of change from 1968-to-2020, the rate of change appears to have increased in most littoral cells over the past 10 years, with the

Average Rate of Coastal Change (m/yr) for Low Plain Shore Types						
Littoral Cell	Coastal Exposure			Estuary Exposure		
	1968-2010	2000-2010	2010-2020	1968-2010	2000-2010	2010-2020
Bedeque	0.42	0.57	0.26	0.09	0.06	0.06
Boughton	-0.87	-2.60	0.01	0.05	0.57	0.03
Brackley	NA	NA	0.00	0.14	1.57	0.08
Cardigan	0.22	0.57	0.11	0.10	0.23	0.04
Cavendish	NA	NA	NA	0.05	0.08	0.04
Egmont	0.61	0.61	0.37	0.10	0.25	-0.18
Hillsborough	0.24	0.49	0.09	0.05	0.44	0.04
Malpeque	-0.66	-3.87	0.68	0.06	0.01	0.09
Murray Harbour	-0.47	0.06	-0.50	0.03	0.21	0.07
Naufrage	0.22	0.42	0.19	0.48	-5.63	0.00
Northeast	-0.04	0.14	0.13	0.01	0.18	0.26
Southeast	0.34	0.73	0.32	-0.09	-0.30	-0.06
St. Peter's	NA	-0.35	0.26	0.13	0.38	0.02
Tignish	0.32	-0.33	0.77	-0.76	0.02	0.70
Tracadie	0.21	1.00	0.00	0.07	0.11	0.25
Tryon	0.46	0.69	0.81	-0.08	0.15	0.12
West	0.37	1.16	0.26	0.06	0.26	0.00

Table 34. The average rate of coastal change (m/yr) for low plain coastlines with coastal and estuary exposures for the time periods 1968-2010, 2000-2010 and 2010-2020.

biggest differences being observed in the Boughton and Cavendish cells. In contrast, the Southeast and St.Peter's cells both appear to be changing at a reduced rate of change.

As noted earlier in this report, there are significant variations between the average rate of change for coastlines with different exposures (coastal vs estuary) and shore type. And sudden dramatic changes in the coastline resulting from an extreme event do not necessarily represent a new normal in annual trends.

When using the historic rate of change of a particular area to assess a future hazard level, context is extremely important. Changes in land use, vegetation cover, development, and changes in the sediment transport (supply/accumulation) of the littoral cell, can all influence the rate of change observed in a particular shoreline.

Shoreline Structures

Shoreline armouring currently covers over 237 km (7.3%) of PEI's total coastline and over 22% (or 1/5) of the length of coastline adjacent to properties with civic addresses, in other words, on properties with some form of development.

Shoreline armouring has been installed at a rate of about 7.2 km per year since 2018.

The Bedeque, Tryon, Cardigan and Tignish cells have the highest percentage of shoreline structures to total shore length. However, Tignish's structures are predominantly associated with marine and transportation infrastructure rather than private properties which are the dominant type in the other three cells.

The Bedeque and Cardigan cells have experienced the greatest change in the length of armouring on their coastlines over the past 5 years with an increase from 13-to-16% (Bedeque) and 8-to-13% (Cardigan).

The Boughton cell has the least amount of armouring present and there were no new installations identified since 2018. Like the Boughton cell, the other 3 cells that experienced the least amount of shoreline armouring over the past 5 years are also in the northeast end of the Island (St. Peter's, Naufrage, Northeast).

Littoral Cell	2018 Structures (km)	2018 Structures by % of total Cell Length	2023 Structures (km)	2023 Structures by % of total Cell Length	Rate of Installation (km/yr)
Bedeque	17.32	13%	21.62	16%	0.86
Boughton	2.86	3%	2.86	3%	0.00
Brackley	10.79	7%	11.43	8%	0.13
Cardigan	15.74	8%	26.33	13%	2.12
Cavendish	9.80	6%	11.74	7%	0.39
Egmont	8.63	5%	9.39	5%	0.15
Hillsborough	29.79	6%	36.35	7%	1.31
Malpeque	32.11	4%	36.20	5%	0.82
Murray Harbour	7.73	6%	9.29	8%	0.31
Naufrage	4.35	5%	4.37	5%	0.00
Northeast	8.51	5%	9.04	5%	0.11
Southeast	7.86	5%	8.64	5%	0.16
St. Peter's	9.05	6%	9.60	7%	0.11
Tignish	7.41	11%	7.97	12%	0.11
Tracadie	4.24	5%	4.78	6%	0.11
Tryon	19.43	14%	21.24	15%	0.36
West	5.96	6%	6.73	7%	0.15
Total	201.58	6%	237.59	7%	7.20

Table 35. Shoreline structure inventory (2018 and 2023) by length (km), percentage of coastline and the annual rate of installation over the past 5 years (km/yr) (2018 dataset, UPEI, unpublished)

Waterfront Properties and Ownership

Littoral Cell	Coastline with Municipal Land Use Planning	Count: Waterfront Properties (WP)	Average Frontage per WP (m)	Developed WP	Coast Length of Developed WP
Bedeque	11%	1,926	70.01	54%	33%
Boughton	26%	758	131.14	33%	24%
Brackley	20%	1,746	84.94	50%	50%
Cardigan	95%	2,292	87.37	43%	38%
Cavendish	27%	1,508	105.41	48%	42%
Egmont	0	1,199	159.15	32%	22%
Hillsborough	37%	5,567	91.34	51%	36%
Malpeque	3%	5,174	149.39	40%	24%
Murray Harbour	3%	1,209	101.30	40%	37%
Naufrage	50%	832	100.61	29%	35%
Northeast	46%	1,353	125.37	42%	28%
Southeast	0	1,157	139.80	39%	42%
St. Peter's	0	1,472	97.51	35%	22%
Tignish	5%	710	93.36	39%	33%
Tracadie	42%	865	90.63	43%	44%
Tryon	25%	2,328	60.51	48%	34%
West	0	1,030	95.57	34%	35%
Total	22%	31,126	105.35	43%	32%

Table 36. Length of coastline with land use planning and number of waterfront properties (WP), average size and development status.

Only 22% of the Island's coastline is within a jurisdiction with municipal land use planning. Four (4) of the 17 littoral cells have no municipal land use planning, and three (3) have 5% or less of their coastlines within municipal boundaries.

While municipal land use planning is not a direct correlation on waterfront lot size or density of development, only those areas with municipal land use planning and shared water/sewerage services may approve lots smaller than the minimum lot size permitted under provincial legislation. As such, one would expect a higher number of small waterfront properties in the areas with land use planning.

The Island's coastline has been subdivided into approximately 31,000 individual parcels (waterfront properties, WP), with an average length of frontage at 105m per property.

There are approximately 13,500 (43%) WP that are considered developed, meaning that a development permit was issued and/or a civic number has been assigned to the property. The length of coastline adjacent to the developed WP accounts for about 32% of the total coast length.

The cells with the highest percentage of developed WP are Bedeque, Hillsborough, Brackley, Tryon and Cavendish.

Littoral Cell	WP owned by Non-Residents	Coast length owned by Non-Residents (km)	Percentage of Coast length owned by Non-residents
Bedeque	17%	13.33	10%
Boughton	29%	25.64	26%
Brackley	27%	18.53	12%
Cardigan	18%	32.50	16%
Cavendish	23%	21.44	13%
Egmont	24%	33.41	18%
Hillsborough	9%	40.91	8%
Malpeque	20%	72.31	9%
Murray Harbour	17%	22.29	18%
Naufrage	36%	38.09	46%
Northeast	21%	21.54	13%
Southeast	23%	33.01	20%
St. Peter's	33%	23.46	16%
Tignish	23%	12.57	19%
Tracadie	24%	10.01	13%
Tryon	26%	19.97	14%
West	24%	17.83	18%
Total	20%	456.85	14%

Table 37. Non-resident ownership of waterfront properties and coast length.

Approximately 20% of WP are owned by non-residents, individuals who do not have a primary residence in PEI, or corporations registered outside the province. These properties account for about 14% of the total length of the coastline.

The cells with the highest percentage of coastal properties owned by non-residents are Naufrage (35%), St. Peter's (33%) and Boughton (29%). The properties owned by non-residents in the Naufrage cell have frontage on 46% of the coastline in this area.

The non-resident ownership statistics offer insight into the percentage of lands used for recreational and/or seasonal dwellings, for which the province does not have a database on.

It also provides context for interpretation of the *Lands Protection Act* which is intended to regulate the amount of water frontage an individual non-resident can own. However, as there are no regulations on the cumulative purchases of waterfront properties by different non-residents, the *Lands Protection Act* appears to have done little to reduce the number of non-resident purchases of the Island's coastal properties.

Next Steps and Final Remarks

Figure 72. Drone and survey training workshop. UPEI Climate Research Lab. (D. Jardine, 2017)

THIS SECTION INCLUDES:

Next Steps and Future Research

Given the dynamic nature of the coast, it is important that the *PEI State of the Coast Report* be updated as new data becomes available and to address new and emerging issues in coastal zone management. The following sections describe projects, future research and tracking exercises that are recommended to address the existing gaps in data, and to improve accessibility and transparency in policy and regulation implementation.

Ongoing monitoring of the physical environment, development trends, and impacts following future extreme weather events will be necessary to evaluate the effectiveness of new coastal zone management policies, plans and programs, and to measure progress towards the established targets.

New Perspectives

1. INDIGENOUS KNOWLEDGE SYSTEMS

The current study on the State of the Coast and interim policy recommendations was based on a desktop literature and data analysis. The scope did not include the opportunity to engage or collaborate with First Nations, Indigenous communities or rightsholders. Indigenous knowledge systems build upon the experiences and worldviews of Indigenous Peoples of earlier generations, inform the practice of current generations, and evolve in the context of contemporary society. An Indigenous-led study on coastal management that reflect Indigenous worldviews should be undertaken to inform long-term policy decisions.

2. PUBLISH COASTAL STORIES ABOUT THE PEOPLE IMPACTED BY COASTAL HAZARDS AND THEIR EXPERIENCES WITH ADAPTATION

One of the primary gaps in research, including this current project, is the dependence on quantitative data (i.e., field measurements and computer models). To date, the impacts of coastal hazards on people, neighbourhoods and communities have not been adequately captured. Future research should include the documentation of the climate stories of people impacted by coastal hazards, including qualitative evidence such as photographs and interviews. These stories are likely to include descriptions of impacts, how decisions were made relating to rebuilding and adaptation, and will consider variables such as grief and financial loss, unlikely heroes, and resilience. PEI climate change coastal stories should be published in a manner that can be continuously updated over time.

Figure 73. Waterfront cottages damaged in a severe storm event. Maximeville, Egmont Bay PE (D. Jardine, 2006)

Research, Field Work and Modeling

3. PILOT AND DEMONSTRATION PROJECTS

To date field monitoring of the coast has primarily focused on documenting natural processes to further understand how those processes function and how they are responding to a changing climate.

It is equally important to monitor and evaluate the built environment with pilot and demonstration adaptation projects. Research should be conducted on the effectiveness of various types of coastal adaptation strategies over time, including but not limited to:

- understanding the effectiveness of erosion mitigation structures and nature-based solutions to protect coastal properties and infrastructures,
- the system-wide (littoral cell) impacts of built infrastructure on natural systems and other built shorelines, and
- the full-costs over time to build, maintain and repair built coastal infrastructure.

Strategies to be implemented need to be tested to inform decisions based on long-term policy directions.

4. EROSION MONITORING AND ASSESESSMENT

Erosion monitoring is currently done at many locations around the Island. This field work has recorded the physical change in the coastline, but it is not possible to infer the cause of erosion from this data alone. Wave action is only one cause of coastal erosion and yet shoreline armouring is used almost exclusively to address the issue.

The locations in which the monitoring is currently conducted require further analysis including soil type, geomorphology, stormwater drainage patterns, vegetation cover type, and land use and development.

5. FIELD VERIFICATION OF SHORE TYPES

Recent research on the suitability of nature-based solutions to different shore types in PEI led to field investigations of several case study sites across the Island. The field work conducted found that the shore type of a number of sites had been incorrectly identified, more specifically errors were found in saltmarsh, sand dune and low plain shore types (*pers. comm.*, van Proosdij, 2023). As shore type classifications were originally assigned based on GIS analysis and a desktop study (Coldwater, 2012), field investigations to update and verify this data is recommended.

6. MONITOR THE COASTAL IMPACTS OF SIGNIFICANT EXTREME WEATHER EVENTS.

Collecting data following the impacts of extreme weather events is important to maintaining a record to support ongoing research, but the opportunity to collect this data is limited to a short period of time. A funding reserve should be held to ensure that following an extreme event, researchers can immediately be deployed to collect data and document the impacts. Contracts for data collection should be established in advance of the annual hurricane/winter season and should include details on the type of data and methods to be used to ensure that collection can happen swiftly when needed and that results will be made available to the public in a timely fashion.

Improved forecasting of wave induced coastal overtopping is needed and can be accomplished by the collection of highwater marks after storms to enable improved estimation of risks to coastal exposures (Jardine, 2023; Webster, 2011).

7. ANNUAL AERIAL SURVEY

The aerial survey of the Island's coastline is an efficient and cost-effective way to document changes in environmental, land use and development conditions. In approximately 12-15 hours of flying time, the entirety of the coastline can be photographed. A comparison of the photos from one year to the next is invaluable to the qualitative study of coastal processes, human activities, and regeneration of the coast. The photo record also serves as a cost-effective tool for enforcement of coastal management and environmental protection regulations.

8. COASTAL AND MARINE ECOSYSTEMS

The current study described in detail the geomorphology of the coastline but is light on information relating to coastal and marine ecosystem processes, habitats, and vulnerable species. The project team did not include a coastal ecologist or biologist. Additional information should be included in the next 'State of the Coast' to account for the current body of knowledge with respect to the Island's living coastline.

9. WATER CONDITIONS

The impacts of land use change and development on water conditions should be better understood to help guide coastal zone and environmental policies based on the specific context in which coastal development is proposed.

Data is currently collected on water conditions around the Island based on the needs and research objectives of the fisheries and aquaculture industry and additional data is collected by local watershed groups. The data exists but is not currently being used for interdisciplinary research.

Tracking Regulatory Activities

10. POST APPROVED WATERCOURSE, WETLAND AND BUFFER ZONE ACTIVITY PERMITS.

As is done with development permits issued under the *Planning Act*, Buffer Zone Activity Permits should be posted and made publicly accessible to support transparency in the administration of policies relating to coastal zone management.

Permitting data should also be readily available to support monitoring and evaluation of new policies.

11. UPDATE AND PUBLISH THE PROVINCIAL SHORELINE STRUCTURES INVENTORY (SSI) REGULARLY.

The provincial SSI is based on field data collected in 2017, 2018 and 2023, however this data has not been previously published. It is recommended the data be added to the Coastal Hazards Information Platform (CHIP) and should be updated regularly to track shoreline alterations in real-time.

12. STANDARDIZE THE PROVINCIAL/MUNICIPAL DEVELOPMENT RECORDS

Research completed as part of this project included the collection of development permit data from the provincial planning (Land) division, as well as from coastal municipalities. Unfortunately, a number of municipalities did not respond to the request and the gaps in the data made the analysis unusable. Furthermore, those records that were collected were obtained in many different formats and used a range of terminology and abbreviations.

Planning records, which are required to be posted publicly under the *Planning Act*, should be collected in a consistent manner across provincial/municipal planning authorities so that province-wide trends can be studied. This benefits not only future coastal development analysis but supports all future studies relating to province-wide development trends.

Open Data and Reporting

13. CREATE AN OPEN DATA PORTAL FOR PERMITS, STUDIES AND DATA RELATED TO THE COASTAL ZONE

The government, and more specifically the Department of Environment, Energy and Climate Action (DEECA), has access to data and information relevant to decision-makers and policy/regulation enforcement. Data that informs government decisions should be freely accessible to the public.

For example, the Corporate Land Use Inventory (CLUI) contains important information relating to land cover classifications including the location of sand dunes and salt marshes in the coastal zone. This and other datasets, including information on coastal hazards, critical habitats, species at risk, and permit approvals, should be made accessible.

14. UPDATE THE STATE OF THE COAST REPORT

This report provides a detailed description of the PEI coastal environment and processes as well as statistics on the built environment, status of ownership, and at-risk infrastructure.

An updated (*abbreviated version*) should be published on a regular basis of at least every 5 years to report on changes to the state of the coast, impacts caused by recent extreme weather events, and to provide transparency on the results of the monitoring and evaluation of new policies for coastal zone management.

Alternatively, a website dedicated to reporting on this information could be created and updated as new data becomes available.

Final Remarks

In reflecting on the current state of PEI's coast, several key insights emerge that are critical to understand to effectively plan and manage long term sustainability of the coasts.

Firstly, with regards to the natural environment, the coast is a dynamic system. It has always been in a state of flux, and change is its only constant. While we cannot halt these natural processes, we can adapt and find ways to coexist resiliently. Adaptation strategies should be rooted in understanding and working with these natural processes rather than against them.

Municipalities currently providing land use planning services are better poised to implement effective coastal zone management strategies. They have the tools in place to create policies and plan actions accordingly. Through their existing land use planning tools, they can prioritize the protection of vulnerable areas and guide future developments towards areas of low risk. However there remains a pressing need for the unincorporated areas and municipalities without such planning to catch up.

Without a clear vision for how and where coastal development will be permitted in the future, planning for the impacts of coastal hazards, and safeguarding the Island's beaches for future generations will not be possible.

Figure 74. Darnley - Thunder Cove, PE (D. Jardine, 2017)

It's important to differentiate between coastal infrastructure and infrastructure that's merely proximate to the coast. The former's function is dependent on the coastal environment, while the latter is within the coastal zone by choice. When priorities need to be set, these are the land uses and properties that are most suitable for relocation and/or decommissioning.

There is an urgent need to enhance the design, approval, and inspection processes for shoreline erosion mitigation (armouring) systems. As our coast faces increasing threats, the robustness and effectiveness of these systems is paramount. Where shoreline structures are installed without standards for the design, materials, and maintenance requirements, these structures are destined to become debris on our public beaches. All property owners – the province, municipalities, communities, and individuals – should be held to the same standards of design and construction, and accountability for shoreline restoration should their structures fail. The benefits of nature-based solutions, including protection, conservation, and restoration strategies can help counteract these trends, preserving our coastline for future generations.

Finally, PEI is currently experiencing a 'greying' of its coastline, not due to the passage of time but because of the influx of imported armour rock. The grey stone that now lines a significant portion of our coastal landscape not only deprives our beaches, dunes, and other features of their source of sand but also diminishes the natural beauty that draws tourists to our shores. The state of PEI's coast reflects both nature's beauty and human intervention. As we move forward, it's imperative to strike a balance between development and preservation, ensuring that our actions today don't compromise the coast's future.

The coast is not just a geographical feature; it's a legacy, a responsibility, and a treasure that we must protect and cherish for generations to come.

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