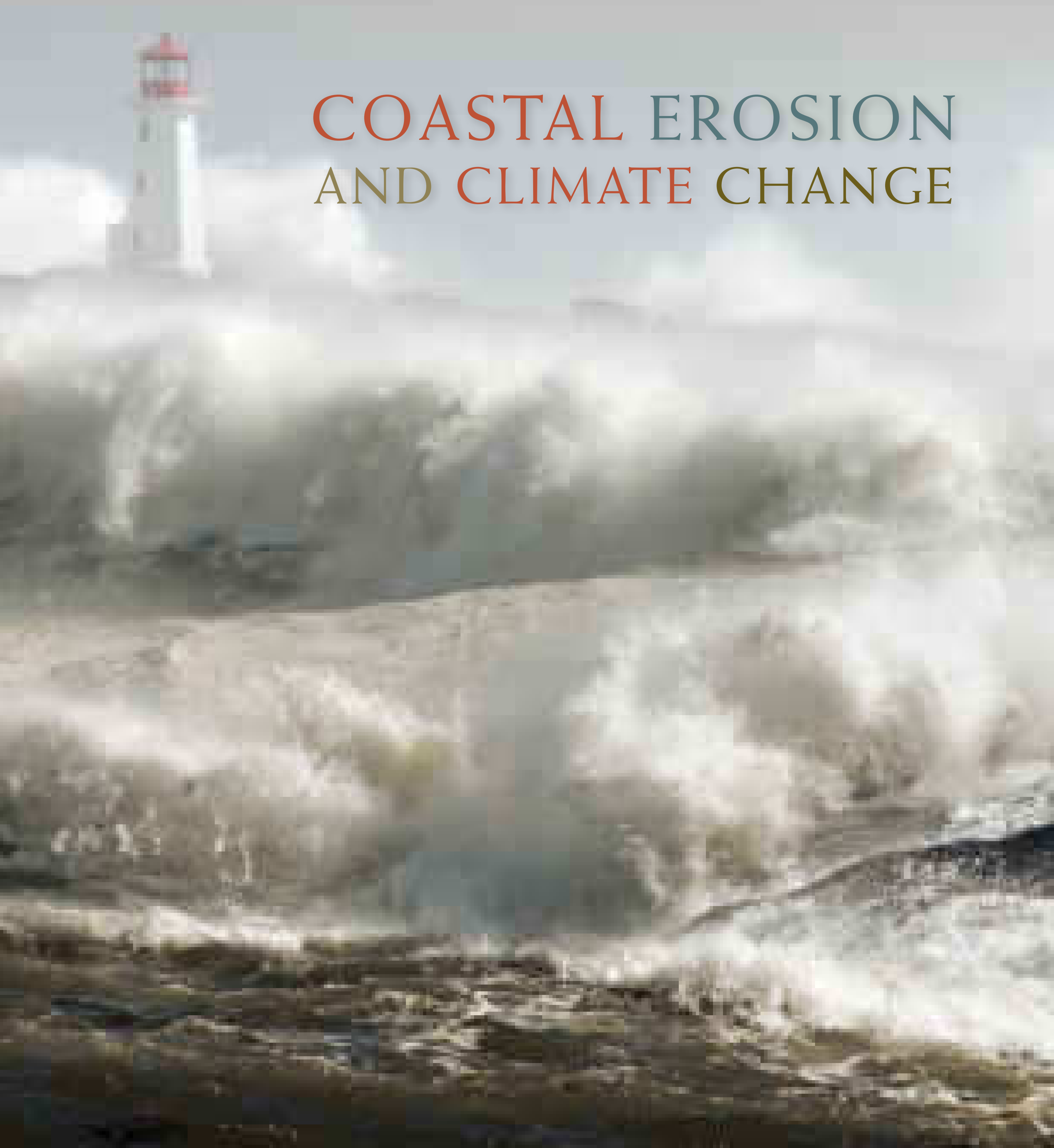
COASTAL EROSION AND CLIMATE CHANGE



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COASTAL EROSION AND CLIMATE CHANGE

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ACASA is a non-profit organization formed to coordinate project management and planning for climate-change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador. ACASA is supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada, and regional municipalities and other partners.

SACCA est un organisme à but non lucratif formé pour coordonner la gestion de projet et la planification des initiatives d'adaptation au changement climatique en Nouvelle-Écosse, du Nouveau-Brunswick, Île du Prince Édouard et Terre-Neuve et soutenu par la collaboration pour l'adaptation régionale, une entreprise commune entre les provinces de l'Atlantique, Ressources naturelles Canada et municipalités régionales et d'autres partenaires.

This report is also available on the Internet at **www.atlanticadaptation.ca**

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EXECUTIVE SUMMARY

Coastal erosion is a natural process that consists of the breakdown (or "weathering") of rock and sediments at the shoreline, both above and below the water surface. In Atlantic Canada, coastal erosion happens as a result of the action of waves, and to a lesser extent tidal action, wind, storm surge, ice, rain, and surface runoff.

Rates of erosion and deposition are different at different points on the coast. Factors such as exposure and tides can each influence the degree to which a shoreline may erode. The type of shoreline, and the type of sediment of which it is composed, are also influential: cliffs, beaches, barrier systems, and salt marshes resist erosion to different degrees. Changes to climatic conditions and sea level will also influence the rates of erosion and deposition. Human activities can also affect rates of coastal change.

Coastal erosion results in the landward movement of the shoreline as cliffs recede or as beach and dune systems "migrate." In some places dunes and salt marshes may disappear altogether, while in other places new depositional features may appear. Landward movement of the shoreline often poses a problem for human activities by threatening roads, buildings, and other coastal infrastructure related to fishing, agriculture, and transportation. It may also result in a change in coastal habitat. Similarly, deposition and the seaward movement of the shoreline may cause its own series of challenges for human activities, as well as changes to the natural habitat. The recession of the shoreline caused by both coastal erosion and sea level rise can be measured through use of historical maps, aerial photography, and other technology.

Climate change is expected to result in a rise in sea level and a reduction in sea ice, which will likely increase the rates of erosion in many locations along our coasts. Different coastlines, however, will be affected to varying degrees. Cliffed coasts developed in bedrock, such as granite, or cohesive glacial till, such as those found in Newfoundland and Labrador and Cape Breton, are highly resistant to erosion and will remain so despite climate change. Cliffs composed of weaker rock, such as the sandstone found along the coast of Prince Edward Island, are much less resistant and will see a greater increase in the rate of erosion. The dynamic beach and barrier systems that line many parts of the coastline in Atlantic Canada will also be affected. Rising sea levels and more intense storm activity will cause beaches and barriers to migrate, or even disappear, as sediment is carried from one area to another. Salt marshes, too, will be affected by climate change as they become inundated by rising sea levels; these areas are likely to migrate further inland as long as there is adequate space and sediment supply. While it may be difficult to know the exact rates at which sea level will rise and shorelines will erode, both rates are nevertheless certain to increase. A strategy for adaptation is both possible and necessary.

EXECUTIVE SUMMARY (cont'd)

Adaptation to such changes could take many different forms. Compared to other coastal regions of North America, the populations of Atlantic Canada are small, and erosion has therefore had a relatively limited impact on human activity in the region. Only a few large urban or industrial areas face potential threats to major economic infrastructure. Nevertheless, coastal erosion has had, and will continue to have, an impact on coastal communities in the region, and a range of adaptation options should be considered. Many coastal communities will face the decision either to protect the shoreline against erosion through engineering approaches or to retreat through use of setbacks and land use zoning. The right decision, of course, will not be the same for all communities, as no one approach will be appropriate for all coastal locations in Atlantic Canada. Local decision makers must consider the specific characteristics (shoreline type, sediment type, etc.) that are unique to their coastline, and they should always seek the advice of professional coastal engineers when considering which engineering approaches (if any) are most appropriate for their area.

Finally, coastal erosion is best viewed not so much as a problem but as a natural process to which we must adapt. The coast must be managed as a system, where the impacts of decisions and polices in one location affect other locations. Careful planning and design, built on a foundation of understanding the natural processes that shape our coasts, will lead to more successful engineering and policy responses. Many agencies from within government, academia, non-government organizations (NGOs), and the private sector are already engaging in valuable work to this end. Continued climate change will only increase the need for such research and planning as coastal communities in Atlantic Canada work hard to adapt their own local situations to changing conditions.

INTRODUCTION

What is Coastal Erosion?

What Are the Impacts of Coastal Erosion?

Coastal erosion results in the landward movement of the shoreline as cliffs recede or as beach and dune systems "migrate" (change location). In some places dunes and salt marshes may disappear altogether, while in other places new depositional features (such as beaches and spits) may appear.

It is important to recognize that coastal erosion and coastal deposition are natural processes that by themselves are neither "good" nor "bad." Both processes have long shaped the coast along with other factors such as changes in sea level, inputs from rivers, and tectonic activity (movements beneath the earth's surface). Nevertheless, landward movement of the shoreline often poses a problem for human activities by threatening roads, buildings, and other coastal infrastructure related to fishing, agriculture, and transportation. It may also result in a change in habitat (through the loss of areas of marsh, lagoon, or sand dunes, for example). Similarly, deposition and the seaward movement of the shoreline can cause a different series of challenges for human activities and changes to the natural habitat. It is important, then, to avoid labelling the processes of coastal erosion as the problem; rather, we should focus on the nature of human activities in areas where coastal erosion is taking place.

Impacts of coastal erosion in Atlantic Canada are relatively limited in comparison to many other areas of the world. The population is quite small, and only a few large urban or industrial areas have potential threats to major economic infrastructure. The extensive barrier island systems in Prince Edward Island and the Gulf of St. Lawrence coasts of New Brunswick and Nova Scotia—which are highly dynamic and sensitive to the impacts of major storms, coastal erosion, and sea level rise—are largely free of significant development. In contrast to the situation in the highly developed barriers of the east and Gulf coasts of the United States, adaptation to ongoing erosion (and the effects of sea level rise) in Atlantic Canada is relatively simple, and it should be possible to accommodate ongoing activities related to tourism, fishing, and aquaculture. Extensive sections of the Atlantic coast of Nova Scotia, including Cape Breton, and of Newfoundland and Labrador are composed of resistant bedrock that erodes too slowly to pose a threat to economic activities; this will not change with the projected rise of sea level in the next 100 to 200 years. In areas where ongoing erosion and sea level rise do pose a problem for human activities (including much of Prince Edward Island, the Gulf of St. Lawrence coasts of New Brunswick and Nova Scotia, and parts of the Bay of Fundy and Atlantic coast of Nova Scotia), coastal communities must adapt. While it may be difficult to know the exact rates at which sea level will rise and shorelines will erode, both rates are nevertheless certain to increase. A strategy for adaptation is both possible and necessary. *cont'd*

What Factors Control the Rate of Erosion?

A number of factors influence, or control, the extent to which a shoreline is eroded. These controls include exposure, sediment type, weather and climate, and tides.

Exposure

Exposure to the sea is one way in which shorelines can differ; it influences the degree of erosion that a given shoreline is likely to undergo. Exposed coasts, such as those facing the Atlantic Ocean or Gulf of St. Lawrence, are subject to large waves exceeding 2 m in height during major storms and are therefore more likely to erode. Sheltered coasts, such as those found within estuaries and lagoons where waves are less than 0.5 m in height, erode much less.

Sediment Type

There is a range of different sediment types within Atlantic Canada. Some of their differences are important to understanding coastal erosion processes.

Different sediments, or rocks, have different resistances to erosion; that is, they are more likely or less likely to erode. Coasts formed in bedrock or tightly packed material such as glacial till, for example, are highly resistant to erosion and therefore do not experience much recession. Coasts formed of loosely packed sediments such as sand (0.1–0.4 mm diameter) and gravel and cobbles (0.5–25 cm diameter) are much less resistant to erosion and are therefore much more likely to experience recession.

It is also worth noting that some erosion is permanent while other erosion is temporary. Erosion of bedrock or tightly packed material is irreversible, or permanent (for example, once material is detached from a bedrock cliff it cannot be put back again). On the other hand, beaches and dunes composed of gravel and sand often undergo erosion during storms, yet during subsequent non-storm conditions, wind and wave action may gradually deposit new gravel and sand so that the beach and dune systems are built up again. Long-term conditions of continuous loss of sediment, then, result in continuous shoreline recession, while short-term erosion–deposition cycles have a less predictable impact on the shoreline. See Appendix 1 for a more detailed description of how shorelines erode differently in Atlantic Canada.

Weather and Climate

Atlantic Canada often experiences storms associated with mid-latitude cyclones and with hurricanes, which track northeastward off the US east coast and are often extra-tropical when they reach Canadian waters (Forbes et al. 2004). These storms are the primary drivers of coastal erosion in the region.

Coastal processes are also affected by the development of shorefast ice and sea ice during the winter in the Gulf of St. Lawrence, parts of the coast of Labrador, and the upper portions of the Bay of Fundy. Ice may play a role in erosion of the platform (see Figure 1), both directly through freezing onto the bed and plucking material off, and indirectly through enhanced scour by waves against the ice foot or grounded ice. In general, however, ice erosion is much less significant than erosion by waves and is balanced by a reduction of wave erosion in the presence of sea ice in winter.

Tides

Tides influence how far wave action may reach inland. Tidal range in Atlantic Canada is generally <2.5 m, with the exception of the Bay of Fundy coasts of New Brunswick and Nova Scotia, where it ranges from 4 m to over 12 m in the Minas and Cumberland Basins.

How Is Coastal Erosion Measured?

Erosion can be measured as a mass or volume of material eroded (e.g., cubic metres per metre length of shoreline, m3/m) or as a horizontal rate of retreat (e.g., metres per year, m/yr). An average annual rate of retreat can be determined by mapping and measuring the movement of the shoreline using historical maps, aerial photographs, and other technology such as Light Detection and Ranging (LiDAR). The methodology is now well established (see Appendix 2).
It should be noted, however, that not all shoreline recession (i.e., the inland movement of the shoreline) is the result of coastal erosion. Shoreline recession may also result from relative sea level rise. As the sea level rises, the shoreline moves inland. Sea level rise can occur either because the land is sinking (caused by movements beneath the earth's surface) or because the actual level of the sea is rising (from the warming of the ocean and the melting of glaciers and ice sheets). Similar to coastal erosion, sea level rise acts to move the shoreline further inland. In the Maritime Provinces most of the coast of Nova Scotia, Prince Edward Island, and New Brunswick (except for the northeast coast of the Gulf of St. Lawrence, where uplift of the land is still occurring) is experiencing sea level rise as a result of a rising sea and a sinking earth surface. It is most significant along the low- lying shorelines of estuaries, lagoons, and coastal plains, and it especially affects barrier islands, spits, and salt marshes.

Within protected estuaries, almost all measured recession may be due to inundation by sea level rise rather than erosion. On the sandy barrier systems of the Gulf of St. Lawrence, recession reflects both the effects of sea level rise and erosion of sediment. On cliffed bedrock shorelines, almost all measured recession is from erosion, though the rate of erosion may increase as a result of relative sea level rise.

We will explore these issues of coastal erosion more fully in the following sections dealing with different shoreline types and the potential effects of climate change and sea level rise.

Shoreline and Sediment Type

Cliffs

Different types of shoreline and sediment erode at different rates. Coastal areas can be divided into several different types, which are classified in greater detail in Appendix 1. For purposes of simplification, this primer will focus on three categories of coastal systems: cliffs, beach and barrier systems, and salt marshes.

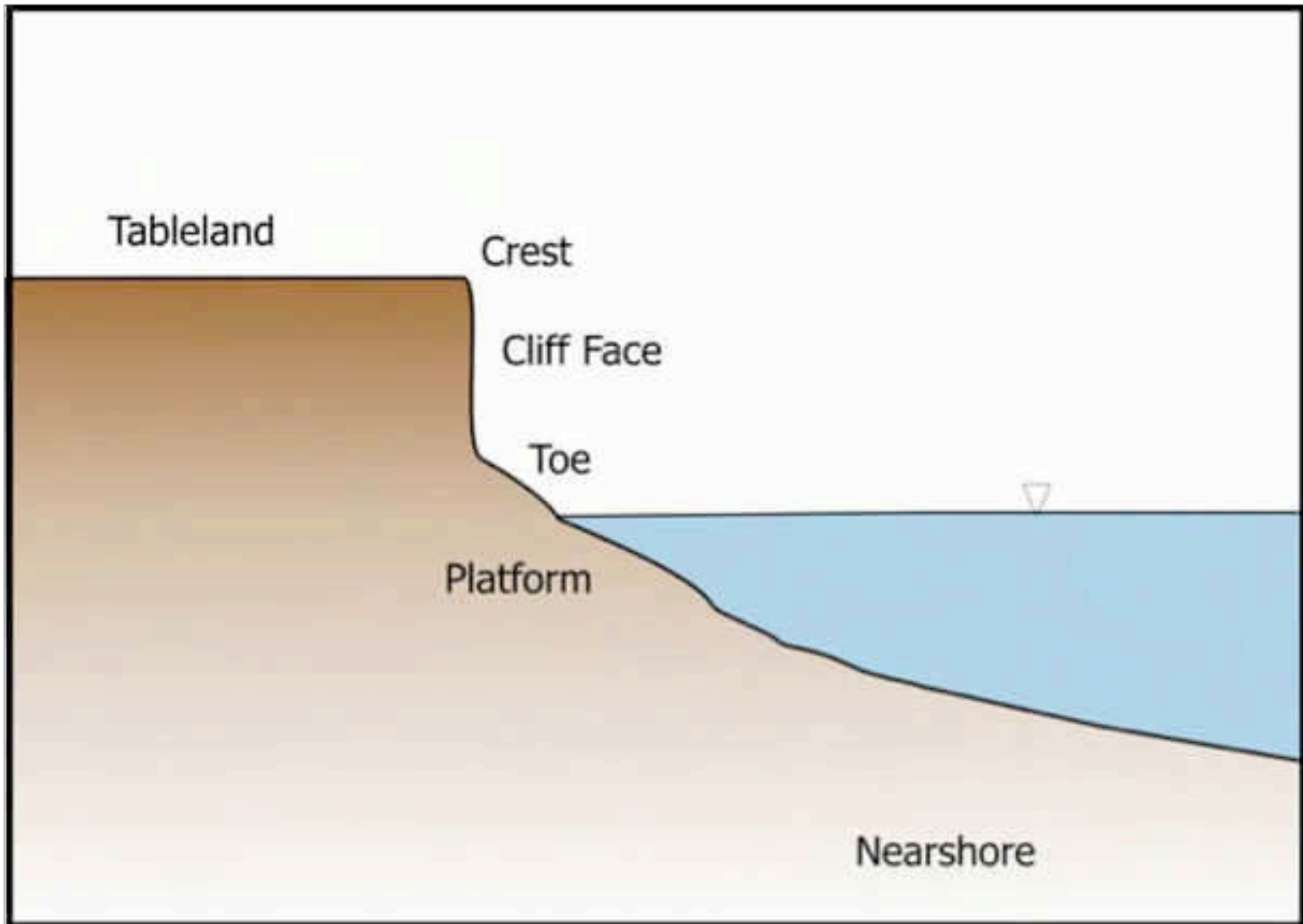


Figure 1: A cross section of a cliff coast and the major components of the profile.

Cliffs can erode in different ways, which can in turn affect the stability of the cliff in different ways. For example, a cliff can experience erosion on its cliff face (from wind, rain, surface water runoff, etc.), and it can experience erosion at the toe (usually from wave action). If the erosion of the cliff face is faster or more severe than the erosion at the toe, the cliff will start to have a gentler slope, creating more-stable conditions. But if the erosion at the toe is faster or more severe than the erosion of the cliff face, the cliff will be much steeper—and much less stable. However, while the cliff face and toe may retreat at different rates over a short period (years to a few decades), the two generally recede at an equal pace over the medium term (decades to centuries) (see Figure 2).

Shoreline and Sediment Type cont'd

Cliffs

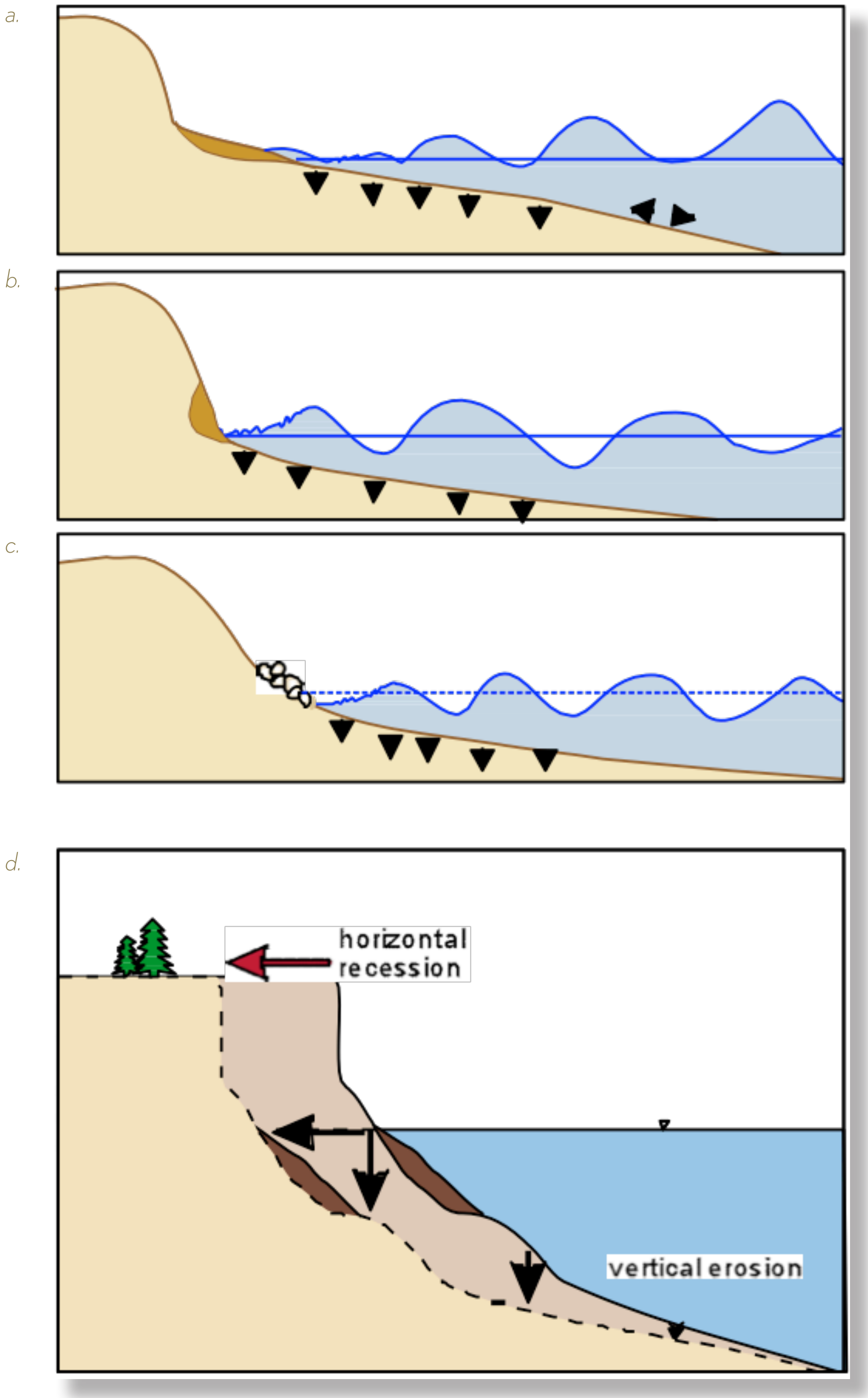


Figure 2.

Recession of the coastal cliffs: (a) erosion of the cliff face and reduced slope angle; (b) undercutting of the cliff by toe erosion leading to an increase in slope angle and slumping; (c) temporary protection of the toe by debris from the slope; (d) long-term equilibrium between horizontal recession of the cliff face and downcutting of the platform. (2d from Davidson-Arnott 2010.)

The degree of erosion experienced by a particular cliffed shoreline is also influenced by the strength of the material making up the cliff face and the platform. Strong rocks such as granite and basalt (common in Newfoundland and Labrador and Cape Breton), for example, are highly resistant to erosion, while sedimentary rocks such as sandstone and shale (common in PEI, for example) have a weak resistance.

Shoreline and Sediment Type *cont'd*

Beach and Barrier Systems

In many parts of the Maritime Provinces a considerable portion of modern beach and nearshore sediments may have been deposited by glaciers over 10,000 years ago. In general, fine sediments (silt and clay) tend to be kept in suspension under wave action (that is, they are carried by the water) and are deposited in quiet water offshore or in estuaries and lagoons. Sediments on the beach and nearshore are primarily composed of coarse material ranging in size from sand to gravel and cobbles. Beaches with large amounts of sand are usually backed by sand dunes, the sand being transported off the beach by wind action and deposited within pioneer dune plants such as marram grass. Gravel and cobble sediments are too large to be transported by wind, and thus these beaches do not have sand dunes behind the

a.

b.

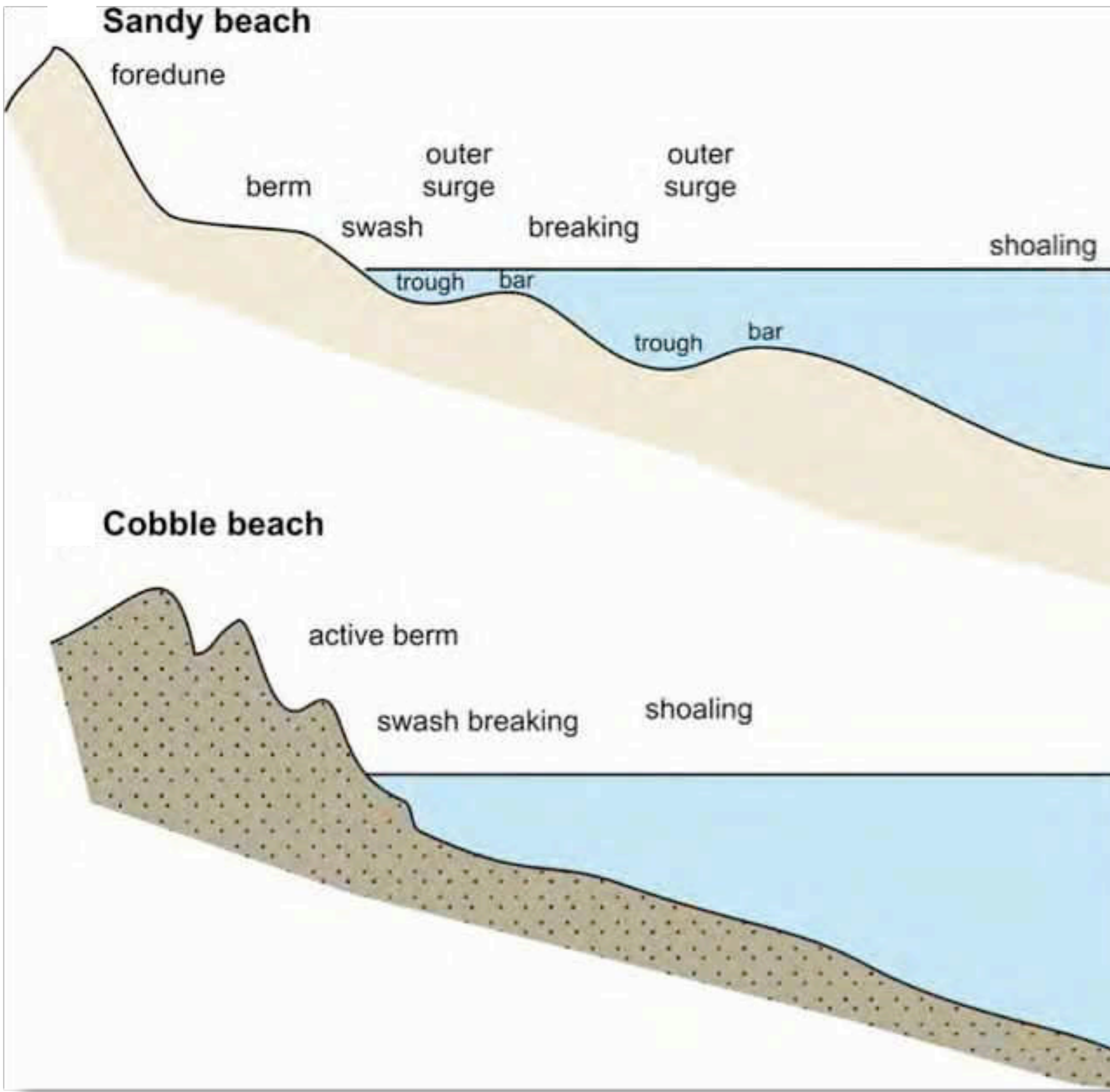


Figure 3. Schematic of beach and nearshore profile and terminology of common features for (a) a sandy beach system and (b) a cobble beach system. (From Davidson-Arnott 2010.)

Beach systems are highly dynamic; that is, they constantly have sediment eroded away while new material is deposited. Depending on the nature of the erosion and deposition taking place within a beach system, a beach may gradually appear, disappear, or migrate to a different location.

Beach and Barrier Systems

a.

b.

c.

Figure 4.

Beach types: (a) mainland sandy beach, North Shore, PEI; (b) cobble barrier, Cape Breton, NS (note the low height of the cobble barrier in the absence of a dune); (c) sandy barrier system, Miramichi, NB.

Both mainland beaches and barrier beaches undergo erosion and deposition, though they can react in different ways. For example, the beach and any associated dune deposits on mainland beaches overlie older floodplain or glacial sediments (or bedrock), and the deposits tend to grade into the land behind (see Figure 4a). Often the land behind the beach slopes upward, restricting any landward migration of the beach. Barrier beaches on the other hand are characterized by the presence of a body of water (lagoon, bay, or estuary) or extensive salt marsh that separates it from the mainland. Erosion of the barrier usually results in movement of the barrier across the lagoon or bay (see Figures 4b, c). As a result, barrier beach systems tend to change and move more than mainland beaches, often as a response to both erosion and sea level rise. Similar to mainland sandy beaches, sandy barrier beaches usually have extensive dune systems built above sea level and may be wider than gravel or cobble barriers, which cannot be built above the level of wave uprush.

Shoreline and Sediment Type cont'd

Sandy Beach Systems

Unlike bedrock cliffs, sand is loose and has no strength to resist erosion by waves. Under wave action, sand is constantly moved onshore, offshore, and alongshore. The continued existence of beaches reflects how sand that eroded at one location and point in time is replaced by a similar amount of deposition at another time. This erosion–deposition cycle is common to all sandy beach systems, although wind, waves, and exposure affect different coastlines in different ways.

Sand is carried alongshore by wave and wind action on the beach and by currents in the nearshore zone (longshore transport). The direction of transport on any day is determined by the wave direction (and also by wind direction). In many cases the amount of sand leaving the shore in one direction is more-or-less equal to the amount deposited on the shore from the other direction, so there is no effective change to the beach. In other cases there can be a substantial difference in the amounts of incoming and outgoing sand, often resulting from the type of wave action and the alignment of the coast. For example, under the influence of northerly storm waves on the northeast coast of New Brunswick, there is a net transport of sediment to the south along the whole coast from the Acadian Peninsula to Shediac. Understanding the site-specific wave dynamics is essential to local decision makers seeking to manage their coastlines. If the inputs to a coastal area are greater than the outputs, net deposition occurs and the shoreline will prograde (extend seaward).

Figure 5.
Trapping of sand behind a harbour in Richibucto Cape, NB.

If the outputs are greater than the inputs, the beach will erode, leading to recession of the shoreline. In many areas longshore transport is the largest input source, and any interruption of it leads to erosion. Erosion of sandy beach systems, then, is often associated with areas downdrift of structures, such as harbours and jetties at the entrances to inlets. These structures interrupt longshore sediment transport, leading to deposition of sediment on the updrift side of the structure, forming a filet beach, and erosion takes place on the downdrift side (see Figure 5). Destabilization of sand dunes by human activities may also lead to beach recession if the sand is blown inland beyond the limit of the normal beach/dune erosion cycle, since the sand would then be permanently lost from that localized erosion–deposition cycle.

Sandy Beach Systems cont'd

The dynamic nature of beaches can pose challenges. First, the changing phases of a beach make it difficult to determine exact rates of erosion. For example, rates of erosion are often calculated by comparing aerial photos from two different years, and then calculating the difference in shoreline location over that time period. Depending on the length of the time frame used—and whether or not the beach was in a phase of erosion or deposition at the time the photos were taken—the calculated rate of erosion could differ greatly from a rate calculated using two different years (see Figure 6).

Second, the changing phases of erosion and deposition can have an impact on nearby infrastructure. Erosion by storm waves poses a problem for any infrastructure (such as beach access, roads, buildings) close to a beach that is continually advancing and receding. Using historical records such as aerial photos, however, it can be fairly easy to determine whether or not infrastructure is located in the beach's zone of influence. Most beach–infrastructure conflicts can be addressed easily through simple land use zoning and management of the dune system.

a.

b.

c.

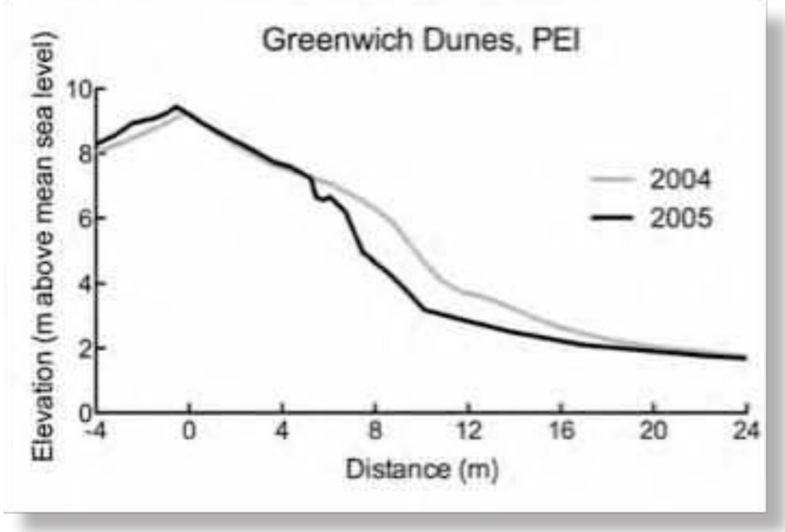


Figure 6. Dune erosion, Greenwich Dunes, PEI: (a) the beach and dune, May 2004, showing extensive sand deposits; (b) same location in 2005, following the storm of December 28, 2004, showing erosion of the dune; (c) surveyed profiles before and after the storm.

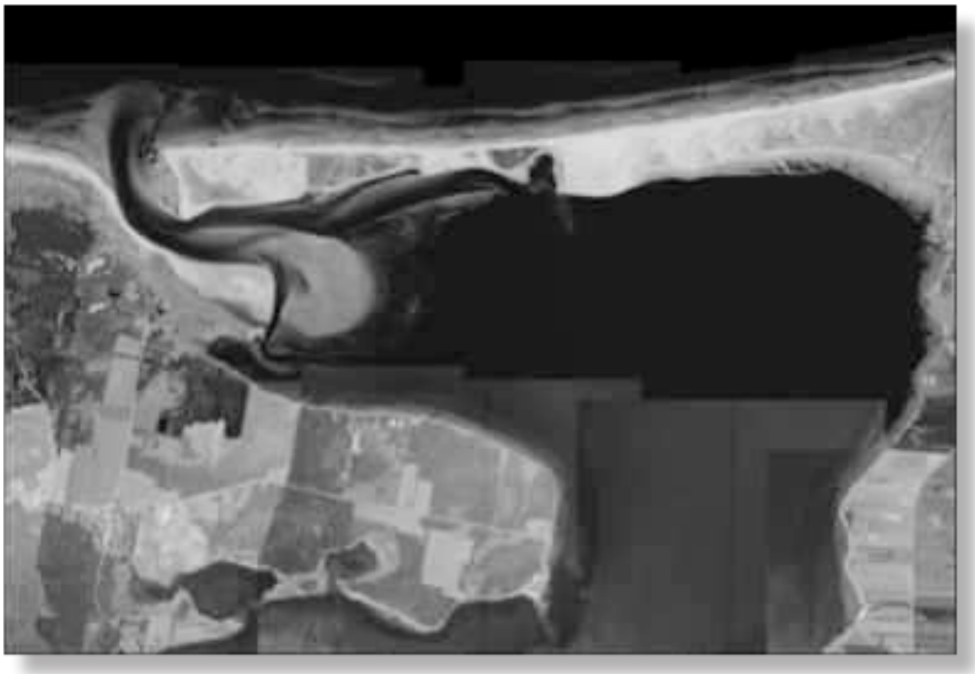
Sandy Barrier Systems

Much of the coast of Prince Edward Island, New Brunswick, and Nova Scotia within the Gulf of St. Lawrence is characterized by the presence of barrier islands and barrier spits developed on a gently sloping coastal plain (McCann 1979; Shaw et al. 1998). Smaller barrier spits and barriers built across the entrance to bays are found on the Atlantic coast of the region. As with sandy mainland coasts, erosion and recession in barrier systems are controlled largely by longshore transport.

Figure 7.
Erosion of a sandy barrier leading to destruction of the foredune and creation of washover fans, Cavendish Spit, PEI.

The presence of a lagoon or bay landward of the barrier, rather than a surface that slopes upward, results in a somewhat different response to extreme storm events and to ongoing erosion. Intense storms accompanied by storm surge and high waves can erode the foredune completely, leading to overwash, which transfers large amounts of sediment onto the lagoon side of the barrier and potentially into the lagoon itself (see Figure 7). Over time, this leads to landward migration of the whole barrier system over the backbarrier marsh and lagoon sediments. Under some circumstances, outflow of water from the lagoon during a storm can lead to the formation of a new tidal inlet (see Figure 8), which may survive for a few years or which may become the dominant inlet for a system, leading to the siltation of the pre-existing inlet. The shoreline in the vicinity of tidal inlets is generally highly dynamic, as is the updrift end of barrier spits such as the Bouctouche Spit in New Brunswick (Ollerhead and Davidson-Arnott 1995).

a.



b.

Figure 8.

Erosion at Tracadie, Bay, PEI.

(a) An orthophoto from 2002 shows how, until recently, Blooming Point nearly closed off the mouth of the bay; (b) by 2010, erosion has cut through the dunes, creating a second point of access.

PEI Department of Environment, Labour and Justice

Cobble Beaches

Beaches developed in gravel or cobbles are generally not found along the coasts of the Gulf of St. Lawrence because the bedrock breaks down quickly into sand and silt. Along the Atlantic coast of Nova Scotia, including Cape Breton, and the coasts of Newfoundland and Labrador, cobble beaches occur as a result of cliff erosion of moderate to strong bedrock that only breaks down slowly under wave action. Cobble beaches are also formed in some locations where cobbles erode out of glacial till (northeast of Halifax, for example, where the coast is formed in drumlins) (Forbes et al. 1991). Gravel and cobble beaches are steeper than sandy beaches, and their large mass compared to sand-size sediments makes them harder to transport under wave action. These beaches are therefore not as sensitive to individual storm events as sand beaches. Nevertheless, cobble beaches can erode from longshore transport. Gravel and cobble sediments are too large to be transported by wind action, so these beaches do not develop significant sand dunes landward of the beach. The beach is therefore built up only to the limit of wave action, and cobble barriers are often subject to overwash during intense storms, resulting in quite rapid landward migration in some areas (Orford et al. 2003).

Coastal Salt Marshes

Salt marshes form in the intertidal zone in areas sheltered from high wave activity, where salt-tolerant vegetation adapted to periods of submergence is able to establish (Reed et al. 2009). They are therefore found mainly within the lower estuaries of drowned river valleys and within lagoons and bays behind barrier islands and spits. Most salt marshes are areas of deposition of fine sediments (clay, silt, and some sand) as well as organic matter from the decomposition of the marsh vegetation. They therefore tend to expand inland toward the elevation of the highest tides; they may also expand laterally and seaward as vegetation becomes established on tidal sand and mud flats. Erosion of salt marshes takes place in response to shifting tidal channels in estuaries and lagoons, and also to storm wave action. In many areas erosion during the winter can result from the freezing of blocks of ice to the marsh surface and the subsequent removal of vegetation and sediments when the ice block drifts away during high tides (Dionne 2000). Erosion in one area is often balanced by new salt marsh development and accretion in another part of the system. In parts of the Bay of Fundy, salt marshes may undergo cycles of erosion followed by outward expansion and vertical growth (Ollerhead et al. 2005; van Proosdij et al. 2006).

CLIMATE CHANGE AND POSSIBLE FUTURE IMPACTS

Climate change in Atlantic Canada will likely lead to changes in the rate at which some of the weathering processes operate. The impact of these potential changes on coastal erosion rates, however, is likely small and should be easily accommodated within planning for uncertainties in future recession rates.

Climate Change and Cliffed Shorelines

From the perspective of planning and adaptation to cliff erosion, the best predictor of future recession rate is measured recession over a period of a few decades or more (that is, a time span that is readily derived from measurements using historic aerial photographs). It is useful to distinguish three cliff types on the basis of their resistance to coastal erosion, as shown in Table 1 (Sunamura 2004; Davidson-Arnott 2010).

Table 1. Cliff Types in Atlantic Canada

Cliff Type	Rock Types	Erosion Rate	Locations in Atlantic Canada
Resistant	Granite; thickly-bedded limestone	<0.5 cm/yr	Newfoundland and Labrador; some locations in Cape Breton and along Atlantic coast of Nova Scotia
Moderately resistant	Thinly-bedded limestone; well-cemented sandstone; some metamorphic rocks	0.5 cm/yr to 5 cm/yr	Exposed coasts of Newfoundland and Labrador; Atlantic coast of Nova Scotia; some areas in the Bay of Fundy
Weak	Rock developed in till and other glacial sediments; poorly-cemented sandstone and shale	>5 cm/yr	Exposed coasts in Gulf of St. Lawrence, including PEI, New Brunswick, and much of Nova Scotia; some parts of Bay of Fundy

Resistant cliffs are found primarily in Newfoundland and Labrador and at a few locations in Cape Breton and along the Atlantic coast of Nova Scotia (See Figure 9a). Erosion of these cliffs occurs too slowly for recession to be a concern for planning and adaptation purposes, and erosion is unlikely to increase under future sea level rise scenarios. In these areas, therefore, it is necessary only to address issues of cliff stability and to set back buildings and infrastructure appropriately.

Moderately resistant cliffs occur on exposed coasts in some parts of Newfoundland and Labrador, the Atlantic coast of Nova Scotia, and a few areas in the Bay of Fundy (see Figure 9b). They are also found where cliffs develop in relatively weak material such as sandstone and glacial till. They also exist in sheltered bays and estuaries, where wave energy is sufficiently low that cliff erosion takes place much more slowly than similar cliffs on an exposed coast. Examples are found especially in sandstone and shale cliffs along the estuaries and lagoons of Prince Edward Island, Nova Scotia, and New Brunswick.

Weak cliffs are developed primarily in sedimentary rocks, such as sandstone and shale, and in glacial sediments, including till (Figures 9c, 10). They are found extensively along exposed coasts of all three Maritime Provinces in the Gulf of St. Lawrence and in similar rock formations exposed along much of the Bay of Fundy (Trenhaile et al. 1998). Weak cliffs are also formed by erosion of till in drumlins along the Atlantic coast of Nova Scotia north of Halifax (Forbes et al. 1991) and in other locations such as McNabs Island in Halifax harbour (Manson 2002) and Cape Jourimain, New Brunswick.

Climate Change and Cliffed Shorelines cont'd

a.

b.

c.

Figure 9.

Examples of coastal cliffs in the Atlantic provinces:

(a) resistant cliffs, Cape Breton, NS;

(b) moderately resistant cliffs, Five Islands, Bay of Fundy, NS;

(c) weak cliffs in sandstone, PEI.

Climate Change and Cliffed Shorelines cont'd

Where cliffs occur in estuaries and lagoons, wave energy may be so low that even those formed in till, shale, and sandstone recede at rates that generally put them in the moderately resistant category. In these areas shoreline recession from inundation by rising sea level may be at least as significant as cliff erosion. Caution should be exercised in sheltered areas protected by barrier systems in the event that the barrier itself is destroyed, thus exposing the cliffs to much higher waves from the open sea.

Figure 10. Weathering and erosion of till in coastal cliffs, Storey Head, NS.

Sea level rise over the next century or more may lead to an increase in the recession rate for weak cliffs because deeper water over the platform close to the cliff toe will permit more wave energy to reach the cliff toe (Dickson et al. 2007; Walkden and Dickson 2008). Modelling of these effects for cohesive clay coasts by Trenhaile (2010) suggests that this will occur for most weak coasts but that the effect will be modest. Global warming could also increase wave energy through reduced sea ice and shorefast ice in the winter, and potentially through increased storm intensity and frequency (Shaw et al. 1998). However, these increases are difficult to predict and are likely to be comparatively small, perhaps on the order of 5–30 per cent. The effects of sea level rise will be negligible for cliff coasts that are moderately resistant and irrelevant for those that are resistant. A map of the varying coastal sensitivity to sea level rise in Atlantic Canada is shown in Figure 11.

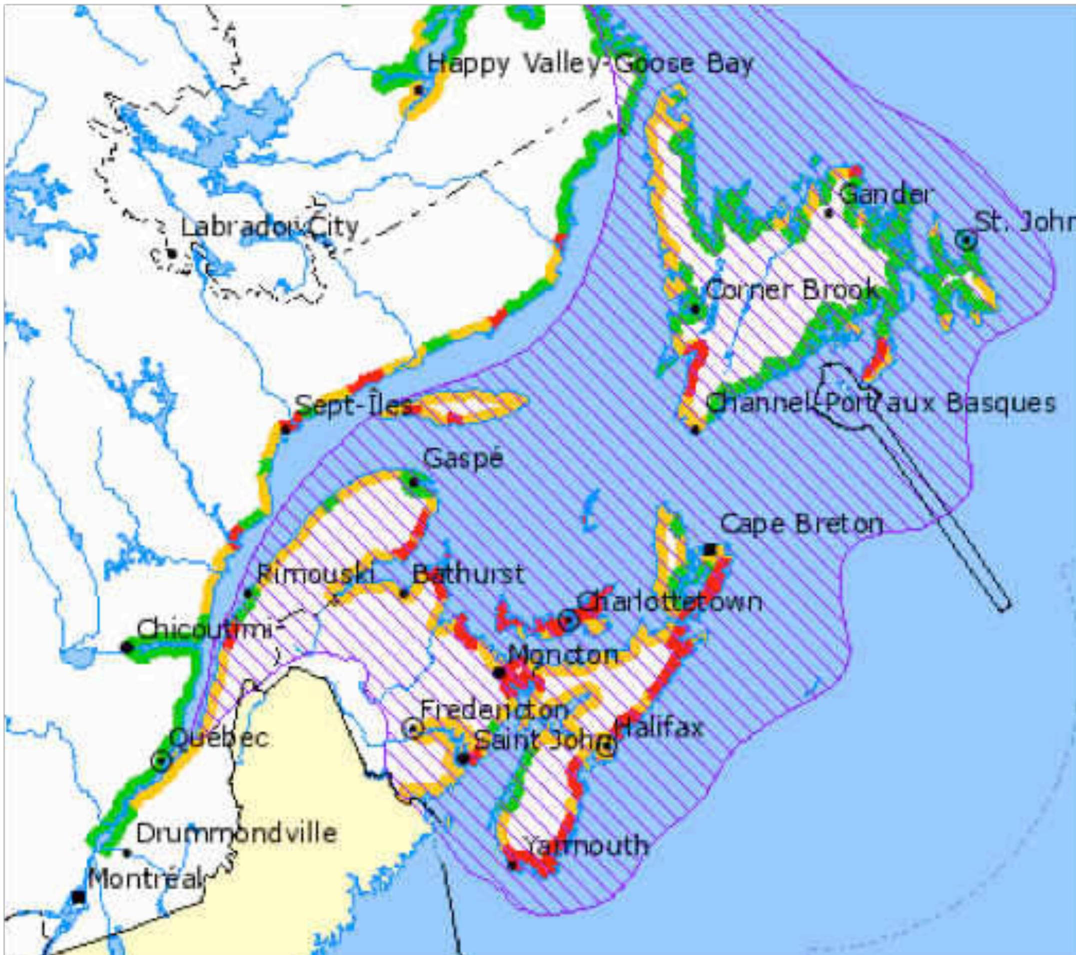


Figure 11. Sensitivity of Atlantic Canadian coastal areas to sea level rise. The areas in red are classified as the most sensitive to sea level rise. Sensitivity here is defined as the degree to which a coastline may experience physical changes such as flooding, erosion, beach migration, and coastal dune destabilization. It is measured by a sensitivity index, which is a modified version of the coastal vulnerability index of Gornitz (1990). (Source: Shaw et al. 1998.)

Climate Change and Beach Systems

As sea level rises, so too will the elevation at which wave processes operate. In particular, the elevation of wave attack during intense storms will rise, and as a consequence, the erosion of sand dunes and overwash of sand and cobble barriers will become more frequent. The shoreline will then recede and increase in elevation so that it maintains an equilibrium determined by the wave climate and sea level.

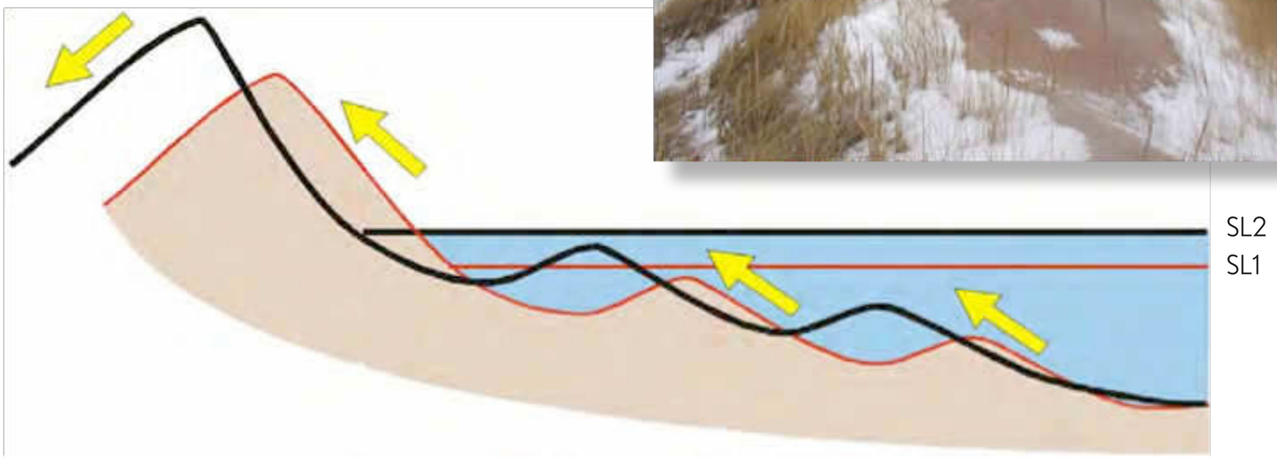
On mainland sand and cobble beaches, prediction of recession caused by sea level rise has until recently been based on the so-called Bruun Rule (Bruun 1962, 1988; Schwartz 1967), which predicts large transfers of sediment offshore. The concepts on which the Bruun Rule is based have been shown to be applicable in only a few cases (Dean and Mauremeyer 1983; Davidson-Arnott, 2005; Cooper and Pilkey 2004). However, horizontal recession owing to sea level rise on mainland sand and cobble beaches is likely to be similar to that predicted by the Bruun Rule and is on the order of 50 times the vertical rise in sea level (that is, 1 m of sea level rise = 50 m of horizontal recession).

Not all erosion, however, will result in the transfer of sediment offshore. In the Maritimes, coastal erosion and recession of sandy mainland and barrier systems in response to sea level rise have been accompanied by the landward transfer of sediments through inland migration of dunes (see Figure 7) and the landward migration of barriers across lagoons through overwash and migration of the foredune (see Figure 12a), as predicted by the models of Dean and Mauremeyer (1983) for barrier coasts and Davidson-Arnott (2005) for mainland dune systems (see Figure 12b). A critical principle of management of these coasts is to permit, wherever possible, this process of landward movement to continue so that the beach and dune (and barrier) systems are preserved through time though their position changes (Reed et al. 2009). In effect this means managing human activities so as to provide the accommodation space on land for the transfer of sediments.

Figure 12. Response of sandy beaches to sea level rise: (a) deposition of sand on lee slope of foredune leading to landward migration, Greenwich Dunes, PEI; (b) schematic model of the response to sea level rise of a sandy beach and dune system, where red is before and black is after sea level rise (after Davidson-Arnott 2005).

a.

b.



Climate Change and Salt Marshes

If sea level remains constant for some time, large portions of the marsh surface reach an elevation close to the highest tides, and they become stable. However, with ongoing sea level rise the marsh surface becomes flooded more frequently. This continued submergence may promote loss of plant life and erosion of the marsh unless there is enough sediment supply to keep pace with the rate of sea level rise (Temmerman et al. 2004; Reed 1995). In the upper basins of the Bay of Fundy, accretion rates are likely high enough to counteract sea level rise in many areas. However, sea level rise promotes flooding of areas that were previously above the intertidal zone, and these are prime areas for colonization by marsh vegetation such as Spartina patens and Spartina alterniflora. This promotes expansion of the marsh surface inland and thus preserves the existence of the marsh system in the face of erosion at the coast. The major problem posed by salt marsh erosion from sea level rise comes from hardening of the shore landward of the marsh through the construction of dykes and sea walls to protect agricultural areas, roads, and buildings. This restriction of the potential for inland migration of salt marshes is termed coastal squeeze (Pethick 2001; Doody 2004).

CLIMATE CHANGE ADAPTATION

Adapting to Erosion of Cliffs

For people living, working, or simply travelling in a zone close to the cliff-top margin, coastal cliff recession poses a problem of safety in the event of a sudden failure. Cliff erosion can also result in economic losses through erosion of agricultural land and damage to roads, buildings, and other infrastructure. Two components of the problem should be addressed:

1. The stability of the cliff face, which may result in recession of the cliff top through sudden failures, such as landslides, or more gradual retreat through erosion by water flowing over the cliff face. This may be significant on cliffs that are more than a few metres high and can occur even though there is no ongoing toe erosion.

2. Recession of the cliff related to ongoing toe erosion. Adaptation to the expected recession distance over the planning horizon (taken here as 100 years) is necessary as well as adjustment to the problems posed by slope instability.

Both of these components of the problem can be addressed by either implementing a suitable setback from the cliff top through land use zoning or attempting to mitigate the hazard itself through protective engineering works.
The criterion used in this paper to distinguish coastal cliff resistance to erosion is based on the recession rate rather than any intrinsic properties of strength. This is a practical approach to defining strategies for adaptive management. In effect, where coastal erosion is less than 5 cm per year (cliffs fall into the resistant and moderately resistant classes), the likely recession over a planning horizon of 100 years is <5 m, and thus adaptation can focus primarily on measures designed to address issues of slope stability. On weak cliffs, significant cliff recession can be expected over a planning horizon of 100 years.

It is worth noting here that projections of cliff recession—or, for that matter, recession of any type of shoreline—are often based on a fixed, historical erosion rate. In order to account for increasing rates of erosion, then, a prudent planner would want to assume a future erosion rate as much as 1.5 to 2 times higher than it has been over the past 50 years.

Setbacks and Land Use Zoning

In almost all cases the simplest and least expensive approach to adapting to problems posed by coastal cliff stability and erosion is to implement a setback for all new building and infrastructure construction so that it is outside a zone defined by the combination of slope stability and the average annual recession rate for a time period defined by the planning horizon (Kolberg 1995). The setback for slope stability can be defined generically to accommodate almost all scenarios (for example, assume a stable slope of 1:3 so that the horizontal setback at the cliff top is 3 times the height of the cliff above the cliff toe). In many areas the cliff material may be strong enough to reduce the factor of safety, and thus the setback required. However, this can only be determined case-by-case and might require a detailed engineering study at considerable expense.

In the absence of toe erosion, the setback for slope stability can be fixed on a land use zoning map once it is deter determined. Where existing structures fall within or close to the setback zone for slope stability, engineering measures can be taken to enhance stability through, for example, diversion of water away from the cliff face, terracing, and the construction of various structures designed to hold the slope in place. These can be quite costly and are best carried out only where there is no significant ongoing toe erosion; otherwise, undercutting of the toe will lead to a steeper slope and rapid failure of these measures.

Where significant toe erosion is taking place, the setback must include allowance for the likely recession rate in addition to the amount for slope stability. The recession rate can be established from historic aerial photographs and may be based on an analysis of recession of the cliff toe as well as the top of cliff. Because recession of the cliff top especially is often highly variable over short periods of time and short distances along the cliff (Brooks and Spencer 2010), it is desirable to improve the accuracy by determining the recession over several intervals of time and averaging the rate obtained at points spaced for some distance along the crest.

Cliff recession is an ongoing process, and it is therefore unrealistic to define a setback by a fixed line on a map, since it would have to be adjusted frequently. One way around this is to require that the setback be determined at the time an application is made for development; this is the approach taken in management of cliff recession in the Ontario Great Lakes (Kolberg 1995; McKeen 1995). It may be prudent to incorporate an additional setback equal to about 30 per cent of the historical rate for a couple of reasons: uncertainty in the predicted recession rate arising from the precision and accuracy of mapping techniques, and uncertainty about the effects of sea level rise and climate change. This is much easier to do than attempting to reduce the errors and uncertainty in the calculated value.

Engineering Approaches

Where there is existing development within the hazard zone defined by the factor of safety and any cliff recession, or where there is a need or advantage to place new construction within this zone, it is necessary to consider methods to increase slope stability and reduce or eliminate toe erosion. Proper studies must be carried out to address the nature of the problem, the practical approaches to be considered, and the economic benefit/cost ratio (which should incorporate consideration of any environmental impacts on the adjacent unprotected coast). There is an extensive literature on slope stability and methods for addressing it.

A key element of any attempt to use shore protection structures to combat toe erosion of cliffed coasts is that such structures must be designed by, and the construction supervised by, a qualified coastal engineer. It should also be recognized that structures designed to prevent erosion on a weak coast over a time horizon of 50–100 years are of necessity expensive to build and require funding for periodic maintenance and upgrading. It is an unfortunate fact that, with the exception of some large government-initiated schemes, most shore protection in Atlantic Canada (and indeed throughout the rest of Canada) is not designed or supervised by qualified coastal engineers. Many projects are built by construction or landscaping firms without having been properly designed. As a result, most of these structures are ineffective; they fail within a short time period, and they may produce adverse impacts on the adjacent coast (see Figure 13a).

a.

b.

Figure 13.

Structural approaches to managing cliff erosion: (a) Material dumped at top of beach to provide toe protection. Non-standard materials and absence of engineering design result in protection that is largely ineffective and that remains in place for only a short period.
(b) Properly designed and constructed armourstone revetment on an eroding till bluff. With proper maintenance this can provide protection for 75-100 years.

Engineering Approaches cont'd

Erosion of soft coasts takes place not only at the cliff toe but also on the shore platform. This is an important consideration for the design of toe protection because erosion of the platform can lead to undermining the toe of the protective structure, thus threatening its integrity. Platform erosion also permits greater wave energy to reach the structure over time. This erosion requires that the structures be engineered to tolerate some movement and to incorporate toe protection out to a greater distance. In most of the Atlantic provinces, ongoing sea level rise also means that the crest elevation must be designed to prevent overtopping under conditions where sea level may be 0.5 m or more higher near the end of the design life than when the structure is put in place. Experience in the Great Lakes with protection of eroding glacial till bluffs indicates that vertical seawalls in concrete or similar material fail rapidly because of undercutting of the toe, which is promoted by wave reflection from the vertical face. The most robust structure is an armourstone revetment (Figure 13b). The large armourstone blocks are heavy enough and interlock sufficiently well to maintain stability under large wave attack, while the sloping face and high permeability promote efficient absorption of wave energy and minimize reflection and scour. Unfortunately, armourstone is expensive, and many of the vulnerable areas in Atlantic Canada (such as Prince Edward Island and the coast of northeast New Brunswick) are distant from a source of armourstone, thus making construction even more expensive.

Note that protecting one portion of an eroding weak cliff coast can generate problems that may increase the vulnerability of the protective structure. Ongoing erosion of the adjacent portions of the coast leads to exposure of the structure to wave attack from the side (flanking). In some cases the presence of the protective structure may result in an increase in cliff erosion in the stretch of coast on either side. It is therefore prudent to examine potential environmental impacts of any structure as part of the overall consideration of benefits and cost.

Finally, protecting a cliff coast from erosion may also have the unintended consequence of depriving some other part of the coastal system of sediment, which can result in greater erosion in the sediment-starved areas.

Adapting to Erosion of Sandy and Cobble Beaches

As is the case for cliffed coasts, erosion and shoreline recession on sand and cobble beach and dune systems can have a negative economic impact on any infrastructure located landward of the beach. In the Atlantic provinces the most common impacts are on infrastructure associated with recreation and tourism; this includes seasonal cottages and permanent housing located close to the beach, businesses such as restaurants and others geared to recreation, and facilities associated with municipal, provincial, and federal parks. Recession may have an impact on the many small-craft harbours along the coast, especially on infrastructure such as jetties and seawalls constructed at inlet entrances. Finally, recession of these coasts can threaten roads and services such as electricity, water, and sewage. Recession of barrier systems may also be so fast as to pose a threat to aquaculture activities. The preferred course for adaptation to erosion of sand and cobble coasts is again through implementing setbacks that prevent exposure to the threat posed by recession of these coasts within the relevant planning horizon (time period—currently 60 years in PEI, for example). There is a wide range of available engineered structural and non-structural (beach nourishment, for example) approaches to reducing or halting recession, but again, successful measures are usually very costly. Because of the rapid response of these coasts to any change in sediment supply or changes to wave energy and coastal currents, even greater caution should be exercised in taking this approach. Before implementing a major project, an assessment of all possible environmental impacts on the adjacent coast is essential.

Setbacks and Land Use Zoning

Because of the cycle of beach (and dune) erosion during storms and restoration during non-storm periods, setbacks to locate infrastructure outside the hazard zone should incorporate the likely maximum extent of storm surge plus an allowance for wave erosion. At any point on the coast this will be influenced by the wind and wave climate, the slope of the beach and nearshore zone, the potential storm surge, and the tidal range, especially during spring tides. This hazard zone may be only 20–30 m from the top of the beach for mainland cobble beaches, but it is likely to be >50 m for many sandy beaches on exposed coasts.

On sandy beaches backed by foredunes it is preferable to set housing and roads landward of the lee slope of the foredune rather than on the dune, where the foundations may be undermined by dune erosion during a storm. This is also desirable because of the likelihood of severe environmental impact on the dune plant communities in the foredune. On barrier systems, the potential for complete overwash of the barrier means that in most instances no buildings should be permitted, and roads and recreational facilities should be designed with the likelihood that they will be subject to overwash at some time. Long-term planning should incorporate the need to remove the roads from the barriers altogether on all coasts where there is relative sea level rise.

Where there is ongoing erosion because of sea level rise or a negative littoral sediment budget, the setback should incorporate the historical average annual recession rate. As noted earlier, this is more difficult to determine on sandy coasts than on cliff coasts because it is harder to define the shoreline exactly, especially because of the variation arising from the erosion and deposition cycle.

Engineering Approaches

There is a wide variety of approaches to reducing the impact of erosion on sand and cobble beaches, including many that involve engineered structural solutions. On sandy beach and dune systems, proper dune management—through protection of dune vegetation from trampling and the impact of recreational vehicles—is important for maintaining the structural integrity of the foredune and preventing excessive loss of sand inland. This is a key to maintaining systems where there is no long-term recession and for reducing the potential for catastrophic erosion on those where long-term erosion occurs.

Where it is desirable to maintain a sand or gravel beach in place, nourishment is increasingly being used as an alternative to structural solutions (Dean 2003). In part, this method is favoured in areas where the beach itself is economically important, usually as a recreational resource; many structural solutions have adverse environmental impacts and may prevent shoreline recession only at the expense of maintaining the beach. The volume of sand required for nourishment is often on the order of tens to hundreds of thousands of cubic metres, depending on the length of shoreline to be replenished and the rate of erosion. A major consideration, therefore, is where to obtain the sand, how to transport it to the site, and whether there are any adverse environmental impacts to the source area or the replenishment site. A second consideration is that in most instances, the nourished area continues to lose sediment, so there must be a long-term commitment to continue the process—with all the additional costs involved. In some instances, such as where sediment is being lost to a sink such as a spit or bay in the immediate vicinity, it is possible simply to recycle sediments at a relatively low cost. An example of this is beach nourishment at Parlee Beach in Shediac, NB (see Figure 14). In the Atlantic provinces the economic costs of nourishment on a large scale (such as has been applied to many beaches along the US east coast) are not economically feasible, but small-scale projects like that at Parlee Beach may be justifiable in some locations.

Engineering Approaches

Figure 14.
Beach nourishment at Parlee Beach, NB. This is a relatively simple operation using earthmoving equipment and recycling sediment transported from the beach into Shediac Bay by longshore currents.

Structural approaches to reducing or eliminating erosion of sand and cobble beaches can be grouped into two major classes:

1. Those designed to provide a physical barrier that protects the coast behind from wave attack.
2. Those designed to reduce sediment transport alongshore or offshore and thus to trap sediment and build the beach.

The first group includes seawalls and revetments built in concrete, wood, or steel at the back of the beach. They may be vertical or sloping and may be constructed to be impermeable or, in the case of armourstone, to absorb wave energy and reduce wave reflection. A properly designed seawall placed as far back from the active beach as possible can provide protection against storm surge and large waves. It is best used in circumstances where an existing facility cannot be relocated immediately or where a new structure has to be built within the hazard zone.

On an eroding coast or where there is relative sea level rise, such structures become difficult to justify. Even with sloping revetments, there is always some reflection, and this leads to scour in front of the structure, thus requiring very robust toe protection. As the beach becomes narrower due to shoreline recession, water will be at the toe of the structure under most conditions, thus leading to a loss of any recreational amenity. Over time, the structure is subject to greater wave energy and a greater potential for overtopping during storms so that more maintenance is required and eventually the structure must be abandoned. These same concerns exist for offshore detached breakwaters, which may be used to reduce wave energy at the shoreline and promote sand deposition under conditions of ongoing sea level rise.

Groynes are shore-perpendicular structures designed to trap sediment being transported alongshore, thus building a wider beach and reducing wave erosion. They work only on beaches where there is longshore sediment transport and abundant sediment supply from updrift. They should be installed only as part of a properly designed groyne field, and they must be filled properly to avoid problems of sediment starvation downdrift. Groynes are subject to failure because of erosion of the toe at the seaward end, and under conditions of severe erosion or sea level rise, the landward end of the groynes is subject to erosion as the shoreline migrates landward. Because most sandy coasts in the Atlantic provinces have a limited sediment supply and are also subject to sea level rise, there are few, if any, areas where a groyne field is likely to provide a suitable protective measure.

Adapting to Erosion of Salt Marshes

Adaptive measures to address natural erosion and erosion cycles of salt marshes in estuaries and lagoons include development setbacks, dyke reinforcement, and salt marsh restoration.

Setbacks and Land Use Zoning

The key adaptation in response to erosion of salt marshes due to sea level rise is to remove hard structures within the zone close to the shoreline where expansion of the marsh can be expected. These areas can be identified based on proximity to existing salt marshes and on the elevation and configuration of the land surface. Little else can be done short of importing sediment to build a marsh surface.

Engineering Approaches

A more significant issue is the relationship between marshes and dykes in many areas of Maritime Canada, particularly in the Bay of Fundy. Dykes cannot adapt to sea level rise except through human intervention. If the dykes are to be maintained, expensive construction projects will be required to raise and reinforce dykes in preparation for sea level rise and climate change. In areas where incurring these costs makes less sense, one option will be to remove dykes (or sections of dykes) to promote the growth of natural salt marshes. Natural salt marshes are an excellent buffer against erosion and coastal flooding. Given a sufficient sediment supply, they grow vertically with sea level and offer natural protection without the need for expensive maintenance.

Research into the restoration of salt marshes in Atlantic Canada is still relatively new, but early indications are that it can be done successfully. A number of projects have been undertaken around the Bay of Fundy over the past few years, primarily by government agencies and NGOs, and the marshes are recovering (see, for example, Bowron et al. 2009). If many marshes were restored simultaneously, sediment supply could become a limitation. Realistically, however, that level of restoration is unlikely to occur in the foreseeable future, and thus the prospects for this adaptation strategy are very good.

CURRENT PROJECTS AND KEY RESOURCES

New projects and assessments related to coastal erosion are being started all the time in Atlantic Canada. They are undertaken by a variety of agencies, institutions, and companies. Some projects are limited in scope (see, for example, the work of Ollerhead [2005] on shoreline change at Cape Jourimain, NB), while others are major undertakings (see, for example, the NB Sea Level Rise Project by Daigle et al. [2006]). Except for projects undertaken for specific clients, most of the outcomes for these projects are available in the scientific literature, either as peer-reviewed papers or as reports (some peer-reviewed and some not).

The following are key organizations:

Government Agencies Governments, both federal and provincial, are involved in assessing erosion in Atlantic Canada. The Atlantic Geoscience Centre (AGC) is part of the Geological Survey of Canada, which is part of Natural Resources Canada. Staff at AGC have led a wide variety of coastal studies in Atlantic Canada and in Canada as a whole over many years (Shaw et al. [1998], for example). AGC often partners with provincial agencies (such as natural resources departments) and the academic sector. A good example of such an effort is the recently released NB Sea Level Rise Project report (Daigle et al. 2006). Most of the literature (reports) published by government agencies is now relatively easy to find and obtain from various government websites.

Academic Institutions Faculty and students at many of Atlantic Canada's post-secondary education institutions are involved in research on coastal erosion (Memorial University, Dalhousie University, Saint Mary's University, Acadia University, Saint Francis Xavier University, Mount Allison University, Université de Moncton, University of New Brunswick, etc.), and there are some participants from other universities in Canada and the US. In some cases the studies involve other partners such as provincial agencies. Most work completed by faculty and students is published at some point in literature that can be found by searching university libraries or the Internet.

Non-Government organizations (NGOs) Some NGOs are involved in studies of coastal erosion (a large NGO like Ducks Unlimited Canada might assess erosion at one of its properties, for example). However, NGOs tend to be involved in relatively specific projects related to their own interests or properties, or they tend to be in partnership with others as part of a larger study. Most NGOs make reports of their work freely available on their web sites. Some of these reports must be read with caution, however, as they vary in quality, and interpretation of results may be biased by the particular mission of the organization publishing the report.

Consulting companies Consulting companies range from one-person operations to large multi-nationals. They tend to be involved in relatively specific projects related to their clients' interests or to be in partnership with others as part of a larger study. Reports completed by consulting companies can be hard to find, as they are in general delivered only to the client. In some cases, it may not even be apparent that a study has been done in an area (an erosion study using aerial photographs could easily be completed without anyone other than a company and its client knowing). If a given report is made available, it too should be read with caution as the interpretation of results may be biased by the particular goal(s) of the client who commissioned the report.

CURRENT PROJECTS AND KEY RESOURCES cont'd

Finally, it is worth noting that an excellent barometer of coastal research being carried out in our region (Atlantic Canada or even Canada as a whole) is abstracts from international, national, and regional conferences where coastal research is presented. Conferences of particular interest are those organized by the Coastal Zone Canada Association (CZCA) and the Canadian Coastal Conference series sponsored by the Canadian Coastal Science and Engineering Association (CCSEA). Abstracts from the most recent Coastal Zone Canada meeting held in June 2012 in Rimouski, Quebec, are available online (http://www.czc2012-zcc2012.org). These abstracts provide an overview of some of the work being done in Canada on coastal erosion and other related topics by individuals and institutions in universities, government agencies, and consulting companies. Researchers often present their work at conferences before it appears in published literature in order to both test ideas and get key results out to various "communities" relatively quickly.

SUMMARY

Erosion is a natural process that acts, to varying degrees, in all coastal environments. It is neither "good" nor "bad." Erosion is part of a larger coastal system whereby sediment is removed from one place and subsequently deposited at another location within the system. Put another way, stopping or slowing erosion in one location may reduce the supply of sand to a beach or barrier spit downdrift, thus causing that system to begin eroding.

In the coastal zone, it is primarily waves that erode the coast. Water currents, including tidal currents and those generated by wind, are important too, especially in transporting sediment that has been set in motion by waves. On sandy beaches, winds erode sediment from the beach and transport it landward, where it is deposited to form coastal dunes. Expected climate change and sea level rise will likely increase the rates of erosion in many locations along our coasts. Over time, coastal erosion produces a recession (landward movement) of the coast, which can be seen by the movement of the shoreline at the top of the beach or at the edge of the cliff top. The average annual rate of coastal retreat can be determined by measuring the difference in the position of the shoreline mapped, for example, on aerial photographs taken 20 or 30 years apart (Appendix 2, Figure 15). The average recession rate, then, is the total distance of shoreline change divided by the number of years between the dates when the photographs were taken (Appendix 2).

Cliffed Coasts

Cliffed coasts developed in bedrock or glacial till possess a strength that has to be overcome by processes of wave erosion. The recession of rocky and till coasts is a one- way process; once material weathers and is eroded by waves at the cliff base, it cannot be put back together. Coasts developed in resistant rocks, such as granite, erode very slowly and can be considered relatively stable from a planning perspective. It is necessary only to consider a setback from the top of the cliff sufficient to avoid damage in the event of a failure of the cliff face and to ensure that any infrastructure is placed well enough back and at a sufficient elevation to avoid damage from wave run- up, spray, and ice. It is also necessary to allow for a possible rise in sea level of 0.5–1.0 metre over the next 100 years.

Many coasts in Atlantic Canada are developed in relatively weak rocks or glacial till; this is especially true for cliffed coasts in all of Prince Edward Island and the coasts of New Brunswick and Nova Scotia on the Gulf of St. Lawrence. Here, cliff recession rates almost always exceed 5 cm/yr, and in many areas they are greater than 25 cm/yr. It is possible to construct shore protection, such as seawalls and revetments to protect the toe of the cliff from wave erosion. But because of erosion of the underlying rock material, and the need to account for rising sea level in most areas, such structures will quickly be damaged and destroyed unless they are constructed using resistant materials (such as granite armourstone) and are designed by a qualified coastal engineer. These structures are very expensive to build and maintain and therefore can be used only to protect infrastructure that is very valuable or cannot be located elsewhere. In general, in these areas this method is not economically feasible for protecting private homes and cottages or extensive stretches of road. Instead, the best approach is to relocate all buildings and infrastructure behind a setback that accounts for the cliff stability and a distance determined by the average annual recession rate. Since the rate of erosion will likely increase as a result of climate change, a prudent planner would want to assume that the rate of recession for a given section of coast might be as much as 1.5 to 2 times higher than it has been in the past 50 years.

SUMMARY (cont'd)

Beaches and Barrier Systems

From a tourism perspective, some of Atlantic Canada's most important coasts include beach and barrier systems (PEI, Kouchibouguac and Gros Morne National Parks, for example). Assessing erosion in these areas is more challenging. It is the nature of these coasts to be constantly changing. Sand dunes may be eroded and "destroyed" in a storm only to form again over a few years to decades, sometimes in roughly the same location and sometimes further inland, depending on local sediment availability and sea level rise. It is even more difficult to design shore protection structures for these coasts, especially in areas where sea level rise is occurring. In addition, extreme care must be taken to avoid creating an environmental impact on nearby parts of the coast. While beach nourishment (using sand brought to the beach from offshore or alongshore) is an option, it is also very expensive, and there is potential for environmental impacts in the area from which the sediment is taken.

In these systems, the crucial factor is the balance between sediment supply, erosion potential, and sea level rise. Given adequate room to migrate inland, beaches and barrier systems will not disappear in the face of climate change and sea level rise; rather, they will be remoulded, they will move, and they may change character to some extent—but they will continue to exist. They will only be "threatened" if they have no place to migrate to or if sediment supply is cut off or greatly diminished. The best way to manage these systems, then, is to implement land use planning practices that provide them with space to migrate and to ensure that sediment supply is not significantly limited by erosion protection schemes elsewhere in the system. If we manage well, we will preserve not only these sandy beach systems for tourism and recreation but also the significant ecological environments associated with them.

Salt Marshes

Salt marshes and mudflats are composed of fine sediments and organic materials that can be eroded and then re-formed. Particularly in the Bay of Fundy, salt marshes and mudflats appear to undergo cycles of erosion and rebuilding. Given that there is limited infrastructure in most salt marsh and mudflat environments, the key management response is to allow room for these features to maintain themselves in the face of rising sea level. Coastal marshes in particular are excellent buffers against coastal erosion and sea water inundation, but they must have room to migrate landward as sea level rises or they will gradually be lost unless there is a sediment supply great enough to allow them to grow vertically in place with rising sea level.

In conclusion, coastal erosion is not so much a problem as it is a natural process that we adapt to rather than fight against. The coast must be managed as a system, where the impacts of decisions and polices in one location affect other locations. This is not to suggest that erosion control will not be needed in select locations and in specific circumstances, as it undoubtedly will. However, where erosion control is needed, it should be carefully planned and professionally designed. With careful management, built on a foundation of understanding the natural processes that shape our coasts, most of the features that we see on our coasts today will remain a part of our coastal landscape for centuries to come. These features will not necessarily be in the same locations as they are today, because with rising sea level many will have to migrate. But if we plan for this migration, the character of our coasts need not be lost, and infrastructure that will be threatened by recession of the shoreline can be moved in a planned and orderly fashion.

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APPENDIX 1

A Simple Classification of Coastal Types for the Atlantic Provinces

1. *Exposed Coasts*

1.1 Cliffed coasts (including thin, narrow fronting gravel and sand beach sediments)

1.1.1 Cliffs in bedrock

1.1.2 Cliffs in till and other soft sediments

1.2 **Mainland low plain (including banks <2 m high)**

[rare—usually fronted by sand or cobble beach and thus fall into 1.3]

1.3 Mainland beaches

1.3.1 Mainland sandy beach and dune systems

1.3.2 Mainland gravel and cobble beaches without dunes

1.4 Barrier systems

1.4.1 Sandy barrier islands and spits (including dunes and tidal inlets)

1.4.2 Gravel and cobble barriers (including tidal inlets)

2. Sheltered Coasts

2.1 **Cliffed coasts (including thin, narrow fronting gravel and sand beach sediments)**

2.1.1 Cliffs in bedrock

2.1.2 Cliffs in till and other soft sediments

2.2 Mainland low plain (including banks <2 m high)

2.3 Mainland sandy beach and dune systems

2.4 Salt marshes in estuaries and lagoons

APPENDIX 2

Shoreline Mapping and Change Rate Analysis

Rates of shoreline recession have historically been determined by tracing the shoreline on two maps surveyed at different dates. Typically, these maps have been derived from aerial photographs that have been rectified to correct for radial distortion in the photographs and possibly orthorectified to account for distortion due to topographic displacement. Until quite recently, rectification and orthorectification were carried out manually using stereo photogrammetric machines. However, in the last two decades it has become possible to use digital imagery produced from high-resolution scanning of either negatives or prints of historical aerial photographs and to carry out rectification using a software package such as PCI Geomatics' Geomatica OrthoEngine and ERDAS's IMAGINE OrthoMAX.

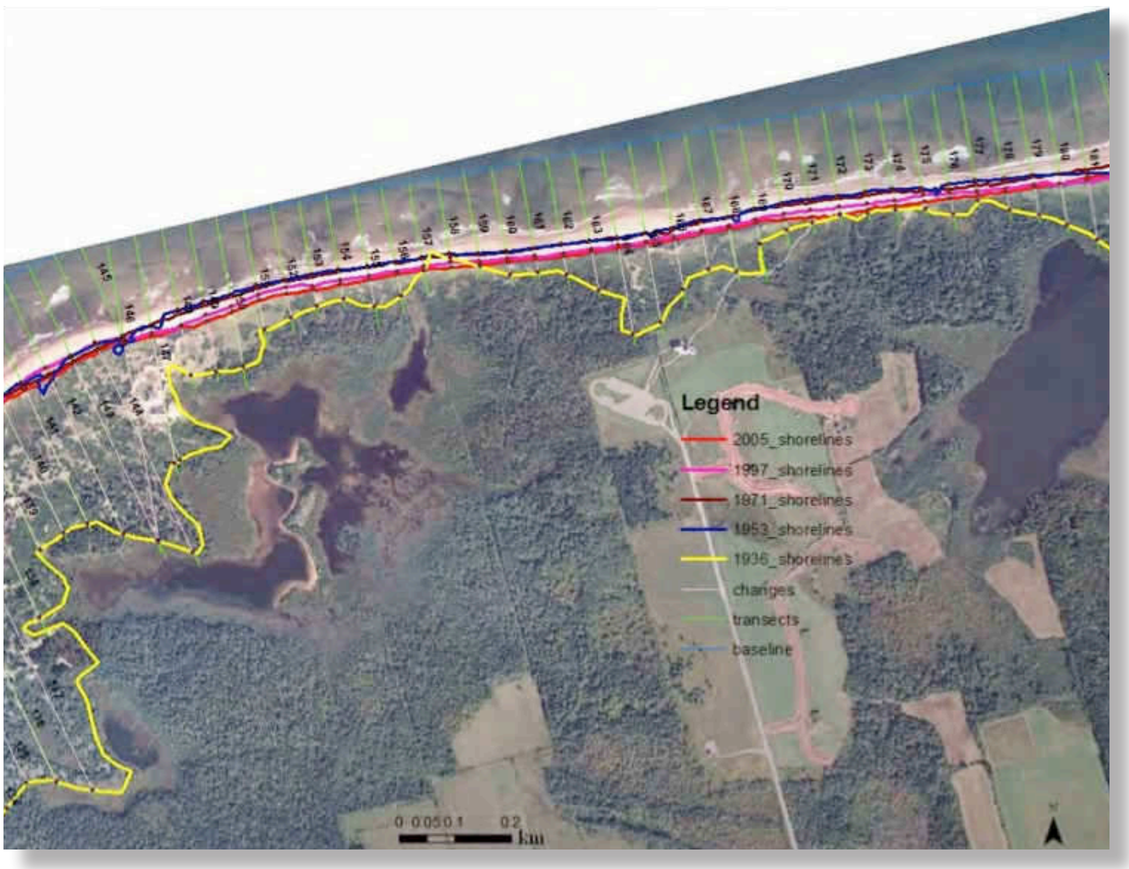

Figure 15.
Example of shoreline change mapping, Greenwich Dunes, PEI, based on historic aerial photographs. Shoreline change is measured at lines spaced at 40 m intervals. The shorelines are drawn on aerial photographs flown in 2005 (from Mathew 2007).

APPENDIX 2 cont'd

Shoreline Mapping and Change Rate Analysis cont'd

The shorelines for two different times can then be exported to a geographical information system (GIS), which allows them to be plotted on a map. The change at any point can be measured as the distance between the two shorelines along a line plotted at right angles to the local shoreline trend. In effect, this provides a vector for shoreline change, showing the direction and amount of shoreline change at that location. Dividing this distance by the number of years between the dates of the two photographs gives an annual average recession rate. Usually, this is done for points spaced at regular intervals along the shoreline, and then an average value can be obtained for each shoreline reach. There are now dedicated routines within common GIS software programs that allow automation to a considerable degree (Thieler et al. 2003). An example of this is shown in Figure 15 for a portion of the shoreline within Greenwich Dunes, Prince Edward Island National Park, using orthorectified images from 1936, 1953, 1971, 1997, and 2005 (Mathew 2007). The average recession rate along this stretch of coast between 1953 and 2005 is 0.4 metres per year.

In addition to sources of error associated with the precision with which the shoreline can be drawn, the scale of the aerial photographs, and errors associated with the rectification process, errors arise from the difficulty of defining the shoreline precisely and consistently on each set of photographs. Thus, for example, the shoreline on a sandy beach system can be defined as the observed high-tide line, the edge of vegetation, or the base of the foredune slope. Each one of these will delineate a different position, and there are difficulties associated with the mapping of each. On cliff coasts the base of the cliff slope is most often used to delineate the shoreline, but it may be obscured by slumped debris, by vegetation, or by the shadow thrown by the cliff. A good review of these issues is given in Boak and Turner (2005).