

MONITORING COASTAL CHANGE IN NEWFOUNDLAND AND LABRADOR: 2014 UPDATE

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ABSTRACT

The objectives of the coastal monitoring program described in this paper are to quantify coastal erosional and accretionary rates, to determine processes leading to coastal change, and to delineate areas at high risk from flooding, erosion and slope movement. The program, which began in 2011, builds upon earlier work by the provincial and federal geological surveys. During the fourth year of the program, fieldwork was conducted at 48 of 112 sites.

Rates of coastal change are variable. Extremely rapid erosion was measured during the last year in dunes in southwestern Newfoundland: in the Sandbanks Provincial Park (up to 600 cm) and the J.T. Cheeseman Provincial Park (over 900 cm). At Parson's Pond on the west coast, the cliff top retreated 73 cm between 2013 and 2014. At Chamberlains, a cliff site located in Conception Bay, erosion rates are much less: between 2002 and 2014, the cliff top receded at an average rate of 4.8 cm/a, and the base receded at an average of 9.5 cm/a.

The variability of erosion at the different sites is likely a result of the interaction of a range of factors including wave dynamics (offshore topography, aspect and exposure of the coastline, and shoreline protection); sediment composition and morphology of the cliff and beach; sediment supply; surface run-off; groundwater flow and wind. Ongoing work will consist of monitoring the coastal sites at regular intervals (yearly, biyearly, or triennially, depending on the site) to provide reliable estimates of coastal change, to identify areas vulnerable to coastal erosion, and to determine how coastal evolution may change in the future.

INTRODUCTION

The coastline of Newfoundland and Labrador, at 17 540 km, is the longest of any Atlantic Province; over 90% of the population live adjacent to coastal environments (Economics and Statistics Branch, 2002). Coastlines are dynamic, and hazards (defined as components of the physical environment that can negatively impact infrastructure or the safety of the population) can result from coastal changes in areas where the population lives and works (*see Batterson et al.*, 1999, 2006; *Liverman et al.*, 2003). Recent examples of coastal damage include coastal flooding and erosion in Placentia (Figure 1, Site #36) where, in December 2013, large waves superimposed on a high tide resulted in extensive damage to the boardwalk and caused Beach Road to flood (Plate 1), and landslides at Daniel's Harbour in 2013 following a period of heavy rain, which resulted in several metres of shoreline recession (Figure 1, Site #354; Plate 2). Slow, continual erosion occurring along the cliff (Figure 1, Site #312; Plate 3), adjacent to the highway between Grand Bank and Fortune on the Burin Peninsula is a risk to infrastructure.

The coastline is dominated by cliffs, composed of both unconsolidated material (silt, clay, sand and/or gravel) and bedrock, but also includes beaches and barriers, sand dunes, fiords, and estuaries (Forbes, 1984). Some of these coastal environments are more sensitive than others to change, depending on the interaction between terrestrial and marine processes and characteristics of the local landscape.

Coastal areas that are particularly sensitive to change include low-lying areas, *e.g.*, Ferryland (Plate 4); unconsolidated cliffs of sand and/or silt, *e.g.*, Parson's Pond and Point Verde; and sand dunes in southwestern Newfoundland *e.g.*, Sandbanks Provincial Park (Plate 5).

Understanding the erosion processes and factors that make an area susceptible to change is critical when predicting coastal evolution. Accurate predictions of coastal evolution are important in determining the vulnerability to flooding and erosion. Town planners, policy makers, and other stakeholders can utilize this information to prioritize mitigation efforts, to guide planning decisions, or to ensure that the necessary adaptations are made if development is necessary.

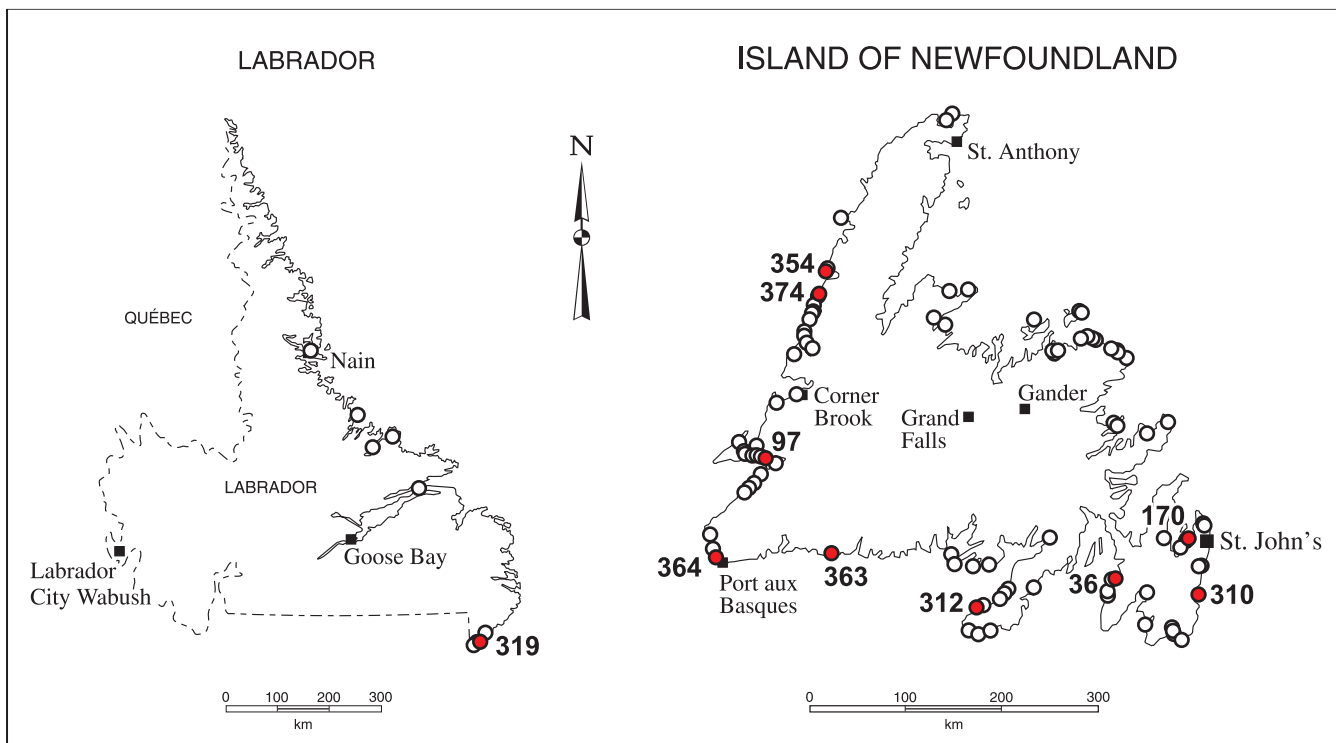


Figure 1. Coastal monitoring sites in Newfoundland and Labrador. Numbered sites are referred to in the text.



Plate 1. The modern beach in Placentia is a 1.2-km-long pebble-cobble beach. There is a long history of flooding in Placentia, with the area directly landward of the beach at risk from inland flooding and from water overwashing the beach during storm surges and high tides (Liverman et al., 1994). In December 2013 large waves associated with a storm surge caused significant damage to the boardwalk and Beach Road was flooded.

As the climate changes, there will be a modification of the impact to the key variables that influence the evolution of coastal environments. Based on the integration of observations and regional climate model projections, projected changes in climate indices for the 21st century include an increase in number of days with substantial (greater than 10 mm) precipitation, an increase in the maximum precipitation



Plate 2. In November 2013, a large amount of sediment was displaced in Daniel's Harbour during a landslide, damaging part of the old roadway that was closed in 2007 due to a previous landslide in the area.

over 3, 5 and 10 day periods, and an increase in extreme precipitation (Finnis, 2013). These changes may result in an increase in the vulnerability to flooding and erosion due to an increase in the potential for groundwater flow, surface run-off and slope movement.

Predictions of coastal evolution are also driven by the level of the sea, relative to the land surface. This is dependent on the interaction of crustal (isostatic) and ocean level (eustatic) changes (Batterson and Liverman, 2010). A rise in relative sea level will cause coastal processes to occur far-



Plate 3. The glaciofluvial cliffs adjacent to the highway between Fortune and Grand Bank on the Burin Peninsula are eroding.



Plate 4. The main beach and tombolo in Ferryland (Figure 1, Site #310) are highly sensitive to erosion and flooding caused by combination of local factors; the tombolo has a low elevation, is narrow, is frequently exposed to storm surges and large waves, and lacks natural protection from sea ice (Catto, 2012a, b). The area has a history of flood events, which have caused extensive and repeated damage to the road leading out to the headland. Photo credit: Eric Watton.

ther inland, and can increase the rate of coastal erosion, and the vulnerability to storm surges and flooding. Compared to the sea level in 1990, the Avalon Peninsula is projected to experience the greatest rise in relative sea level: greater than 100 cm by 2099 (Batterson and Liverman, 2010).

KEY FACTORS INFLUENCING RATES OF EROSION

This study shows that rates of coastal change are variable along the Province's coastline. Change occurs due to a combination of marine and terrestrial processes, and the variation in rates is due to the interaction of the following factors:



Plate 5. Sand dunes are not common in coastal environments in Newfoundland and Labrador, but where present these environments are vulnerable to relatively rapid change. At Sandbanks Provincial Park (Figure 1, Site #363), the seaward edge of the sand dunes eroded up to 6 m between 2013 and 2014. This coastline is highly vulnerable to erosion as it has a narrow beach, is exposed to large waves and storm surges from the south, and is composed of sandy material.

Erosional Processes

- **Wave energy:** The potential for waves to result in bluff or beach erosion is strongly influenced by fetch, nearshore geometry, orientation of the coastline relative to the effective storm direction, foreshore width and presence or absence of shoreline protection such as boulders, offshore bars or islands. Wave erosion can cause a bluff to become unstable and oversteepen if rates of erosion at the toe of a slope are higher than the top, leading to increased erosion of the top of the cliff until it returns to its angle of repose.
- **Wind:** In coastal areas that have high wind speeds, wind will remove sand from the cliff face, and the top of the cliff may become undercut resulting in the formation of overhanging turf mats. Wind can also result in dune erosion.
- **Surface run-off:** Water flowing over a cliff face will promote sheetwash and gulying, in particular in cliffs with high sand content.
- **Groundwater flow:** Groundwater flow can promote creep, slides and slumps in coastal bluffs with a high clay or silt content.

Site Characteristics

- **Sediment composition:** Cliff and beach sites composed of sand and gravel are susceptible to erosion from surface run-off and wind. Silt and clay are more resistant to erosion, but may slump or slide if the area is undercut or becomes saturated with water. Boulders, falling

out of cliffs as the cliffs retreat, can provide protection to the cliffs from the impact of waves.

- **Beach, bluff and nearshore geometry:** In areas with a wide foreshore, an offshore bar and/or an island, wave energy can be partly dissipated, decreasing the erosion potential from waves at the base of a cliff or sand dune. The nearshore slope will also impact the erosion potential from storms or waves. On reflective beaches, where the slope is steep, the potential for erosion from a storm will be greater than on a dissipative beach, where the slope is more gentle. The shape and orientation of the bluff will also impact the potential for erosion from marine and terrestrial processes, and bluffs oriented toward the effective storm direction will have a higher susceptibility to erosion from waves and wind.
- **Sediment budget:** Depending on the sediment transport within the littoral cell (defined as a portion of the coast containing sediment sources, a continuous alongshore sediment transport and a sediment sink), the quantity of sediment on a beach may be maintained from sources that include rivers or eroding cliffs. In areas where there is no source of sediment, a beach may experience a decrease in sediment over time.
- **Vegetation:** Vegetation can stabilize a slope and decrease the susceptibility of erosion from wind and water.

Coastal Monitoring Program

This paper describes field work conducted in 2014 as part of a multi-year coastal monitoring program (*see* Irvine, 2012, 2013, 2014; Forbes, 1984). Measurement sites have now been established at 112 coastal locations (Figure 1). Site selection took into account the range of different coastal environments (unconsolidated cliffs, gravel and sand beaches, and dunes), evidence of hazards such as landslides, availability of prior data, or at specific requests of stakeholders; sites in the last category consist of Norris Point, Witless Bay, Shoal Point and Mistaken Point. Data collected from repetitive measurements, over a minimum five years as recommended by Liverman *et al.* (1994), will enable quantification of the rates of coastal change (Norcross *et al.*, 2002; Harley *et al.*, 2011), and a delineation of areas vulnerable to coastal hazards. The main processes affecting coastal change, and the local characteristics which impact the mechanisms and rate of coastal evolution will be identified.

Data on the erosion rates of the coastlines and changes in beach profiles are available from the Geoscience Atlas (<http://geoatlas.gov.nl.ca>). For cliff-monitoring sites, the database includes the average, minimum and maximum end-point erosion rates, net shoreline erosion, and a link to summary information about each site. For beach-monitoring sites, a link to summary information about the site, and a

graphic chart showing changes in beach profiles, are included.

FIELD SEASON 2014

During the 2014 program, 48 sites were surveyed. New sites were established in Witless Bay, Shoal Point, Boswarlos, Norris Point and Wreckhouse by the Geological Survey of Newfoundland and Labrador (GSNL), and in Nain, Makkovik, and Rigolet by the Geography Department at Memorial University (MUN), which brings the total number of monitoring sites to 112. Collaborations have also been established with the Northeast Avalon Atlantic Coastal Action Program (NAACAP) to provide year-round monitoring of a site in Witless Bay.

APPROACH

Studies of coastal areas use topographic-survey equipment. In the current study, use was made of a Real Time Kinematics (RTK) instrument, which collects precise (millimetre-scale) location data. The RTK equipment comprises a stationary base receiver (referred to as a 'base station'), one or more roving receivers, and a radio link. The base station continually collects satellite signals of its static location, and the positional errors (caused by factors such as satellite orbit errors and tropospheric delays) are determined by the base station. These error values are transmitted to the roving receivers, allowing for the coordinates of the roving receivers to be corrected in real time, resulting in precise relative and absolute location data (Pardo-Pascual and Garcia-Asenjo, 2005).

The surveys were conducted using a Leica GS09 Global Navigation Satellite System (GNSS). The base station was set up next to the radio link and over a permanent survey benchmark whose position was known. Location data were recorded by two roving receivers, each equipped with an antenna, a radio modem to receive values, and a handheld computer to enter site observations, *e.g.*, sediment type, geographic feature(s), vegetation cover and infrastructure. At most sites, a second survey benchmark having a known position was used to verify the accuracy of the data. The base station was established within 10 km of the monitoring site and in line-of-sight of the roving receivers.

Coastal features, including the cliff top and toe, vegetation line, and beach features, such as berms and cusps, were surveyed. Cliff tops are identified by a distinctive edge, or on vegetated slopes not having a distinctive edge, by a break in slope. Depending on the size and characteristics of the site, between one and ten transects were established; the most common number of transects was three. For each transect, two survey markers, consisting of plastic pins attached to

two-foot (0.61 m) pieces of rebar, were aligned perpendicular to the shoreline and hammered down until their heads were flush with the ground. The survey markers were installed landward of areas of active beach processes and located near a distinctive, nonmetallic object, if possible, for ease of subsequent location. Repetitive surveys from the landward survey marker to the water were conducted along the same transect lines. For this study, the inaccuracy associated with collecting RTK data, which does not exceed ± 10 cm, is primarily related to human error. Sources of the error include inadequately ensuring the RTK rover pole is vertical in strong winds, and definition and measurement of the cliff edge in areas where the latter is not well defined. Human error is least on sandy beaches, where it is easiest to set up and maintain the position of the rover pole, and more serious on cobbled surfaces.

DATA PREPARATION AND ANALYSIS OF SHORELINE CHANGES

SHORELINE CHANGE AT CLIFF SITES

To provide coastal-change statistics for cliff sites, the Digital Shoreline Analysis System (DSAS) software application for ArcGIS was used (Thieler *et al.*, 2009). To calculate the rates of change, shoreline locations for more than one date, and a baseline, are required. The shoreline is defined as the location of a feature (*e.g.*, top or toe of a slope, or the high-water line) measured at a specific time, and the baseline serves as a reference to calculate rate of change statistics (Thieler *et al.*, 2009).

To prepare the data for analysis, the following steps are taken:

- Data from the two roving receivers are downloaded and integrated into Leica Geo Office software and exported as shapefiles into ArcGIS.
- Using the “Points to Line” tool in ArcGIS, a line representing the location of the top and/or toe of the cliff is created for each period of data collection.
- All of the shoreline data are merged into a single feature class and imported into a geodatabase. Attribute data associated with the shorelines consisted of the date and level of data uncertainty (± 10 cm).
- A baseline, situated onshore of the shorelines, is created by using the ArcMap Editor tool.
- Shore-normal transects at 1 m intervals along the baseline, extending from the baseline to the shorelines are cast using the DSAS application toolbar.
- Rate-of-change statistics are determined based on the intersection points of the transects and shorelines.

SHORELINE CHANGE AT BEACH SITES

To determine changes in beach profiles, data from the two roving receivers were downloaded and integrated in Leica Geo Office software and exported as shapefiles into ArcGIS. Pythagorean distances between each measured RTK point on the transect were calculated, and profile graphs plotting elevation change against distance from the survey pin to the ocean were generated.

VARIABILITY OF COASTAL CHANGE

Rates of coastal change vary across the Province and it is too early in the program to provide quantitative analysis of change of all coastal monitoring locations; some sites were only monitored once. It is also premature to quantify how different types of coastal environments are changing, or to determine long-term trends of coastal change. The time frame over which data were collected is generally four years or less, with the exception of sites established by the GSC; a minimum of five years (Liverman *et al.*, 1994), or even ten years (Dillenburg *et al.*, 2004) is required for reliable estimates of rates of coastal change. When short-term data are used in analysis, rates of shoreline change may be over- or under-estimated as longer periods of data collection are required to smooth out the variability in coastal evolution that are inherent in natural environments. However, examples of recent changes in the coastline of five monitoring sites, representative of the range of environments, are provided below. The processes causing coastal change and factors impacting rates of change are highlighted.

REGIONAL ANALYSIS

Forteau, Southern Labrador

Forteau (Figure 1, Site #319) is located on the north shore of the Strait of Belle Isle in southern Labrador. The area is low-lying, with houses commonly less than 5 m above sea level (asl) and less than 100 m from the edge of low cliffs. The beach is a sandy tidal flat 15 to 20 m wide, scattered with boulders up to 2 m in diameter, and there is exposed granitic bedrock (Gower, 2010) on the foreshore at several locations (Plate 6). The backshore is primarily vegetated with underlying sand.

In 2012, the seaward edge of the dunes was surveyed and five shore-normal transects, extending from the grassy backshore to the water line, were established (Figure 2). In 2014, the same features were re-surveyed, and a sixth transect established (Line 6). The survey pin installed on Line 5



Plate 6. View looking northeast across the sandy foreshore with some boulders in Forteau, southern Labrador. Note the overhanging grass mats and the slumps, both signs of erosion, visible at the base of the sandy banks. The backshore is composed of grass with sand underlying, and residential homes border the shoreline along portions of the site.

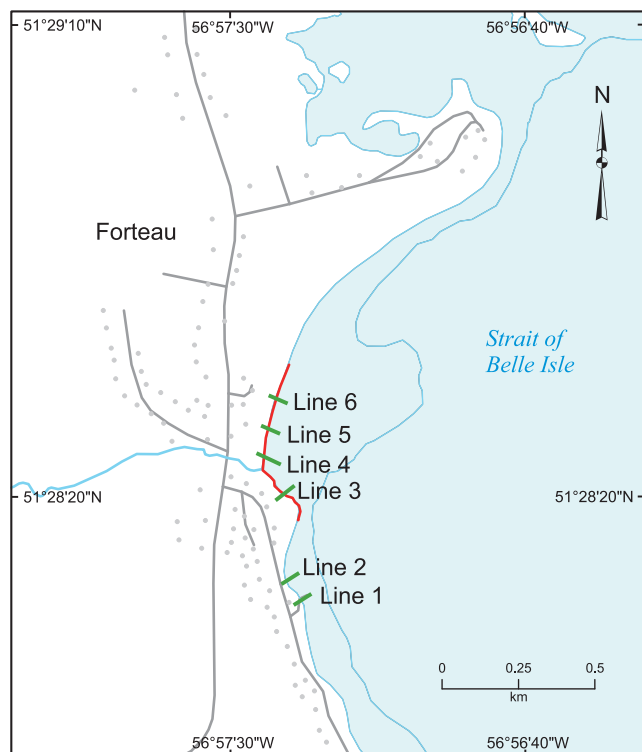


Figure 2. Location of the transect lines (green lines) and surveyed portion of the coastline (red line) in Forteau. Grey circles show the locations of buildings.

in 2012 could not be located in 2014; the pin was likely lost due to erosion and two new survey pins were installed landward of the position of the lost pin. Between 2012 and 2014, the edge of the sand dunes eroded at an average rate of 48.67 cm/a (Figure 3). During this period, Line 1 showed accretion, Line 2 showed insignificant change and Lines 3, 4 and 5 showed erosion (Figure 4). Lines 3, 4 and 5 are eroding as

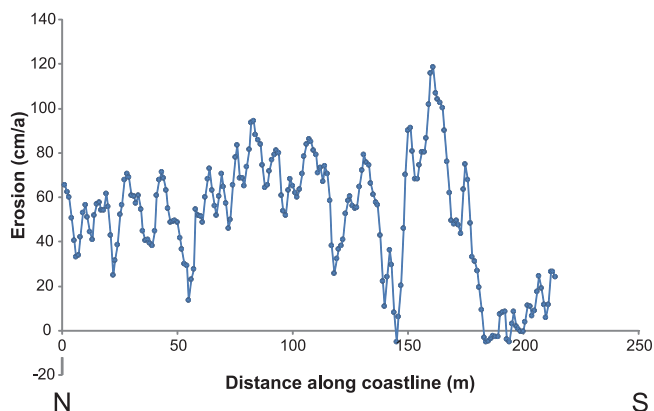


Figure 3. Shoreline erosion as a function of distance along the seaward edge of the sand dune at Forteau between 2012 and 2014. The average rate of retreat was 48.67 cm/a, with a range from -5.33 to 118.67 cm/a. The shoreline near Line 1 was excluded as there was man-made shoreline accretion, resulting from the dumping of sediment. Additional areas excluded from the shoreline change analysis were the portion of the shoreline protected by a rock wall, and areas of bedrock.

a result of waves removing sediment from the base of the sand dunes, and wind and water removing sand from the dune face. Line 2 is in a more protected portion of the bay than the other transects, and is less vulnerable to erosion from waves.

Stephenville, West Coast

The Stephenville site (Figures 1 and 5, Site #97) is situated on the north shore of St. George’s Bay and is about 5 km long. The site includes a barrier complex of Holocene beach ridges composed of well-rounded, flat gravel. A sea-wall runs parallel to the beach along the south-eastern section. At the northern portion of the site, in the vicinity of Line 4, there is sand and gravel in the foreshore, and vegetation (grasses) overlying a sand substrate in the backshore. At the southern end of the beach is a man-made channel, providing boat access to Port Harmon (Plate 7).

The RTK survey was conducted over four years (Figure 5). The results (Figure 6) show that the volume of beach sediment is increasing at Lines 1, 2 and 3 because of longshore drift of sediment eroding from the cliffs to the west, and the barrier complex will likely continue to be maintained as long as sediment supply continues. At Line 4, located just west of the Stephenville beach (Figure 5), the beach ridge (and the beach) is receding landward. The beach may also be receding landward at Line 4, as the foreshore is narrow compared to the other transects, and waves are reaching the sandy beach ridge (as evident by driftwood and rounded beach cobbles on the backshore), resulting in erosion.

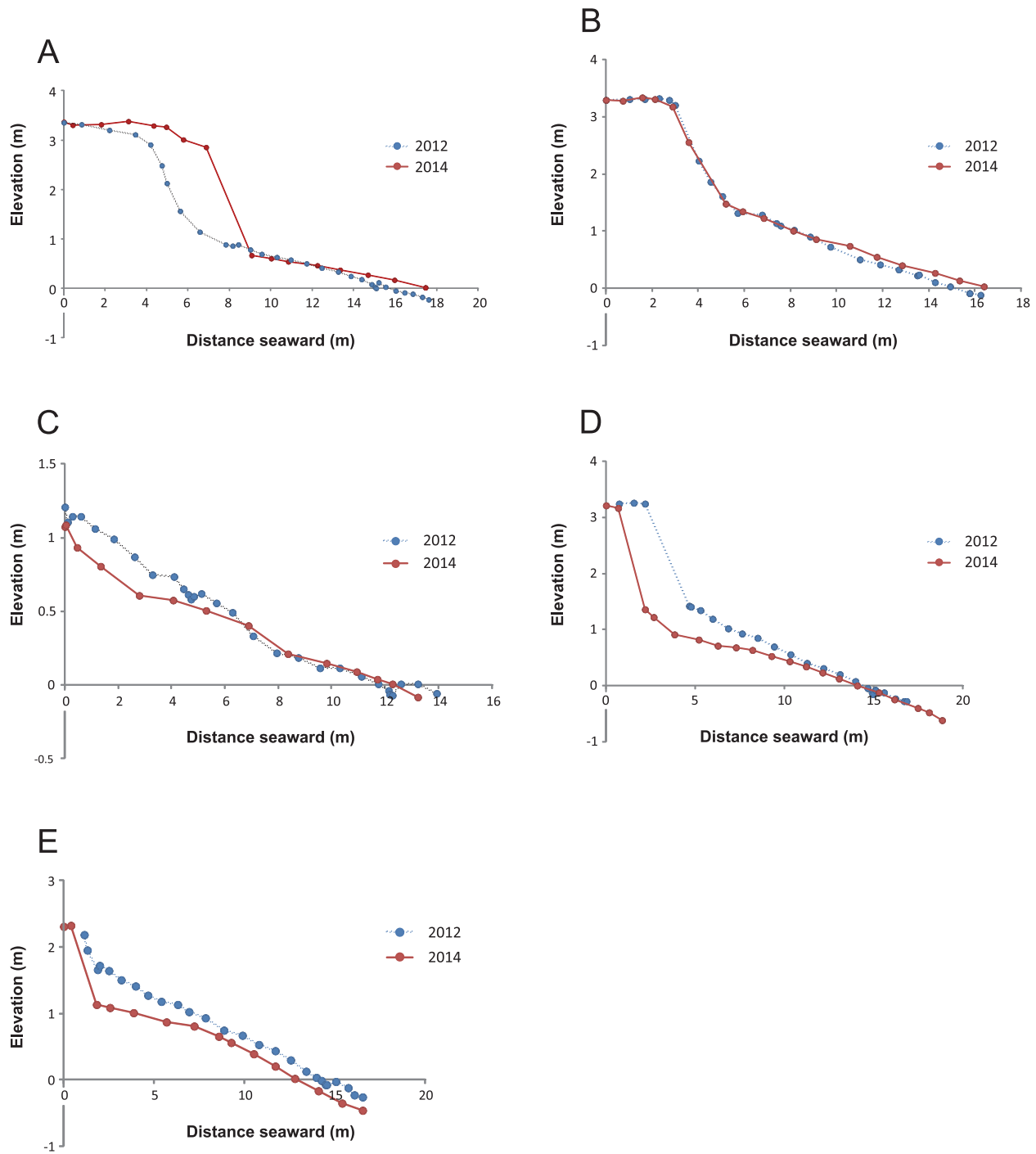


Figure 4. Beach profiles at Forteau in 2012 (dotted blue line) and 2014 (solid red line) for Forteau. A) The two profiles of Line 1 show an increase in the volume of sediment and shoreline accretion, caused by earthmoving activities; B) The two profiles of Line 2 show minor variation between the two surveys. The seaward edge of the sand dune migrated landward 10 cm between the two surveys, and additional surveys will be conducted to determine if this trend in erosion continues; C) At Line 3 the profiles show a decrease in sediment volume in the upper portion of the transect, with sediment being removed from the face of the sandy dune. The lower foreshore was similar during the two surveys; D) Line 4 is situated in an area of active shoreline erosion. The two profiles show coastal erosion of 1.48 m at the top of the dune, and 2.55 m at its base, between the two surveys. Erosion was more rapid at the base of dune compared to the top, resulting in a progressive steepening of the dune face; and E) The seaward edge of the backshore dune migrated landward approximately 1.1 m between the two surveys, there was a steepening of the dune face, and an overall decrease in sediment volume.

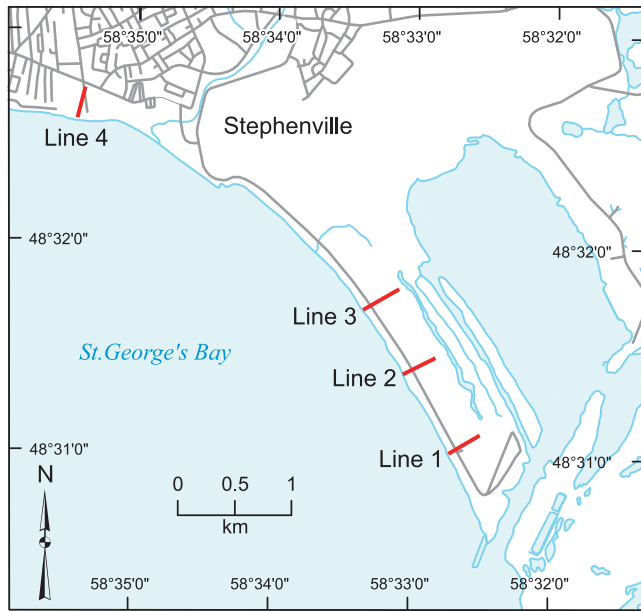


Figure 5. Location of transect lines (red lines) in Stephenville.



Plate 7. View looking east over the rounded gravel beach at Stephenville. The point of land in the distance indicates the man-made channel that opens into Port Harmon. Indian Head, which limits the eastward longshore transport of material, is in the background.

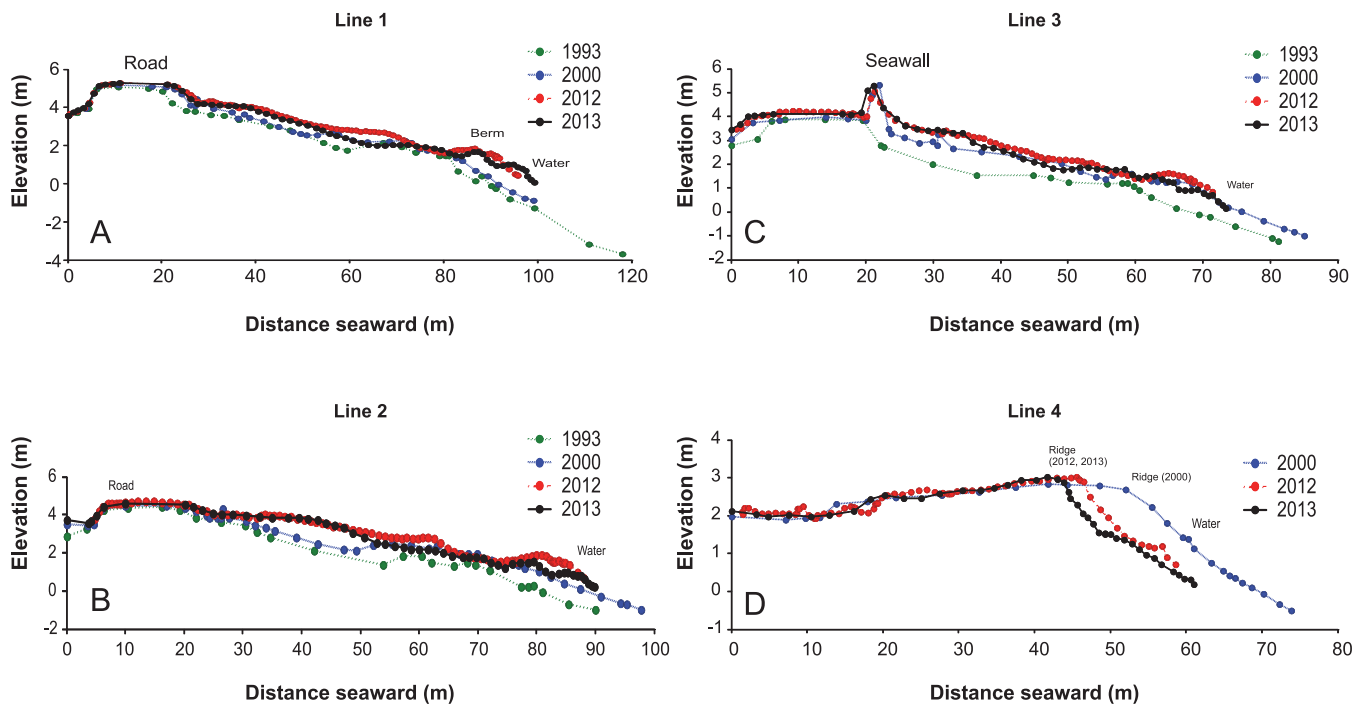


Figure 6. Beach profiles in 1993 (green line), 2000 (blue line), 2012 (red line) and 2013 (black line) for Stephenville. A) Line 1 shows a small increase in the volume of sediment over time, and variations in the location of the beach berms, with a vertical accretion in the lower foreshore in 2012 and 2013 compared to the previous years; B) On Line 2, the profiles show an increase in the beach volume between the earlier surveys (1993 and 2000) and the later survey years (2012 and 2013); C) Line 3 there is an overall increase in the volume of sediment between 1993 and the more recent survey years (2000, 2012, and 2013); and D) Line 4 the beach ridge is migrating landward and the beach face was steeper during the 2012 and 2013 surveys than in 2000.



Plate 8. Sand dune at J.T. Cheeseman Provincial Park. The seaward edge of the sand dune eroded 922 cm between 2013 and 2014, exposing an old section of railway.

J.T. Cheeseman Provincial Park

The J.T. Cheeseman site (Figure 1, #364) is on the eastern shore of the Cabot Strait, east of the community of Cape Ray, in southwestern Newfoundland. The site consists of a sandy tidal flat whose maximum width was 41 m at the time of the survey, and vegetation (grasses) overlying a sand substrate in the backshore (Plate 8). The site faces the Gulf of St. Lawrence and has a fetch of 100 to 200 km. The site consists of two beaches of marine and glaciomarine sand, bordered by bedrock headlands.

The area was surveyed in 2013 and 2014. In 2013, seven transects were established from the grassy backshore to the waterline (Figure 7). In 2014, an eighth transect (Line 8) was added in an area of high erosion. Profile changes between 2013 and 2014 varied between transects; the greatest change occurred at Line 6, with over 900 cm of erosion measured in one year (Plate 8; Figure 8). The width of the foreshore at this transect in 2013, which was 10 m, was more narrow compared to the other transects. This characteristic could be a factor impacting the high rate of erosion; beach width is a key factor affecting the rate of dune-volume change due to marine processes (Keijsers *et al.*, 2014).

Parson's Pond

Parson's Pond (Figure 1, Site #374) is located on the eastern shore of the Gulf of St. Lawrence. The site has a westerly exposure, with a maximum fetch of greater than 660 km due west. The site consists of a non-vegetated cliff 11 to 16 m high, composed of glaciomarine sand and gravel with some silty clay (Plate 9), fronted by a narrow beach (8.5 m wide at the time of the 2014 survey), with a low slope composed of sand, gravel and boulders.

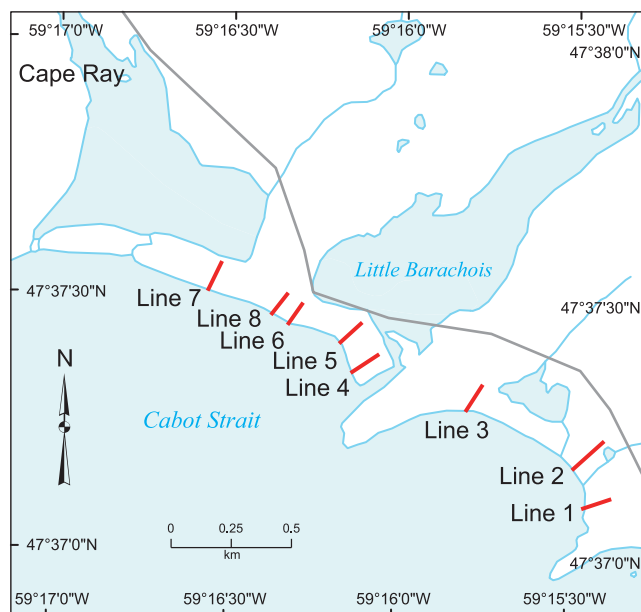


Figure 7. Location of transect lines (shown by red lines) at J.T. Cheeseman Provincial Park.

About 250 m of the cliff top was surveyed during 2013 and 2014 (Figure 9); the average recession of this interval was 73 cm during this period (Figure 10). The maximum amount of erosion along the cliff top was 300 cm, which occurred at the northern section of the cliff (Figure 10). Areas of accretion (negative erosion values) are likely the result of slumping along the edge of the cliff top.

The high rates of erosion at Parson's Pond compared to other locations are due to a combination of factors. Due to the narrow foreshore, waves reach the base of the cliff and remove sediment; evidence of this includes the presence of driftwood, seaweed and wave notching at the base of the cliff. Although the slope of the beach is low, the incoming waves have a high potential to cause erosion as the site has a large fetch and is exposed to the effective storm direction. The composition of the cliff, which is mainly sandy, allows water to create large gullies in the cliff face (Plate 9), and groundwater is visible in contact between the sandy-gravel and silty-clay layers. The cliff is exposed to wind, which is removing sand from the cliff, as evident from the overhanging tuff mats along the top of the cliff.

Chamberlains

The Chamberlains site (Figure 1, Site #170) is located on the eastern shore of Conception Bay, which is exposed to the northeast, although fetch is limited by several offshore islands. The Chamberlains coastline consists of a cliff 3.5 to 11 m high, of unconsolidated gravel, sand and boulders, which is primarily vegetated in the east, and non-vegetated in the west. The cliff is fronted by a steep, narrow beach (13

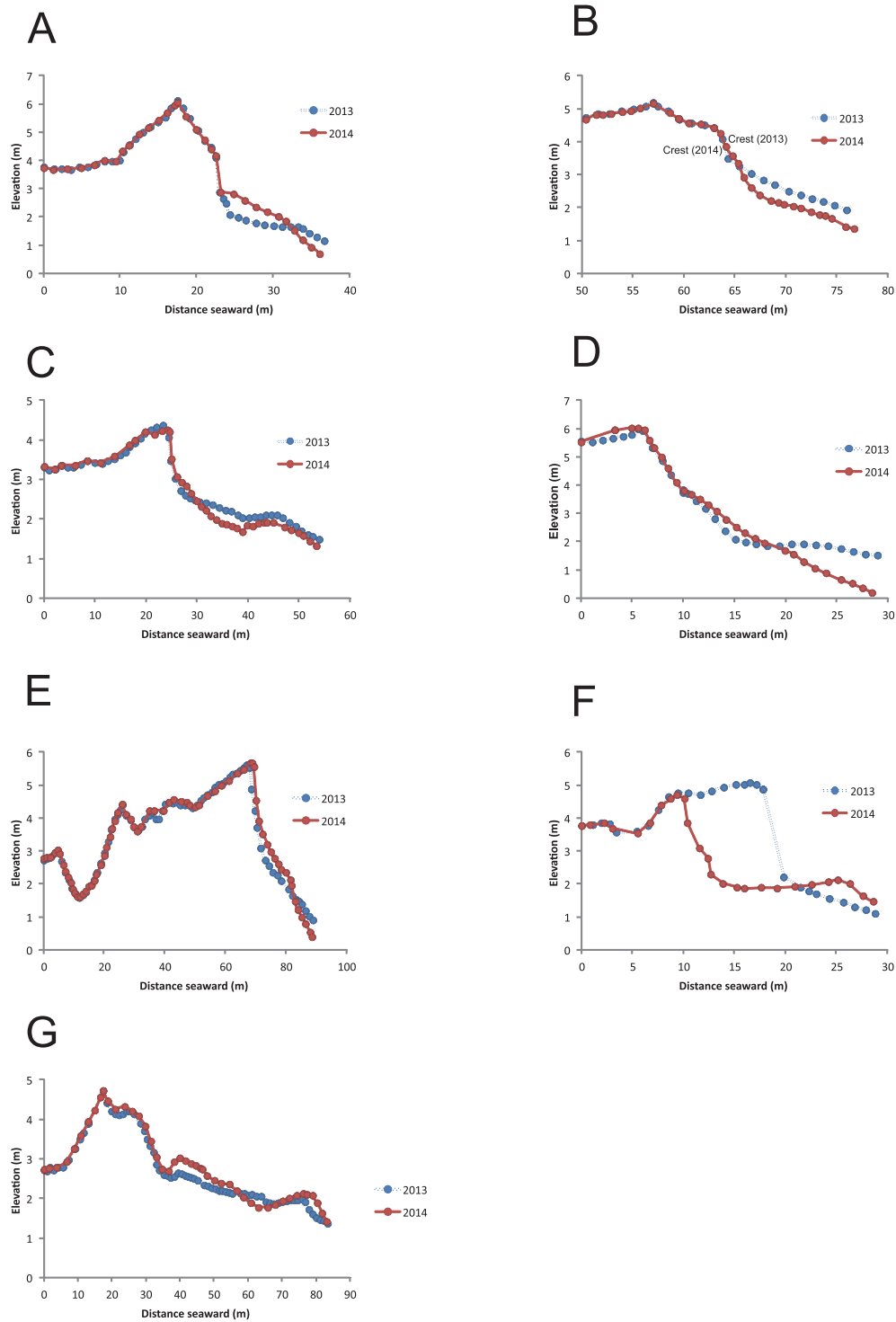


Figure 8. Beach profiles at J.T. Cheeseman Provincial Park in 2013 (dotted blue line) and 2014 (solid red line). A) Between the two years, the profile showed an increase in sediment in the upper foreshore and a decrease in sediment in the lower foreshore. Dune crest erosion was minimal (less than 2 cm); B) The face of the dune became steeper between the two surveys, and the dune crest eroded around 10 cm/a; C) At Line 3 there was a decrease in sediment volume on the sandy foreshore, and the dune crest erosion was minimal (less than 2 cm); D) Between the two years, the profile showed minimal change, with the exception of a decrease in sediment volume in the lower foreshore; E) At Line 5 the profile was invariant; F) At Line 6 the dune crest migrated landward 943 cm between the two surveys; and G) At Line 7, there was minor accretion of sediment on the foreshore.



Plate 9. One of the large gullies that are forming in the glaciomarine sand, clay and gravel cliff at Parson's Pond.

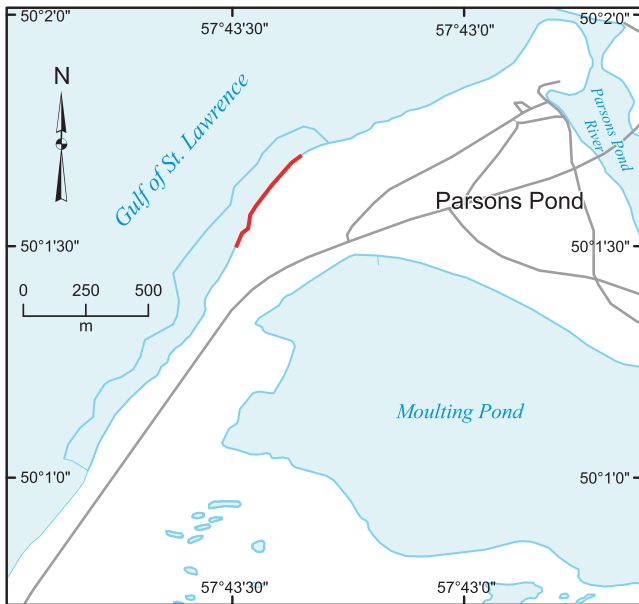


Figure 9. Location map of the surveyed portion of the cliff (shown by the red line) at Parson's Pond.

m wide at the time of the 2014 survey), composed of gravel and sand and some boulders are located in the nearshore.

The cliff top and base were surveyed in 2002 by the GSC (D. Forbes, personal communication, 2011), and by Irvine (2012, 2013 and 2014; Figure 11). Between 2002 and 2014, the average rate of erosion along the cliff top was 4.8 cm/a, and erosion ranged from -10.67 cm/a (indicating accretion) to 20.33 cm/a (D. Forbes, personal communication, 2011; Figure 12). The average rate of erosion of the bottom of the cliff, over the same time period, was 9.49 cm/a, and retreat rates ranged from -5.33 to 24 cm/a (Figure 12). Areas of accretion (negative erosion values) along the top of the cliff are likely the result of either slumping, or of

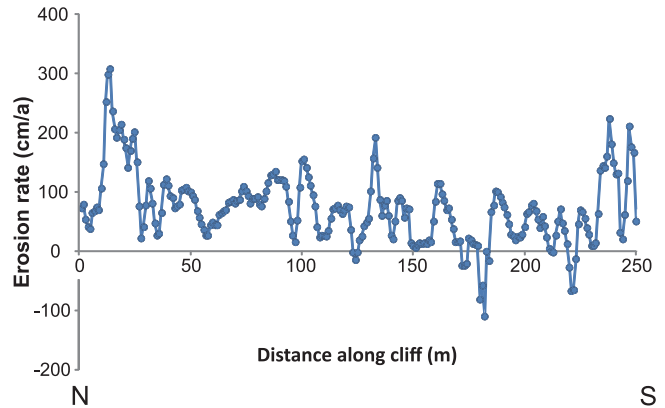


Figure 10. Rate of cliff top erosion as a function of distance at Parson's Pond between 2013 and 2014. The cliff eroded at an average rate of 73 cm/a, ranging from -100 cm to 300 cm/a. Areas of more rapid erosion were at the northern and southern extremities of the site. Areas of negative erosion (i.e., accretion) are likely attributable to slumping along the top of the cliff.

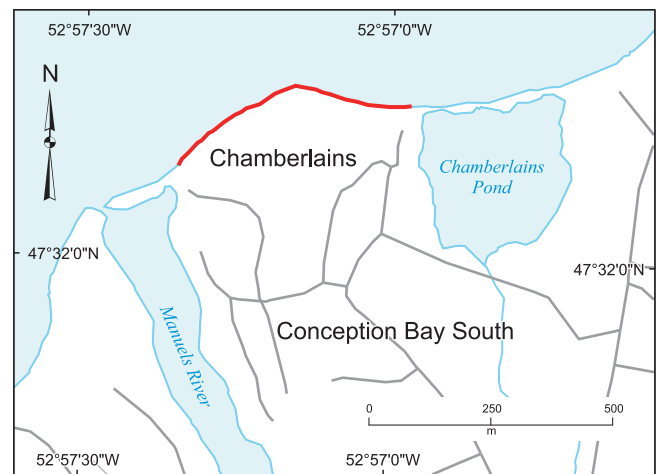


Figure 11. Location map of surveyed portion of the cliff line, as shown by the red line, in Chamberlains.

home owners depositing material (grass and sediment) along the cliff edge.

The results show a more rapid retreat rate of the base of cliff compared to the top, resulting in a progressive steepening of the cliff face. Cliff top erosion rates are not as high as at Parson's Pond, Holyrood Pond (Irvine, 2014) or Point Verde (Irvine, 2013). Although waves are eroding the base of the cliff, as evident by wave notching visible along the base of the cliff, Chamberlains is less vulnerable to wave erosion than the cliff sites described above. The fetch is limited, and there are boulders in the nearshore that are dissipating incoming wave energy. Boulders in the cliff face are falling to the toe of the slope as the cliff erodes landward, and are providing shoreline protection. Portions of the cliff

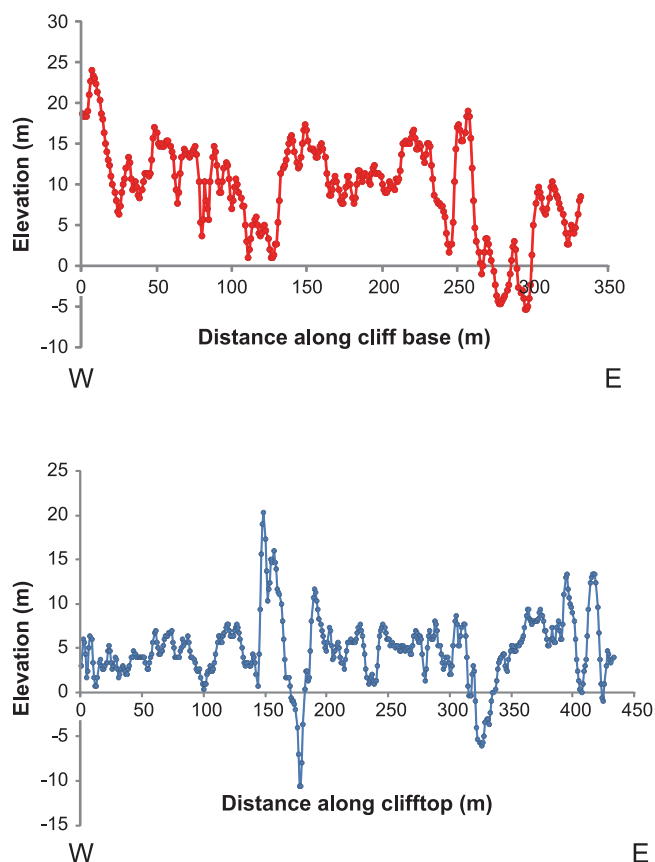


Figure 12. Rate of cliff erosion as a function of distance at Chamberlains between 2002 and 2014. The clifftop (blue line) eroded at an average rate of 4.8 cm/a, ranging from -10.67 to 20.33 cm/a. The average rate of erosion for the base of the cliff (red line) was 9.49 cm/a, ranging from -5.33 to 24 cm/a.

face are vegetated, resulting in a decrease in the erosion potential from surface run-off and wind.

COMPARISON WITH COASTAL EROSION IN OTHER ATLANTIC PROVINCES

In New Brunswick, the average rate of erosion for coastal areas with long periods of data acquisition (>45 years) was 19 cm/a for cliffs and 35 cm/a for dunes; for areas with older datasets (generally before 1975) the rate of erosion was 39 cm/a for cliffs and dunes, and for coastal areas with recent datasets (generally after 1975) the rate of erosion was 21 cm/a for cliffs and 23 cm/a for dunes (D. Berubé, personal communication, 2014). The average rate of coastal erosion for Prince Edward Island (PEI) between 1968 and 2010 was 28 cm/a, and between 2000 and 2010 erosion rates were higher, at 40 cm/a. These rates of erosion are not specific to a certain type of environment, and include areas that experienced shoreline accretion (Webster, 2012). Relative sea-level rise has also increased in PEI between

1968–2010 at a rate of 27 cm per 100 years, and the rate of rise has increased sharply since 2004. As suggested by Webster (2012), the rate of coastal erosion is expected to increase with increased rates of relative sea-level rise, as the impact of storms will move farther inland. Relative to the average erosion values observed in other Atlantic Provinces, Point Verde, Sandbanks Provincial Park, and Holyrood Pond are experiencing rapid rates of change.

CONCLUSIONS

There are 112 monitoring sites in the coastal monitoring program, 48 of which were monitored in 2014. This program shows that rates of coastal change vary. Areas showing high rates of coastal change include the sand dunes in the Sandbanks and J.T. Cheeseman provincial parks in south-western Newfoundland; portions of the coastline in Forteau, southern Labrador; Point Verde and Holyrood Pond on the Avalon Peninsula; and Parson's Pond on the west coast of Newfoundland.

Based on findings from this program, the following factors should be considered when examining coastal change:

- Coastal evolution of cliff, dune and beach environments is variable, and caused by a combination of processes: wave action, groundwater flow, surface run-off, and wind. As seen at Parson's Pond, Forteau and Sandbanks Provincial Park, wave action is predominately resulting in erosion to the base of cliffs, or dunes, if they lack shoreline protection, are exposed, or have a narrow foreshore. Surface run-off is resulting in erosion on sandy cliffs which lack vegetation, including Parson's Pond. Groundwater flow is an important erosional agent in bluffs composed of silty clay, as exemplified at Parson's Pond. Wind is an effective erosional agent in sandy areas that lack vegetation; this is occurring at Parson's Pond.
- The impact of erosional agents is controlled by local characteristics, which will reflect the mechanisms and rate of coastal evolution.
- Relative to other areas in Atlantic Canada, certain areas (Parson's Pond, the Sandbanks and J.T. Cheeseman provincial parks, Point Verde and Holyrood Pond) are displaying high rates of coastal erosion.
- Predicting coastal evolution is challenging, but based on climate-change projections and relative sea-level rise, current rates of coastal erosion will likely continue.

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