SENSITIVITY OF THE COASTS OF THE BRAS D'OR LAKES TO SEA-LEVEL RISE

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SUMMARY

Research was carried out in the Bras d'Or Lakes, Nova Scotia under the aegis of Project X-29 in NRCan's Geoscience for Ocean Management Program, with additional funding from the Climate Change Impacts and Adaptation Program,. The goal was to provide the scientific information that would help resolve management problems arising from the expected impact of accelerated sea-level rise on the coasts of the Bras d'Or Lakes. The specific objectives of the work were:

- Define the recent, present and future trends of water-level increase in the Bras d'Or Lakes. Knowing the recent (last 5000 yr) trend would allow us to understand how rising water levels triggered changes to coastal environments in the lakes. Knowing the modern trend would help us to understand coastal changes over the past 100 years. Some idea of future water levels would be a prerequisite to assessing how the modern coasts will change.

- Map the modern coastal environments.

- Assess future impacts on the range of coastal environments, particularly those environments that we suspected to be most sensitive and hence vulnerable.

- Transfer of information on coastal vulnerability to sea-level rise to stakeholders in GIS formats suitable for their systems.

The results of the work are summarized as follows:

1) The lakes were fresh until ca. 6,350 calendar years ago, when rising sea level crossed the -25 m sill and connected them with the ocean. The rate of sea-level rise at the start of inundation was 79 cm/century, and has declined throughout the past 6000 years. Coastal landforms such as spits, barrier beaches, and cuspate forelands were submerged when exposed to the high rate of relative sea-level rise. Submerged shores are visible on multibeam sonar imagery, mainly in the southern lakes, where sediment supplies were abundant. Submerged river networks occur in St. Patricks Channel and Denys Basin.

2) The trend of modern sea-level rise in the region is 36.7 cm/century. Assuming the median increase predicted by the International Panel on Climate Change (2001) (48 cm/century from 1990-2001) and assuming it is distributed equally around the globe, then sea level in the Bras d'Or Lakes will increase by 75 cm over the period 1990-2100 AD. The rate of increase will be 60 cm/century by 2030 AD, 99 cm/century by 2080 AD, and 115 cm/century by 2100 AD.

3) Total shoreline length is 1272 km, or 14.4 % of the Nova Scotian coastline (8811 km). Shorelines are grouped into eleven classes: three types of rock shore, seven types of non-rock shore (unconsolidated), and artificial shores. Coastal barriers make up 12 % of the

shoreline. 39 % of these barriers are building and established, 44 % are in the breakdown and collapse phase, 13 % are in transition, and 4 % are artificially constrained.

4) We group the shoreline types into three sensitivity classes, depending on the likelihood that changes will be triggered by sea-level rise. 18.8 % have high sensitivity, 73.9 % have moderate sensitivity, and 7.3 % have low sensitivity. The most sensitive shoreline types are unconsolidated cliffs, coastal barriers, and artificial shores.

5) Coastal barriers will continue to change in their natural cycles of growth and decay over the coming century, but at higher rates. There will be an increasing tendency for complete submergence of coastal barriers by 2030 AD, and a strong likelihood of submergence by 2045 AD. We predict accelerated unconsolidated cliff erosion and increasing effort and expense to maintain coastal defenses, particularly those on barrier beaches that would otherwise migrate or submerge.

6) The recommended response to these future changes is to allow them to take place with as little interference as possible, that is, to allow the coast to respond in a natural way as it did in the past. Having a natural coast will ultimately benefit the region more than having a coastline constrained by coastal protection structures.

INTRODUCTION

General statement

The purpose of this report is to examine the coasts of the Bras d'Or Lakes and determine their response to future changes in sea level, in particular the predicted increase in the rate of sea-level rise attributed to anthropogenic climate change and predicted by the International Panel on Climate Change (2001). This amounts to 0.48 m from 1990 to 2100 globally, based on median scenarios.

Shaw et al. (1998) examined the entire coast of Canada in an attempt to assess its sensitivity to sea-level rise. On the basis of seven factors they concluded that the coasts of the Bras d'Or Lakes had moderate sensitivity. This assessment provides a clue that there may be some aspects of the coasts to be concerned about, but is not specific enough for coastal 'managers'. In this report we take a more focused view of the Bras d'Or Lakes, and try to assess how they might respond to the anticipated water-level increase. Our approach is broadly two-fold.

- Firstly, we examine the changes that happened in the past. We demonstrate that the lakes were formerly fresh and that the coasts drowned when the lakes became connected with the ocean just before 6000 years ago, and were immediately exposed to the high rate of sea-level rise then pertaining in Atlantic Canada. We also examine the modern trend in water levels in the region and predict the future trend.

- Secondly, we report on the modern coasts, describe the processes of change that they experience under modern conditions, and assess their future in the light of the predicted acceleration of the rate of sea-level rise.

The Bras d'Or Lakes

The Bras d'Or Lakes constitute an inland sea on Cape Breton Island, Nova Scotia (Fig. 1). The lake system consists of Bras d'Or Lake in the south, which includes: West Bay, East Bay, Denys Basin, and St. Peters Inlet (Fig. 2). Barra Strait provides the connection between Bras d'Or Lake and the northern bodies of water in the system - Great Bras d'Or - that include: the Great Bras d'Or Channel, St. Andrews Channel, St. Patricks Channel, Little Bras d'Or Channel, and Whycocomagh Bay. The Bras d'Or Lakes are connected to the Atlantic Ocean at three locations: Great Bras d'Or Channel, which connects to the ocean across a least depth of about 8 m; Little Bras d'Or Channel, a 6-m-deep sinuous estuary that connects St. Andrews Channel to the sea, and at St. Peters Inlet, where boat locks on St. Peters Canal connect Bras d'Or Lake with the ocean.

The lakes are renowned for their extremely rough, choppy seas that can be generated rapidly by strong winds, funnelled along the channels by the surrounding uplands. Prevailing wind direction in summer is from the southwest and stronger winds from the north-northwest dominate the fall and winter (Parkes and Gray, 1992). Wave fetch, which is the distance over water that wind can generate waves, varies from 5 - 50 km. Wave measurements are limited to those collected by Environment Canada using a wave rider buoy in the North Basin (just north of Barra Strait) from June to December 1992 and Bras d'Or Lake from June to November 1993 (Petrie and Bugden, 2002). Wave periods were 2 to 4 seconds and the significant wave heights (average of highest one-third of the waves) were roughly twice as large in Bras d'Or Lake as in North Basin during the periods of measurement. For example, for a 20 knot wind from the SW, the median significant wave height was close to 1 m in Bras d'Or Lake and only 0.5 m in the North Basin.

Based on 30 years of sea ice data collected by the Atmospheric Environment Service, Petrie and Bugden (2002) found sea ice coverage normally begins to develop in January. It decreases rapidly in April and has generally disappeared by the first week in May. The most extensive sea ice cover is from late February to mid March south of Barra Strait, and slightly longer, until early April, north of Barra Strait. Sea ice blown by strong winds against the more exposed headlands and cuspate barrier beaches creates large grounded shore ice pile-ups in early and late winter.

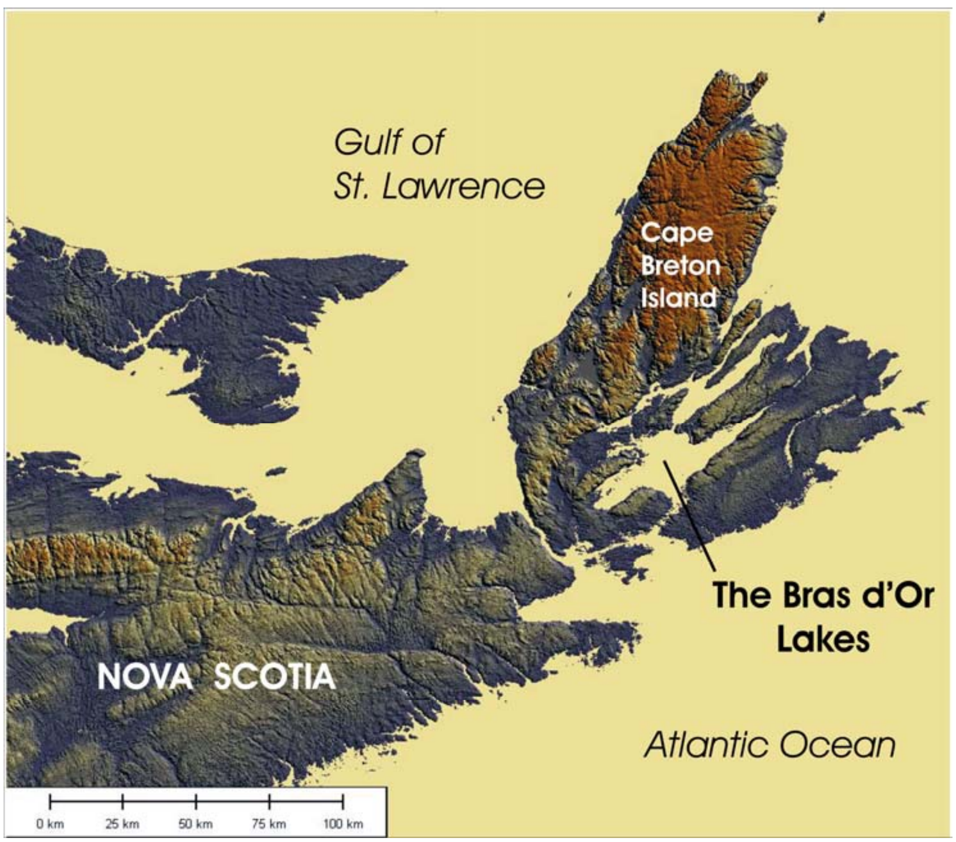


Figure 1. Location map. The Bras d'Or Lakes form an inland sea on Cape Breton Island, the easternmost part of Nova Scotia.

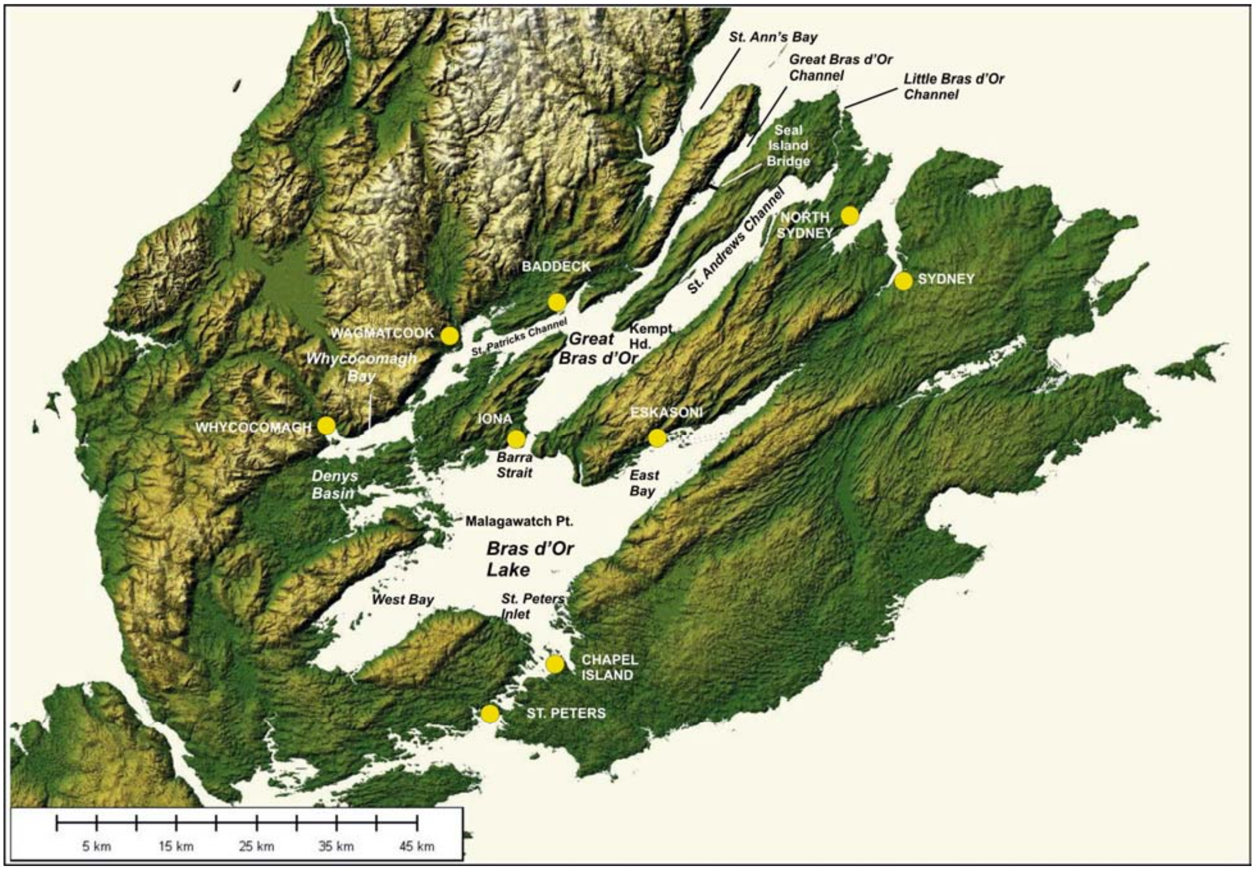


Figure 2. Locations noted in the text.

The relief and physical character of the Bras d'Or Lakes basin are the product of successive episodes of crustal uplift, erosional planation, fluvial incision, partial submergence and most recently, glacial deposition and scouring (Grant, 1994). The Lakes are carved out of younger, more easily eroded sedimentary rocks and the adjacent uplands consist of older, resistant, metamorphic and igneous rocks (Shaw et al., 2002). Grant (1988, 1994) and Stea et al. (1992) have mapped the surficial sediments of Cape Breton Island. In the Bras d'Or Lakes most of the shores are covered by till 1-50 m thick which is finer over sedimentary rock lowlands and more bouldery in crystalline rock areas. Mounds or hills of thicker glacial deposits called drumlins form the islands in West and East Bays. These drumlins are part of a much larger field of drumlins that extends across southeastern Cape Breton Island.

The physical oceanography of the lakes is described by Petrie and Bugden (2002) and is briefly summarized here. From spring to fall there is a surface flow of water out of the lakes and a subsurface flow in. Currents are weak, except in the principal connection with the ocean - Great Bras d'Or Channel - and in Barra Strait, where speeds of semi-diurnal tidal currents range up to 3 m/sec and 1 m/sec respectively. The amplitude of the M2 tide attenuates along Great Bras d'Or Channel. It is 16 cm at Big Bras d'Or (compared with 36.8 cm at North Sydney), 7.3 cm at Seal Island Bridge, 4 cm at Iona and 3 cm at Baddeck. There are non-tidal variations in sea level of up to 0.5 m in the lakes, caused by variations in atmospheric pressure. These variations in part of May 2003 are shown in Figure 3.

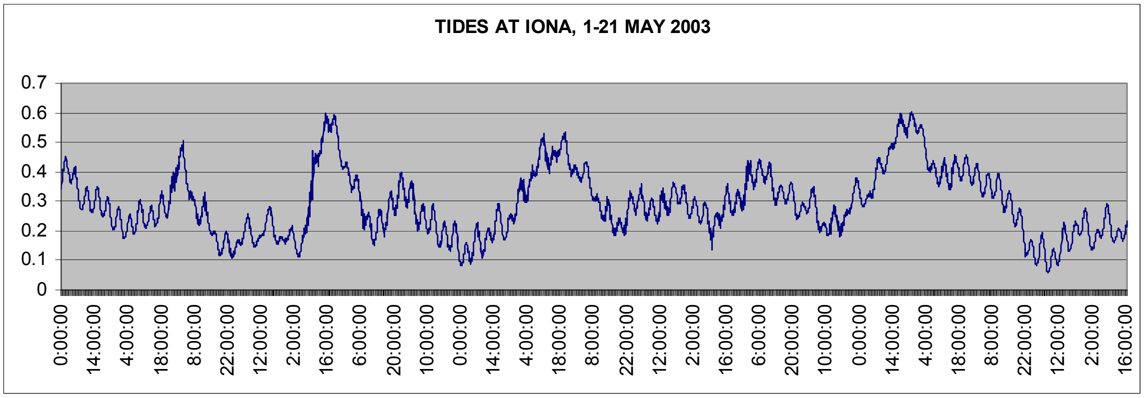


Figure 3. Tides at Iona, Grand Narrows, in May 2003, during a survey by CCGS *Matthew* (Cruise 2003-015). The vertical axis is in metres, horizontal axis in hours.

The coastline of the Bras d'Or Lakes

In an earlier mapping exercise using 1:50,000 Natural Resources Canada topographic maps, the length of the Bras d'Or lakes shoreline was estimated to be 1234 km, including 285 km of island shores (Taylor and Shaw, 2002). In the present mapping project using 1:10,000 scale maps, the total shoreline length was estimated to be 1272 km. This total also included lagoon shores of all the large coastal barriers. The Bras d'Or Lakes shores represent 14.4 % of the total length of the 8811 km of Nova Scotian coastline (Canada, 1972). Coastal topography is extremely variable in the lakes because of the complex underlying geology. Shores of 76 m or higher are found scattered throughout the lakes, as are shores less than 15 m high; however, low shores are more common in western parts of the lakes. The highest shores reach over 300 m along the uplands of Great Bras d'Or Channel. Most low shores would be vulnerable to flooding as sea level continues to rise.

The coastline is described more fully in a later section. The accompanying ARC-GIS product on this CD shows the coastline classified into eleven types - and one type comprising unmapped areas - based on aerial video surveys supplemented by ground surveys. Several important points must be made. First, coastal landforms along the lake shores are similar to their counterparts on the Atlantic coasts of the region. For example, unconsolidated landforms are composed of mixed sediment, commonly sand and gravel. However, because of limited fetch, landforms are generally lower in elevation, with maximum heights typically about half those on outer coasts. Coastal bluffs composed of till are similar in many respects to those on outer coasts, but rates of erosion - based on limited evidence - are less. Second, a group of coastal landforms is unique to the lake. These are the cuspate barrier beaches, generally triangular in shape and enclosing small lagoons. These form along the shores of elongated embayments (e.g., East Bay) where longest fetches are either up the embayment or down the embayment.

LONG-TERM SEA-LEVEL RISE IN ATLANTIC CANADA

Over the long term sea-level rise has been pervasive across most of Atlantic Canada during the Holocene, the recent 10,000 year-long period during which climate has been similar to that of today. The Halifax area relative sea-level curve (Forbes et al., 1991; Shaw et al., 1993; Stea et al., 1994; Edgecombe et al., 1999) shows that relative sea level in that region was about 45 m below the modern level ca. 10,000 radiocarbon years BP (BP = before present, where present is defined as 1950 AD). Relative sea level at Halifax rose rapidly after the start of the Holocene, and attained a maximum rate of 1.1 m/century ca. 7500 BP (Shaw et al., 1991). The rate declined thereafter, so that the average rate of increase for the last 3000 years has been ~0.2 m/century. This is important when it is realized that tide gauges in the region (see below) show rates exceeding 0.3 m/century, suggesting a recent acceleration in the rate of sea level rise. Whether or not this acceleration is a signal of sea-level rise caused by global warming, or has another cause, is discussed later.

LAKE-LEVEL CHANGES IN THE BRAS D'OR LAKES

Previous research on lake-level changes

Miller and Livingstone (1993) discussed Late-Holocene changes in sea level at Otter Harbour, near Seal Island Bridge, Great Bras d'Or. Siliceous microfossils indicated that sea level in Great Bras d'Or had risen over the previous 4000 years, reaching 1.5 m below the present level by 950 BP. The assumed rate of sea-level rise was 16 cm/century. The authors made an interesting observation that has been echoed by several other workers (e.g., Carrera and Vaníček, 1988), namely that there was a discrepancy between the long-term rate of sea-level rise and the higher rate determined from tide-gauge observations. In the Maritime Provinces, where tide-gauge rates of increase are generally 30-35 cm/century, the long-term rates, based on radiocarbon data, are commonly 10-15 cm less over the past few thousand years.

The core analyzed by Miller and Livingstone was from Captain Dix's Cove, Otter Harbour. The cove is connected to the sea by a narrow channel. At high tide, sea level is 1.5 m above the level of the sill. The maximum depth of water in the basin is 10 m. The core was 812 cm long. It is safe to assume that the top of the core was at ~-10m, and the core reached to -18.12 m. The core contained a freshwater diatom assemblage from 6.6 to 8.1 m. From 6.0 to 6.5 m was a transitional zone. Above 6.0 m marine micro-organisms dominated.

The detailed scenario envisaged by Miller and Livingstone is that at 4020 BP rising sea level caused the bottom of the cove to be flooded by fresh water. Between 4020 and 1100 BP sea level continued to rise to ~ 3 m below the sill. At 950 BP sea level at high tide rose above the sill, flooding the cove with marine water. Four bulk radiocarbon dates were reported by the authors (see Table 1).

Depth in core (m)	Weight (g)	Radiocarbon age (BP)	Calendar age (cal. BP)	Beta Lab #
1.4-1.6	13.4	910±60	510±60	37865
3.0-3.3	10.8	1260±80	780±80	37866
6.1-6.4	13.6	1520±80	1050±80	37867
7.5-7.7	23.4	3680±90	4020±90	31834

Table 1. Radiocarbon dates published by Miller and Livingstone (1993).

Important contributions to understanding sea-level changes in the lakes were based on data collected during a marine survey in 1985: cruise 85-036 (Lynch, 1995). Hillaire-Marcel (1987) described the isotopic composition of sedimentary organic carbon in core 85-036-016 and de Vernal and Jetté (1987) conducted a palynological analysis of the same core. The core was collected in East Bay and penetrated the entire thickness of Lynch's Unit 4 (postglacial mud) and was stopped by a bed of sand and gravel (clasts <1 cm). The core site is located about 5 m deeper than a nearby erosional terrace. The basal sand and gravel are interpreted as sediment swept off the erosional terrace in the littoral zone and corresponds to a strong reflection in seismic reflection profiles.

The basal metre of sediment in core 16 contained sparse marine dinoflagellates (de Vernal and Jetté, 1987) and very rare marine diatoms (Lortie, 1987). Although the sparse flora might be interpreted as reworked older material, the marine character of this interval is confirmed by isotopic analysis of organic carbon (Hillaire-Marcel, 1987). It is overlain by 1 m of sediment with mostly cold freshwater diatoms and freshwater dinoflagellate cysts. That layer is overlain by a 1.5 m thick layer containing a rich variety of marine diatoms and dinoflagellate cysts, with evidence of an upward increase in salinity and temperature. The transition between freshwater and marine diatom floras is marked by a mixed assemblage of freshwater, brackish water and marine species. No material suitable for radiocarbon dating was found in the cores.

Correlation of the pollen assemblages in Core 16 with the regional palynostratigraphy of Livingstone (1968) suggests that the basal marine interval dates from the *Picea* and *Betula* zone at 10,000 to 9,000 BP, the lacustrine interval from 9,000 BP to 4,000-5,000 BP, and the upper marine interval is younger than 4,000-5,000 BP (de Vernal and Jetté, 1987). de Vernal and Jetté (1987) stated that the penetration of 'North Atlantic water' through Great Bras d'Or Channel occurred at ca. 5000/4000 BP. Since the sill depth is 8 m today, this implied that a mean submergence rate during the Late Holocene was 16 -20 cm/century.

Shaw et al. (2002) inferred the evolution of the Bras d'Or Lakes since the retreat of the last ice sheets 15,000 years ago on the basis of (limited) multibeam bathymetry, seismic reflection profiles, and sediment cores. The thickness of stratified sediment in the lakes overlying till shows that there was a step-like retreat of ice toward a late ice centre in the western part of the Bras d'Or Lakes. As ice retreated, a lake formed in the area of the modern Bras d'Or Lakes and probably drained through Little Bras d'Or.

On the continental shelf off south-eastern Cape Breton, multibeam bathymetry imagery reveals channels incised into bedrock. These were interpreted by Shaw et al. (2002) as proglacial subaerial river channels, from which they inferred that relative sea level was at -50 m ca. 15,000 BP. Rising sea level then flooded the ancestral Bras d'Or Lakes at 10,000 to 9,000 BP and the water level supposedly rose to -15 m before falling again in the early Holocene. This falling early Holocene relative sea level resulted in the creation once again of freshwater lakes, with a prominent erosion surface at -25 m marking the lake level. These lakes were finally flooded by the sea at 4,000 to 5,000 BP. The problem with this interpretation is that it results in a very complex relative sea-level curve, unlike any other in the region.

The existence of a very early (15 ka) low sea level was postulated to accommodate D.R. Grant's observation (1994) that the channels formed sub-aerially, probably when ice had retreated to the west, and spilled meltwater across an emergent shelf. In retrospect, we believe that a more viable interpretation is that the channels were formed under glacier ice, and that, as occurs in most other areas near former ice margins, relative sea level was highest as the land emerged from below the ice cover, and fell to an early postglacial lowstand. In other words, the relative sea-level curve is the usual 'j' shape. Elsewhere in the region, sub-ice channels occur in the southern part of the Bras d'Or Lakes, and perhaps also off the north coast of Prince Edward Island (D.L. Forbes, pers. comm., 2003).

In summary, previous research shows that the lakes were initially marine, became fresh in the early Holocene, and that about 4000 to 5000 years ago they became marine again. The most recent work shows that the former lake level was 25 m below the modern level. However, this contradicts earlier work that the former sill depth of the lakes was only 8 m below modern sea level.

New research on lake-level changes

Sill depth of the lakes

The statement by de Vernal and Jetté that relative sea level rose at rates between 16 and 20 cm/century since 4000/5000 BP is based on an assumed sill depth of the Bras d'Or Lakes of 8 m. However, as noted above, Shaw et al. (2002) concluded that the lowstand in the lakes was 25 m below modern sea level. How is this possible, if the sill depth at the ocean entrance is only 8 m? The answer lies at the entrance of the lakes. Just landward of the narrows in Great Bras d'Or Channel (Fig. 4) the sea floor is shallow and sandy. Tidal flows are very strong in the narrows (Petrie and Bugden, 2002). Flood-tidal currents are strongest, and are predominately landward (to the southwest) at the seabed. Sand transported from the high, eroding coastal bluffs just outside the narrows has been deposited landward of the narrows to form an elongated flood-tidal delta. A seismic reflection profile through the delta (Fig. 5) shows that it consists of a landward-prograded prism or wedge of sand and muddy sand. The base of the flood-tidal prism lies at ~25 m below modern sea level. In other words, the true sill of the lakes is not -8 m, as suggested on the hydrographic chart, but is -25 m. This means that the rate of sea -level rise since the lakes became marine is higher than formerly believed: a water-level increase of 25 m has occurred since the mid-Holocene, not 8 m.

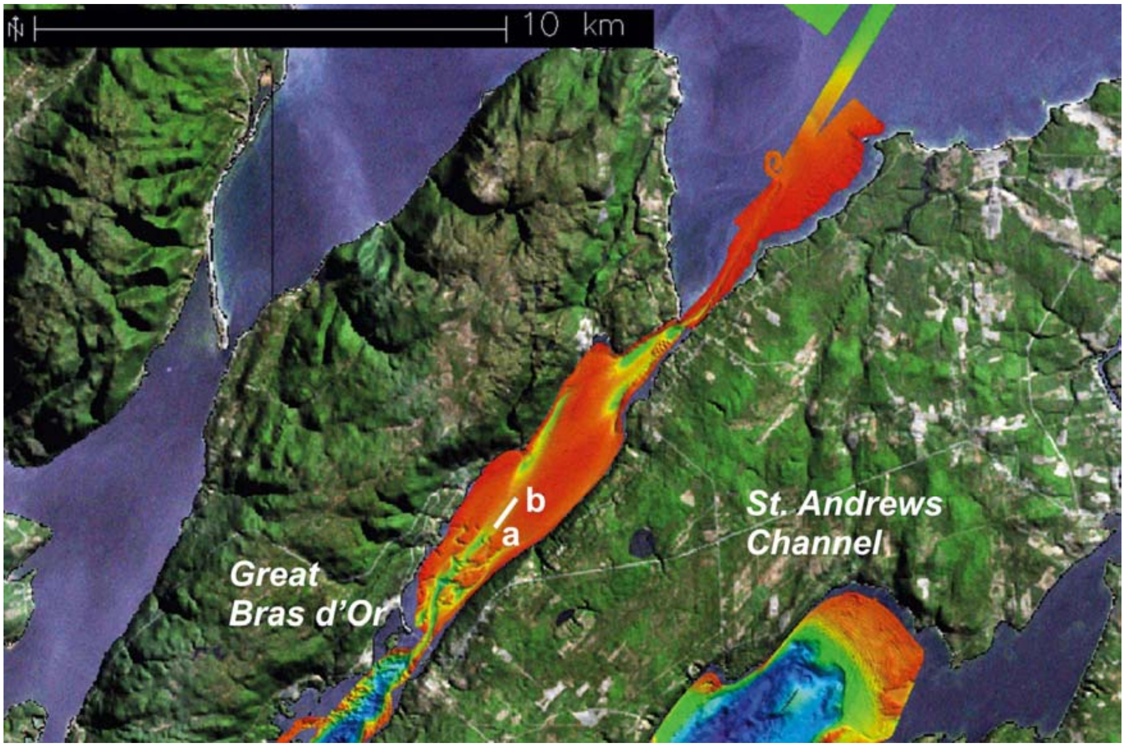


Figure 4. The entrance to Bras d'Or Lakes, showing the extensive shallows south of the narrows, formed by tidal action. Cross-section a-b is shown below.

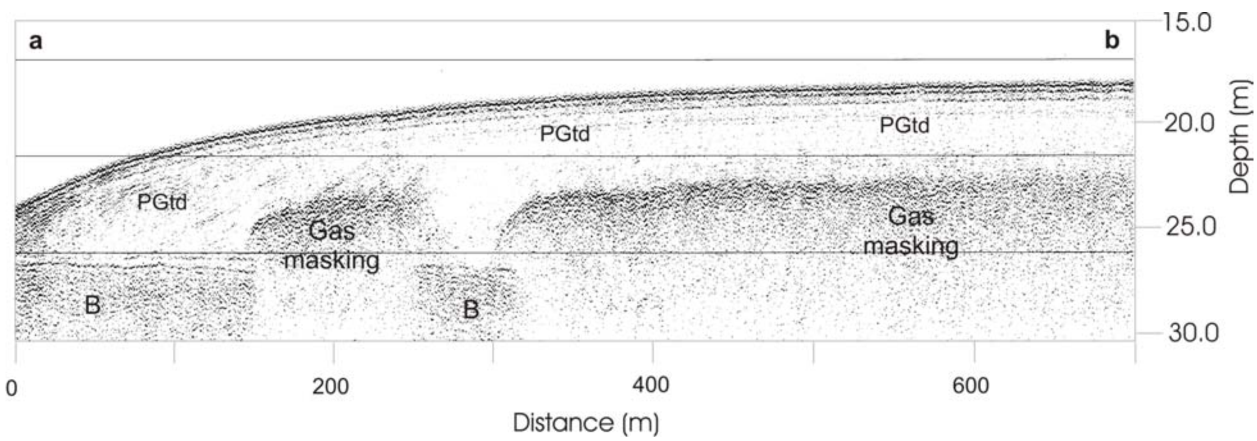


Figure 5. High-resolution sub-bottom profile of flood-tidal deposits at the landward side of the entrance to the lakes (Fig. 4). B = bedrock; PGtd = postglacial tidal delta deposits.

New seabed coring data from the lakes

An unpublished GSC internal report based on a 1995 survey showed that St. Patrick's Channel contained ancient river channels, buried by mud. The inference was that the channels constituted a former river that drained eastwards to a delta at -25 m, and hence the former lake level was - 25 m. Imagery based on multibeam surveys (Fig. 6) shows the former river system. South of Baddeck the river appears as a braided stream, incised into earlier sediments. Immediately to the west the river is faintly discernable as meandering channels. The former river channels are overlain by variable thicknesses of mud, deposited after the incursion of the ocean. Relatively strong tidal currents have prohibited mud deposition south of Baddeck, so that channels are clearly observed on Figure 6; weaker currents farther west have allowed up to 3 metres of mud to accumulate on top of the former channels.

Coring programs took place in 2002 (GSC cruise 2002-066) and 2003 (Shaw et al., in press) in order to penetrate the mud and sample the underlying sediments in St. Patricks Channel. Table 2 shows cores collected in St. Patricks Channel, Figure 7 shows their distribution, and Figure 8 is a simplified description of the cores and their associated radiocarbon dates.

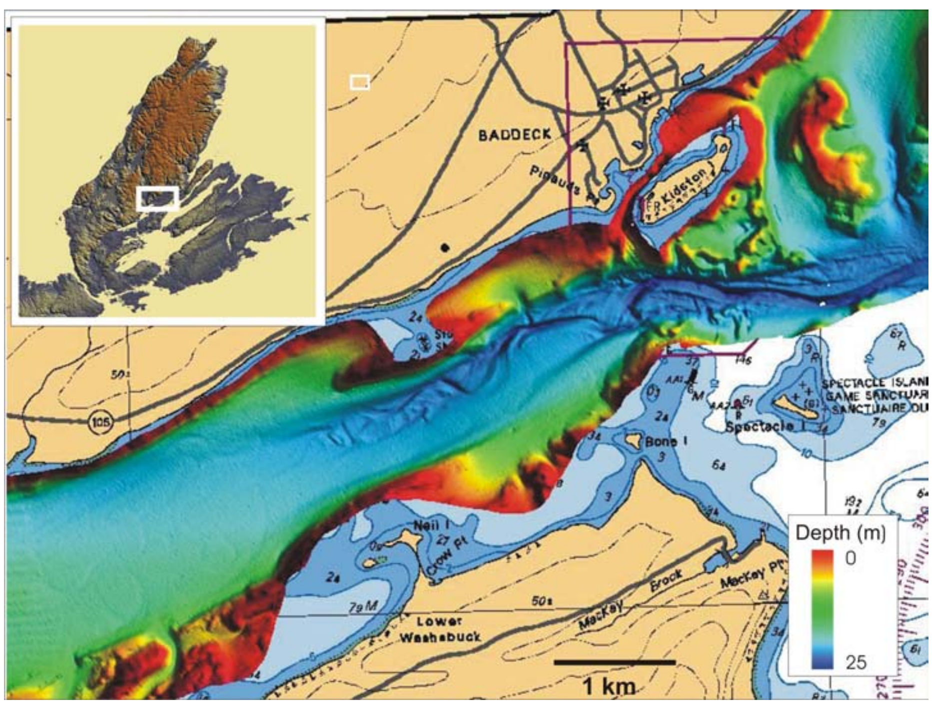


Figure 6. Multibeam bathymetric image showing submerged river channels near Baddeck.

Core #	Depth (m)	Length (m)	^{14}C dating	Macros	Forams	Geo-tech
2002-066-081	21.2	0.80				
2002-066-082	21.0	1.52				
2002-066-083	20.5	0.69				
2002-066-084	19.4	1.56				
2002-066-085	19.9	1.58				
2002-066-086	15.9	1.40				
2002-066-087	14.8	1.54				
2002-066-088	13.7	1.57				
2002-066-089	13.7	1.60		x		
2002-066-090	13.6	1.63	x	x		
2002-066-091	11.5	1.21				
2002-066-092	11.6	1.25				
2002-066-093	11.7	1.50				
2002-066-094	12.0	1.55	x	x		
2002-066-095	11.7	1.38				
2002-067-096	13.2	1.22	x			
2002-066-098	10.9	0.64	x			
2002-066-099	13.7	1.99				
2003-015-070	11.2	0.98				
2003-015-075	15.9	1.17				
2003-015-076	20.2	1.36				x
2003-015-077	20.2	1.74	x		x	x

Table 2. Gravity cores collected in St. Patricks Channel, Bras d'Or Lakes on Geological Survey of Canada cruises 2002-066 and 2003-015. Macros = macrofossil analyses completed; Forams = Preliminary foraminifera analyses completed; Geotech = Geotechnical analyses completed. Depths are not those quoted in the cruise reports but have been taken from the multibeam bathymetry data. They are reduced to Chart Datum, which is lowest normal tide. Tidal range is about 0.1 m.

All the cores contained soft mud in their upper parts, and seven cores bottomed in organic-rich sediment. The variable thickness of the mud is caused by hydrodynamic conditions. The thinnest mud is where the channel is relatively narrow and the tidal flow relatively strong, i.e., near Baddeck. The area of high backscatter down the middle of the channel on Figure 7, approximately from core 2002066-082 to core 2002066-084, represents the axis of strongest tidal currents and thinnest postglacial mud. Core 2002066-081 penetrated 0.4 m of mud and terminated in sand, perhaps representative of the fluvial or glacio-fluvial material that lies underneath the postglacial mud. The mud is featureless dark grayish brown to olive gray silty clay with scattered fragments of shell and organic material. Intact specimens of the marine gastropod *Cerastoderma pinnulata* were present in cores 2002-066-084, -085, -087, -088, -090, -092 and -093, and some were sent for radiocarbon dating (Table 3).

The upper mud unit contained foraminifera. An analysis was completed for core 2003015-077. Abundance of foraminifera declined downcore. From the top down to 0.75 m samples were described as estuarine, and this characteristic increased down core. All species were agglutinated, and the coarse fraction of the top sample (0.05 m) contained over 90% *Ammotium* *cassis*. The second sample (0.22 m) was about 80% *Ammotium cassis*, but also contained more marine agglutinated species. The most common species in core 2002066-077 were *Rhumblerella humbolti* and *Verneulinulla advena*.

The uppermost unit was also examined for macrofossil remains. The analyst noted, in addition to foraminifera, numerous ragworm (Nereidae) mandibles. The uppermost unit in the cores is interpreted as postglacial estuarine to marine mud, deposited in St. Patricks Channel under conditions of increasing marine influence. The sediment source is postulated to be glacial deposits eroded by wave action plus sediment brought into the channel by rivers.

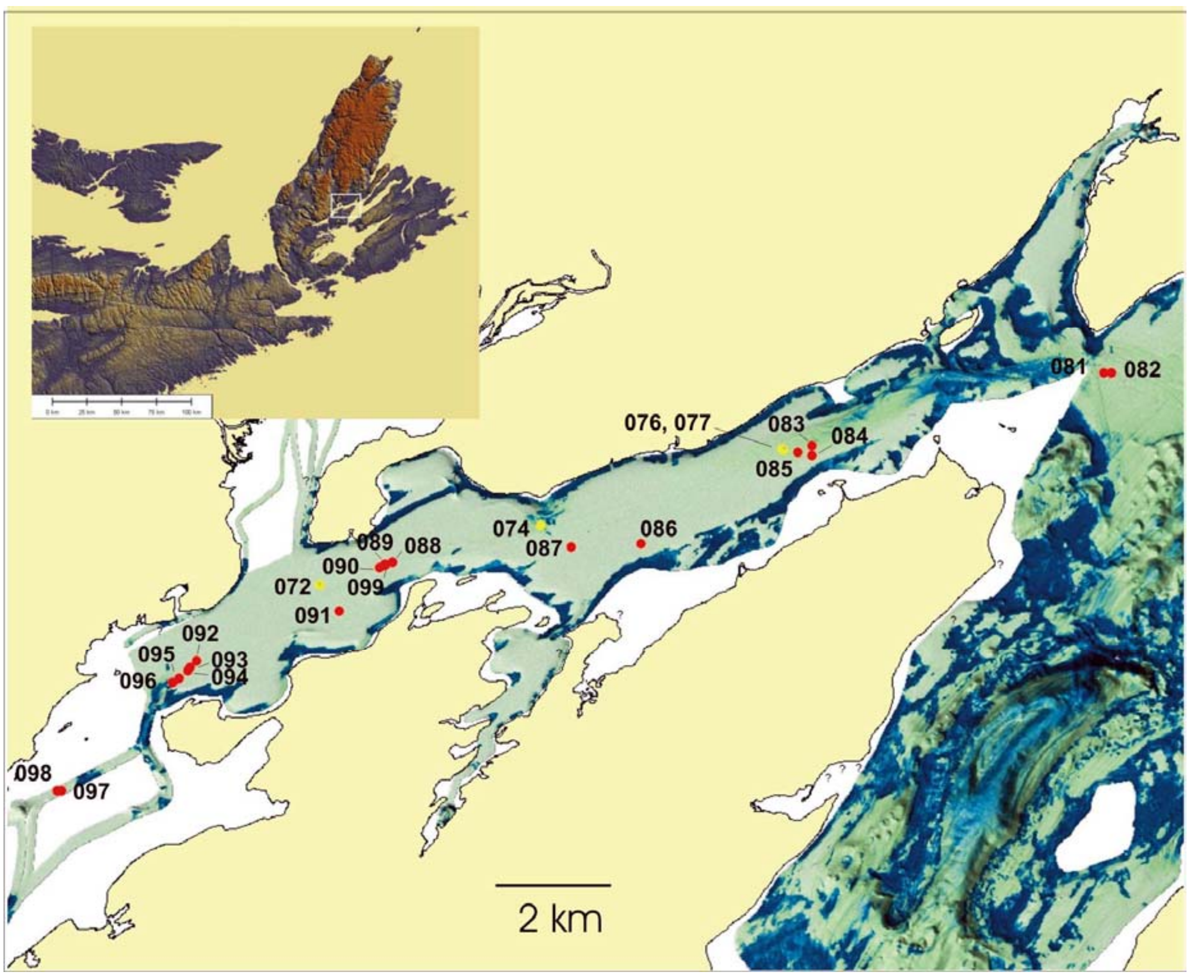


Figure 7. Gravity cores collected in St. Patricks Channel. Red circles are cruise 2002-066; yellow circles cruise 2003-015. The background is the backscatter data from the lake: pale gray = mud; indigo = hard bottom (muddy gravel).

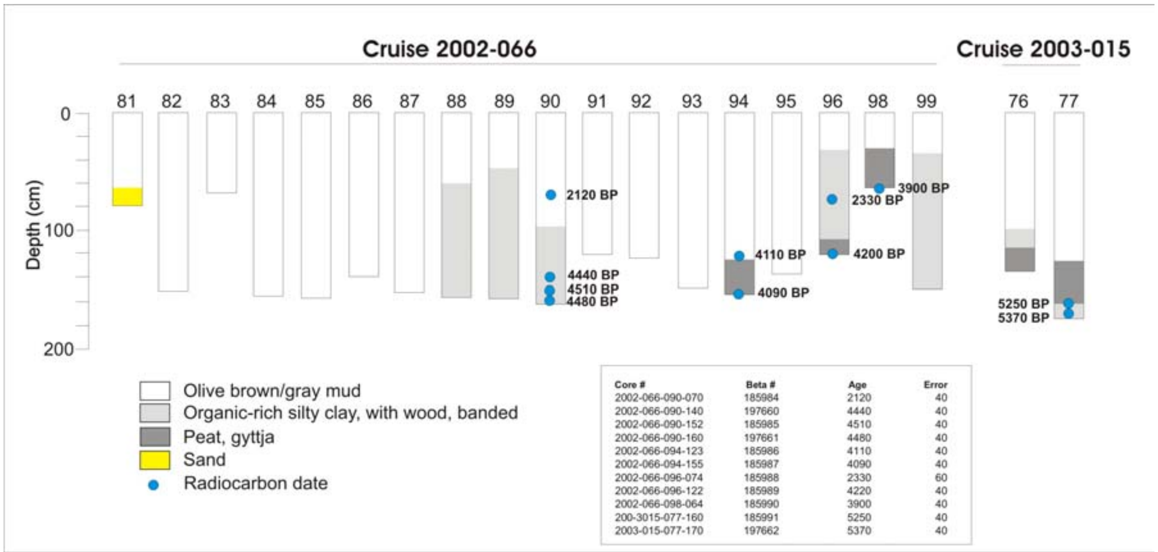


Figure 8. Summary of gravity cores, St. Patricks Channel.

Nine cores sampled the organic units that underlie the postglacial mud. The organic material is grouped into two types. The first is organic-rich clay, with gray clay layers interbedded with highly organic layers several centimeters thick, and containing scattered woody remains such as twigs and small branches. Core 2002-066-090, for example, was highly banded in appearance. The second type is peat or gyttja – fibrous, highly organic layers, commonly containing well-preserved twigs and tree leaves, sometimes compacted into mats. Plant macrofossil analyses revealed the presence of numerous well-preserved macrofossils. In core 2002066-089, for example, the sample at 64 cm, in banded organic rich clay, contained, among other types, seeds of aquatic plants such as Typha sp., *Sparganium americanum*, and seeds of *Alnus incana*. A few foraminifera were noted in some parts of the organic units, but not in others.

A new sea-level curve for the lakes

The relative sea-level curve for the lakes (Fig. 9) is based on 15 radiocarbon dates. Date 1 was from a shell sample in the postglacial mud unit, and poorly constrains the curve. Dates 2, 3 and 4 are from the organic unit in core 2002066-090. No foraminifera were counted in the parts of the core containing dates 2 and 3, while a few were counted in the sediment containing date 4. Thus, dates 2 and 3 suggest no marine influence, and are placed slightly higher above water level than date 4. Dates 5 and 6 were from core 2002066-094 and both contained some foraminifera. Core 96 was not examined for macrofossils, but date 7 was clearly marine (shell sample from the postglacial mud). Date 8 was from a basal 12 cm thick layer of unit of gyttja overlain by a 2-cm thick layer of clay; the extent of marine influence is uncertain. Date 9 was from a sample of fibrous peat with no supporting macrofossil or microfossil evidence.

Dates 10 and 11 were from a unit of detrital peat (gyttja) with woody fragments at the base of core 2002066-077. The uncompleted foraminiferal analysis for this part of the core shows a few foraminifera. The total numbers in samples at 153-156 cm and 164 - 167 cm were 50 and 37 respectively. By comparison, the total at 22-25 cm in the upper postglacial mud unit was 23,753. Again, a very weak marine influence is apparent. Dates 12, 13, 14 and 15 are from Miller and Livingstone (1993) who claim that sea level overtopped the -1.5 m sill at Captain Dix's Cove (Great Bras d'Or) by 950 BP. The remaining dates are on samples from the organic-rich units (Table 3) which probably accumulated near the former water levels.

The relative sea-level curve (Fig. 9) reveals that sea level was at -25 m ca. 6350 yr cal (calibrated years) BP. The lakes were then instantly exposed to the rapid rate of sea-level rise pertaining in the region at that time. We can calculate the past rates by approximating the sea-level curve with a second order polynomial of the form $y = -6E\text{-}7x^2 - 0.0003x - 0.4167$ where y = water level and x is age in years. At 6350 yr cal BP the rate was 0.79 m/century, comparable to rates elsewhere in Nova Scotia at this time (Shaw et al., 1993; Edgecombe et al., 1998) (~0.70 and 0.67 m/century respectively). As seen in Figure 10, by 5000 cal yr BP the rate had declined to 63 cm/century and by 2000 BP it was only 27 cm/century.

#	Core & depth	Material dated	Depth (m)	Beta #	13C/12C ratio	Age	error	Calibrated age (95.4 %)
1	2002066-090-070	Shell*	14.3	185984	0.3	2120	40	1598-1806
2	2002066-090-140	Twig	15.0	197660	-25.3	4440	40	4871-5074 5103-5138 5162-5282
3	2002066-090-152	Wood	15.1	185985	-28.1	4510	40	4996-5006 5039-5306
4	2002066-090-160	Twig	15.2	197661	-26	4480	40	4975 - 5019 5028 - 5296
5	2002066-094-123	Peat	13.2	185986	-27.7	4110	40	4449 - 4465 4519 - 4732 4752 - 4818
6	2002066-094-155	Wood	13.6	185987	-27.3	4090	40	4442 - 4487 4504 - 4655 4667 - 4709 4720 - 4727 4756 - 4813
7	2002066-096-074	Shell	13.9	185988	-0.5	2330	60	1813-2095
8	2002066-096-122	Peat	14.4	185989	-28.1	4220	40	4591 - 4595 4616 - 4766 4789 - 4855
9	2002066-098-064	Peat	11.5	185990	-27.7	3900	40	4158 - 4168 4180 - 4200 4229 - 4422
10	2003015-077-160	Wood	21.8	185991	-28.2	5250	40	5924 - 6060 6068 - 6112 6142 - 6170
11	2003015-077-170	Twig	21.9	197662	-28.2	5370	40	5997 - 6078 6087 - 6103 6105 - 6150 6166 - 6211 6218 - 6279

Table 3. Radiocarbon dates on samples from St. Patricks Channel. Numbers in column one refer to dates in Figure 7. Column two shows the core number and sample depth down core. Sample depths are reduced to Chart Datum, which is lowest normal tide. Tidal range is about 0.1 m. The calibrated ages were obtained using Calib 5.0.

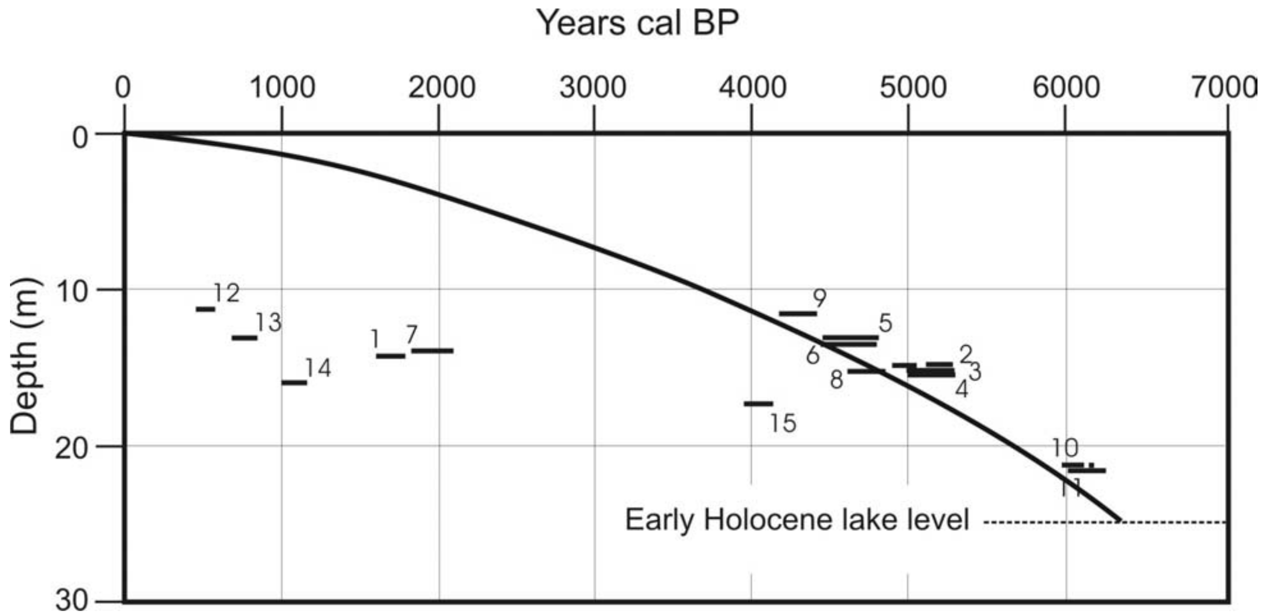


Figure 9. Trend of sea-level change in the lakes during the middle - late Holocene epoch.

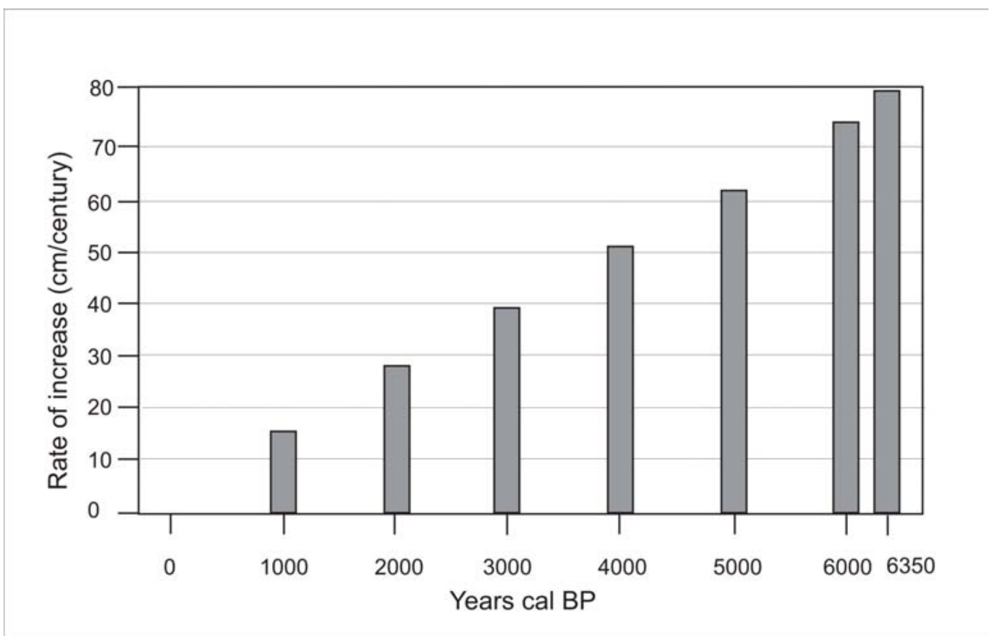


Figure 10. Rates of water-level increase in the Bras d'Or Lakes.

CHANGES IN GEOGRAPHY DUE TO SEA-LEVEL RISE

Palaeogeography of the region

In the early Holocene, when the lake level stood at -25 m, St. Patricks Channel was subaerially exposed. A river that drained east along the channel formed a delta just southeast of Baddeck. On multibeam bathymetry the delta appears as a flat-topped terrace with a steep slope facing east. Sub-bottom profiler data reveal steeply dipping foreset beds and less steeply dipping bottomsets. The river – informally named St. Patricks River – was incised into steep bluffs just south of Baddeck, and the flat valley floor contained channel bars. Farther west the river meandered across the flat valley floor. The river's gradient was low, and the valley floor was an ideal environment for wetland development. There were alder thickets, and scattered ponds and swamps in which gyttja and peat accumulated. As the ocean made its incursion into the lake, the marsh sediments may have been intermittently inundated by brackish water, forming banded organic-rich muds. Farther west the valley contained several small lakes that stood higher than the main lake. Today these former lakes appear as basins, e.g., the basin off Whycocomagh.

The lakes were fresh for many thousands of years, and coastlines developed under conditions of relative water-level stability. Examination of multibeam sonar data shows that these submerged coastlines have been well preserved, mainly because when the ocean breached the sill, the lakes were instantaneously subject to rapid water-level rise (79 cm/century).

The preserved coasts are more common in the southern lakes where glacial sediment sources for beach-construction were more abundant than north of Barra Strait. Figure 11 shows an approximation of the geography of the region during the early Holocene. There was probably a difference of about 1 m between the north and south lakes, but in this figure a -25 m water level is applied throughout. Also, smaller lakes upstream from rivers would have had former elevations higher than -25 m, and would have been larger than depicted here. This applies to the head of St. Patricks Channel, and East Bay.

The modern Barra Strait (Fig. 2) was narrow, but open. South of the strait was a small lake basin, into which a large river entered, meandering across a wide, flat delta. This river drained what is now Denys Basin. The Denys Basin river (Figs. 12, 13) is clearly seen on multibeam imagery, despite the fact that it lies below a drape of several metres or more of late Holocene mud.

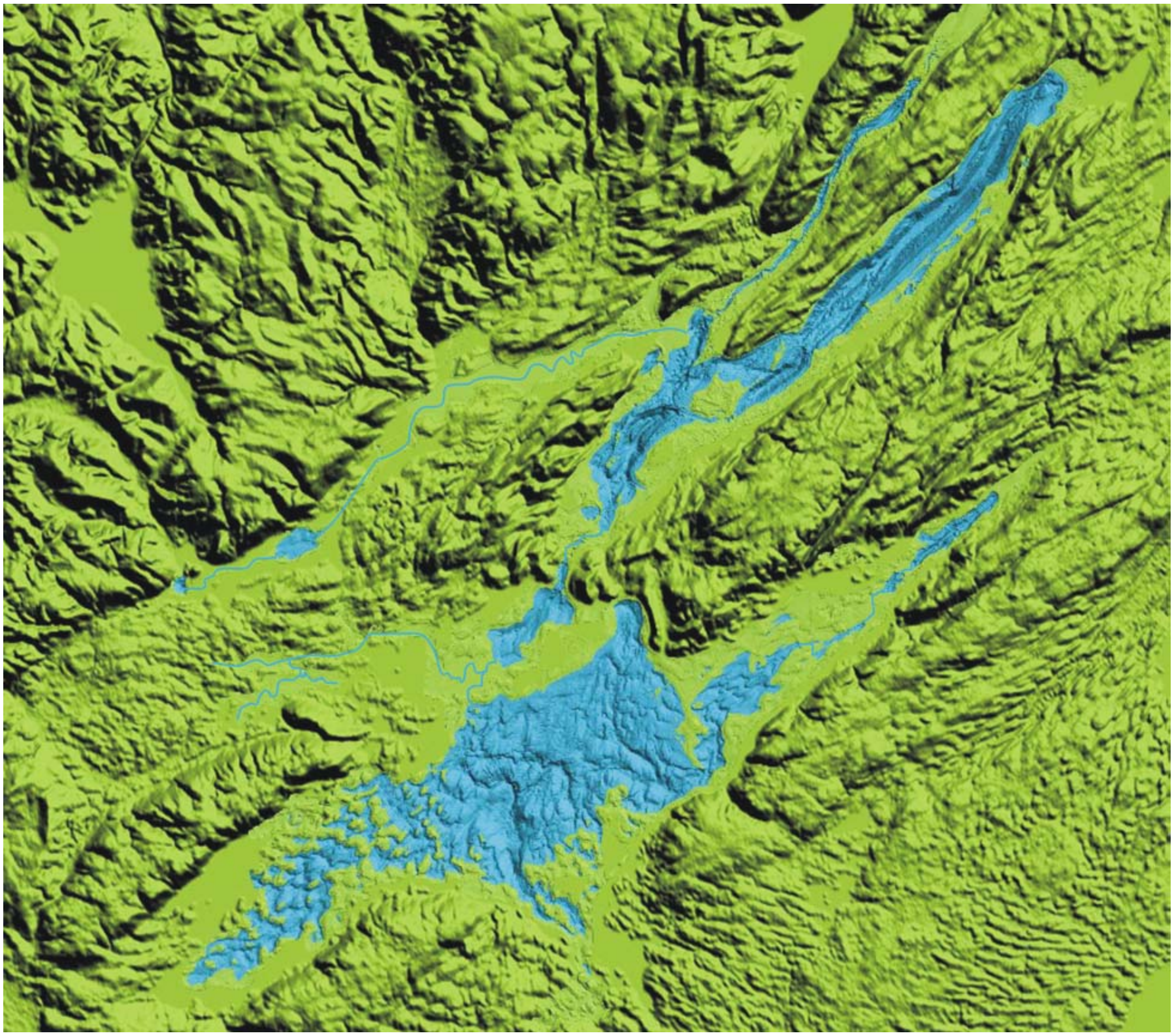


Figure 11. Palaeogeography of the region, with a -25 m water level. Land is shaded green, and water blue. Only a couple of rivers are shown, namely the rivers draining along the modern St. Patricks Channel, and those draining the modern Denys Basin.

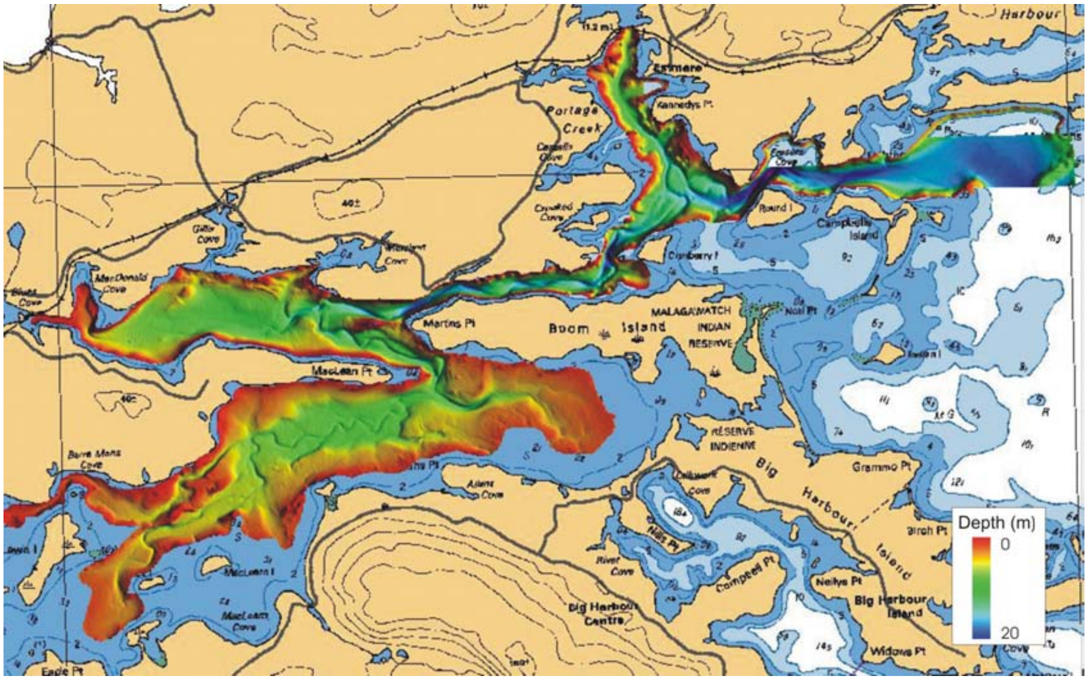


Figure 12. Fluvial system buried by mud in Denys Basin.

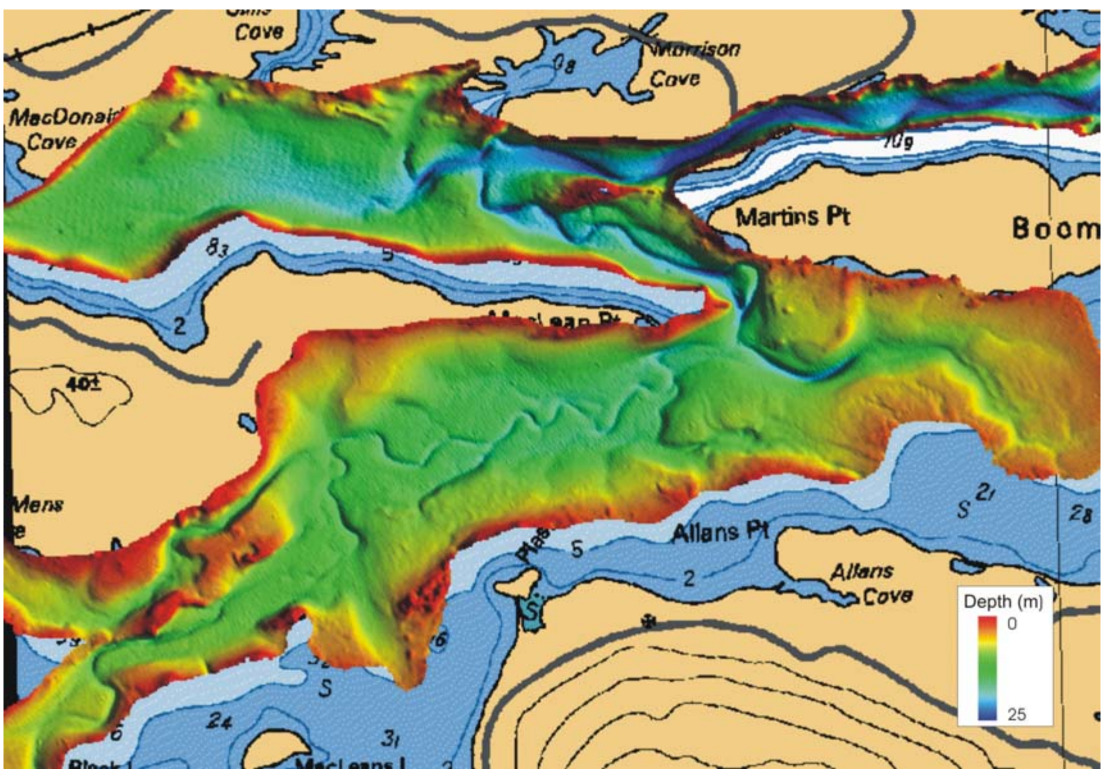


Figure 13. Enlarged view of Denys Basin river channels.

Submerged coastlines in the Bras d'Or Lakes

Well-preserved and recognizable submerged coastal landforms are common south of Barra Strait, in Bras d'Or Lake. East Bay (Fig. 14) contains tombolos, spits, and barrier beaches, either graded to a former water level of -24 m, or, in some instances located at shallower depths. This indicates that with rising sea levels, some beaches did migrate, as happens today, and were submerged when further migration ceased because of bathymetry (i.e., beaches cannot migrate downhill during a transgression). The landforms are composed of sub-rounded sandy gravel, and have high backscatter in multibeam imagery. They appear on seismic profiles (e.g., Fig. 15), superimposed on older deposits.

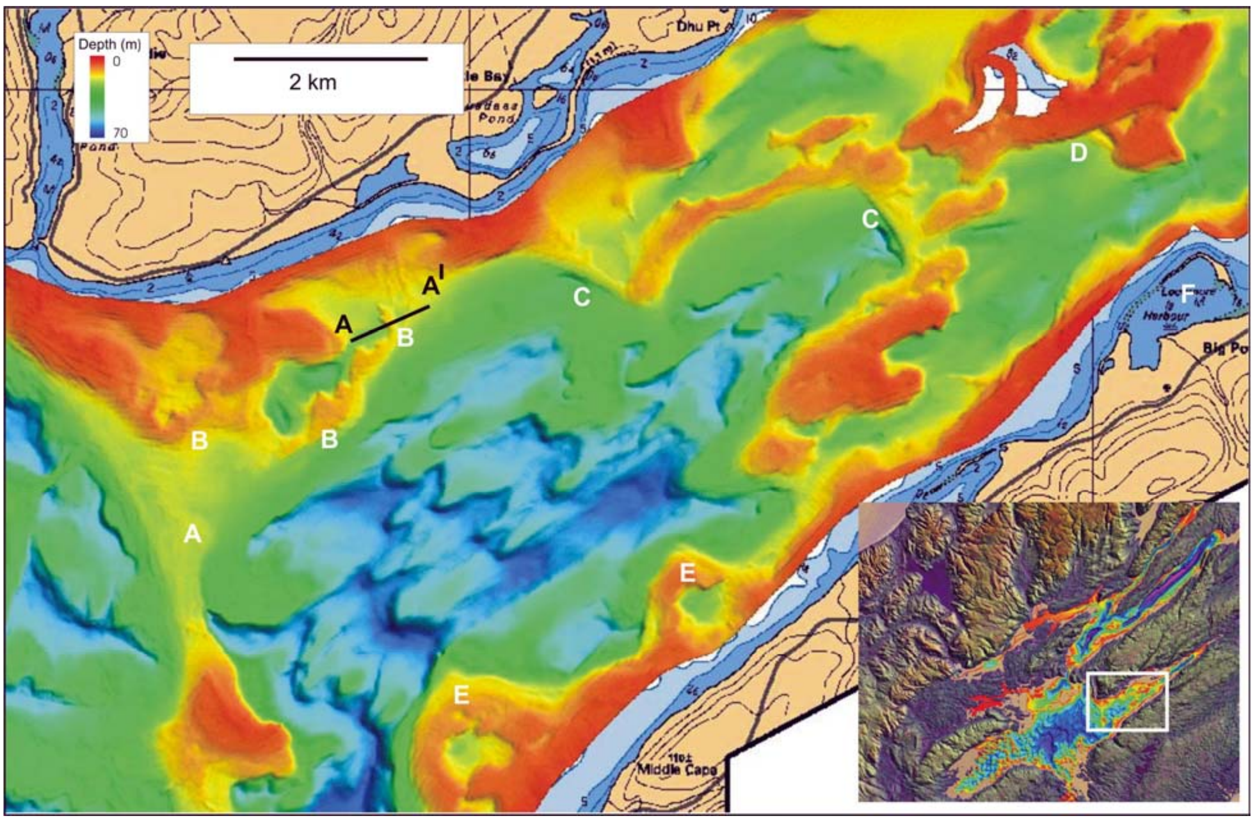


Figure 14. Submerged coastal landforms in East Bay. These include a tombolo (A), spits (B), barrier beaches (C), and a relatively shallow barrier beach (D) that was stranded during the process of migration. The structures at E are probably barriers enclosing lagoons, and are commensurate with the modern analogs in the region (F). The line AA' marks the location of the seismic profile in Figure 15. All the submerged landforms have high backscatter on multibeam images; bottom photographs and samples show that they are composed of gravel or sandy gravel.

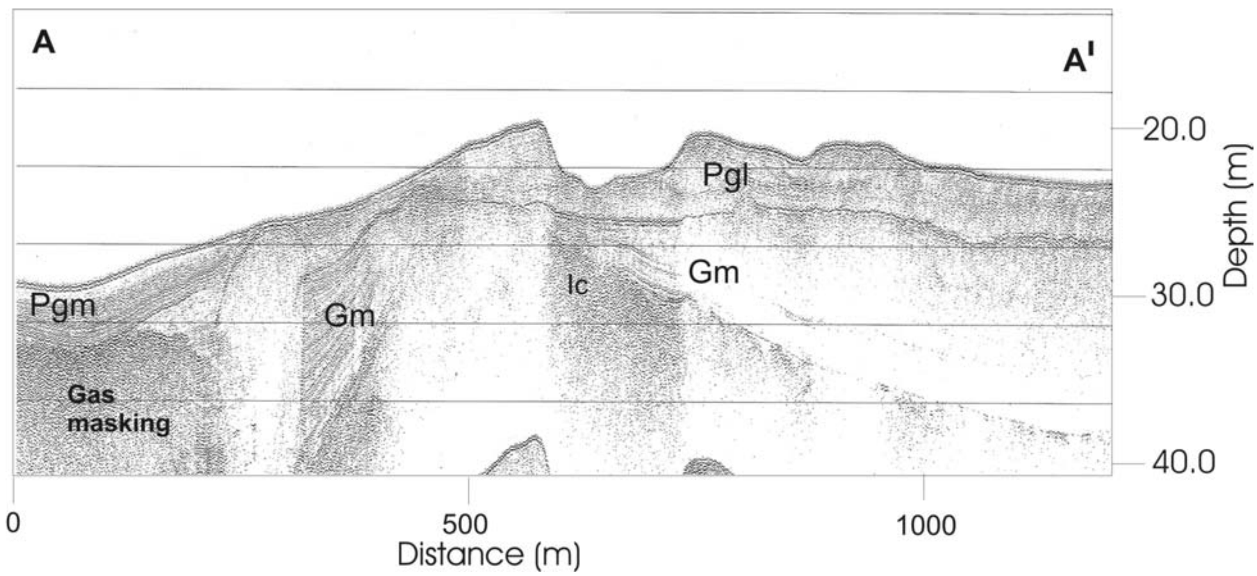


Figure 15. High-resolution sub-bottom profile across submerged spit deposits in East Bay. Pgl = Postglacial littoral deposits; Pgm = Postglacial mud; Gm = Glaciomarine/glaciolacustrine mud; Ic = Ice-contact sediment (till). Location of profile shown on Figure 14.

In West Bay, fields of drumlins oriented mostly NE to SW, were modified by littoral processes to produce a series of beaches that were subsequently submerged. They are accordant in elevation with a -24 m water level, slightly shallower than north of Barra Strait (-25 m). However, other features can be seen in multibeam imagery that are not so apparent elsewhere. These include a well-developed shore platform (Fig. 16) that developed in a part of West Bay that was almost separated from the rest of the former lake by a field of partly emergent drumlins linked by barrier beaches. It suggests a -24 m water level. The erosional platform developed under the influence of waves developed by a large fetch to the southwest.

Another distinctive feature of this area is the presence of distinctive 'tails' attached to submerged drumlin shoals (Fig. 17). These 'tails' are former trailing spits that have many modern analogs in the lakes. As sea level rose, the spits migrated to the rear of the shoals, coalesced, and formed attached 'tails' that finally drowned. During field surveys we observed that lobster fishermen used some parts of shoals and not others. It appears that they were setting traps on the former drumlin shoal, which has a boulder gravel surface, and not the 'tail', which is composed of well-sorted beach gravel, with few boulders

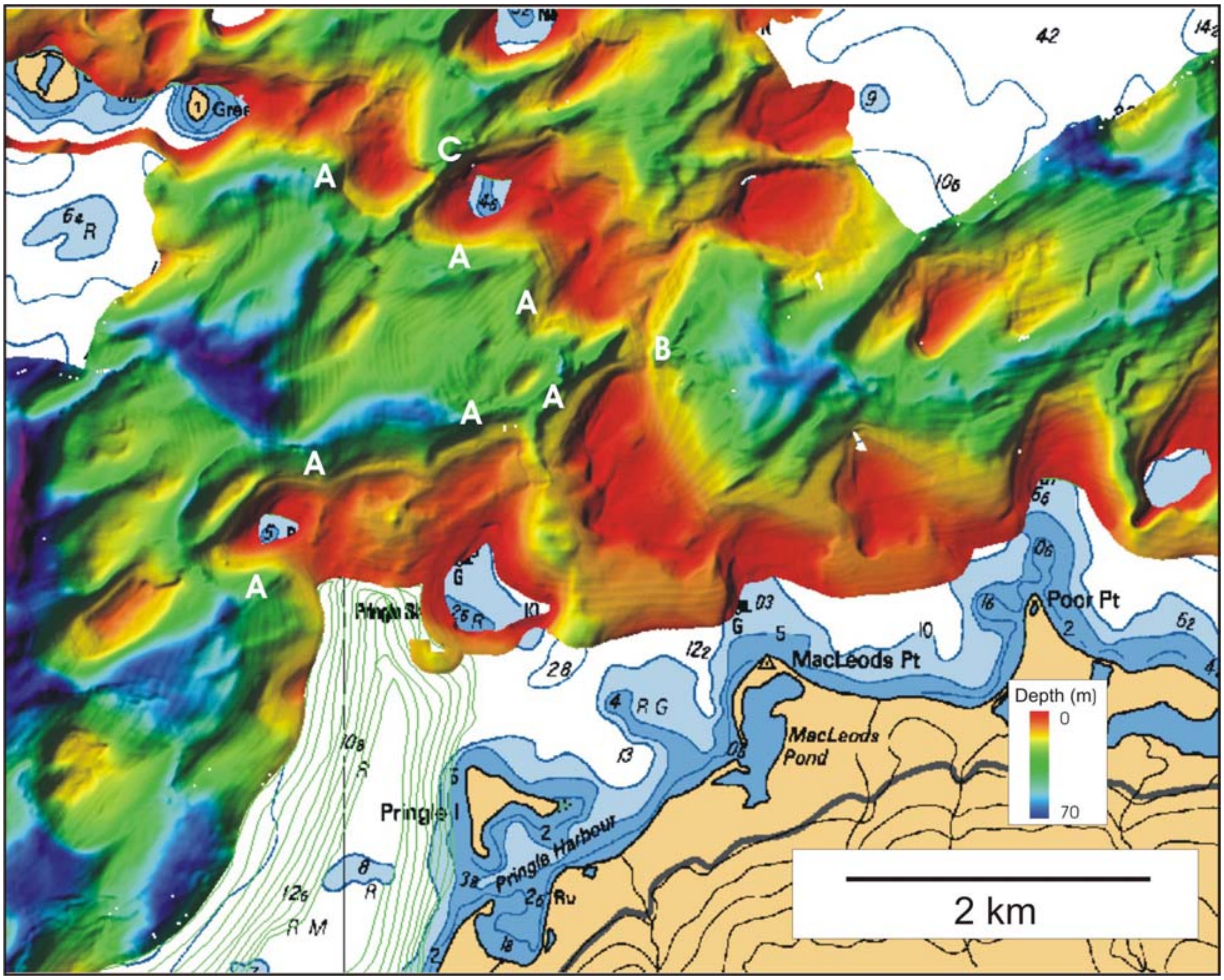


Figure 16. Multibeam imagery from West Bay, showing the submerged erosional platforms (A) and barrier beaches (B). When the lake stood at -24 m, a narrow channel (C) connected the lake in the southwest (left) with the main lake (upper right).

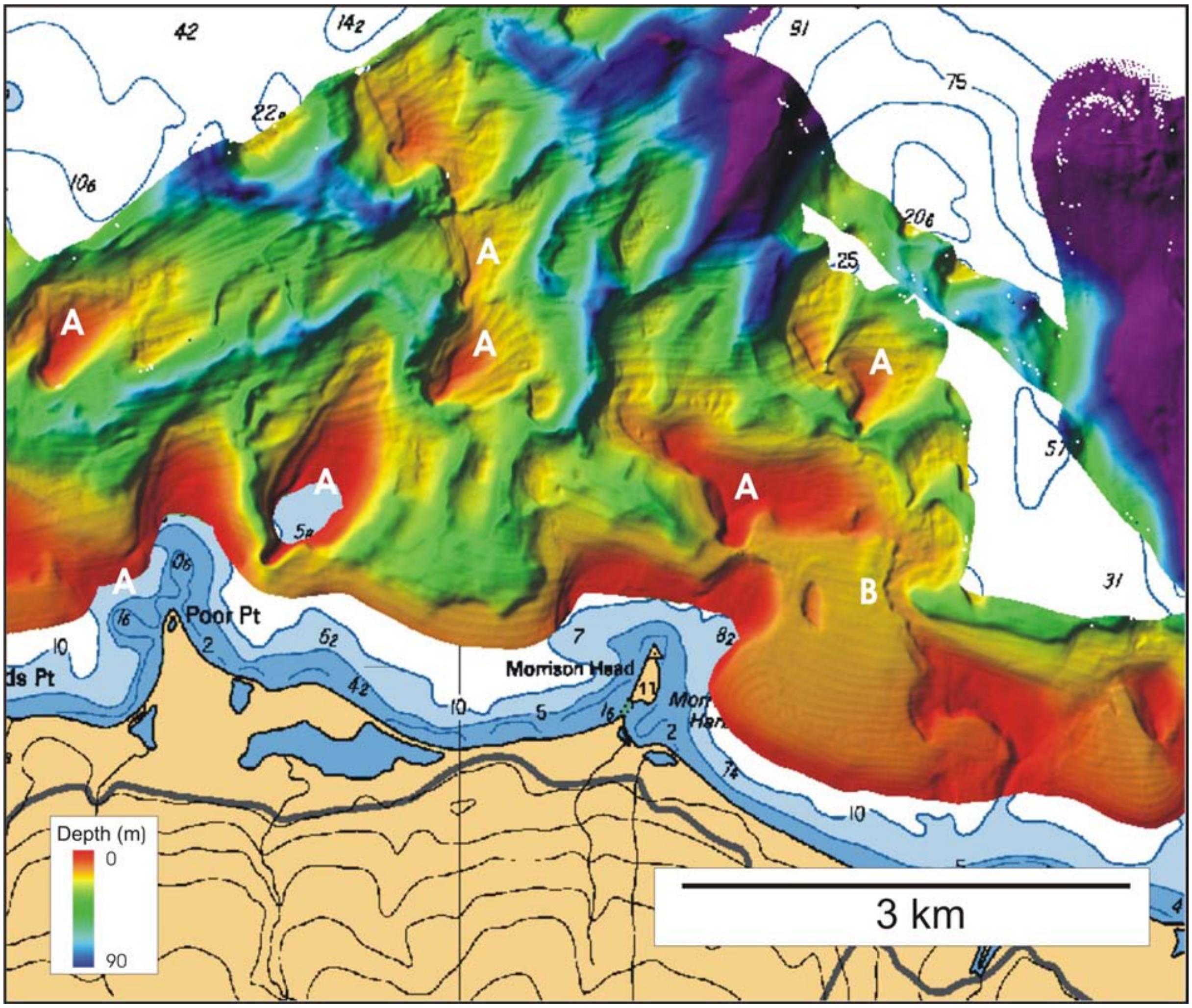


Figure 17. Submerged trapped spit deposits attached to former drumlin shoals (A). An example of a submerged and trapped barrier beach is seen at B.

SOME IMPLICTIONS OF THE CHANGES IN GEOGRAPHY

Implications for coastlines under projected climate change

Elevations of drowned coastal features identifiable on the multibeam imagery, chiefly spits and barriers, including the drowned 'tails' that are the remnants of former beaches, shows that they lie at depths of 7-25 m. The majority are in the range 15-20 m, with a nearly equal number in the range 20-25 m. Comparing these depths with the sea-level curve for the lakes, we can see that *in situ* and near *in situ* drowning of coastal systems occurred mainly before 4500 cal yr BP, and the majority of drowning was in the period 5500 to 6000 cal yr BP (Fig. 18). The rate of water-level increase at 4500 BP was 57 cm/century, and from 5500 to 6000 BP it ranged from 69 to 75 cm/century. The rate at the time of the onset of marine conditions at ca. 6350 yrs cal BP was 79 cm/century. In other words, future rates of sea-level rise greater than ~60 cm century would cause *in situ* drowning of coastal systems, and rates >70 cm/century would almost certainly do so.

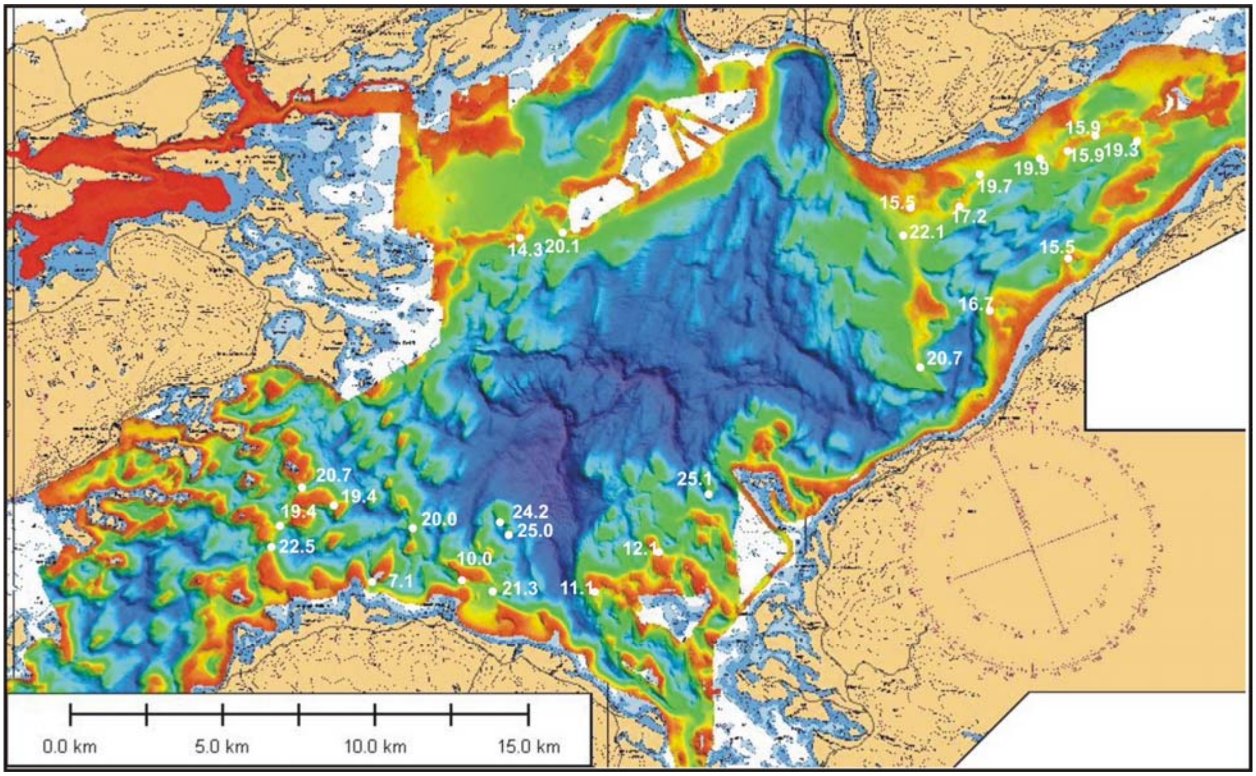


Figure 18. Locations of a selection of drowned coastal landforms in the southern lakes, with associated water depths.

Time cal yr BP	Water depth (m)	No. of features	Rate of sea-level rise (cm/century)
2500-3000	6.0-7.5	1	33-39
3000-3500	7.5-9.0	0	39-45
3500-4000	9.0-11.5	2	45-51
4000-4500	11.5-14.0	1	51-57
4500-5000	14.0-16.0	5	57-63
5000-5500	16.0-19.0	4	63-69
5500-6000	19.0-23.0	10	69-75
6000-6350	23.0-25.0	3	75-79

Table 4. Table illustrating when beaches and other coastal landforms were submerged in the Bras d'Or Lakes.

Archaeological implications

While First Nations may have occupied this region for a long time, this has not been strongly supported by the archaeological evidence. The reason may be that the evidence is submerged. If aboriginal peoples occupied the region during the early- to mid-Holocene, occupational evidence may lie along the submerged shorelines of the lakes, most of them 24 to 25 m below modern lake level. Given the resolution of multibeam sonar systems, it is not surprising that we are unable to identify signs of human activity. However, there is one rather curious feature on the sea floor that raises some interesting questions.

When sea level was lower, the northern Bras d'Or lakes had a level of -25 m. Immediately south of Barra Strait (Fig. 2) the level was similar, but south of Cod Shoals – which formed an arcuate isthmus about 10 km south of Barra Strait – the lake level was perhaps slightly higher, at ~ -24 m. Located in West Bay is a flat-topped shoal at depths of 23 to 24 m upon which is a circular ridge (Figs. 19, 20). Elevation of the ridge is about 0.5 m, the outer diameter is about 100 m, and the width of the ridge about 28 m. The ridge has high backscatter compared with the surrounding shoal. Preliminary bottom photography (G. Bugden, pers. comm., 2006) shows that the ridge contains boulders.

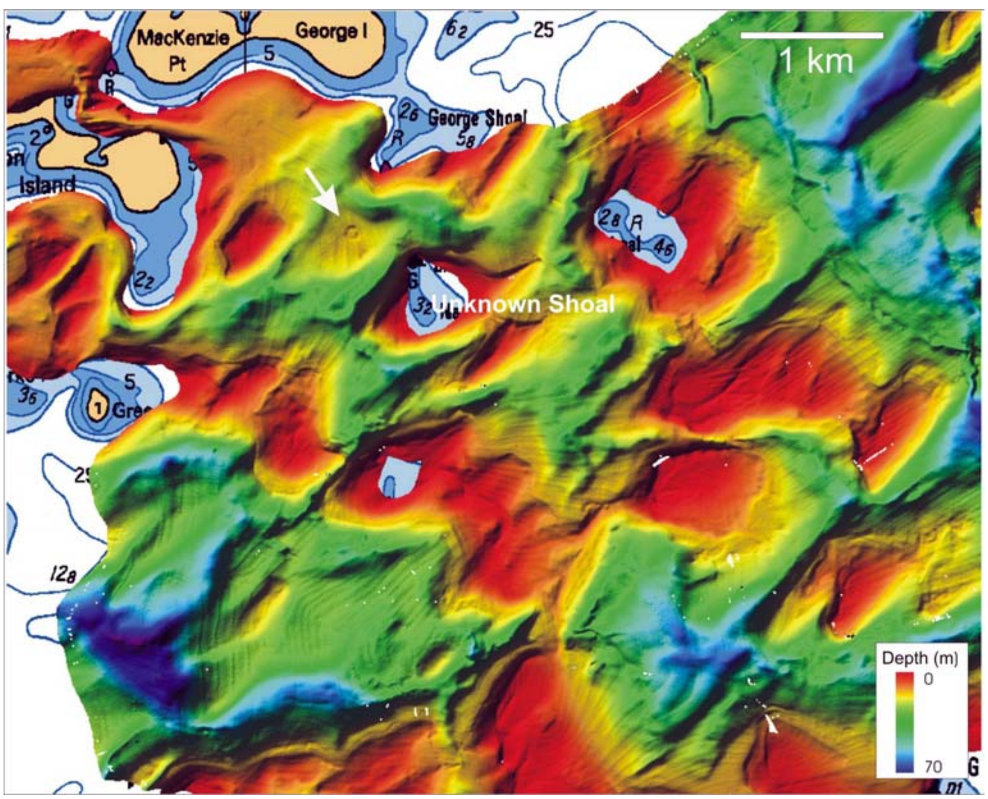


Figure 19. Multibeam imagery showing an enigmatic circular structure (arrow) in West Bay.

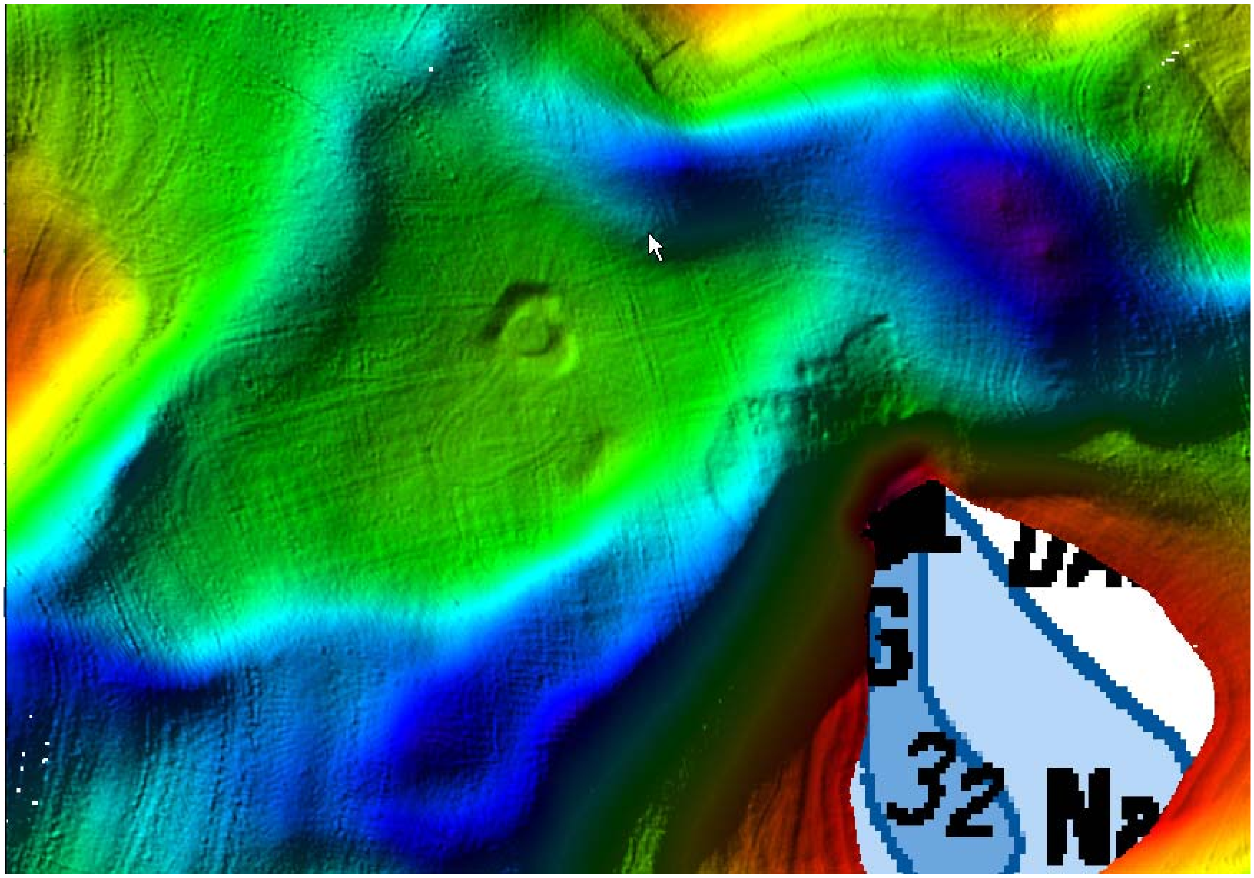


Figure 20. Close-up view of the circular structure, which has an outer diameter of 100 m. (Small white arrow was captured during screen grab - it has no significance).

There are several hypotheses that might explain the circle:

1) Pockmark. No. Pockmarks develop in thick Holocene mud.
2) Sinkhole. No. Sinkholes have steep sides, are usually deep, and have no raised rim.
3) Meteorite impact crater. This is a possibility (Pierazzo and Melosh, 2000).
4) Dredge spoil. Probably not. Dredge spoil commonly forms ring shapes, but only when impacting on a soft bottom. Any mud on this submerged plateau is probably thin.
5) Remains of a coastal landform. No. Coastal processes form ovate looped barriers that might, in some situations, be almost completely enclosed. However, this feature is nearly circular, rather than ovate.
6) Explosion crater. The feature is perhaps a crater resulting from an underwater explosion, probably of a depth charge. Unlike most bombs, that are designed to explode upon impact, depth charges are triggered by pressure, and hence depth. Possible a depth charge was exploded here during World War II. Escort vessels were stationed at nearby Sydney.
6) Human construction. Before ca. 6000 years BP - ancient peoples located on adjacent islands arranged boulders on a nearly-emergent shoal to form a circular holding area into which fish were herded. However, the boulder ring is nearly 20 m wide in places, and fish traps tend to

have structures that channel the fish into the trap, so this hypothesis is unlikely to hold. The origin of this feature remains unknown at present.

HISTORIC SEA-LEVEL TRENDS IN THE REGION

Like all other places in Nova Scotia, sea level has been rising in the lakes during the past century, the period of historical records. Figure 21 shows relative sea level at North Sydney, Nova Scotia, just outside the lakes. The data, after manipulation to remove the annual cycle, which has a range of 0.15 m (Fig. 22), contain a trend of 0.29 m/century. When Shaw and Forbes (1990) reported on the trend here between 1970 and 1988 it was 0.13 m/century, and not statistically significant. Carrera et al. (1990) derived a similar linear trend of 0.148 m/century for the period 1970-1989. However, using their propagating differences method they deduced a trend of 0.389 m/century.

The gauge appears to show steady water level until ca.1980 and a rapid rise thereafter. However, this should be viewed with caution. Long-term mean water-level records in the region commonly display periods with differing trends. For example, the Halifax gauge showed what amounted to a cessation of sea-level rise beginning in 1970 (Shaw and Forbes, 1990). This flattening of the formerly rapidly increasing mean water level continued until 1995, after which an increase occurred.

The water-level record for North Sydney is relatively short compared with other places in the Maritime Provinces (Shaw and Forbes, 1990), therefore several steps must be taken to produce a more reliable indication of the sea-level trend. The steps are illustrated in Figures 23 to 28. Figure 23 shows the 'raw' monthly mean sea-level for North Sydney, with the linear trend superimposed. Note that the gradient, 0.000249, is a rate in metres per month. This converts to a rate of increase of 29.9 cm/century.

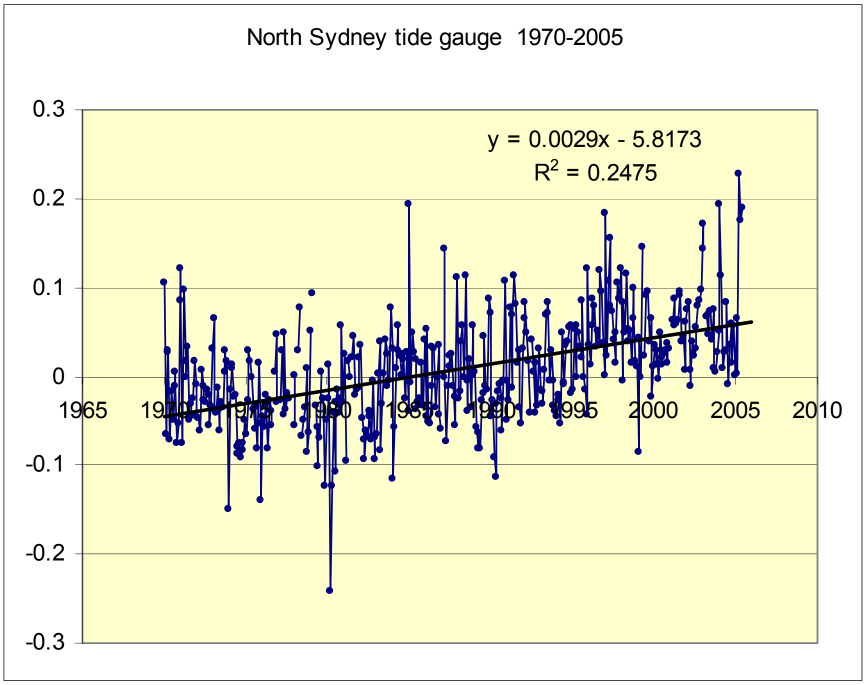


Figure 21. Mean sea-level trend at North Sydney, NS. Courtesy of B. Petrie, Department of Fisheries and Oceans, Bedford Institute of Oceanography. Horizontal axis years, vertical axis metres.

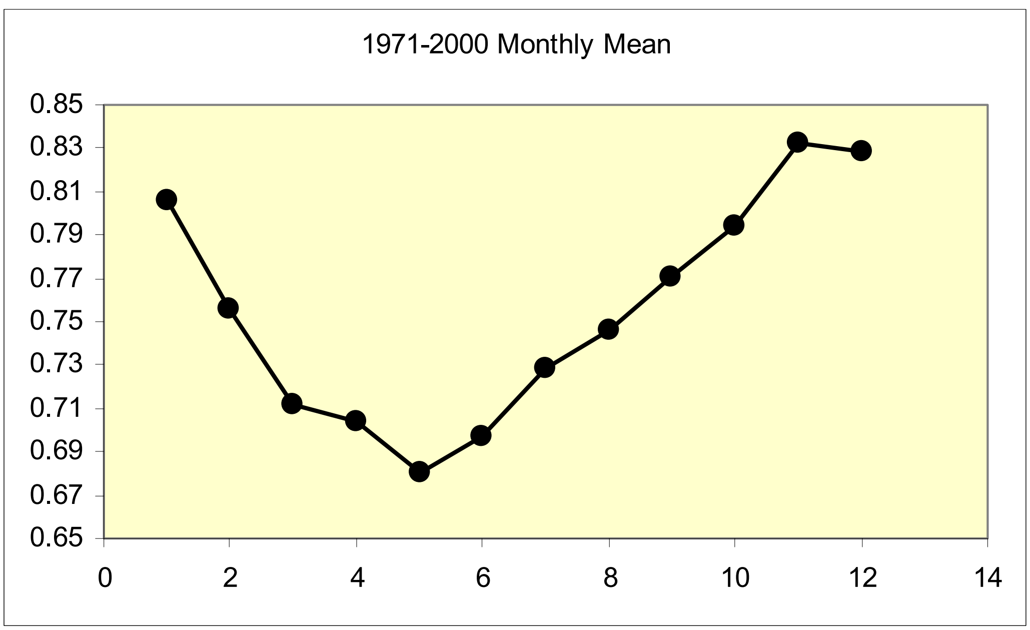


Fig. 22. The monthly variation of sea level at North Sydney has a range of 15 cm. Horizontal axis months, vertical axis metres.

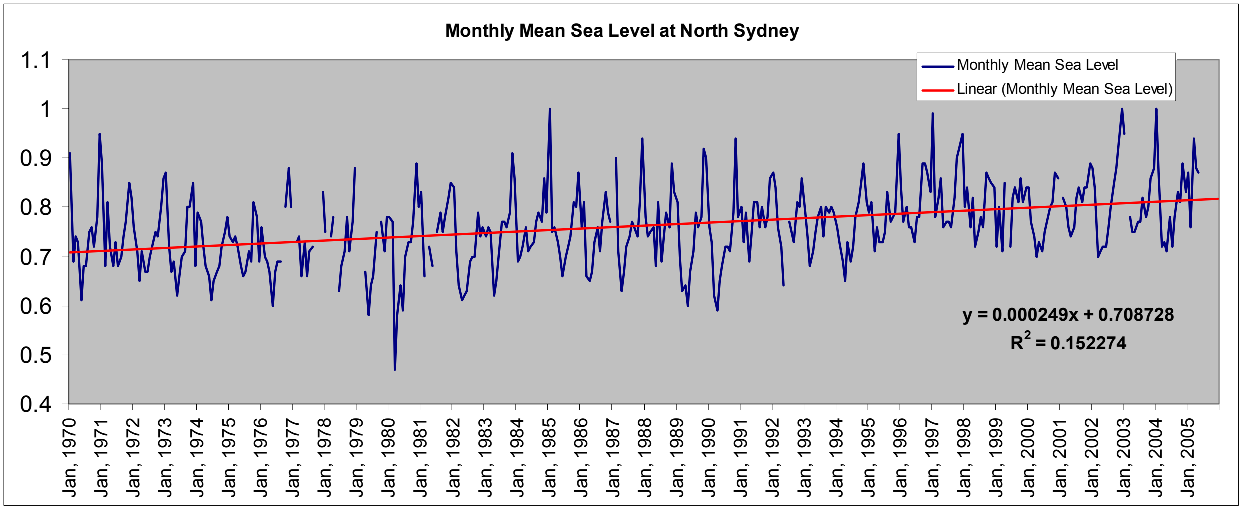


Figure 23. Monthly mean sea level at North Sydney. The linear trend is 29.9 cm/century. Vertical axis in metres.

The next step is to adjust for variations in atmospheric pressure. To do this we used the atmospheric pressure record for Charlottetown. The result is shown in Figure 24. The linear trend is similar to that in the 'raw' monthly mean sea-level data, and now has a value of 33.2 cm/century. The next step to improve the quality of the data is to correct for the normal monthly variation in sea level (shown on Fig. 22). The corrected data is shown in Figure 25. The trend in the data is now 32.6 cm/century. In order to see the reduction in variance in the data as a result of these two steps, the original data, the data corrected for atmospheric pressure, and the data further corrected for monthly sea-level variation are all shown on Figure 26.

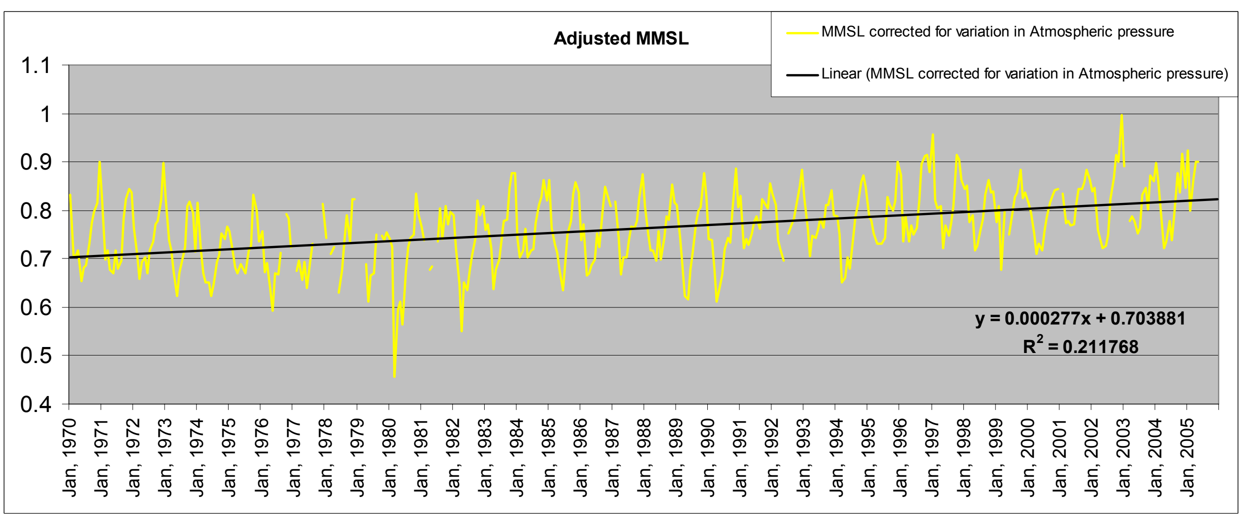


Figure 24. Monthly means sea level at North Sydney corrected for variation in Atmospheric pressure. The trend is 33.2 cm/century. Vertical axis in metres.

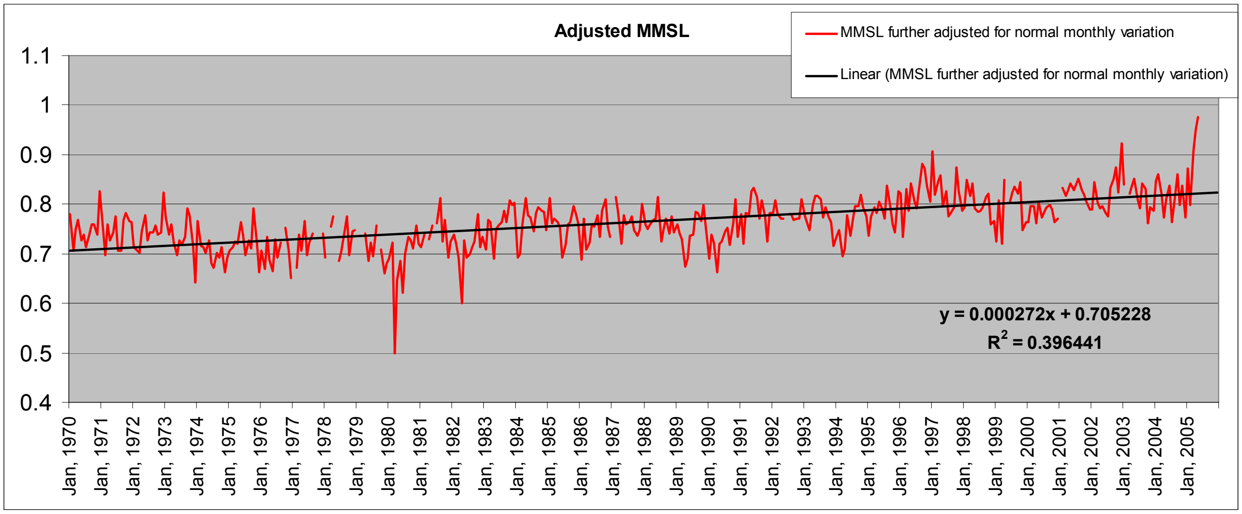


Figure 25. Monthly mean sea level at North Sydney further adjusted for normal monthly variation in water level. The trend is now 32.6 cm/century. Vertical axis in metres.

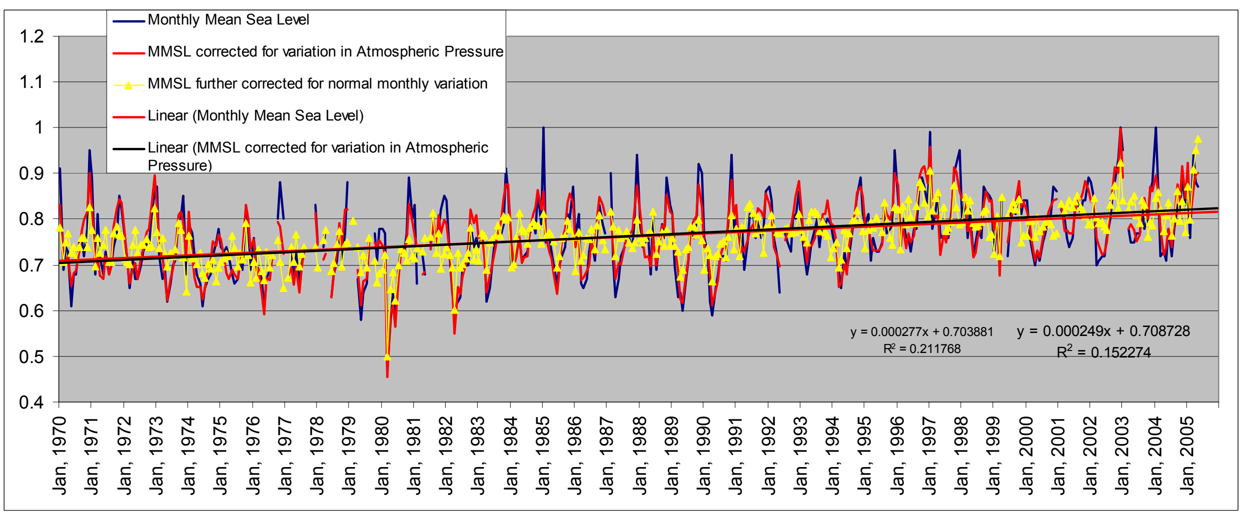


Figure 26. The 'raw' monthly mean sea level data for North Sydney, together with the data adjusted for atmospheric pressure, and the data further adjusted for monthly water-level variation. After the final step, the resulting data (yellow) line has considerably less variance than the initial data (blue line). Vertical axis in metres.

Although the record can be improved by making the corrections described above, it is still deficient in one important aspect, namely its length. However, the shortness of the record can be compensated for by using the method of propagating differences. Put simply, we compare the record with a nearby site with a long record, and derived a long-term trend. We used the long-term trend at Charlottetown, which is 32 cm/century. The two time series are shown on Figure 27, over the duration of the North Sydney record. Figure 28 shows the two records together, with the datum difference removed by subtracting the difference in the means. We can see a strong similarity between the peaks and troughs in the records. In doing this comparison, we remove data for times where data are available at North Sydney but not Charlottetown, and vice versa.

The final step is shown in Figure 29, in which we put trend lines on the two data sets. Over the duration of the North Sydney record the trend at North Sydney is 30.384 cm/century and that at Charlottetown is 25.692 cm/century. The difference is 4.692 cm/century, which represents the amount by which the rate of water level rise at North Sydney exceeds that at Charlottetown. However, we know that the long term rate at Charlottetown is 32 cm/century. Therefore, the long term rate at North Sydney is 4.692 + 32.000 = 36.692, rounded off to 36.7 cm/century.

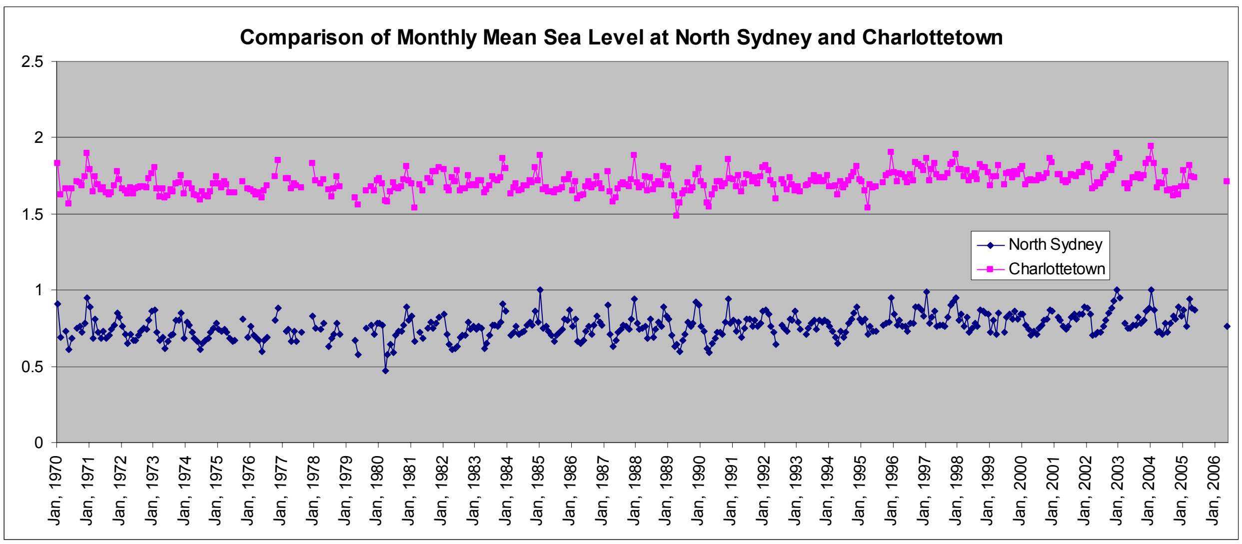


Figure 27. Monthly mean sea level at Charlottetown, PEI (mauve), and North Sydney, NS (blue), over the duration of the North Sydney record. Vertical axis in metres.

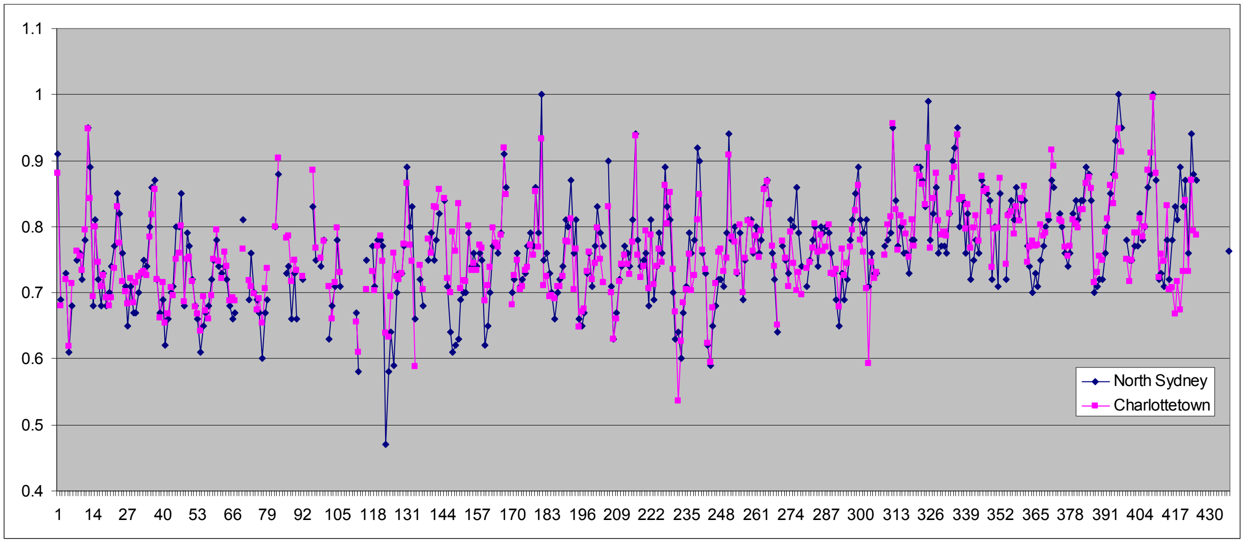


Figure 28. Monthly mean sea level at Charlottetown, PEI and North Sydney, NS over the duration of the North Sydney record, datum difference removed. Vertical axis metres, horizontal units months.

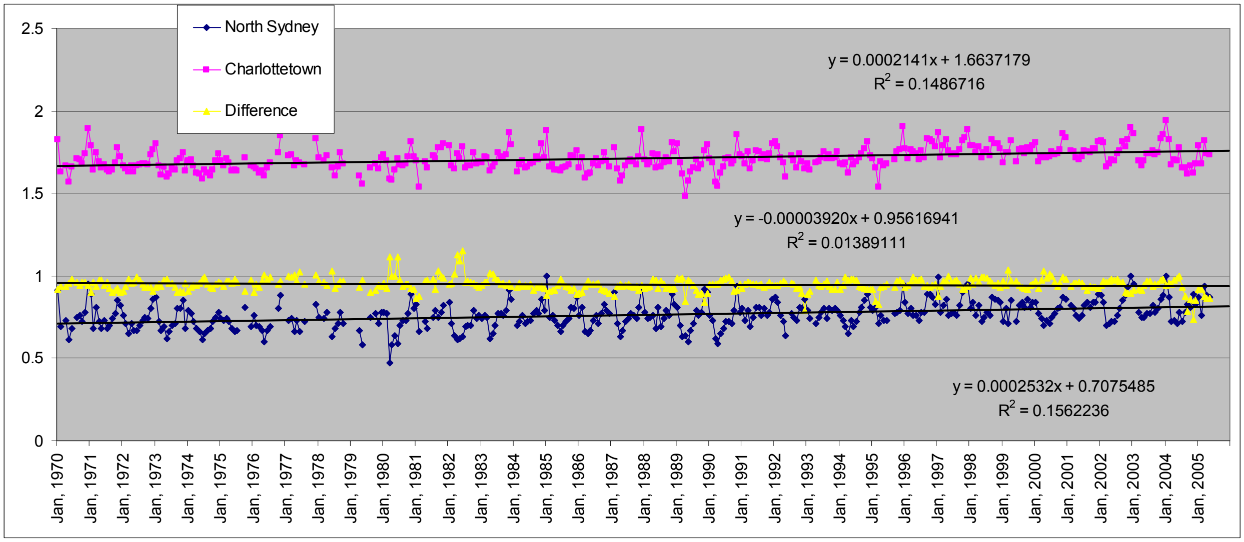


Figure 29. Monthly mean sea level at Charlottetown, PEI, and North Sydney, NS, over the duration of the North Sydney record, with trend lines shown. The yellow data are the difference between the two. Vertical axis in metres.

FUTURE SEA-LEVEL CHANGES

According to the International Panel on Climate Change (2001) the central value for sea-level rise under the various emission scenarios is a global increase of 0.48 m from 1990 to 2100 AD. We propose to adopt this ‘middle of the road’ prediction for the purposes of this paper. However, there are some problems. Firstly, it is generally assumed that in Atlantic Canada, a major component of modern sea-level rise is ongoing glacio-isostatic crustal subsidence, so a reasonable approach is to add only the subsidence component to the predicted 0.48 m. Carrera and Vaníček, (1988) argued that the mean water level increases recorded by the Halifax (NS), Yarmouth (NS) and Charlottetown (PEI) tide gauges exceeded the long-term ‘radiocarbon’ trends by an average of 0.1 m/century. Thus, to derive the future sea-level increase, we subtract 0.1 m from the modern rate of 0.37 m/century to derive the crustal subsidence rate (0.27 m/century). We than add the 0.48 m, and find that sea level in the Bras d’Or Lakes will increase by 0.75 m over the period 1990-2100 AD.

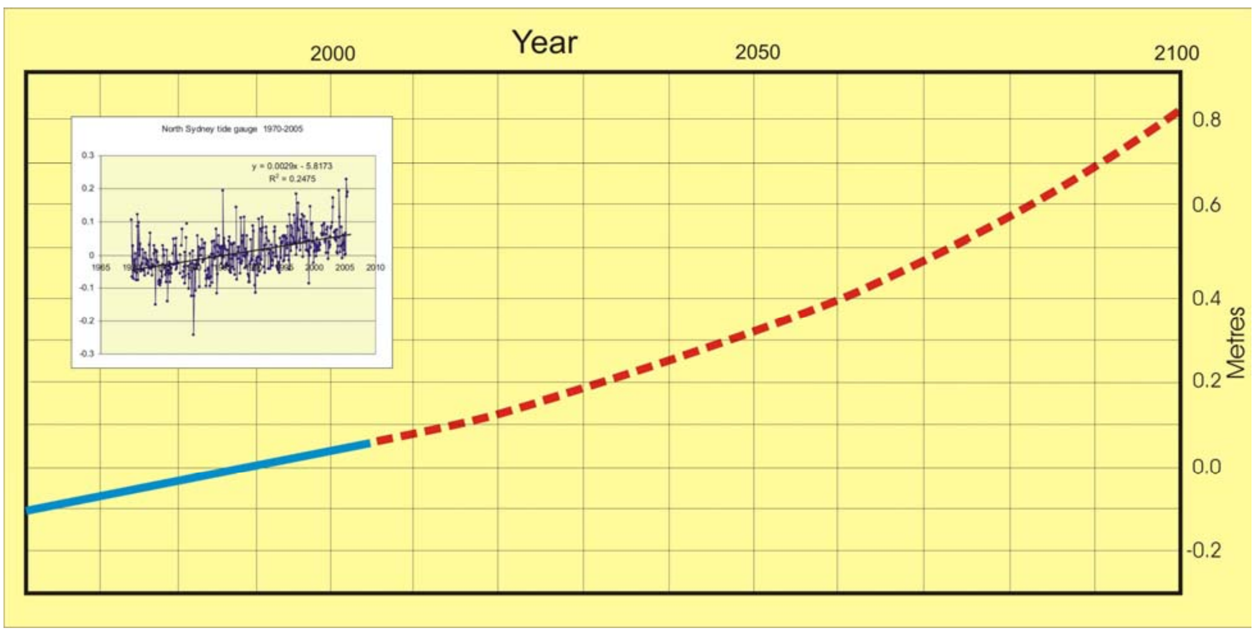


Fig. 30. Projected sea-level rise in the lakes by 2100 AD. The blue line represents the historic trend (also shown in the inset which shows the tide-gauge record at North Sydney).

There is an additional problem. As pointed out by Mikolajewicz et al. (1990), the ocean response to greenhouse warming is complex. For example, their model calculated a global mean sea-level rise of 19 cm in 50 years (projected warming 2.9 degrees Centigrade by 2050). However, regional values varied, with a rise of 0.40 m projected for the North Atlantic. From their figure 1 the projected values for areas closer to the eastern coast of Canada were in the 20 – 30 cm range. This work underscores the uncertainty of future sea-level rise, even assuming that the IPCC warming scenarios are correct.

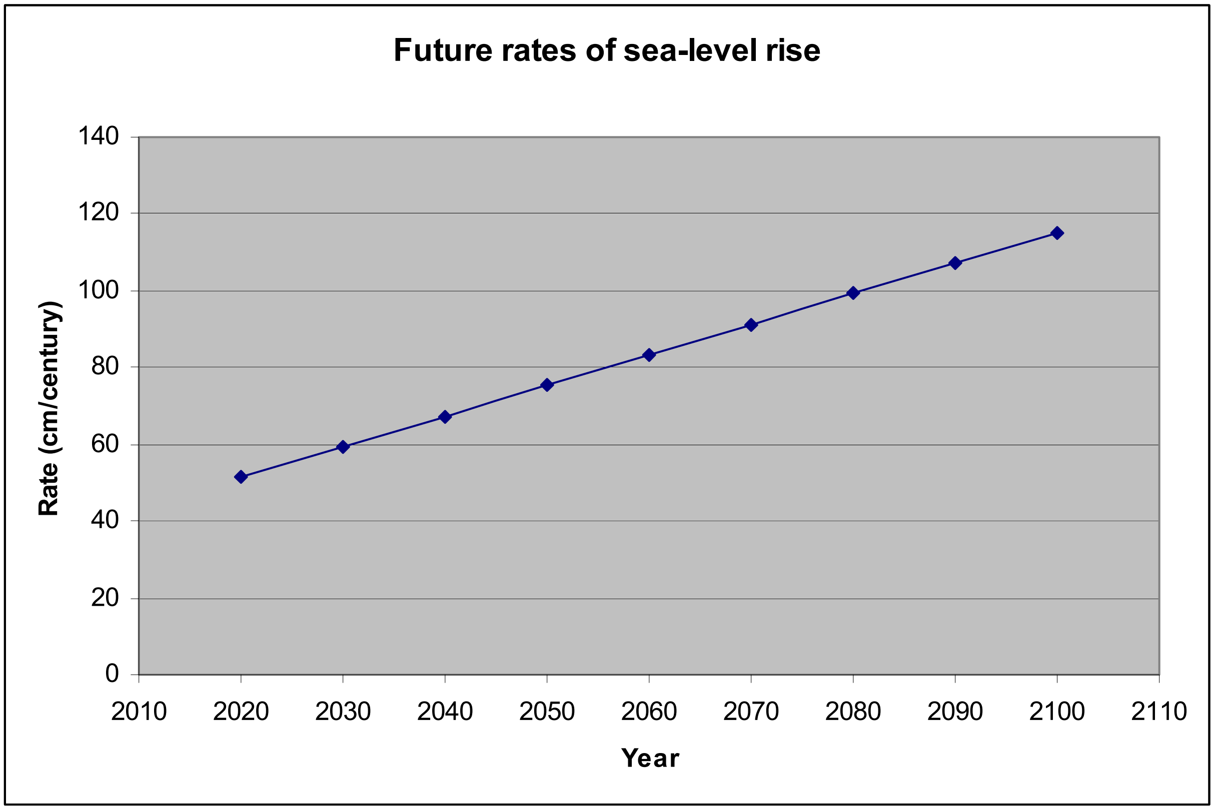


Fig. 31: Future rates of sea-level rise in the Bras d'Or Lakes.

Finally, it is worth considering future rates of sea-level rise, shown on figure 31. These are derived by taking the first derivative (or gradient) of the projected sea-level curve at selected dates. By 2030 the rate will already be 60 cm/century, and a rate of 70 cm/century will be reached by 2045. These rates of water-level increase signal danger. As noted before, the ancient beaches of the Bras d'Or lakes started to submerge with rates of sea-level rise ≥70 cm century, and submergence was still occurring when rates had decreased to about 60 cm/century. By 2030, therefore, it is likely that coastal systems will start to drown, and by 2045 is very likely that they will drown. For 2080 the predicted rate of water-level increase is 99.2 cm/century and for 2100 it is 115.1 cm/century. These rates would be catastrophic for the coastline of the lakes.

SUMMARY OF SEA-LEVEL CHANGES

- The present configuration of the Bras d'Or Lakes is relatively recent. With the departure of glaciers, the lakes were marine for a brief period. With falling relative sea level they were isolated from the ocean and existed as a system of freshwater lakes in the early- to mid-Holocene epoch.

- The ancient lakes included a large lake that drained to the ocean via the modern Great Bras d'Or Channel. It lay 25 m below modern sea level. St. Patricks Channel was occupied by a river that formed a delta southeast of Baddeck. Smaller lakes lay at higher elevations farther west, e.g., at Whycocomagh.

- In the southern part of the ancient lakes, a large river drained Denys Basin and formed a delta northeast of modern Malagawatch Point. A narrow stream drained across the modern Cod Shoals, and connected to a second large lake that was about 24 m below modern sea level. Thick glacial deposits were reworked by coastal processes to form beaches, spits, barriers and other coastal landforms along the lake shores.

- Radiocarbon, microfossil and macrofossil evidence show that the ocean flooded across the sill c. 6350 calendar years ago. The rate of water-level rise at that time was 79 cm/century.

- Coastal landforms were drowned *in situ* or migrated a short distance before drowning. The rates of sea-level rise that caused drowning ranged from 60 to 79 cm/century

- Sea level continues to rise in the lakes today at a rate of 36.7 cm/century.

- Total sea-level rise from 1990 to 2100 AD will amount to about 75 cm. However, there is great uncertainty in this figure, because of uncertainty regarding the global increase in water level due to climate change, and the regional distribution of the sea-level increase.

- We expect that low coastal barriers will start to drown *in situ* by 2030 with a rate of water-level increase of 60 cm/century, and drowning will be pervasive by 2045, with a rate of 70 cm/century. By 2100 AD sea level will be rising at 115.1 cm/century. The consequences of such a rapid rate are unknown, but are bound to be serious.

COASTLINE OF THE BRAS D'OR LAKES

Introduction

In the preceding section we examined past, present and future sea-level rise, and made some statements about the future impact of the rising water levels on the coasts. In this section we examine the physical characteristics of various shore types presently observed around the lake and discuss in more detail how we anticipate each type will be impacted by future sea level rise. Portions of this section were taken from an earlier publication published in the Proceedings of the Nova Scotia Institute of Science (Taylor and Shaw, 2002).

The Bras d'Or Lakes have been a favourite recreational location for more than 100 years and while there are many residents and visitors who sail the lakes and who know the area intimately, there have been few scientific investigations of the coastline. In the early 1900s it was the remarkable assemblage of depositional features, primarily coastal barriers that attracted the earliest coastal investigators such as Tarr (1898) and Woodman (1899). Goldthwait (1924) and Johnson (1925) also used the features to illustrate their classic texts on New England and Atlantic Canadian coastlines. No coastal geology studies are known to have been completed in the lakes since the early 1900s; however, there have been a number of other studies related to the coast. For example, Smith and Rushton (1964) described a number of coastal ponds or barachois in their study of potential sites for trout farming, and Grant (1988, 1994) mapped the surficial deposits of Cape Breton Island including the shores of the Bras d'Or Lakes. The maps by Grant provided a starting point for dividing the coast into rock and non-rock shores and for obtaining a general understanding of the backshore composition and distribution of specific types of deposits (e.g. glacial) and their abundance. Sailing guides also provide a general description of the shores.

In June 1996 an aerial video survey provided the first continuous view of these shores (Taylor and Frobel, 1998). The aerial video was collected primarily for mapping the physical character of the shoreline and for use in emergency oil spill response activities by the Canadian Coast Guard, but it has a variety of other uses. At the request of the Eskasoni Fish and Wildlife Service, the tapes also include brief coverage around Malagawatch, Whycobah (formerly Whycocomagh), Wagmatcook, Eskasoni, and Chapel Island Indian Reserves, traditional herring spawning grounds and all native and non-native aquaculture sites. The survey was also completed in support of the broader scientific investigation of the Bras d'Or Lakes that was initiated during the Bras d'Or Lakes Workshop held in Sydney on March 23, 24 1996. The aerial video was used to describe the physical characteristics of the shoreline along each of the main bodies of water within the Bras d'Or Lakes (Taylor and Frobel, 1998), for an analysis of coastal barriers (Taylor and Shaw, 2002), and in the present study.

A coastal classification

The Bras d'Or Lake coastline can be subdivided into three principal classes on the basis of composition and resistance to physical change: **Rock Shores** - primarily composed of bedrock; **Non-Rock Shores** - primarily composed of unconsolidated material; and **Artificial Shores** - composed of material added or constructed by people. Table 5 lists three types of rock shore (1-3) and seven types of non-rock (unconsolidated) shore (4-10). All **Artificial Shores** are combined into one group (11). Where there was insufficient information to assign shores to a specific type, they have been mapped as undifferentiated; most are assumed to be non-rock shores. The shoreline mapping is presented as an ARC-GIS product on the accompanying CD.

Shore types within each of the three coastal classes are differentiated on the basis of their physical character and changes across shore, (e.g., barrier beaches are backed by water and fringing beaches by non-cliffed rising backshores). The shore types also provide a qualitative measure of the processes reworking the shoreline and shore stability. For example cliffs are erosional features and beaches are depositional. Within the non-rock shores vegetated shores which exhibit little or no evidence of wave-built beach features have been placed in separate categories. Vegetated shores develop in areas of very limited wave fetch and some such as riverine shores can be dominated by non-marine processes, e.g., fluvial. The shore types provide a measure of coastal sensitivity to physical change caused by rising sea level but only provide a measure of sensitivity to flooding when they are examined in conjunction with maps of backshore elevation. Nevertheless, rock and cliffed shores (classes 1 to 6) are less sensitive to flooding than barrier beaches (class 7) and vegetated shores (class 8-10), because they have higher backshores.

Detailed description of shore types

In this section, we provide a description of the primary shore types which have been mapped along the Bras d'Or Lakes using the GIS program ARCINFO (contained in the CD). The description is based upon aerial video flown in 1996 and brief field surveys completed at a number of representative sites in 2004 (Taylor and Frobel, 2005). In the present mapping project we have used a slightly different approach than in the mapping completed earlier by Taylor and Shaw (2002). For the mapping in 2002, shores were lumped into dominant backshore categories. For example, along Great Bras d'Or Channel near Campellton, although the backshore is predominantly high bedrock and was mapped as rock in 2002, much of shoreline is fringed by a road and is therefore mapped in this exercise as artificial (unit 11) or as vegetated (unit 8). We have also subdivided the shoreline into more divisions than were used by Taylor and Shaw (2002). There is also a difference in the total shoreline length used: the total length of shoreline is 1272 km, whereas Taylor and Shaw (2002) used a length of 1234 km. The increase in shoreline length is attributed to the higher resolution maps 1:10,000 vs 1:50,000 used in the present program, and the inclusion of all backbarrier lagoon shores in the present mapping exercise, which also resulted in an increased length of undifferentiated shores.

An estimated 10 % of the Bras d'Or lakes coastline is mapped as rock. Rock shores are concentrated along the upland shores of Great Bras d'Or and St. Andrew's Channels, the north shore of Bras d'Or Lake, and a few small areas along East Bay (Fig. 2). The physical character of these shores is closely correlated with the underlying local bedrock and its resistance to erosion. The highest backshores (76 m) exist in areas with the oldest and most resistant rocks: granites in the north and volcanics in the south. Rock shores have been subdivided into three categories: low rock outcrop, rock cliff, and rock with fringing beach.

An estimated 74 % of the shoreline is non-rock. Much of the coastline of the Bras d'Or lakes was covered by glacial deposits (Grant, 1988) which are the primary source of sediment for the unconsolidated shores. We differentiate the non-rock shore initially by differences in cross-shore morphology into cliffed (types 4 and 5) from non cliffed shores (types 6 and 7) and coastal barriers (type 7) which are backed by water from shores with a higher backshore (type 6). The unconsolidated cliff (type 4) most closely represents the original glacial deposit and it forms the critical roles of an anchor and sediment supply for adjacent shores.

Shore types 8, 9, and 10 are mapped as vegetated, representing 30.4% of all the shoreline in the lakes. Vegetated shores are generally in wave sheltered embayments and lack well-defined wave-built beach features. The shores are covered by emergent or submergent vegetation including, trees, shrubs, and grasses. Plant growth acts as a protective cover for backshore areas by reducing and filtering surface runoff. Vegetated shores are often less accessible by vehicle, and thus less developed.

In this mapping exercise three types of vegetated shores were identified based on their wave exposure and geomorphic processes, i.e. fluvial vs marine, and accumulation of organic deposits. We have followed a framework for mapping coastal wetlands suggested by Keough et al. (1999) and Albert et al. (2003) for the Great Lakes. The three categories identified in this study include: exposed-, protected- and riverine-vegetated shores. All of our categories have direct surface water connection with the main part of the Bras d'Or lakes. Protected vegetated shores are near the heads of long narrow bays and inlets, and are less exposed to wave and sea ice action. The riverine shores include wetlands at river mouths and deltas. A fourth category of vegetated shores, found behind coastal barriers and not directly connected to the main lakes, was used by Albert et al. 2003, but was not used in the present mapping exercise since these shores were grouped with the coastal barriers.

Artificial shores include human-built structures such as wharves, jetties, breakwalls and armour rock fill along road and railway lines. These structures are designed to protect or support the shores from erosion and therefore are more resistant to change. The scale of the coastal mapping (on CD) precludes showing individual shore structures so only the more extensive areas of fill along railways and roads are mapped.

Roughly 13 % of the shores, mainly within the long narrow embayments, were either not video taped or visited in the field so their shore type could not be identified. Given their location these shores would probably be unconsolidated and fit into vegetated coastal units 8 or 9.

Table 5. Coastal classification for the Bras d'Or lakes. Classes 1-3 are rock shores; 4-10 are non-rock shores; and 11 includes all artificial shores. All shores that could not be mapped because of a lack of information are designated as undifferentiated.

Shore Type & Coverage (%)			Description
Rock (10 %)	1	**Low Rock Outcrop (0.6)**	Outcrops and ramps, no continuous beaches; low elevation; plan form controlled by bedrock orientation.
	2	**Rock Cliff (6.7)**	Outcrops with cliffs or steep slopes, blow holes and caves; no beaches. Cliffs may have overburden. Moderate to high elevation.
	3	**Rock with Fringing Beach (2.8)**	Cliffed or non-cliffed shores with beaches wider than 10 m. Backshores reached by wave action during high water or storm events. Moderate to high backshore elevation
Unconsolidated (74 %)	4	**Unconsolidated Cliff (3.8)**	Eroding cliffs composed of glacial sediment, moderate elevation, exposed to higher energy waves
	5	**Unconsolidated Cliff with Beach (13.6)**	Cliffs composed of glacial sediment fronted by wide beaches; cliff face only impacted by storm wave action; low to moderate elevation, backshore slope may be vegetated.
	6	**Fringing Beach (13.7)**	Continuous wide beach backed by non-cliffed backshore rising to higher elevation; includes forelands with no backshore water.
	7	**Coastal Barrier (12.3)**	Low sand & gravel or gravel beach backed by water or wetland; can be a barrier beach, spit or tombolo.
	8	**Vegetated - Exposed (11.9)**	Winnowed boulder shore, some scarped backshore, limited wave exposure along narrow channel or limited beach reworked infrequently by waves from restricted fetch direction; little organic accumulation.
	9	**Vegetated - Protected (12.6)**	Emergent and submergent vegetation, restricted fetch and waves; more organic accumulation, no beach development
	10	**Riverine (6.0)**	Delta or drowned river mouth, levees, channels and wetlands
Artificial (3 %)	11	**Artificial (2.7)**	Man-made material including armour rock, vertical walls, fill, bridge structures, causeways, wharves, boat launches
		Undifferentiated (13.3)	No information available - most unconsolidated and vegetated.

Type 1: Low Rock Outcrop

Low rock shores include isolated rock outcrops or more continuous rock ramps. They make up only 7.1 km of the 1272 km of total shoreline along the lakes. Good examples of isolated outcrops are found along East Bay and St. Peter's Inlet, where irregular volcanic outcrops form small headlands.

Figure 32. Aerial view of low volcanic rock outcrops along the shoreline near Irish Vale, East Bay. Glacial deposits are stripped off the top of the rock by waves, and pocket beaches can develop as the shoreline retreats, exposing the rock outcrops (Photo R. Taylor, 25-June 1996).

In some cases the rock outcrops have trapped sediment as small pocket beaches in the adjacent embayments. Low rock shores also are found where waves have stripped off the surficial glacial deposits, exposing rock beneath (Fig. 32). Examples of these low rock shores can be found along the northwest shore of Little Narrows and near Derby Point and Pipers Cove where rock ramps consisting of conglomerate rock exist (Figs. 33, 34). Shore rock ramps facilitate wave run-up and sea ice ride-up and erosion of the upper backshore cover of glacial deposits. Yet an examination of a shore segment near Derby Point in 2004 suggested little significant retreat during the past 32 years based on measurements from an old foundation to the top edge of the shore bank (Taylor and Frobel, 2005).

Figure 33. Aerial view of rock ramp shoreline in Pipers Cove showing the extent of wave runup and possibly sea ice rideup at the seaward edge of the vegetation (Photo R. Taylor, 21 June 2001).

Figure 34. Ground views (a) in winter of sea ice ride- up along the shore cliffs scraping them clear of debris and b) rock ramps consisting of steeply dipping conglomerate rock capped by glacial till, Derby Point to Pipers Cove (Photos T. Lambert, 9 April 2000 (a); and R. Taylor, 21 November 2000 (b).

Low rock outcrops consisting of possibly white gypsum and/or anhydrite also have been observed from the air, extending out from under a number of coastal barriers e.g., Maskells Harbour. No ground measurements were made to confirm the type of rock, but if gypsum, they would be subject to solutional weathering and their deterioration would impact the stability of the coastal barriers and backbarrier lagoons.

Type 2: Rock Cliff

The most conspicuous shore cliffs are cut into Windsor age rocks consisting of white gypsum, and anhydrite, sandstone, limestone or shale. They are generally less than 15 m elevation, and are found along the railway line between Jamesville and Iona, Bras d'Or Lake (Fig. 35), along Island Point, St. Andrew's Channel, and in Big Harbour, Great Bras d'Or Channel. Solutional weathering of the upper slopes and sink holes are associated with these outcrops. Slumping of glacial deposits from above the cliffs may temporarily bury the rock and slow the rate of retreat.

Figure 35. Aerial view of low shore cliffs composed of gypsum. Armour rock covers the rock in places to help reinforce the base of the railway line, west shore Barra Strait (Photo R. Taylor, 21 June 2001).

Other examples of younger clastic rock cliffs are along Pipers Cove, Bras d'Or Lake where well defined shore ramps (Fig. 33, 34) are backed by cliffs of 15 to 20 m. Both the ramps and cliffs are cut in seaward dipping conglomerate rock, topped by glacial deposits. Near Benacadie Point the bedrock is similar but shore ramps do not form because of a change in bedding orientation. Well developed shore cliffs composed of younger more recessive rocks mark Kempt Head at the south end of Boularderie Island; nearly continuous cliffed rock shores along the north side of St Andrews Channel; the low rock cliffs which constrain Little Bras d'Or Channel, and the 45-60 m high cliffs of Indian Island in Whycocomagh Bay.

The most notable granite shore cliffs form the high promontory at Red Point, at the mouth of Baddeck Harbour. The cliffs are estimated to be 15 m high and the caretaker at Beinn Bhreagh (Alexander Graham Bell Residence) reports the cliff tops are very weathered and very crumbly but do not experience rapid retreat. Long Island, St. Andrew's Channel consists of older non-granitic rocks which form 45-60 m high, talus banked cliffs. Upland volcanic rock shores occur at Middle Cape along East Bay.

Type 3: Rock with Fringing Beach

Some of the highest parts of the coastline have steep sloping backshores which reach more than 150 m elevation but are fringed by wide, well defined beaches. They make up 2.8 % of the shoreline and include much of the east shore of Washabuck Peninsula, southeast Boularderie Island, Long Island and parts of upper St Andrews Channel, small areas along the north shore of Whycocomagh Bay and along the shores of Marble Mountain, West Bay. The high rock shores are often forested and covered by thin blocky rubble (Grant, 1988). Rock falls and other slope processes are locally important along these shores.

Figure 36. Aerial view looking southeast along the 45 m high talus-banked rock shoreline (Type 2) of Long lsland, St Andrews Channel. In the foreground a rock headland traps sediment for a wider beach at the base of the cliffs (Type 3) and a small foreland has developed farther alongshore where the shoreline orientation changes abruptly (Photo R. Taylor, 25 June 1996).

Type 4: Unconsolidated Cliff

Unconsolidated shore cliffs are few and are best developed along East and West Bays, Boulardarie Island, and Bras d'Or Lake, where glacial deposits are thicker (Grant, 1988). These shores consist of a steep, erosional free-face cut into till and are fringed by a narrow deposit of coarse rubble overlying till (Fig. 37). The best examples of this shore type are along drumlins, especially where the long axes of drumlins intersect present sea level. The backshore cliff face is generally less than 15 m elevation and forms an isolated and wave-exposed headland position. Most sediment eroded from this shore type is transported alongshore toward the lee of the drumlin. The sizes of the clasts remaining at the base of the cliff depend upon cliff composition, local wave energy and its transport potential. Generally only the coarsest clasts, e.g., boulders, remain at the base of the cliff. As the cliff face retreats additional large clasts can accumulate and, in some cases, provide a natural defense against the sea. During storms, breaking waves cut down the till underlying the large clasts resulting in their lowering and over time the creation of a lag shoal seaward of the cliff. Once consumed by the sea, the drumlins remain as coarse sediment shoals or nearshore platforms just beneath the sea surface (Fig. 38).

Figure 37. View of eroded drumlin on Sheep Island, at the mouth of Malagawatch Harbour. Wave energy is higher at the right end of the drumlin where only the coarsest clasts remain at the base of the cliff. Finer sands and gravels are transported toward the lee of the drumlin where wider beaches develop, such as the double loop bar visible at the back of the island (Photo R. Taylor, 24 June1996).

Much of the shore cliff at Malagawatch Point has been mapped as coastal Type 4 but it changes to Type 5 with a wider beach to both the east and west of the cliff recession site. The cliff site is 300 m long and extends to an elevation of 8 m. The cliff slope consists of uniform reddish brown silt clay with pebble to boulder clasts. The backshore slope is undulating to slightly stepped and covered by grass sods and trees that have slid downslope. The surface sediment when dry is very hard, but when wet, it can become very unstable and flow downslope. The base of the cliff is commonly fringed by a low scarp where waves have cut into the hard material. During spring melt, mud from the cliffs flows downslope over top of the beach sediment. The discovery in 2001 of a Hydrographic survey marker (established in 1972) at the base of the cliff just landward of Macrae Island (Fig. 38) provided an estimate of long term cliff retreat. The benchmark was established just over 10 m back of the cliff edge. It took 29 years before it was eroded - an average rate of cliff recession of 0.34 m/a. Repetitive surveys of Malagawatch cliff between 2001 and 2004 showed less than 0.1 m/a of cliff top recession. The beach consisted of moderately well sorted pebble and granule material with scattered boulders offshore (Fig. 39).

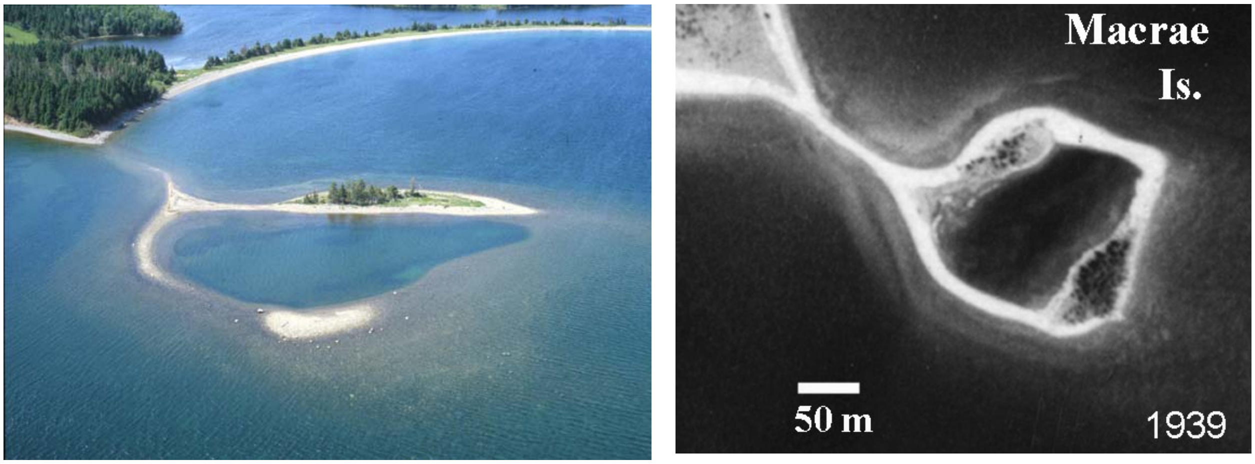


Figure 38. Aerial views of Macrae Island at the mouth of Malagawatch Harbour. Vertical air photo of Macrae Island in 1939 (right) and a view of the same island in 2001 (left). Sixty-one years later all that remains is an extensive lag shoal marking the position of the former drumlin, a depression from the former pond and part of the loop bar which had built in the lee of the drumlin. The ridge at the back of Macrae Island has become submerged but provides a corridor for sediment transport from the island to the Johnson Cove shore in the background (Photo at left, R. Taylor, 21 June 2001).

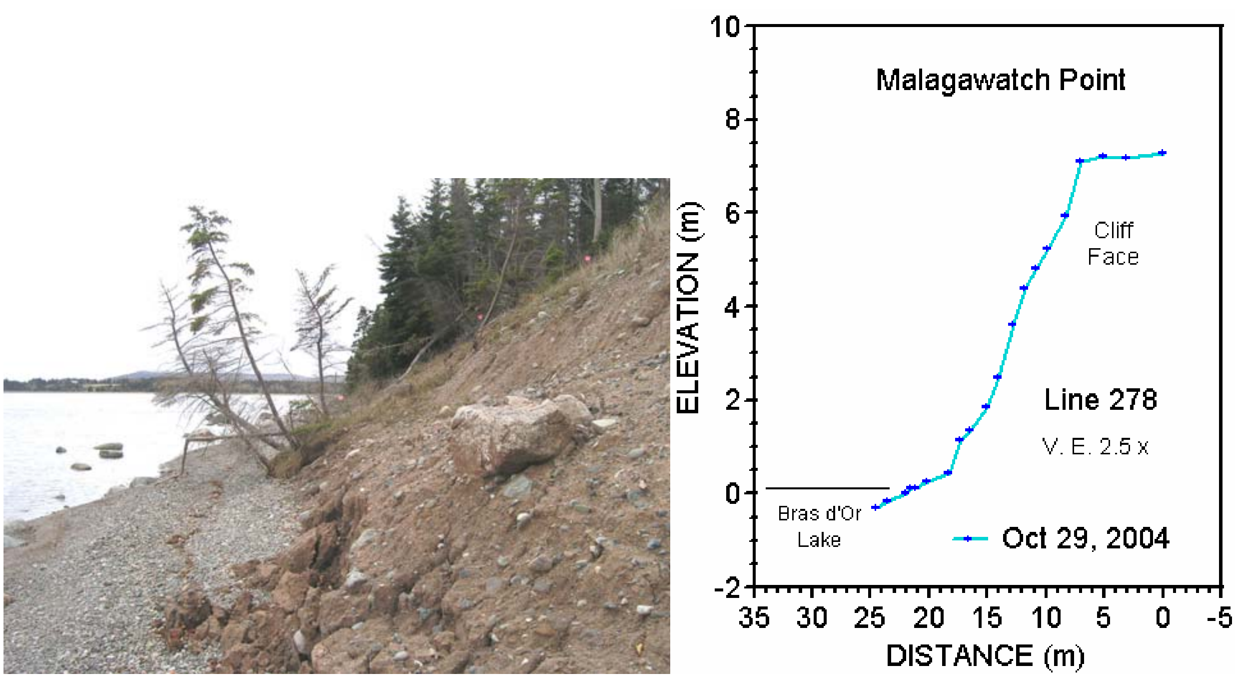


Figure 39. Looking west along the beach and unconsolidated shore cliff at Malagawatch Point, where cliff top change was less than 0.1m/a between 2001 and 2004. The base of the cliff was being trimmed back during higher energy wave events and clumps of vegetation were sliding downslope during wet conditions (Photo R. Taylor, 29 October 2004). The cross-sectional survey of the cliff face (right) was located where the pink flags are shown in the photograph.

Type 5: Unconsolidated cliff with beach

Although having a similar high erosional backshore slope as shoretype 4, the base of the cliff in this case is a much wider and thicker beach (Fig. 40). Beaches are more than 10 m wide and beach material is thick enough to bury the underlying till except in severe storms. Sediment supply for beach development is greater and the shoreline is in less exposed areas where longshore sediment transport and supply are greater. These shores develop more where sides rather than the ends of drumlins intersect present sea level. The wider beach can provide a buffer for the backshore against normal wave attack. The greater protection can allow increased growth of vegetation across the backshore slope, particularly if it is more rounded and less cliff-like. Cape George and Big Pond, West Bay headlands provide examples of this shore type.

Figure 40. Aerial view of a low erosional cliff with fringing beach in the vicinity of Middle Cape, East Bay (Photo R. Taylor, 21 June 2001.)

Figure 41. Aerial view looking east toward Kidston Island and Baddeck showing a typical fringing beach with a rising backshore (Photo R. Taylor, 21 June 2001)

Type 6: Fringing Beach

While shores with a fringing beach can be similar to shore type 5, they differ in that the backshore is non-cliffed and generally the beach is the more dominant feature rather than the backshore (Fig. 41). The backshore rises in elevation in a landward direction and because of the lack of an erosional profile is not considered to be a significant source of sediment supply to the present beach. Thicker and wider beaches develop where sediment supply is more abundant and wave energy is sufficient to transport the clasts. These shores, as with Types 4 and 5, occur everywhere in the lakes but mostly along the lower inner lakes where glacial deposits are thicker. They include 13.7% of the total shoreline. Fringing beaches are the connecting shore feature between coastal barriers and the cliffed shores which supply sediment to the beaches and barriers. Small coastal forelands not backed by water are included in this category, even though they are a wider depositional beach feature. Within very wave sheltered areas, e.g., North Basin, smaller fringing beaches with very small wave formed features occur, but often they are covered by grasses or shrub vegetation hence were classified with vegetated shores. In many parts of East Bay the beach is backed by widely spaced artificial structures such as armour stone and walls but remain in this shore category because of the artificial features remain too small to map at the scale we are using.

Type 7: Coastal Barrier

Coastal barriers include spits, tombolos, and forelands where beaches are backed by water such as ponds or lagoons (Figs. 42, 45, 47, 50, 51, and 53). Woodman (1899) recognized a number of different types of accumulation features in the Bras d'Or lakes including: cusps, loop bars, bay bars spits, tombolos and winged beheadlands (a headland having spits extending from both sides in opposite directions). Many of the names he used to describe the features have changed and evolved, as has our understanding about the evolution and linkage of different shore features. All of the depositional features he cited are still present in the lakes 100 years later. Some have changed significantly; others have not. Even within the same geographic area, where the shores were subject to similar wave energy, significant differences in shoreline change were observed.

Figure 42. Aerial view of Barachois spit, St. Andrews Channel which was completely intact in the 1890s when Tarr (1898, Fig. 2) photographed this feature. In 2001 the proximal end of the spit appeared wider and much shorter than in the late 1800s. A new recurved ridge was building at the end of the present spit (arrow) but the water depths were too great to allow rapid progradation (Photo R. Taylor, 21 June 2001).

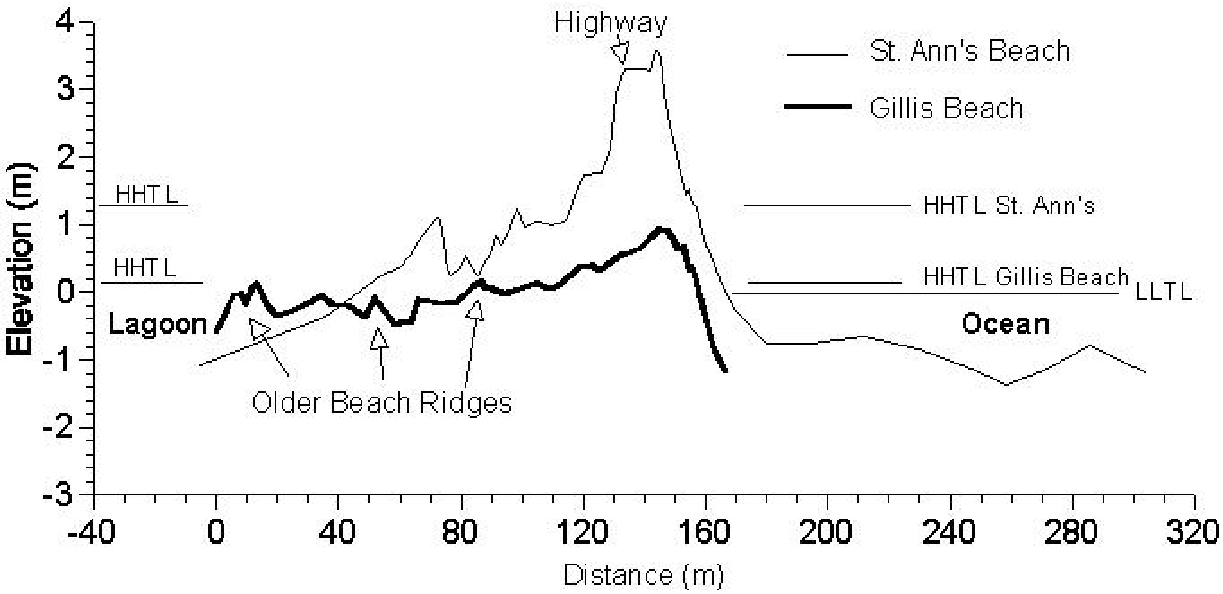


Figure 43. Cross-shore profiles of coastal barriers from St. Ann's Bay on the outer Nova Scotia coast (Fig. 2) and Gillis Beach, Bras d 'Or Lake, illustrate the difference in vertical extent of beach features in the two areas. The large tidal range is 1.34 m at St. Ann's (CHS, 2000) and 4 cm in Bras d'Or Lake (Petrie and Bugden, 2002). The difference between the seaward beach crest elevations is 2.3 m. Both barriers are backed by older submerged beach ridges. Vertical datum for both beaches is set at lower low tide level (LLTL). HHTL is higher high tide level. (St. Anns Beach survey data are courtesy of D.L. Forbes and D. Frobel, GSCA).

Coastal barriers can be a simple, narrow, single beach ridge or much more complex features consisting of multiple beach ridges and anchor points. Coastal barriers develop where sediment supply is more abundant and there are anchor points, e.g., headlands or islands, which the beach can build against or attach to.

Taylor and Shaw (2002) identified 76 coastal barriers which were 250 m or longer within the lakes (Fig. 44; Appendix 2). They included 41 barrier beaches, 1 looped barrier, 15 spits, 12 tombolos, and 8 cuspate forelands. Thirty-two percent of the 76 coastal barriers were cut naturally by permanent tidal channels and 25% by temporary or seasonal tidal channels and 6.5% were artificially cut open by people. The stability and evolution of coastal barriers depends on whether they are swash-aligned, drift aligned or a combination of both. Drift-aligned barriers such as spits (e.g., Fig. 42) are built by waves striking the coast at an oblique angle moving sediment alongshore; swash-aligned systems occur where waves strike more directly onshore and move sediment onshore - offshore (Fig. 47). Some of the larger coastal barrier complexes may include both drift- and swash-aligned components. Swash-aligned barriers tend to be more concave in shape and build across embayments. Drift-aligned barriers tend to be straight to convex in shape and extend alongshore with multiple ridges near their distal end. Barrier beaches can extend to more than 1 km in length. Beach-ridge plains are usually less than 350 m in length; however in a few cases, multiple beach ridges extend to 700 m, such as along East Bay and Bras d'Or Lake. The larger features exist in areas of longer wave fetch.

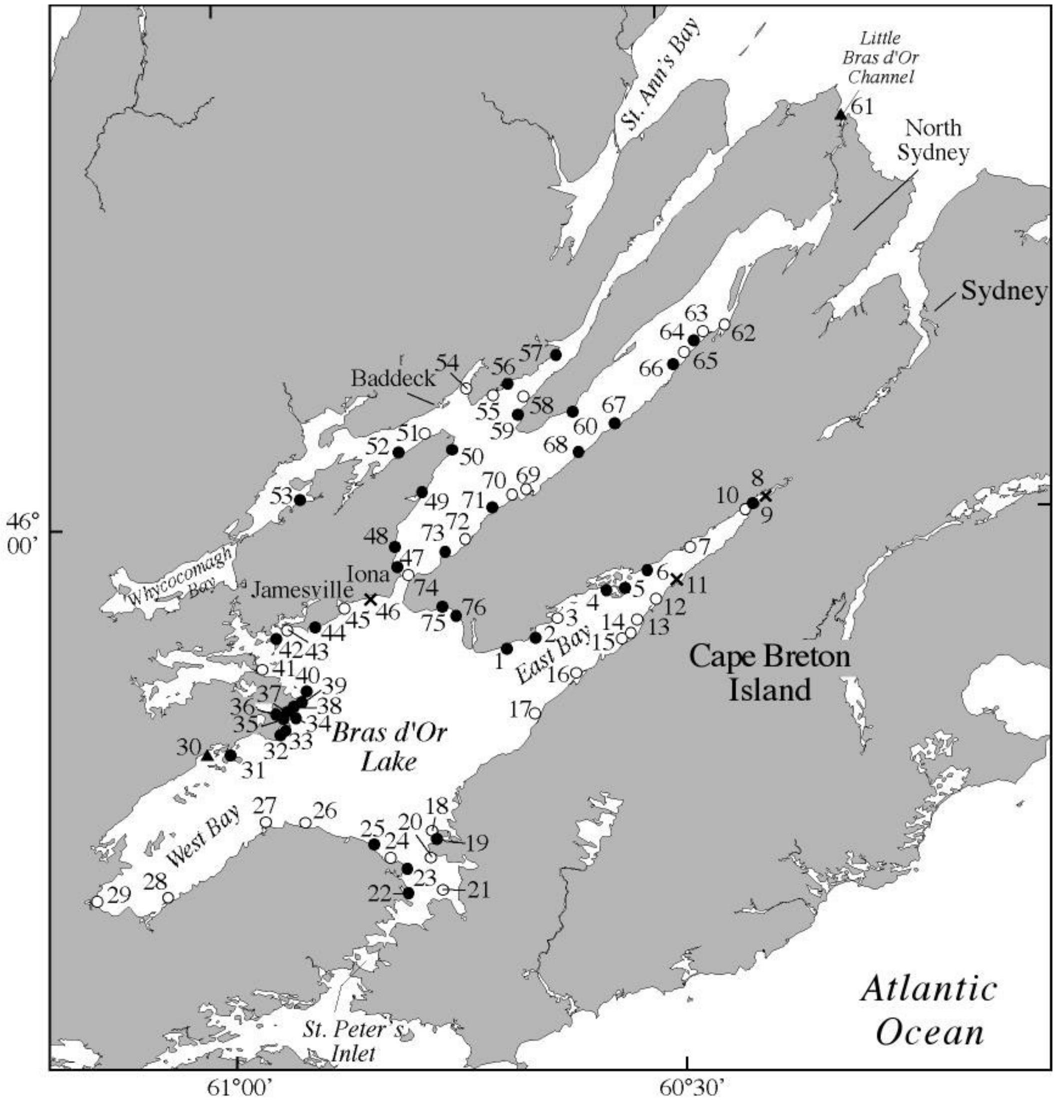


Figure 44. Locations of coastal barriers more than 250 m long in the Bras d'Or lakes. Coastal barriers include 12.3% of the total shoreline. The different location symbols, numbered, denote the stage in the evolution of each barrier: growing (triangle), established / stable (filled circle) degrading (open circle) and artificially constrained (x). The evolution of coastal barriers is discussed in the next section of this report. See Appendix 2 for site descriptions.

During this study, markers for monitoring shoreline change were established at three barrier beaches, Grass Cove, Gillis Beach and Johnson Cove (Fig. 44, sites 48, 45, 38) where detailed surveys were completed. Photographs and notes were collected at two other sites: Poker Dans and McKillop Ponds at the north end of the Lakes (Fig. 44, sites 55, 56).

Geographic Name	Beach Length (m)	Beach Width[1] (m)	Crest Elev. Above HTL (m)	Beach Slope [2] (Tan θ)	Textural Analysis	Mean (mm)	Sorting[3]	% gravel
Grass Cove	400-500	75	0.75	0.14	----	---	---	----
Gillis Beach	700	48	0.69	0.15	Upper Beach Swash ridge	4.14 4.19	6 3	70.7 96.6
Johnson Cove	500	44	0.75	0.17	Upper Beach Swash ridge	4.00 2.54	5 4	77.8 67.3
Poker Dans	100+ 250	10-16	----	----	Swash ridge	3.22	4	85.3
McKillop Pond	100 + 50	15	----	----	Swash ridge	13.36	5	97.0
North Basin	N/A	3-4	0.56	0.14	Swash ridge Lower beach	13.92 33.82	4 1	99.9 99.9

Table 6. Physical Characteristics and sediment texture of coastal barrier beaches surveyed in the Bras d'Or Lakes. Measurements and samples collected from a vegetated protected beach at the head of North Basin provide a contrast to the more wave exposed coastal barriers. [1] Width between lake and lagoon shores at an elevation of 0.6m. [2] Slope of beach below water level. [3] Degree of sediment sorting: 1. very well sorted; 2. well sorted; 3. moderately well sorted; 4. moderately sorted; 5. poorly sorted; 6.very poorly sorted; 7. extremely poorly sorted (Folk, 1974)

Grass Cove, Gillis Beach and Johnson Cove beaches are all large barrier beaches with an established succession of vegetation from dune grass to trees and wetland plants, e.g., cattails, along the backbarrier ponds. At all three barriers multiple lower beach ridges exist in the backshore and the barrier elevation increases in a seaward direction. At Gillis Beach, beach ridge elevation increases seaward from 0.02 m below water level at the most landward ridge to 0.93 m at the most seaward ridge (Fig. 45). The most landward ridges are submerged and covered by wetland vegetation and soft mud varying in thickness from less than 0.1 to 0.5 m over a coarse substrate.

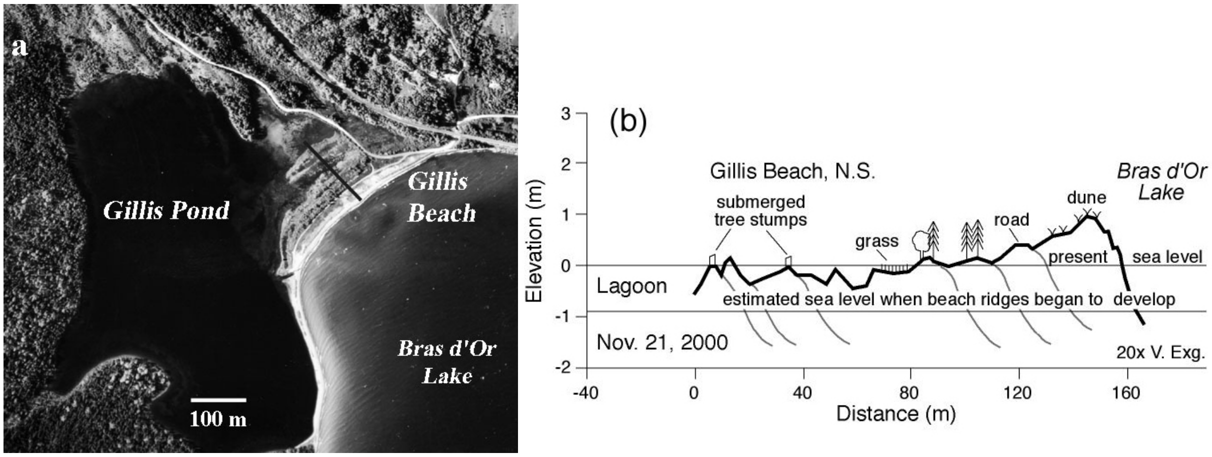


Figure 45. (a) Aerial view of Gillis Beach (air photo 98301-212, 11-June-1998) showing multiple beach ridges at the north end. The line marks the location of the cross-section (b) which illustrates the seaward rise in elevation of the beach ridge crests to the most seaward ridge which is aggrading by wave overwash. Old submerged tree stumps on the back barrier ridges provide evidence of a rising sea level. Based on a rate of sea level rise of 0.32 m/century an estimated minimum age of this beach complex is 300 years.

A similar cross-sectional profile existed at Grass Cove (Figs. 46, 48) except the ridge just seaward of the trees had been modified for highway construction. At Johnson Cove the backshore (Fig. 47, 48) consisted of at least 1.2 m of sand (limit of corer). The field survey could not be extended far enough landward to survey the backbarrier ridges observed on the air photos. The presence of tree stumps on the submerged ridges (Fig. 45) at Gillis Beach, similar to those reported at a number of other sites by Grant (1994), provides evidence of rising water level. The most seaward beach ridge is higher and composed of wave overwashed sand and granule material which suggests the beach is building as it is pushed landward. If one assumes that the tidal range has not changed and beach ridges were built to similar elevations in the past as they are now, then the landward ridges would have been built when sea level was 0.9 to 1.0 m lower. Since sea level has risen at an estimated 0.32 m/century, a minimum age for the Gillis Beach complex would be 300 years.

Both Grass Cove and Gillis beaches are artificially opened from time to time to prevent flooding of the backshore areas. No tidal channels are known to have cut through Johnson Cove. Grass Cove Beach has been impacted in the past by a large gypsum mine operation and the construction of highway along its length. Gillis Beach has always been a popular recreational beach and in 2004 a residence was being constructed less than 0.5 m above sea level on the low backbarrier ridges. Johnson Cove Beach, apart from some ATC traffic along it by local residents, has remained natural.

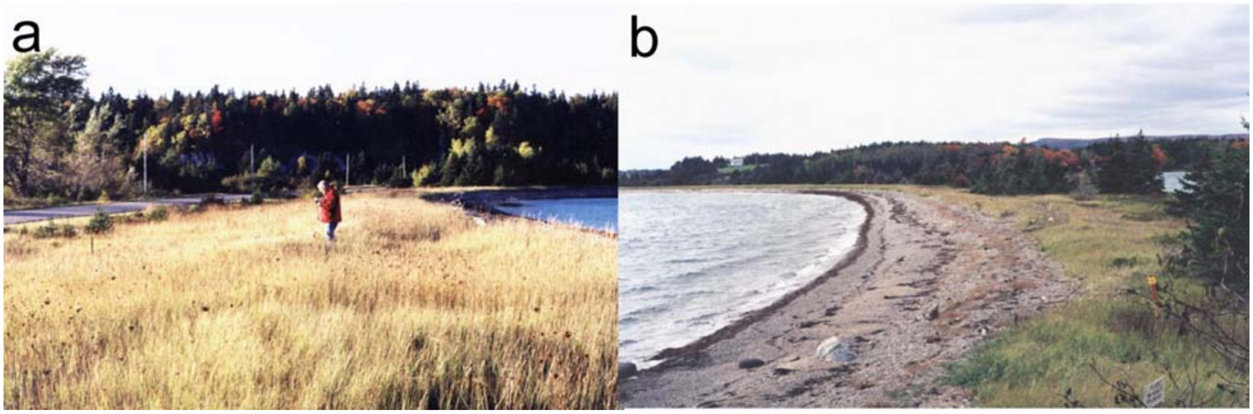


Figure 46. Views (a) of Grass Cove Beach (person on the survey line) and (b) Johnson Cove Beach illustrating the low backshore dune topography and landward succession of vegetation from grasses to trees, shrubs and cattails along the backbarrier pond. The grasses are growing on a substrate of sand and granule material. A highway extends along the backshore at Grass Cove. An aerial view of Johnson Cove beach is provided in Figure 47 and a cross-shore survey across the two beaches is shown in Figure 48. Photos R. Taylor, 15 October 2003.

Maximum potential wave fetch decreases from 48 km off Grass Cove, to 31 km off Johnson Cove, and to 22 km off Gillis Beach. All three beaches consist of a mixture of sand and gravel and have a steep foreshore slope of 8-9º (Tan Φ=0.14 to 0.17, Table 6). The steep slope is attributed to the short period waves that rework these shores. At Grass and Johnson Coves the subtidal slope was steep to the limit of our wading. At Gillis Beach there was a sharp break in slope and a nearshore sand bar. A sand seabed was detected at the seaward extent of our surveys at Grass and Johnson Coves.

Repetitive cross-shore surveys completed between 2000 and 2004 at Gillis Beach and Johnson Cove both indicated the beaches had prograded by 3 m at the upper beach face. In both cases, well defined swash ridges were developed and there was some aggradation of the beach crest at Gillis Beach. The swash ridge at Johnson Cove consisted of more sand and had a mean grain size of 2.54 mm, whereas the swash ridge built at Gillis Beach was coarser. The vertical extent of physical changes observed on these beaches is much greater than would be expected given a 4 cm tidal range at Iona (Petrie and Bugden, 2002). The barrier crest (maximum) elevation of these more exposed beaches was 0.69-0.75 m above high tide level (Table 6). The changes are produced during larger water level fluctuations, which can be as much as 0.6 m (Fig. 3.), caused by atmospheric pressure changes and locally generated waves.

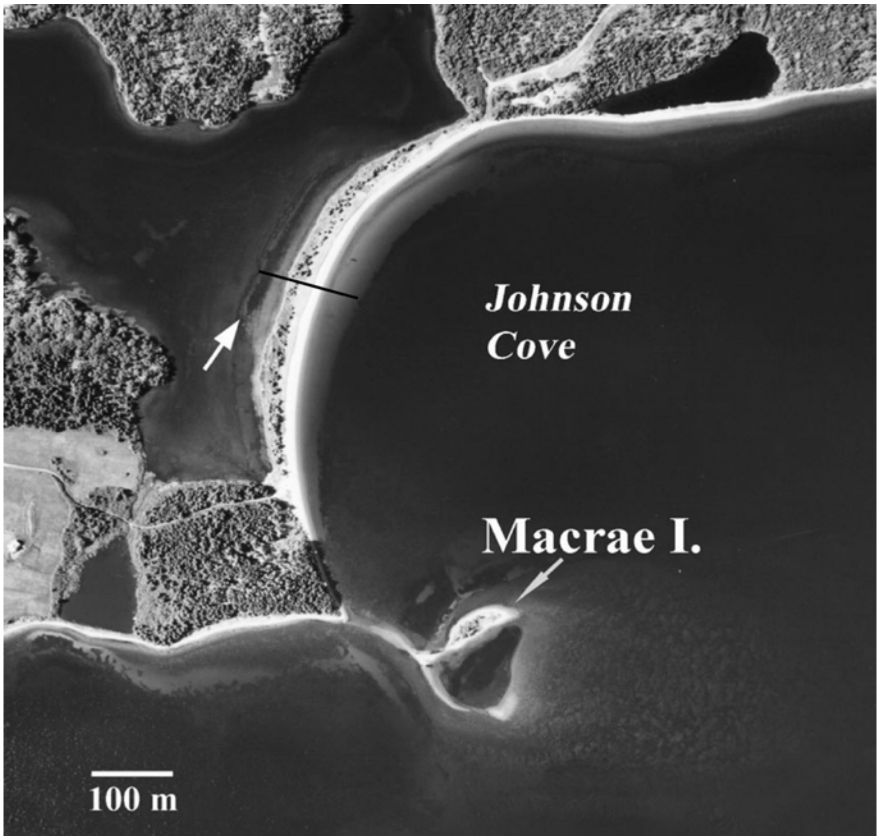


Figure 47. Vertical air photo (98311-183, June 29, 1998) of Johnson Cove, and Macrae Island. The head of the cove is closed off by a well established swash- aligned coastal barrier which consists of dunes and multiple beach ridges (marked by trees). Repetitive cross-shore surveys (Fig. 48, 49) were completed at the line. The survey may not have reached the submerged backbarrier ridge (arrow).

In contrast to the large barrier beaches within the inner part of the Lakes, field observations were also completed at Poker Dans and McKillop Ponds, smaller barrier beaches along Great Bras d'Or Channel (Fig 44, sites 55; 56, Fig. 50). These two barriers were only 9-15 m wide and both showed signs of wave overwash, and less backshore vegetation except where sand was more abundant. At both locations a lag deposit covered the lower beach slope and subtidal. Swash ridges composed of a finer pebble and granule material were transported across the lag surface. Isolated boulders were also scattered across the subtidal zone. The small size of the swash ridges and presence of a lag substrate suggest the thickness of mobile sediment is very small and beach changes are small during normal wave processes. Sediment sampled from mobile beach features shows that waves are capable of transporting sediment from 3.2 to 13.4 mm diameter. The presence of coarser clasts on the upper beach and backshore suggested they also can be moved during storms or when sea ice impinges on the shore. The orientation of backshore wave overwash features suggest the largest waves reworking Poker Dans barrier come from the southwest (Barra Strait) whereas MacKillops Pond barrier is more impacted by waves from the northeast (Bras d'Or Channel). It is not known when or under which conditions the lag surface covering the lower beach is reworked.

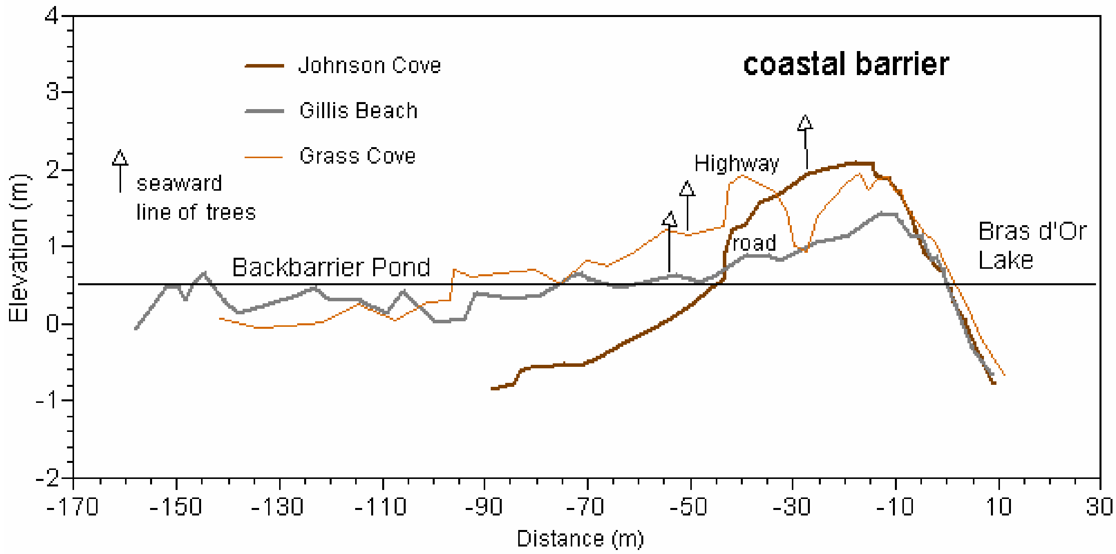


Figure 48. Cross -shore surveys at Johnson Cove, Gillis Pond and Grass Cove coastal barriers illustrating their size and position of the backbarrier ridges. The surveys are aligned by setting the position of water level at zero distance and an elevation of 0.5m. A dirt road extends along the back of Gillis Beach and a paved highway extends along Grass Cove (see Fig. 46a). The seaward limit of tree growth is also marked on each beach survey line. Location of survey lines is provided on figures 45 to 47.

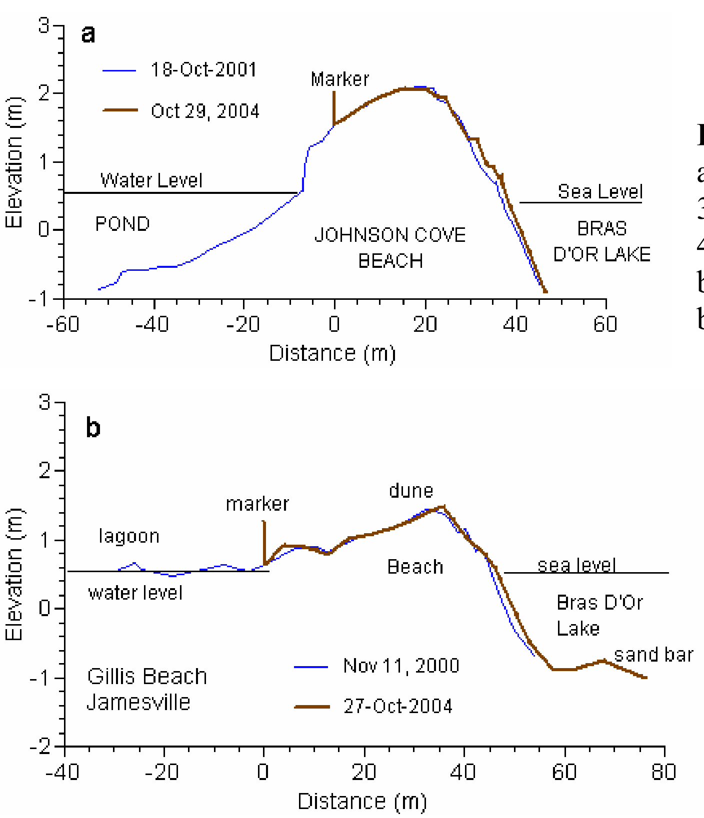


Figure 49. Repetitive cross shore surveys at (a) Johnson Cove Beach (Fig. 44, site 38); and (b) Gillis Beach, Jamesville (Fig 44, site 45). Net progradation of 3 m at both beaches occurred in the form of upper beach swash ridges.

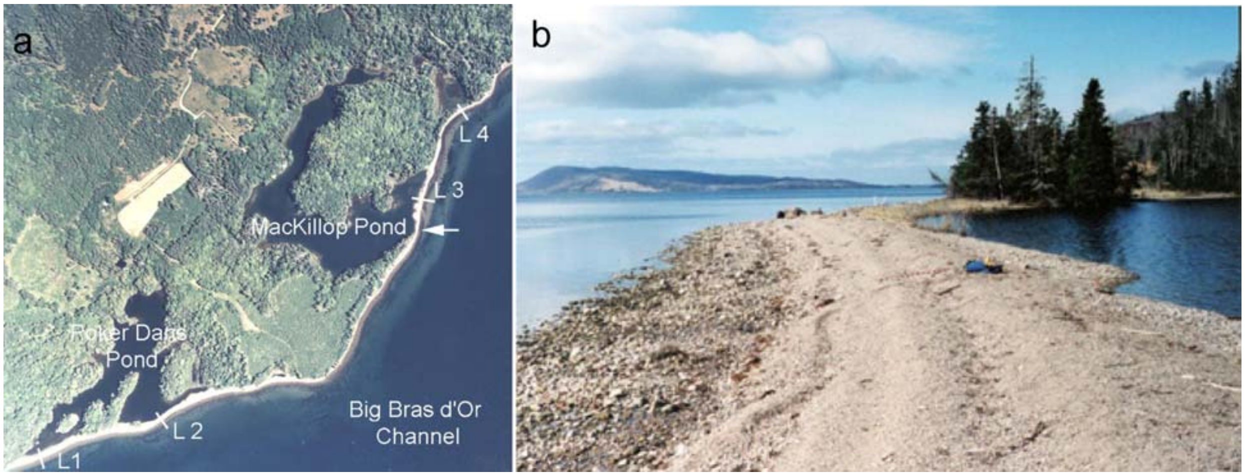


Figure 50. (a) Air photo of shores along Poker Dans and MacKillop Ponds (Fig. 44, site 55, 56) (AP 99307-200, 1:10,000) showing the location of beach observations (L1 to L4); and (b) photo of narrow barrier beach and wave overwash fan at L2 Poker Dans Pond Beach. The swash ridges are transported back and forth across the beach over a less mobile lag surface of coarser pebble cobble. Photo R. Taylor, 23 April 2004.

Within the Lakes there are five coastal barriers which are submerged below present water level and are attached to the present shoreline. We visited the relict barrier beach just northwest of Cape George (Fig. 51) with the intent of completing a cross-shore survey to compare with the multibeam profiles obtained across other submerged ridges farther offshore. The relict barrier, which was just over 300 m long, had an asymmetrical cross-shore profile. The landward side of the barrier was steeper than the seaward slope. The deepest part of the lagoon that could be reached by wading was 1.7 m deep near the centre. Maximum lagoon depth is estimated to be about 2.5 m. The surface of the submerged relict barrier consisted of a coarse pebble cobble lag over finer sediment. On the lagoon slope of the barrier there was firm sand which changed to a soft mud surface over pebble cobble farther landward. The mud covered pebble cobble substrate extended to the back of the lagoon where the narrow mainland beach consisted of mixed sediment.

Based on limited field observations, it appears that the location and extent of the lag surface reflects sediment abundance and possibly wave exposure of a specific beach. Beaches with a more abundant sediment supply would have a better opportunity to reshape themselves in response to rising sea levels whereas beaches with less sediment supply and covered by an extensive lag surface would be less able to adapt to rising sea level and more susceptible to flooding and *in situ* drowning.

The intent in 2004 was to core the backbarrier deposits to see if there were any deposits of peat which could provide ages for the coastal barriers. All four sites sampled contained plant material but little evidence of a consolidated peat. Only a 5 cm thick layer of peat as found on the back of Gillis Beach and it was not submitted for C^{14} age analysis. The absence of consolidated peat and rate of sea level changes provided in the earlier part of this report suggest the coastal barriers are less than 1000 years in age.

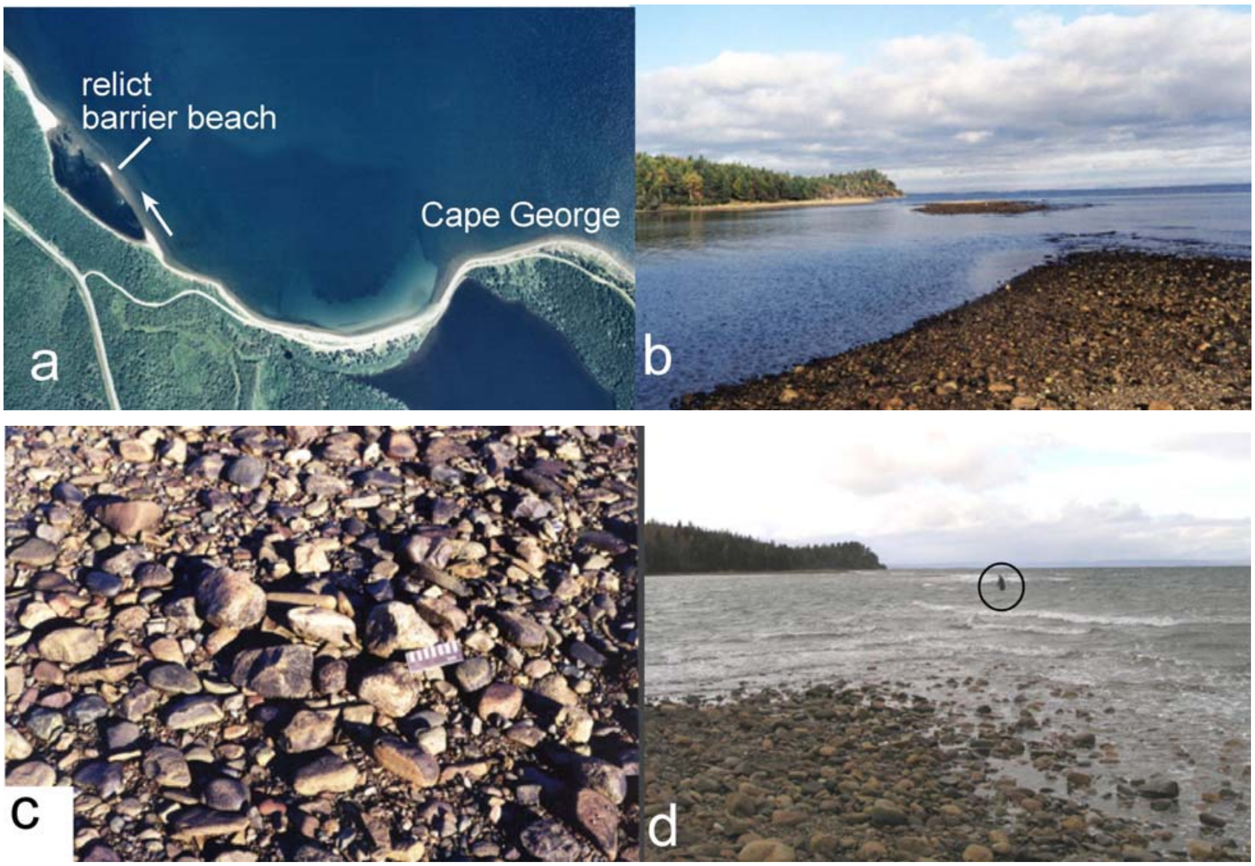
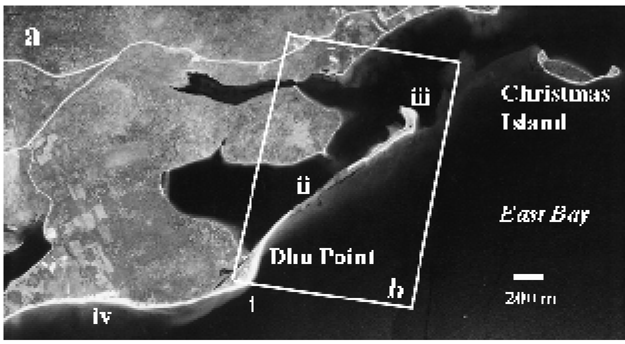


Figure 51. (a) Air photo (AP 93309-36 1993) and (b) ground view during calm sea conditions (location of photo marked by arrow in a) at relict coastal barrier (Fig. 44, site 24) just west of Cape George. (c) surface of coastal barrier is a coarse lag deposit (scale is 15 cm long) and (d) ground view of coastal barrier (person circled for scale) during strong winds from the NE. The depth of the lagoon behind the relict barrier is estimated to be 2.5 m. Photos b & c, R. Taylor, 18 October 2001; Photo d, R. Taylor, 29 October 2004.

Figure 52. View of Macrae Island, mouth of Malagawatch Harbour showing the large shore ice piles that develop on the submerged portion of former headland and some relict coastal barriers. The impacts of grounding ice were not measured, but it is postulated that the ice force would compact the substrate and push it slightly landward (Photo G. Weiland, 14 March 2003)

Only a couple of drift -aligned coastal barriers were visited and photographed in the field, and none were surveyed; consequently, physical changes, during the past 25-60 years, were determined using repetitive air photos. Dhu Point, East Bay (Fig. 44, Site 3) is one of the largest drift-aligned features in the lakes. In 1939 it extended 1600 m alongshore and may have extended even farther to Christmas Island (Fig. 53). Most spits at present, including Dhu Point, are less than 600 m in length. In 1939, Dhu Point consisted of three main shore segments, a beach ridge plain at its proximal end (Fig. 53a, i) a low narrow, partially submerged central part (ii) and a distal end (iii) which consisted of several recurved ridges. On the basis of beach ridge morphology, it appears the beach ridge plain was supplied sediment from the headland and high shore cliffs just west of Dhu Point (Fig. 53a, iv). The cliffs are composed of multiple tills and sandy deltaic deposits (Grant, 1994). It is not known when spit growth began. By 1939 the beach ridge plain had been trimmed along its western shore. The central part of the spit had become very low and overwashed by waves, which transported increased amounts of sediment into the lagoon. Consequently, there was less sediment available to supply the distal end of the spit and by 1998 most of the spit had become overwashed and drowned, leaving only a few small parts above high tide (Fig. 53b). Sediment stored in the beach ridge plain is being eroded to build a new spit.

Another example of change and the resilience of drift-aligned barriers is found at West Settlement, at the head of West Bay (Fig. 44, site 29; Fig. 54). The entire length of the spit was lowered, overwashed by waves and segmented between 1975 (Fig. 54a), when a sediment source was depleted (arrow), and 1993, when longshore sediment transport was resumed from the east and a new spit developed across the foundation of the older one (Fig. 54b, arrow). By 2001, sediment transport from the new spit to the old one had resumed and much of the opening visible at the proximal end of the old spit on the 1993 airphotos had been rebuilt. This example illustrates the importance of maintaining the longshore sediment transport corridors to the coastal barriers. Both examples illustrate how a portion of the shoreline becomes abandoned and drowned, if there is insufficient sediment supply to maintain the whole structure, as sea level rises.



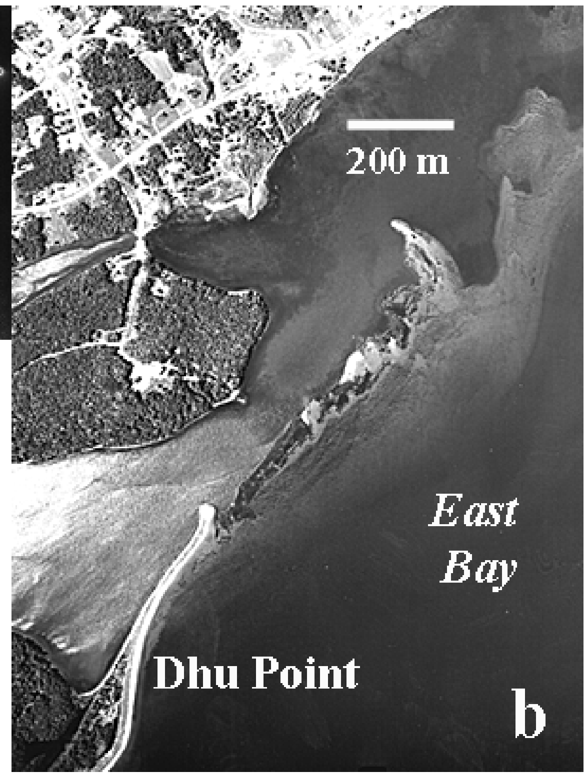


Figure 53. Morphological changes along the drift-aligned spit (i, ii) at Dhu Point, East Bay between (a) 1939 and (b) 1998. The beach complex was supplied sediment mainly from the headland and high unconsolidated cliffs to the west (iv). By 1998 the supply of sediment was insufficient to maintain the spit and much of it had become submerged and abandoned on the sea floor. The south end of the spit was becoming thinner and curling landward. (Air photos A6649-96, 98315-117).

All barriers are initially depositional or accumulation features but can go through varying phases of development including distal extension, progradation of multiple beach ridges, erosion, landward retreat and destruction. A model of how the coastal barrier evolves is discussed in the next part of this report.

Type 8: Vegetated - exposed

These shores can occur along narrow primary channels e.g., St. Patrick's Channel, within the lakes or along the outer part of secondary bays and channels e.g., Nyanza Bay. Exposure to marine processes or sea ice results in little to no organic sediment accumulation. The backshore rises landward, consists of glacial till and is forested or grass and shrub covered. Often at the land sea interface there is a low wave cut bank fringed by a boulder lag (Fig. 55) exposed by the winnowing and removal of finer sediment by water motion. Small forelands or nesses can develop along some of the long narrow embayments, e.g., Benacadie Pond, which suggest active sediment transport but transport may be infrequent. These shores are mapped as vegetated rather than fringing beaches because of the presence of vegetation on the beach face, small beach size and lack of wave-built features. The small beach at the Head of North Basin is a good example where plants can temporally mask the beach face yet there is little accumulation of organic sediment. The beaches slope steeply offshore. The lower beach slope is armoured by a layer of coarse angular pebble and the upper beach consisted of a swash ridge composed of finer pebble which would have formed during episodic infrequent maximum wave activity.

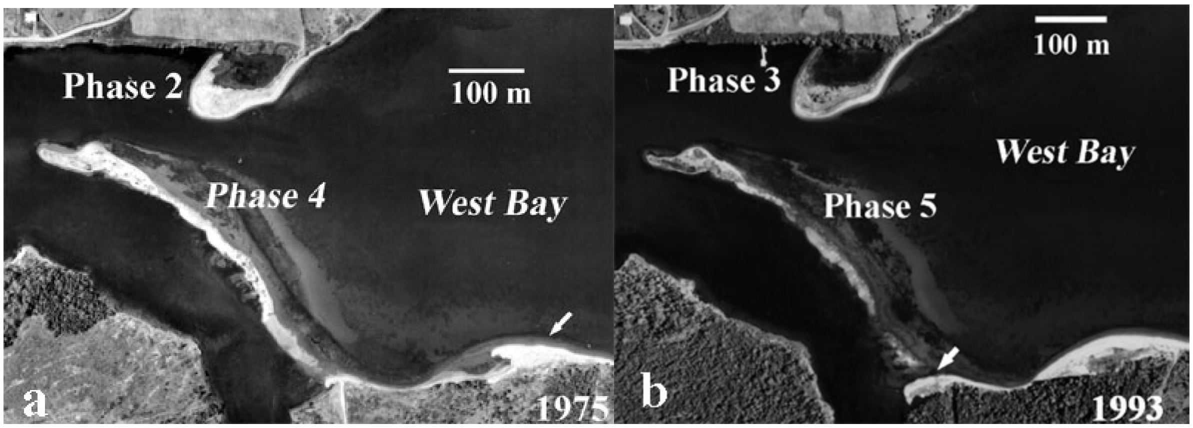


Figure 54. At West Settlement, West Bay the spit was lowered, overwashed by waves and segmented between (a) 1975 (photo 75204-101) when the sediment source was depleted (arrow) and (b) 1993 (photo 93303-29) when longshore sediment transport was resumed from the east and a new spit developed across the foundation of the older one (arrow). Phase 4 and 5 refer to phases in coastal barrier evolution discussed in the next part of the report.

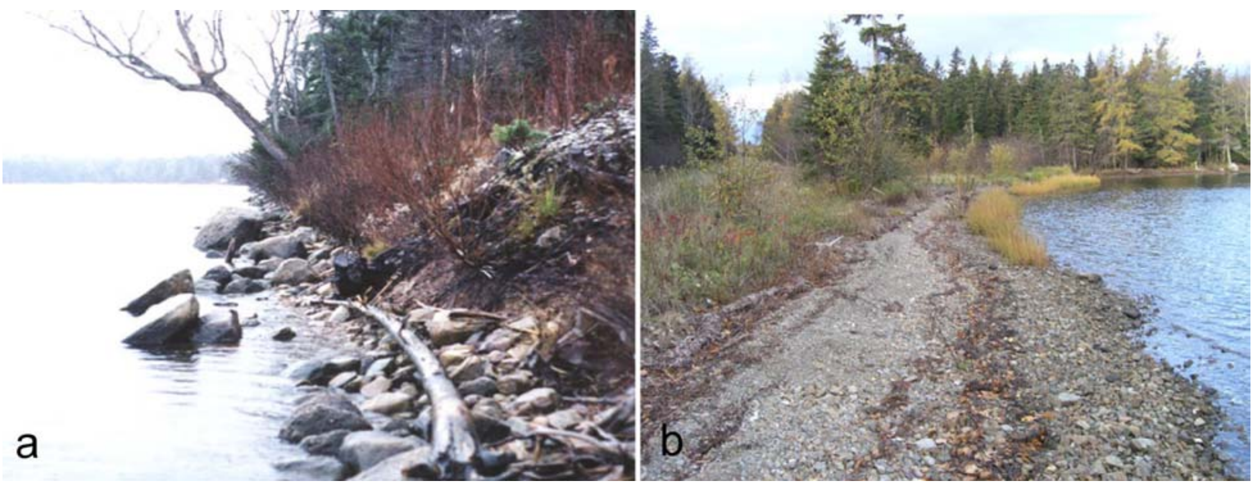


Figure 55. Two examples of exposed vegetated shores: (a) a steeper more wave exposed backshore along outer Cow Bay, St. Patricks Channel where waves have winnowed away the fines leaving a boulder lag deposit at the present shoreline (bt260396, 21-Nov-2000) and (b) a more gradual shore at the head of North Basin which is exposed to waves from a very restricted fetch direction. Vegetation can often cover the shore but small swash ridges can be built by small waves generated during episodic storms from the right direction. The size of sediment available and topographic slope at any given site also impacts the extent of beach development (PA290100, 29-October -2004).

Type 9: Vegetated - Protected.

Toward the head of smaller secondary bays and channels where wave energy is non-existent or where large coastal deposits have protected inner waterways, e.g., Boom Island, low lying shallow areas are natural sites for the accumulation for organic and inorganic material which buildup into extensive low marshes. Grant (1988) mapped many of these sites as organic deposits. We have mapped 12.5 % of the coastline as this type. The largest extent of wetland /marsh shores is within Denys Basin, the north part of Big Harbour Island, and the head of Whycocomagh and East Bays. At and near the head of most secondary channels and bays, the shores drop off sufficiently that beaches do not develop and the shore is a rounded grass covered bank or a very low backshore with a waterline fringed by dense grass or shrub cover (Fig. 54).

Trees grow where the backshore is slightly higher or better drained. Just offshore the bottom consists of a soft mud. A similar shoreline can also be found at the back of some of the smaller backbarrier lagoons. In wave- protected areas where sediment accumulation is higher, i.e., small coves, the band of wetland vegetation can extend metres from the main shoreline (Fig. 54). Most of the larger areas have only been examined using the aerial video. Little is known about sedimentation rates or the spread of vegetation in the larger salt marsh areas.

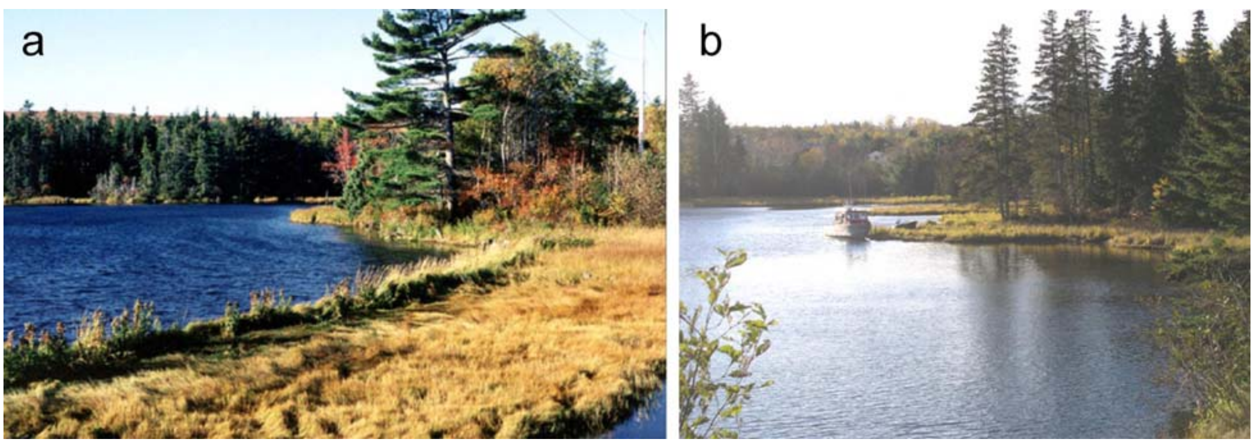


Figure 54. Examples of protected vegetated shores in the Bras d'Or lakes: (a) grass lined shores of inner Little Harbour, West Bay (32a-8-2001, 18-October -2001) and (b) head of Big Harbour, Great Bras d'Or Channel where more organic deposits and marsh grass have accumulated alongshore (R. Taylor, 28 October 2004).

Type 10: Riverine

Extensive wetland and marsh vegetation cover the floodplains and deltas at the mouths of the largest rivers draining into the Bras D'Or lakes (Fig. 55). The rivers include the Skye, Middle, Baddeck, Denys, Washabuck, Black and Benacadie Rivers. They represent 6 % of the total shoreline. The deltas extend beyond the main shoreline at the Skye, Middle and Baddeck Rivers, where bird-foot shaped deposits (Fig. 55b) are incised by one or two primary channel and drained by a number of secondary channels. The inter-channel areas are covered by vegetation and large accumulations of driftwood that were transported down the rivers. The delta deposits exist well back of the main shoreline at the Denys, Black and Benacadie Rivers. The river valley is flooded at its mouth and the main river channel is outlined by vegetated levees (Fig. 55a), presumably built up over time by sediment deposited during bank overtopping. At the Denys River mouth, the wetlands extend more than 5 km upstream. No field investigations were conducted at these shores mainly because of their large size and the difficult access.

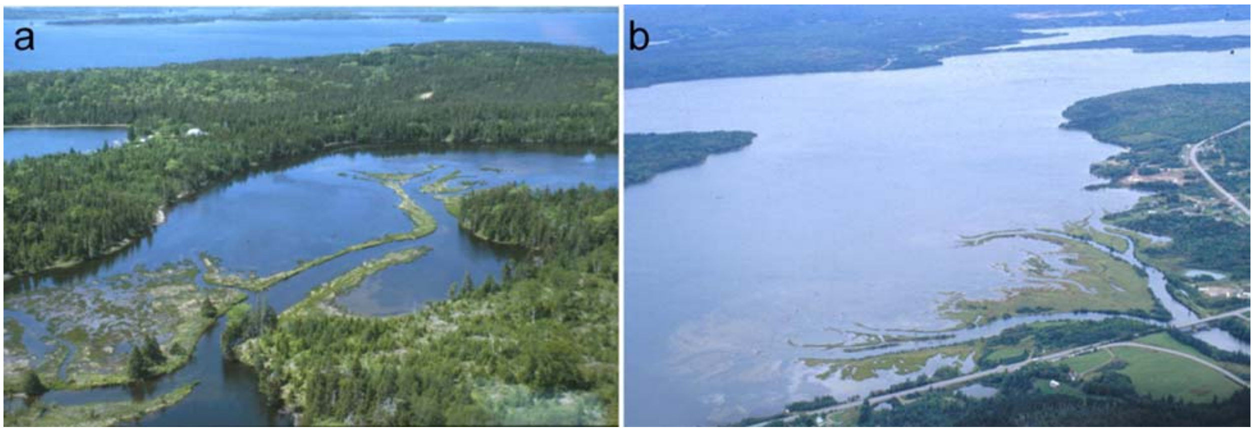


Figure 55: Aerial views of riverine vegetated shores (a) at the mouth of Toms Brook, Hay Cove (bt260343; 25-June -1996) and (b) the Middle River delta, Nyanza Bay (bt260357; 30-sept-1992). Well developed vegetated levees outline the main stream channels; organic and inorganic material accumulates between the channels, facilitating the growth of wetland vegetation.

Type 11: Artificial

An estimated 3 % of the shoreline is mapped as artificial. Artificial shores include human-built structures which increase in abundance toward the more heavily populated areas, or where road access is easy, e.g., south shore of East Bay. Many of the secondary roads closely follow the Bras d'Or lakes shoreline (Fig. 56). Many roads, such as the one following North Basin, are dirt and are armoured by varying amounts of rock along their seaward side. Along North Basin the road is only 0.65 to 0.8 m above present sea level (Fig. 57), and those shores which are armoured are steeper and narrower than those that are fringed by a beach. Railway lines also follow the shorelines but the rail beds are generally higher above sea level and more armoured by rock.

Figure 56: Aerial view of the highway at the head of East Bay where many groynes were constructed at right angles to the shoreline in an attempt to trap sediment and to protect the highway. Artificial structures decrease the ability of natural shores to respond to rising sea level by re-organizing and recycling their sediment to form new beaches. (bt260334; 25-June -1996).

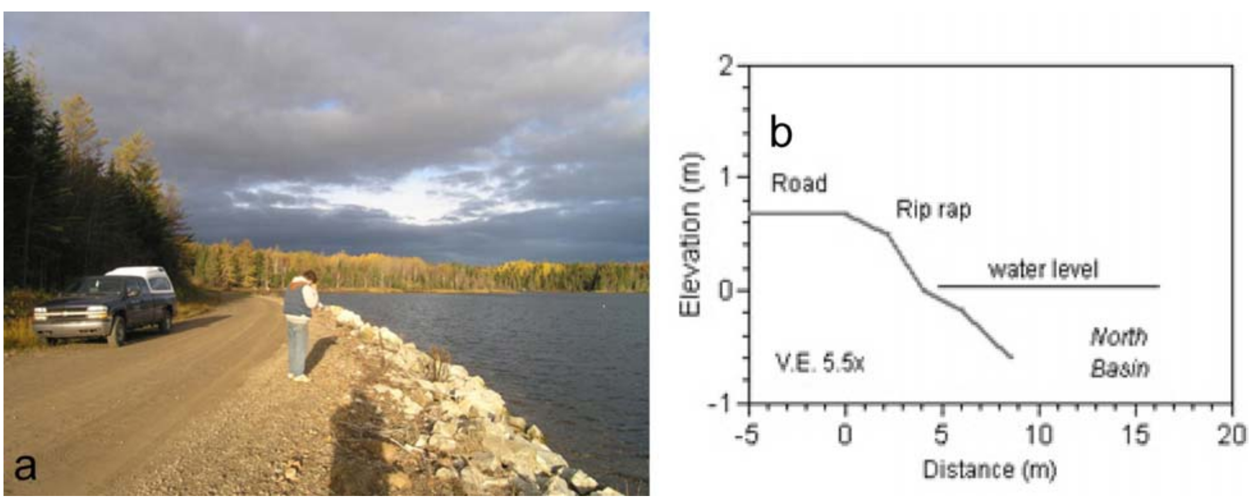


Figure 57: Many secondary roads such as this one (a) along North Basin are armoured by rock (PA290097; 29-October -2004) but are commonly less than 0.8 m above present water level (b).

CYCLE OF COASTAL BARRIER CHANGES

Introduction

Although coastal barriers only constitute 12.3 % of the total shoreline they are extremely important within the lakes. Coastal barriers are a highly visible and utilised landform; they have formed the foundation for transportation routes and an environment high in demand for recreational and fishing activities, and protection for seasonal residences and small craft harbours. Much has been written recently regarding the evolution of similar coarse-grained beach deposits found along the outer coast of Nova Scotia (Boyd et al., 1987; Forbes and Taylor, 1987; Forbes et al. 1990, 1995; Carter et al., 1990; and Orford et al., 1991). While the horizontal extent of the Bras d'Or barriers is comparable to that of barriers on the Atlantic coast of Nova Scotia, their vertical height is much smaller (Fig. 43) because of significant differences in the magnitude of processes affecting them: smaller tidal range, lower wave energy and longer duration of sea ice exist in the Lakes.

In a number of recent investigations, researchers observed that coarse-grained barrier beaches such as those in the lakes, experience long intervals of slow change, punctuated by short periods of rapid reorganization (Orford et al., 1991 and Forbes et al., 1990, 1995). They further observed that the response to external forcing factors such as rising sea level, wave energy and varying sediment supply, varies locally depending on the intrinsic characteristics of each barrier system. These characteristics include its present condition, i.e., erosional or depositional, its ability to recycle sediment alongshore or offshore-onshore, and accommodation space for its growth and development. Accommodation space is a function of water depth and distance between headlands or other anchor points. The same authors developed an evolutionary framework for coastal barriers within a transgressive (rising sea level) setting. Within the model, individual barrier structures are initiated, become established and breakdown before the cycle resumes. The model also differentiates between drift-and swash-aligned barrier systems, but recognises that larger coastal barriers can have components of both, and that over time a barrier may switch from a drift- to a swash-aligned system and vice versa. This evolutionary model has been refined and applied to the Bras d'Or lakes (Taylor et al., 2002) and is discussed next.

A Conceptual model of coastal barrier evolution

The conceptual model consists of a cycle of five natural phases and an artificial constraint phase as follows: (Fig. 58)

Phase 1- barrier initiation

Coastal barriers are initiated by waves transporting sediment from eroding unconsolidated cliffs; they develop at sites of significant change in shoreline configuration. Initially sediment is transported alongshore forming spits or forelands, but with further growth these features can become swash-aligned barriers depending on shoreline geometry and local bathymetry.

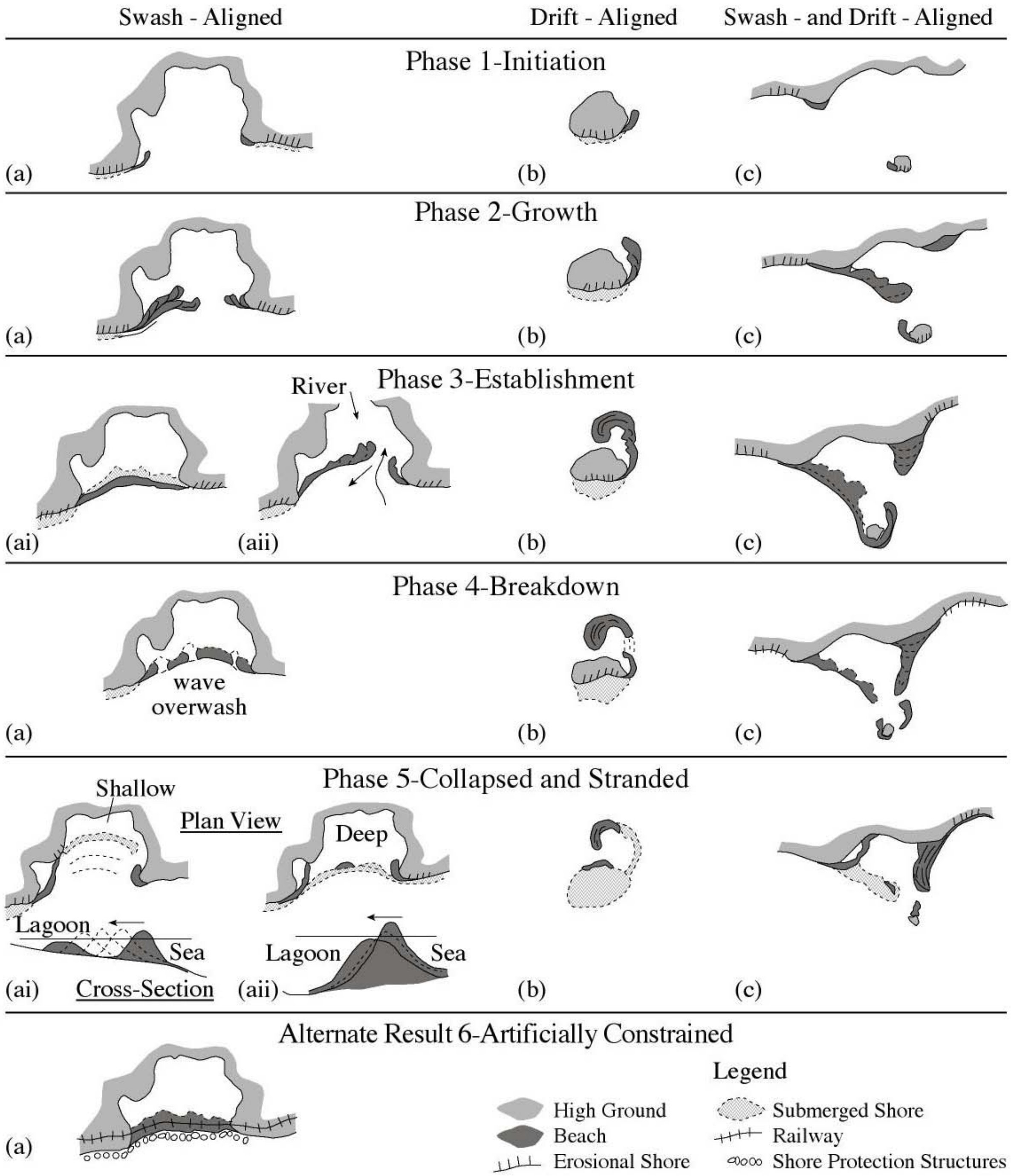


Figure 58. Conceptual model for the evolution of (a) swash-aligned (b) drift -aligned and (c) more complex swash- and drift-aligned coastal barriers in the Bras D'Or lakes. The model is refined from the models of Orford et al. 1991 and Forbes et. al. 1995 for coastal barriers along the outer coast of Nova Scotia. An alternate outcome is phase 6 where a barrier becomes artificially constrained by human activities. Letters (a to c) are used for linking with the text.

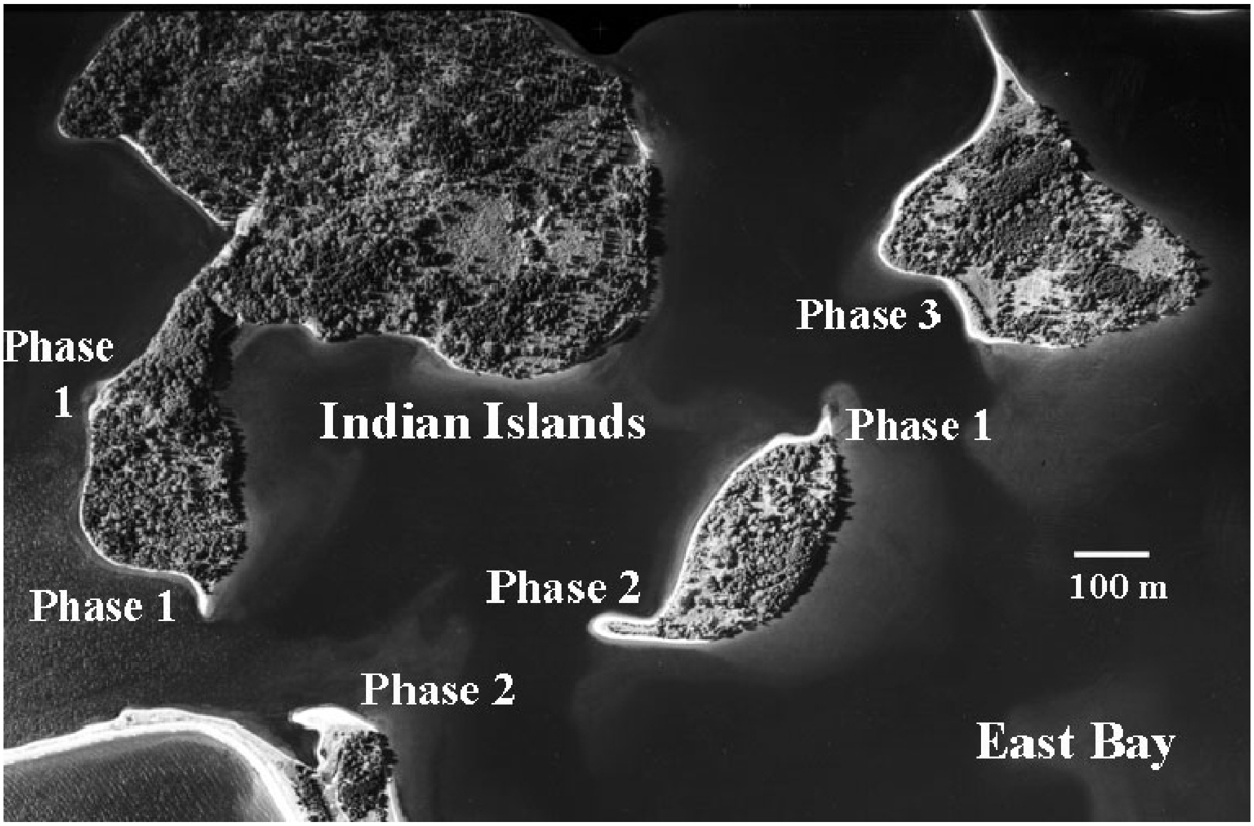


Figure 59. Air photo (98301-237) of the Indian Islands, East Bay where several coastal barriers have been initiated (phase 1). Drift-aligned features are initiated at sharp changes in shoreline orientation. If sediment supply continues and water depth is shallow the features can become extended (phase 2). The barrier marked as phase 3 is small but it includes multiple beach ridges and a succession of vegetation observed on more stable established barriers.

Phase 2 - barrier growth

The growth of a barrier depends on sediment supply and water depths. Where the adjacent waters are shallow, sediment can quickly accumulate and extend farther away from the source. However, if deeper water exists, the accumulation feature will generally be forced to extend close to shore, toward the lee of the source. A barrier may extend in width as multiple beach ridges and /or in length as a series of recurved ridges, or both. Barrier growth may cease if sediment supply is insufficient to infill the depth of water encountered or if tidal currents and/or river flow prevent sediment deposition.

Phase 3 - barrier establishment

If sediment supply is sufficient, the spit can attach to an adjacent shore, outcrop, or island and become a better stabilized barrier beach or tombolo. Established barriers are covered by a natural succession of vegetation from dune grass to trees and lagoon/pond plants. The seaward crest or duneline is continuous and fairly similar alongshore. Once a barrier is established, if sediment continues to be supplied, beach growth in the form of multiple beach ridges may continue over several centuries or millennia. With rising sea level, seaward ridges are built higher than the landward ones, which were built at times of lower sea level.

In a drift-aligned setting, continued sediment supply can result in sediment spill over into the next shoreline compartment and the growth of a new barrier, e.g. Dhu Point, East Bay (Fig. 53). Another situation commonly observed in the Bras d'Or Lakes, is where a spit extends behind its anchor and point source to form a loop structure, e.g., Sheep Island, Malagawatch Harbour (Fig. 37,60). In some instances paired loop structures may develop, and in other cases, two flanking spits may join to form a single spit or tombolo behind the island. Water depth, the size of the island, and wave dynamics control the growth pattern. Established barriers may be altered and eroded during storms but generally have the capability to recover and rebuild.

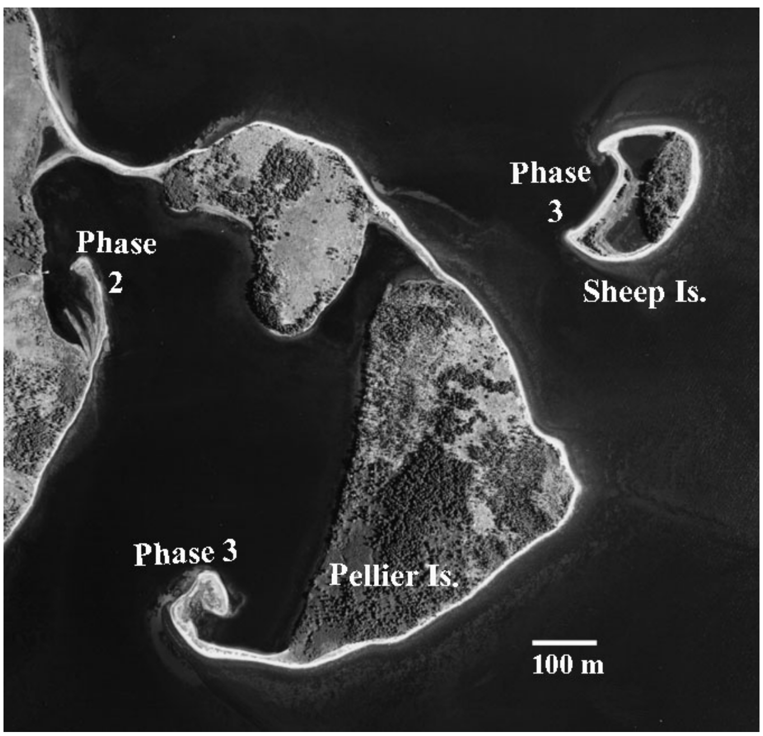


Figure 60: Air photo (98320-49) of Pellier and Sheep Islands at the entrance to Malagawatch Harbour. The spit to the left with multiple ridges appears to be still growing and is in phase 2. The two features marked as phase 3 have become more stable. Growth of the spit on Pellier Island has halted and it has hooked back upon itself and reached phase 3. A double looped structure has formed at the back of Sheep Island. A wider beach with multiple ridges and a connection at both ends provides more stability and therefore it is interpreted in phase 3.

Phase 4 - barrier breakdown

As sediment supply diminishes, either because of depletion of the source through natural erosion, or the interference of sediment supply by human-made structures, the barrier beach or spit narrows at one or more locations alongshore, and its crest exhibits greater irregularity in elevation and increased discontinuity. In some instances, sediment from the degrading part of a spit is transported alongshore to maintain growth of the distal end. Wave overwash channels are cut farther across the barrier crest or dune. In the later stages of this phase, waves commonly transport sediment landward to build the lagoon shore. Short segments of barrier may become lowered and submerged at high tide, leaving a surface armoured by a coarse lag sediment.

Phase 5 - barrier collapse or stranding

A further reduction in sediment supply and depletion of a barrier generally results in its landward migration. Given that sea level is rising, two situations may occur based on observations along the Atlantic Coast of Nova Scotia. If the lagoon is shallow, wave overwash may transfer beach sediment landward and infill the lagoon allowing swash aligned barriers to migrate farther landward, through a series of beach rollover cycles of alternate wave overwash and crest rebuilding. Continued landward migration of a barrier results in longshore stretching, and given a sequence of storms, can result in barrier submergence and stranding before it can reach the far shore (Carter et al., 1987; Taylor et al., 1999). Alternatively, if the lagoon is deep, a coastal barrier can become flattened, submerged and stranded along its original backshore.

In the Bras d'Or Lakes it appears that the wave energy in many places may not be sufficient to rollover coastal barriers and it is the second scenario that is more apt to occur. Finer sediment can be transported into the lagoon, leaving an armoured coarse lag surface across the submerging barrier, as we have observed at a number of present relict barrier sites. The occurrence of the naturally armoured surface would stabilize and halt landward barrier migration, unless the barrier frequently is impacted by sea ice grounding and ridging, which could continue to lower and destabilize the coastal barrier. A good example of an abandoned coastal barrier is found at Big Pond, East Bay (Fig. 44, site 14). Barachois spit, located in the channel east of Long Island, St. Andrew's Channel (Fig. 42), is another example of a relict feature, where the distal end of the spit photographed by Tarr (1898) is now a shoal detached from its proximal end at high tide. By 2000, a new recurved ridge had developed closer to the main shore but water depth was too great to allow appreciable growth.

The model for drift-aligned barriers comes from examining Sheep and Macrae Islands at the mouth of Malagawatch Harbour. The loop structures breakdown as the island anchor and sediment source become depleted, and finally become stranded following erosion of the island (Fig. 60). It was observed at Macrae Island (Fig. 38, 47) and McPhee Island (Fig. 61) (part of the Indian Islands), that a tail or ridge extended landward from the stranded barrier to the present shoreline, suggesting the potential for sediment transfer inshore and the initiation of new coastal barriers and the transformation of shores from one phase to another.

In contrast, an examination of the deeper, older submerged coastal features on the multi-beam images (Figs. 16, 17) suggest many of the drift -aligned features were not fed sufficient sediment in the time available to bridge the deep waters and connect with the inner shores. As a consequence, there are few ridges which extend landward and would facilitate the transfer of eroded sediment onto the new shoreline. The features we observe today linked from relict barriers to the present shoreline have formed in shallower water, and at a time of slower sea level rise, which would allow better potential for the transfer of sediment shoreward.

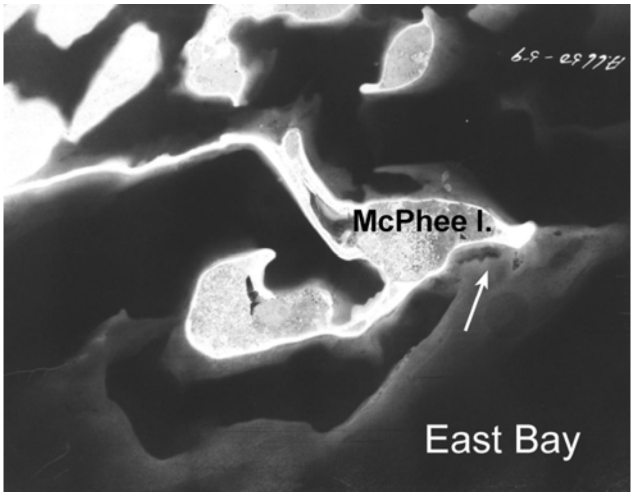


Figure 61. Air photo (A6650-59) of McPhee Island and adjacent waters in East Bay showing the remains of a submerged shoreline and a ridge of sediment extending toward McPhee Island (arrow) where a fan like deposit suggests landward sediment transport to the present shoreline.

There are several examples including Goose Pond, St. Andrew's Channel, where the proximal ends of barriers have migrated landward to form new cuspate barriers, even though the central part of the barrier has been submerged and stranded (Fig. 62). These new barriers, because they are smaller and have reconnected to the main shore, are more stable and considered to have evolved into phase 3. Once barriers have become stranded, new spit growth often is observed at the proximal end of the old barriers such as West Bay Settlement, West Bay, signifying the resumption of sediment supply and re-initiation of phase 1 (Fig. 54).

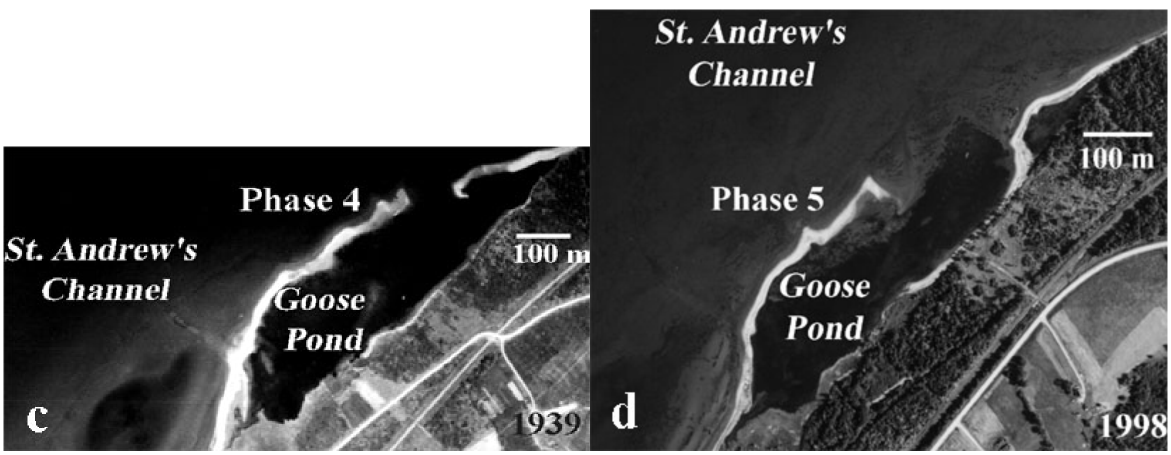


Figure 62. Example of a coastal barrier at Goose Pond, St Andrews Channel evolving from phase 4 to 5. Between (a) 1939 (photo A6651-60) and (b) 1998 (photo 98321-182) the northern portion of Goose Pond barrier formed a separate smaller barrier against the main shoreline and the southern portion of the original barrier became shorter, more narrow, and a new recurved ridge developed as part of the natural breakdown phase.

Phase 6 - artificial constraint of barriers

An alternative outcome of barrier change results when barriers no longer exhibit their natural character because they have been altered or constrained by human activities. In the past many barriers particularly along the south shore of St. Andrew's Channel became the foundation for railways and roads. Fill was required to build the railway bed across low coastal areas and armour rock (boulders and quarry rock) was added to protect the artificial shore structures from wave erosion. The apparent stability of phase 2 and 3 barriers makes them attractive sites for this type of construction and subsequent alteration to phase 6. When natural shoreline erosion is halted it reduces the volume of sediment supplied to adjacent shores and can, in some cases, accelerate their erosion.

Residential developments or recreational activities on large barriers can result in compaction and modification of the natural surface, lowering of crest elevations and change or loss of natural vegetation cover. MacDougall Point, the site of Ben Eoin campground, is an example of a barrier in phase 6. The development of the campground has required significant maintenance to protect the investment, including stabilizing the inlet, modifying the natural beach ridges and the building of many small groynes (a narrow structure constructed of timber, rock or concrete roughly perpendicular to shore with the intent to trap sediment transported alongshore and maintain or increase beach width).

Human activities are expanding along the Bras d'Or Lakes. In East Bay alone, 63 groynes, 44 seawalls and 19 armour rock structures were observed along the shores during the 1996 aerial video survey (Taylor and Frobel, 1998). The high cost of coastal real estate has increased the demands by residents to armour their shores against wave erosion. There are also increased demands by local residents to reopen or modify the tidal inlets through small barriers to improve lagoon circulation and reduce odour; to allow the passage of fish or pleasure craft; and to reduce flooding inland (B. McSween, N.S. Natural Resources, pers. com., 2000). Artificial structures decrease the ability of shores to naturally respond and re-organise and recycle their sediment to form new beaches as sea level rises. Human actions introduce new phases of stability at irregular intervals which tends to disrupt and/or accelerate natural processes. The impacts of such actions have received little attention and are poorly documented. It is known that coastal barriers will breakdown naturally. How much human activities will accelerate the processes is unknown.

Present status of barriers in the lakes

Criteria were developed for identifying the six phases of coastal barrier evolution and applied to 80 coastal barriers of >250 m in length within the Bras d'Or Lakes. Their physical characteristics and phase of development were assessed using the 1996 aerial video. Overall 39% were in the building or established phases 2 and 3; 13.4 % were in transition between phase 3 and 4, 43.9% were in breakdown and collapse phases 4 and 5; and 3.7% were significantly constrained by human activities, therefore phase 6. Barriers identified in transition between phase 3 and 4 exhibited minor erosional and breakdown characteristics which may only be temporary and the result of recent storms. Many of these barriers may recover and remain in phase 3 depending on their ability to recycle and reorganise sediment. Coastal barriers in phase 4 and 5 are most sensitive to human activities.

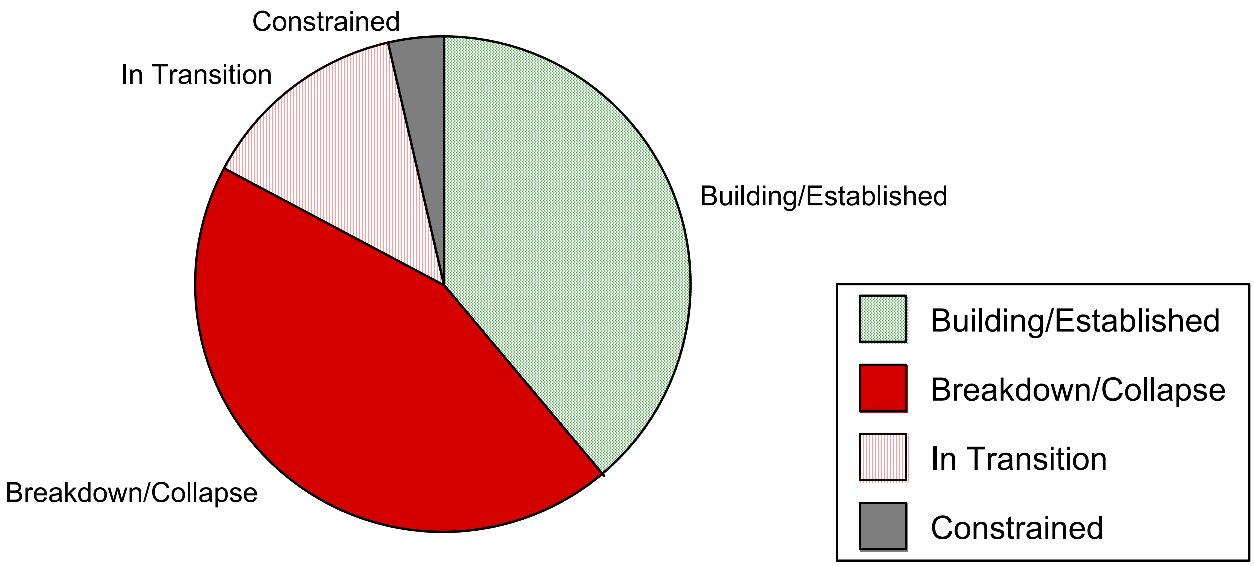


Figure 63. *Present state of barrier beaches in the Bras d'Or Lakes.*

IMPACT OF RISING SEA LEVELS

Shoreline Sensitivity

Previous studies investigating which shores would be sensitive to geomorphic change from a rising sea level used a method similar to or modified from the one developed by Gornitz and Kanciruk (1989) and Gornitz et al. (1991). They suggested shoreline change is dependent on a number of variables: relief, rock type, landform, vertical land movement, shoreline displacement and process modifiers such as waves and tides. Measurements of coastal conditions along large extents of coast were assigned a vulnerability index rating which varied from low to high based on these factors. Shaw et al. (1998) following a similar scheme examined the entire coast of Canada. On the basis of seven factors, they concluded that the coasts of the Bras d'Or Lakes had moderate sensitivity for physical change because of rising sea level. The assessment suggested that there may be some coastal aspects that planners should concerned about, but it did not provide sufficient detail to assist with planning responses to rising sea level. In this report we take a more focused view of the Bras d'Or Lakes, and try to assess how different shores might respond and which will be most sensitive to the anticipated water-level increase.

An analysis of past sea-level changes in the lakes in the first part of this report leads us to some more definite predictions. By 2030 the rate of sea level rise will already be 60 cm/century, and a rate of 70 cm/century will be reached by 2045. These rates of water-level increase signal danger. As noted above, the ancient beaches of the Bras d'Or lakes started to be submerged with rates of sea-level rise ≥70 cm century, and submergence was still occurring with rates of about 60 cm/century. By 2030, therefore, it is likely that coastal barriers will start to drown, and by 2045 they may all be submerged. By 2080 the predicted rate of water-level increase it is 99.2 cm/century and by 2100 it will be 115.1 cm/century. These rates would be catastrophic for low shores of the Bras d'Or Lakes.

Potential impacts

It should be emphasized that shorelines are always changing in response to a variety of processes. The question becomes how will these changes be modified by rising sea level. Rising sea level alters the horizontal plane on which processes, such as waves, interact with the shoreline. Therefore the zone of wave impact shifts higher against a shore. For areas with very low backshores, flooding can occur and the zone of impact can shift to a different location farther inland. The expansion of water bodies by flooding can increase fetch over which winds blow and therefore increase wave energy. Assessing the impacts of rising sea level at the coastal zone is quite complex. One can not simply assume that a 1 m rise in sea level will flood and change all areas located within 1 m of the present sea level. Each specific shore type has both a variable resistance (ability to withstand change) and resilience (speed at which it reverts to pre-impact conditions) to rising sea level. In this section, we discuss the variation in physical responses to rising sea level anticipated by different shore types (Table 5) mapped in the Bras d'Or lakes.

Low Rock Outcrop

Isolated rock outcrops provide anchor points for sediment accumulation and possible beach development, and can thereby delay the inundation of backshore areas by flood waters. As sea level rises, low resistant rock outcrops would be flooded but exhibit little physical change. Waves would strip off more of the surface overburden higher on the backshore, which could contribute sediment to adjacent pocket beaches, but the rock would be left essentially as nearshore rock shoals/outcrops as the shoreline retreats. Offshore rock outcrops impact wave propagation inshore and where the energy is directed onshore. As sea level rises, onshore rocks can become offshore features. The magnitude of physical response by rock shores is a function of their composition, structure, and their exposure to wave and sea ice attack.

Rock Cliff

In general, where sea level is rising, high rock shores limit lake expansion. Although more of the cliff face will become impacted by waves as sea level rises, the physical changes will be much less on cliffs composed of granitic or volcanic rock than sedimentary rock. The amount of change observed across sedimentary rock cliffs will be a function of the composition and bedding. Waves will erode the cliff face and contribute more debris to the base of the cliff, which would intermittently slow the retreat process until waves remove the debris. Where harder cap rock overlies softer rock, undercutting and collapse of the cliff face can occur. Where the bedding is perpendicular to the coast, caves and blow holes would result from differential erosion. Shore ramps would continue to develop as sea level rises at areas such as Derby Point where steeply dipping conglomerate rock exists. The cliffed shores most impacted by rising sea level are those consisting of gypsum and anhydrite, where both mechanical and solutional weathering would occur. Rates of shoreline retreat for rock shores within the lakes are not available but the magnitude of physical change from rising sea level is considered low.

Rock with Fringing Beach

These shores are differentiated because the beach is sufficiently large to buffer the backshore against wave attack. Waves only reach the backshore during high water storm events, or after the beach has been combed down and narrowed. If sea level rise is slow and /or the backshore slope is gentle and sediment supply increases as a result of more changes to the adjacent shores, the beaches may be able to maintain their position and protect the backshore cliffs from wave attack for a long time. However, if sea level rise is rapid, the backshore rises steeply, and there is no significant increase in sediment supply, the beach will be narrowed, pushed against the backshore and eventually drowned. The shore type would then revert to a rock cliffed shore. Therefore the potential for physical change to this shore type is greater, i.e., moderate, because of changes to the beach.

Unconsolidated Cliff

Since these shores are only mapped along drumlins, physical change is a function of wave exposure, cliff height and composition. Assuming wave exposure does not change and remains high then more of the cliff face will be subject to wave attack. Cliffs consisting of more boulders retreat slower because of the build-up of a boulder frame at the base of the cliff as it retreats. Over time the boulder frame subsides as breaking waves erode the underlying till substrate. Shore cliffs composed mainly of muds are undercut and scoured by breaking waves resulting in massive upper cliff failure. Shore cliffs with a near vertical profile retreat faster than those with a more gradual upper slope which can become vegetated and temporarily stabilized. Unconsolidated drumlin deposits when initially exposed to wave attack because of rising sea level will retreat very rapidly, slow as the cliff face becomes higher and wider, and then erode faster again as the low back end of the drumlin is reached and waves can attack on several sides.

Long term erosion rates for cliffed headland shores along the Atlantic Coast of Nova Scotia (where sea level rise is 0.3 to 0.4 m/a) are 0.5 m/a and as high as 10 m/a. The few observations of headland retreat from the inner Bras d'Or lakes suggest that present rates vary from 0.1 to 0.3 m/a. Two sites, Black Rock Light and Carey Point were established for monitoring cliff top recession at the mouth of the Bras d'Or Channel. Measurements suggest rates of cliff top recession were slightly greater at 0.4 m/a and a maximum of 1.5 m/a (Taylor and Frobel 2005). An accelerated rise in sea level would accelerate the rate of cliff retreat and increase the supply of sediment to adjacent shorelines. The anticipated impact of rising sea level is considered high.

Unconsolidated Cliff with Beach

If these shores remain in a similar wave energy environment, then the beaches will buffer the cliff face from wave attack, but as sea level further rises, the beach material may be transported longshore toward lee shores and result in more direct wave attack of the backshore cliff. Furthermore if the shore is on the flanks of an eroding drumlin island, the seaward slope of the drumlin will eventually retreat to the sides and result in these more protected shores evolving into a shore cliff without a beach. Retreat would then accelerate; therefore the rate of shoreline change depends on the local situation, the width of the beach and whether the beach continues to be supplied with sediment to maintain its position. It is anticipated that changes maybe episodic, depending on the frequency of storms, and that change will be less than for unconsolidated cliffs without a beach. Sites for monitoring future change were established at Big Pond, West Bay and Cape George, Bras d'Or Lake, but only one set of measurements has been completed thus far.

Fringing Beach

Fringing beaches are usually drift-aligned features reworked by more oblique waves, therefore the amount of change expected depends on the present width of the beach and its backshore character. A rising sea level will push beach material landward and upward so it is easier for the beach to migrate landward across a gradually sloping backshore than a steep one which prevents beach migration. Therefore a beach may change position but has a better capability to rebuild itself. If the backshore is steep and is actively eroded as sea level rises, then the downdrift beaches would benefit from increased sediment supply. It is anticipated that variable rates of change could be phased alongshore. Physical impact on these beaches is considered moderate.

Coastal Barrier

As sea level rises all coastal barriers will be very vulnerable to change because of their low elevation and exposed location. The resilience and resistance of a specific barrier to change will depend upon its stage of evolution and the rate of sea level rise. Coastal barriers can go through cycles of natural change which are a function of sediment supply, coastal topography, adjacent water depths and whether the barrier is anchored at one or both ends. For example: a new coastal barrier will grow and extend only if sediment supply increases sufficiently for the barrier to infill water depths at the distal end of the spit. Otherwise if the water depths are too deep, the feature will recede landward and become drowned as sea level rises. A barrier in phase 2 will also stop growing if sediment supply decreases and it will quickly switch into breakdown phases 4 and 5 and become drowned. A well established stable coastal barrier anchored on both ends will begin to become overwashed and possibly build higher along its seaward portion thereby delaying major change, but as sea level continues to rise the barrier will become more and more overwashed and begin to migrate landward.

The rate of barrier submergence will depend on the depth of the backbarrier lagoon and the rate of sea level rise. The deeper the lagoon the less chance of barrier migration landward and higher potential of barrier drowning and abandonment. Coastal barriers already in a phase of breakdown or abandonment may continue to experience significant morphological changes or may become drowned; then lagoon shores would become increasingly altered and possibly developed into new beaches. Impact of rising sea level is considered high for all coastal barriers; rates of change will vary depending on the stage of evolution for each barrier.

Vegetated - Exposed

As sea-level rise accelerates, it is anticipated that there will be an initial accelerated retreat of the backshore slope. Retreat may slow with time as the abundance of boulders increases at the base of the backshore and naturally protects the backshore. Increased amounts of trees and sod drape accumulating as a result of increased backshore erosion could further protect the shoreline. Higher water levels will drown roots and kill off trees and other vegetation leaving the shores more vulnerable to slope processes and surface runoff.

Vegetated - Protected

As sea level rises the lowest areas will become flooded unless organic and inorganic deposition keeps pace with the rise in water level. Therefore in many cases the impact to these shores depends on the changes to adjacent and more outer bay shores which supply sediment to the inner bays. The full impacts of rising sea level on these rich biological habitats are not known. We anticipate moderate impacts in the morphology and extent of these shores due mainly to flooding however the biological impacts may be much greater than the physical impacts so more information is needed to assess the biological impacts.

Riverine

Much of what occurs at the river mouths will depend not only upon rising sea level but also changes in sediment supply from more outer shores, and water and sediment discharge from the individual rivers and drainage basins. As with the protected vegetated shores biological impacts may exceed the physical changes and more information is required.

Artificial

Most artificial structures are designed to be used at the present sea level and to withstand a certain fluctuation in water depth, e.g., caused by storms. Within the design constraints, it is anticipated that most shore protection structures will not be impacted significantly by a rising sea level. There could be some subsidence and slumping of rock in some structures and winnowing of fines in behind the structures. However, as sea-level rise exceeds the design conditions, waves and flood waters will increasingly impact the top and back of the structure making it ineffective and may lead to its collapse. Therefore artificial structures require (often expensive) maintenance, if they are to fulfill their objective over the long term. Many low roads will become flooded. Shore structures such as wharves, boat ramps and outflow or intake pipes will need to be rebuilt or significantly redesigned to achieve their original goals. Furthermore, as sea level rises the deck of walkways and wharves are increasingly impacted by wave action, become damaged and need repair or rebuilding.

New residences and building structures built too close to the present shoreline or in very low areas will be very vulnerable to flooding and potential wave attack. Septic and fuel tanks associated with these buildings will also be vulnerable to damage. New residences (Fig. 64) continue to be approved on coastal barriers and other low lying shores. The high cost of waterfront land compels residents to protect their investment, which usually means the addition of protective structures, and in turn upsets the natural balance of shoreline dynamics and the ability of shores to recycle its sediment and respond to rising sea level. Sea level changes should be taken into account when approving land use and building permits in coastal areas, particularly along the coastal barriers. Such planning would lessen the chance of accelerating the natural shoreline breakdown process and loss of human-built structures.

Figure 64. View of a new residence constructed in 2004 on the backbarrier beach ridges at Gillis Beach, Jamesville (Fig. 44, site 45). It is not known where the septic tank is located but it is obvious that the builder has not planned for increasing water levels as the narrow part of Gillis Beach is overtopped, eroded and flooded. The house sits on beach ridges built long ago when sea level was much lower (Photo R. Taylor, 27 October 2004).

Some secondary roads along shores are within 1 m elevation of the present sea level (Fig. 57). If sea level rises as predicted, many access roads will have to be raised, protected or moved by the end of this century. As a result, the impact to artificial structures is considered high, more because of replacement and maintenance costs, rather than significant physical changes.

Shore Type			Sensitivity Rating	Physical Response
Rock	1	Low Rock Outcrop	Low	Minimal impact; solution weathering on gypsum shores
	2	Rock Cliff	Low	Minimal impact; rock falls; solution weathering on gypsum shores
	3	Rock with Fringing Beach	Moderate	Some submergence; removal of overburden; beach adjustment
Non-Rock	4	Unconsolidated Cliff	High	Accelerated retreat; rate depends on composition
	5	Unconsolidated Cliff with Beach	Moderate	Variable retreat depending on local situation; episodic retreat during storms
	6	Fringing Beach	Moderate	Some submergence and landward beach migration; backshore instability; loss of sediment alongshore & offshore
	7	Coastal Barrier	High	Greater mobility; landward migration; breaching and drowning
	8	Vegetated - Exposed	Moderate	Increased backshore instability; loss of vegetation
	9	Vegetated - Protected	Moderate	Flooding; loss of vegetation
	10	Riverine	Moderate	Submergence; loss of vegetation; channel rerouting
Artificial	11	Artificial	High	Submergence of structures; maintenance & relocation

Table 7. Relative sensitivity of shores to rising sea level in the Bras d'Or Lakes. Ecological changes are not included in the assessment. Undifferentiated shores are probably mainly type 8 and 9, so have been assessed as moderate. Blue = low sensitivity; green = moderate sensitivity; red = high sensitivity.

Following the general approach of Shaw et al. (1998), and by compiling the anticipated changes in shorelines, we have subdivided the shores into three sensitivity groupings: low moderate and high (Table 7). Since many of the process variables such as tidal range, and physical conditions, e.g., topography, are similar within the lakes, we have used shore type as the primary factor affecting its sensitivity to rising sea level. Using the three shoreline sensitivity ratings, 18.8% of the shores are ranked as high sensitivity to change; 73.9% as moderate and 7.3 % as low. As more information becomes available the shore mapping and /or sensitivity ratings can be easily updated because the present information is compiled using GIS technology. It is a fairly easy task for future users to reassign or adjust sensitivity ratings to their requirements and refine adaptation strategies where necessary.

ADAPTATION STRATEGIES

There is a public perception that rising sea level, caused by climate change, presents a radically new challenge to our coasts and to the people who live there. Yet it has long been understood, at least in scientific circles, that sea level has been rising for more than 10,000 years in Atlantic Canada and that shorelines have adjusted accordingly. Physical change whether it be erosion, beach migration, or the upward growth of salt marshes, is in accordance with natural processes.

An examination of repetitive aerial photographs, maps, charts, and field surveys show that change is the norm, and it is commonly accelerated during infrequent high-magnitude storm events. A grasp of this simple concept of natural coastal evolution in a region of long-term crustal subsidence and accelerated sea level rise is necessary in order to develop good adaptation strategies and manage the coast properly.

We have shown there are a variety of shore types along the Bras d'Or Lakes. Their physical attributes such as geology, geomorphology and topography vary from high rock cliffs to low vegetated wetland. Many of the shore types are not well known in terms of their inherent longer term stability and ability to adjust to natural processes. This is particularly relevant for the vegetated and riverine shores (Types 8, 9,10), which are not easily accessible and difficult to examine in the field. Also, roughly 13% of the shores have not been mapped; although we would speculate most belong to shore types 8, and 9. We have only just begun to understand some of the shoreline dynamics and we lack information on a number of fronts including the biological impacts of a rising sea level; therefore, we would advocate adopting a flexible approach when developing strategies of shoreline adaptation to rising sea level in the Bras d'Or Lakes. The most flexible adaptive solution would be to let the shorelines respond naturally to rising sea level and allow them to change and recycle their sediment within the coastal system. Realistically this is not possible everywhere because of the previous existence of residential and other infrastructure along the shores. Therefore direction and management of coastal areas is required and engineering adaptive strategies also maybe more appropriate. In this section we will briefly outline three basic response options, some tradeoffs of using each and provide some references for those who wish additional more detailed information about specific adaptive strategies.

General Principles

Adaptation is the adjustment in natural or human systems taken in response to expected or actual changes in the climate or the environment (Klein 2001, Forbes et al. 2002). The objective is to maximize any positive effects and to minimize the adverse impacts of change, thereby reducing vulnerability. Adaptation may be reactive or proactive (planned) and maybe at local (lifestyle), provincial, national or international scales.

The three most widely recognized options (IPCC/CZMS 1990, 1992, 2001; Mimura and Harasawa, 2000; Klein et al. 2001; Forbes et al. 2002) for coastal adaptation to sea level rise include:

- **Retreat**- allows shores to evolve naturally.
- **Accommodation** -human impacts are minimized and shores evolve naturally.
- **Protection** - natural systems are controlled by engineering structures.

The objectives of these options have been: 1) to avoid development in vulnerable areas; 2) to ensure the continued effective functioning of natural systems; and 3) to protect lives, essential properties and economic activities against coastal hazards. Klein et al. (2001) remind us that options to protect can be implemented both reactively and proactively, while most retreat and accommodation options are best implemented in an anticipatory (proactive) manner.

Response Option 1: Retreat

The simplest and cheapest form of retreat involves avoidance of properties vulnerable to flood or erosion hazards by individual buyers or government agencies. This can be encouraged by public education and management strategies including tax, insurance, government incentives, mortgages, and zoning policies. A common approach has been the use of legislated setback regulations. Often they are based on projected shore erosion rates or an arbitrary distance, e.g., 30 m, from high water line.

A uniform setback distance for all the Bras d'Or Lakes would not be appropriate because there is such a large variety of shore types which evolve through a number of natural cycles. The 2004 planning strategy of the Cape Breton Regional Municipality (CBRM) states that "an arbitrary setback imposed without knowledge of the rate of erosion and factors causing it would be too much of an imposition on development in some situations and too little to protect development in others" (CBRM, 2004). Their policy is to work with other levels of government to develop comprehensive setback provisions.

Setback limits should take into account the geomorphology, elevation and evolutionary state of each shore type. For example, high resistant rock shores should not be subject to the same management constraints as low mobile coastal barriers. Also setback criteria for flooding and erosion may vary considerably. Another issue that is often overlooked about setback lines is their implications for the future. Extrapolation of historical shoreline erosion rates may be inappropriate and there needs to be a way of incorporating into plans variable or accelerated erosion rates in the future. Setback limits draw lines on the earth resulting in development on one side and restricted use or none on the other. As a result, land seaward of the setback line is not always used effectively, and if the shoreline continues to retreat to the line, then we are left with a much bigger problem in the future of how to protect all the facilities that have been allowed to be built landward of the line. It could be argued that setback lines only delay and increase the problem for future generations.

More vision and insight into how the shores will evolve in the future are necessary. For example, when a coastal barrier or low marsh area becomes submerged, a shoreline some distance inland may become the new land-sea interface. As a result, there need to be mechanisms, possibly legislative, in place to facilitate adaptation strategies to evolve from more rigid land-based regulations, to more flexible ones that work with shoreline changes, not against them. We have shown that unconsolidated cliff shores, when eroded, contribute sediment for building beaches and marshes. At present many beaches in Nova Scotia are protected under the provincial Beaches Act, but there is no protection for sediment supply areas such as headlands, where people can armour those shores above high tide level without a permit. It is imperative that planners and legislators, who manage the shores, take into account the important links between sediment sources and accumulation sites, to make sure that these links are not interrupted or broken.

Other ideas that have been promoted to enhance retreat include: purchasing of coastal areas by nature trusts, swapping of land, rolling easements, and relocation. An example of swapping of land is where the seaward portion of a park is lost to the sea and another piece of adjacent or nearby land is provided to replace it (Forbes et al., 2002). Park lands vulnerable to flooding or erosion would revert to more natural conditions, e.g., trails, with few or no permanent structures including boardwalks.

Rolling easement (Fig. 65), which has been presented as a possible solution in a number reports (Titus, 2004), sounds like a great idea but would be difficult to establish where abundant structures already exist such as along the south side of East Bay or near Baddeck and other communities. It could however be a very useful mechanism for new coastal development areas, or for allowing the temporary use of some land seaward of set back lines that are less vulnerable to coastal flooding or erosion. For more developed shores, such as areas with multiple rows of cottages, high land values discourage giving up land, but a similar philosophy of phased occupation might be adopted. For example, residents along the shorefront when threatened by the sea would not be allowed to defend, but rather would remove their structure, reverting the shorefront to the next row of cottagers. A phased occupation of shorefront property would also prevent the use of shore protection structures and allow the shores to evolve more naturally.

Relocation of a seasonally occupied structure, e.g. cottage, may be the most prudent action, where adjacent land farther inland is available and there is a desire to remain in that location. Unfortunately land often is not available thus eliminating this option. Relocation is the option of last resort for cities and towns where there is significant capital investment or heritage structures. As part of harbour front development plans, there can be some land swapping and reallocation of structures and the increase of parkland, but generally the other two options of accommodation and protection are utilized.

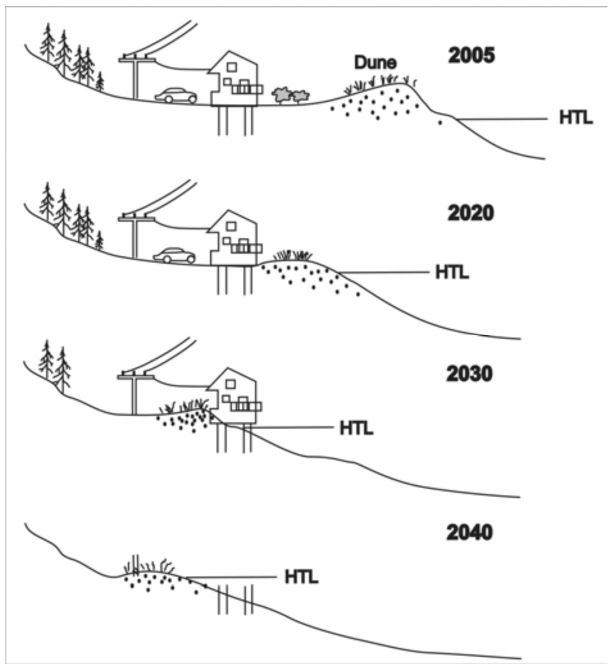


Figure 65. A rolling easement allows construction closer to the shore but requires the property owner to recognize nature's right of way to advance inland as sea level rises. In this example a wide dune exists seaward of the property today. With time, as sea level rises, the shoreline retreats landward along with a portion of the duneline. After 15 years the property is impacted by occasional storms and after 25 years the footprint of the dwelling is seaward of mean high water and therefore on public property. Within 35 years the house has been removed and eventually the entire area returns to nature as the beach is migrated upslope against the higher backshore.

Response Option 2: Accommodation

Accommodation has been described by a number of authors including Mimura and Harasawa (2000), Klein et al. (2001), and Forbes et al. (2002). Human impacts are minimized by adjusting human structures and activities in vulnerable coastal areas. Shores are allowed to evolve naturally to a level where human impacts can no longer be tolerated. In coastal areas where flooding rather than shoreline change is the main issue, accommodation can involve examining more flexible approaches to construction, land use, and planning such as:

- raising and redesign of structures, foundations, boat ramps and roads to minimize the impacts of occasional flooding, e.g., relocate electrical wiring higher in structures, leave lower levels unoccupied and use materials easily cleaned and restored if flooded.
- improve drainage of lands and buildings to eliminate the ponding of water and facilitate its removal or its flow around, e.g., sluiceways, or away from institutions and valuable infrastructure, e.g., hospitals.
- change land use to include activities less affected by water damage, e.g., parkland, parking lots.
- identify and map coastal hazard zones.
- provide emergency planning to insure access routes are available for evacuation or deployment of emergency personnel and vehicles during flooding.
- tolerate and absorb the cost of losses and damage as it occurs.

In coastal areas where shoreline change rather than flooding is more the issue, efforts may focus on improvement of natural resilience and mimicking of natural shoreline responses. Options should be flexible and vary depending on local conditions but may include:

- coastal dune rehabilitation, nourishment of beach sediment, increasing barrier beach crest elevation, wetland restoration.
- minimization of sediment losses in areas of erosion and reuse dredged sediment from nearshore/ harbour areas (clean, if necessary) along eroded shores with similar sediment properties.
- prohibiting the removal of fallen rocks at headlands for construction of shore protection structures elsewhere.
- using bridges instead of causeways to facilitate natural transfers of water and sediment.
- allowing wave overwash of some barrier beaches and the landward transfer of sediment for future beach building.
- leaving a buffer of natural vegetation along shores and eliminating large lawns and surfaces that promote surface water runoff and erosion at the shore (Kipp and Callaway, 2003).
- dispersing outflow and/or relocating backshore drainage pipes so concentrated flows do not scour immediate shores.

Response Option 3: Protection

For more than 100 years, since the advent of railways and road networks, shoreline armouring has occurred in the Bras d'Or Lakes. Many of the dirt roads that wound along the shores since the late 1800s remain in place today. Some were armoured, others not. During that time sea level only rose 30-40 cm. There has never been an assessment of the impact of shoreline armouring on the natural coastal evolution, but we do know that ongoing maintenance has been required to preserve these protective structures.

Before proceeding with any major construction or repair project, it is always important do ask some important questions and do some research. For example: what is the real cause of your shoreline instability? Is it wave or sea ice erosion, backshore surface water runoff or groundwater seepage or some combination of these processes? Is the problem the consequence a long term changes, the result of a specific storm or human interference and development elsewhere alongshore? What are the goals of your action? Is it to preserve your beach or preserve your backshore? Can the problem be lessened using soft, more natural solutions such as planting, or does it require a hard engineered solution? Is the value of the facility or land you wish to protect, worth the cost of protection? Present engineered structures are designed to address present environmental conditions with some level of change built in. How will the chosen solution be affected by a doubling in the rate of rising sea level by 2030? It should also be noted that engineered structures are generally not easily altered when rapidly changing conditions occur and they may only solve one problem. A choice of the wrong action could accelerate shoreline instability rather than solve it.

There are essentially two types of protective options: 1) armouring and bank support; and 2) sediment trapping.

Armouring although often used as the first choice to obtain quick results should be an option of last resort, restricted to situations where infrastructure would be very expensive to relocate if threatened by erosion. Revetments are shore parallel structures with a sloping face designed to protect the backshore from erosion due to wave attack. Revetements can be constructed using a number of materials including rock, timber and concrete. Armour rock has more flexibility to adjust to wave processes, whereas more vertical structures such as concrete or timber seawalls, rock filled wooden cribs or wire baskets are less flexible. Vertical structures are more vulnerable to wave scour at their toe because they tend to reflect more wave energy (Living on the Coast- US Corps of Engineers and University of Wisconsin 2003). Some structures are also used to support the backshore and prevent slope erosion or failure caused by wave undercutting the base of the slope. They generally have techniques to drain away waters flowing down the backshore. Structures built to standards by professional engineers can provide relief from bank erosion and wave attack for many years. Implications of building an engineered hard structure can vary depending on specific circumstances. Engineered shore armour structures:

1) are expensive
2) require ongoing or intermittent maintenance

3) do not promote beach buildup
4) will reduce supply of sediment from backshore erosion
5) will interfere with natural processes and shoreline response
6) can promote wave wrap around the ends of the structure and erosion of adjacent shores
7) are lifeless, can be unsightly and interfere with shore access
8) can also result in the "squeeze" and loss of intertidal habitats as sea level rises.

Figure 66: An example from a section of West Bay shoreline where a variety of adaptation strategies were used including armour rock, brush and leaving it in a natural state (Photo J. Shaw, 2004).

Sediment trapping involves building structure(s) which improve sediment accumulation and result in increased shore width. Two most commonly used methods are: (a) shore structures built perpendicular to the shoreline, e.g., groynes, which intersect and trap sediment transported longshore; and (b) offshore structures e.g. breakwaters, which create a wave sheltered area in their lee and associated sediment accumulation. Groynes (Fig. 56) are only effective along shores where longshore sediment transport is significant. Groynes protect the backshore where sediment is trapped but also cause sediment starvation downdrift of the structures which can cause accelerated backshore erosion or the depletion of sediment supplied to adjacent shores. When used improperly, these structures can also focus wave runup and cause increased backshore erosion. Offshore breakwaters can work but they are very expensive and can redirect and refocus wave energy causing shoreline instability in areas that were previously more stable.

For readers who wish to learn more about specific protection methods we provide links to other published information. Several of the references focus on the Great Lakes environment, where although not marine, there are similar shore types, littoral processes, e.g., wave fetch, ice, and management issues to those arising along the Bras d'Or Lakes. Additional information about the types of engineered structures, their costs and uses can be found in these publications:

Living on the coast:
(http://www.lre.usace.army.mil/coastalprocesses/Publications/Living_on_the_Coast.pdf

Urban or built-up coasts
http://www.seagrant.noaa.gov/themesnpa/pdf/urbancoasts_main.pdf

Meeting the challenges of living by the water (LBW handbook) On the Living Edge
http://www.livingbywater.ca

Magazine "Erosion Control" Hard armor -flexible solutions:
http://www.forester.net/ecm_0509_hard.html

Waterways and Wetlands - a practical handbook. This is a British publication therefore there will be differences in biological species and physical processes but it provides insights into wetland environments which make up a large proportion of the Bras d'Or Lakes shores.
http://shop.btcv.org.uk/shop/level2/104/stock/4253

UK Biodiversity Habitat action plans
http://www.ukbap.org.uk/habitats.aspx

More general information about Canadian and Nova Scotian adaptive strategies can be found at:

Canadian Climate Impacts and Adaptation Network (C-CIARN) coastal sector
http://c-ciarn.bio.ns.ca/home_e.php

Ecology Action Centre-coastal issues in Nova Scotia
http://www.ecologyaction.ca/coastal_issues/coastal_issues.shtm

The broad range of options for adaptation to climate change issues is one reason why adaptation should take place within an integrated or cooperative strategy rather than an individualistic one which can aggravate shoreline stability problems. Adaptation is a complex iterative process which can involve a number of steps (Klein et al. 2001) including:

- Identify possible impacts and raise awareness
- Plan and design
- Implement the measures
- Monitor and evaluate the adaptive measures

We have only begun the first process there is still much to be done in the other three processes within the Bras d'Or lakes and elsewhere in Nova Scotia.

Recommended response options

Accepting that the level of the lakes may rise by 0.76 m by 2100 AD, and almost certainly will rise by 0.36 m by that time, the following guidelines are proposed, based on the idea that in this region a naturally functioning coast is best.

- Do not armour the coast unless important community infrastructure such as highways, bridges, and institutions, which are not easily moved, are threatened by shoreline erosion. Armouring may also be required to provide safety for people working in the coastal zone e.g., harbour breakwaters.
- Before selecting a building location for a residence on or back of shore cliffs, learn and take into account past and predicted rates of cliff retreat at that site.
- Do not develop infrastructure on coastal barriers.
- Allow the coast to function close to the natural state where possible.

SUMMARY OF COASTAL VULNERABILITY TO CHANGE

- The shores of the Bras d'Or Lakes are subdivided into eleven types. There are three types of rocky shores, seven types of non-rock shores, including three types of vegetated shores, and artificial shores. The percentage coverage of each group of shores are: rock 10.0 %, non-rock 74.0 %, and artificial 3 %. Roughly 13 % of the shores could not be mapped but most of those shores probably belong to one of the vegetated shore types.

- The most dynamic or changing shores under modern conditions are the cliffed shores cut into unconsolidated glacial deposits, and the coastal barriers.

- Observations at one site in Bras d'Or Lake suggested unconsolidated cliff shores retreat on average 0.34 m/a (1973-2001). Cliff retreat can exceed 1m/a in more wave exposed locations, e.g. entrance to Bras d'Or Channel. Cliff retreat supplies coarse sediment for the natural building of beaches and fine sediment for infilling of basins in the lakes.

- Coastal barriers were observed to naturally evolve through cycles of change during the past 60 years since air photos have been available. An assessment of the condition of coastal barriers in the 1990s at 76 locations around the lakes suggest that 39% are in building or established phases, 43.9% were in breakdown and collapse phases, 13.4 % were in transition, and 3.7% were significantly constrained by human activities and were considered artificial.

- The vulnerability of specific shore types to physical change given a rising sea level was assessed using three classes: low (7.3 %), moderate (73.9 %), and high (18.8 %). Unconsolidated cliff (Type 4) and coastal barrier (Type 7) were rated as most susceptible to physical change.

- Artificial shores are also rated as highly vulnerable because they will increasingly become ineffective in protecting the backshore as sea level rises. Artificial shores will require increased amounts of maintenance.

- It is anticipated that accelerated rates of erosion and retreat will occur at the unconsolidated cliffed shores. It is difficult to predict what the increased rate of retreat would be. On the wave exposed shores of Atlantic Nova Scotia average rates of change for unconsolidated cliffed shores are 0.5 m/a, and highest rates are10 m/a.

- It is anticipated that coastal barriers will evolve more quickly within the existing evolutionary cycle of change. Based on the drowning of the palaeo-shores roughly 5000 years ago, we predict that complete destruction or submergence of barrier beaches may become very frequent by 2030 AD and typical by 2045 AD. Multibeam bathymetry images of the sea floor suggest entire shorelines were completely submerged within a time period of roughly 300 years given similar rates of sea level to what is predicted by 2100.

- Vegetated shores will become flooded and they may or may not be able to build up sufficiently to maintain their shoreline position. (We have not assessed the biological impacts that may occur along these shores). It is anticipated that there will be a large expanse in lagoon environments but at locations where outer shores break down and erode quickly, they may provide sufficient sediment for the inner shores to aggrade and keep up with at least the slower rates of sea level rise.

- By the end of the century the rates of sea level rise will be in excess of 1 m/century. The impact on the coasts of the lakes may be very severe, particularly in the low lying areas, but difficult to predict at this time.

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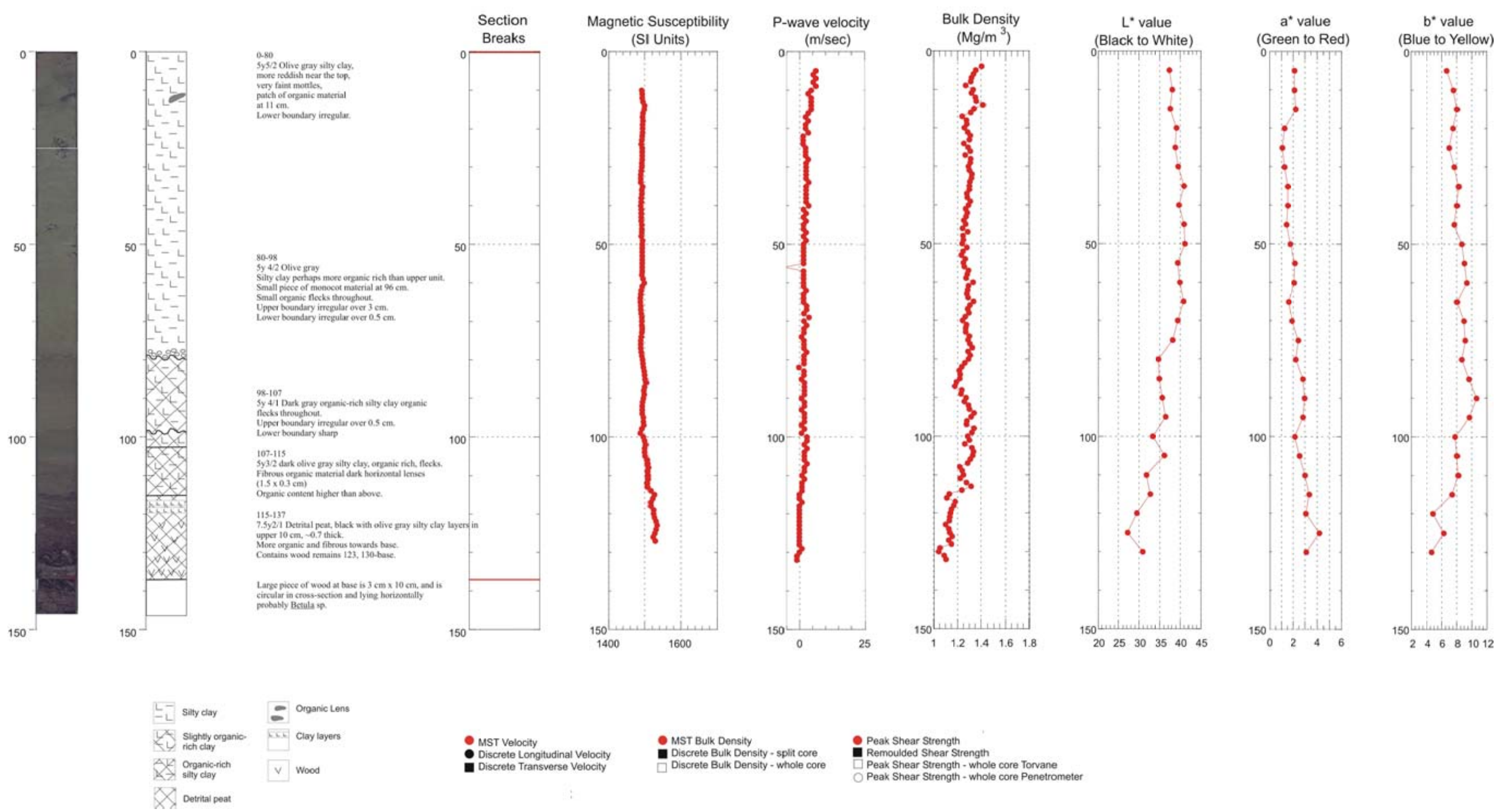
Appendix 1: Gravity cores 2003-015-076 and -077

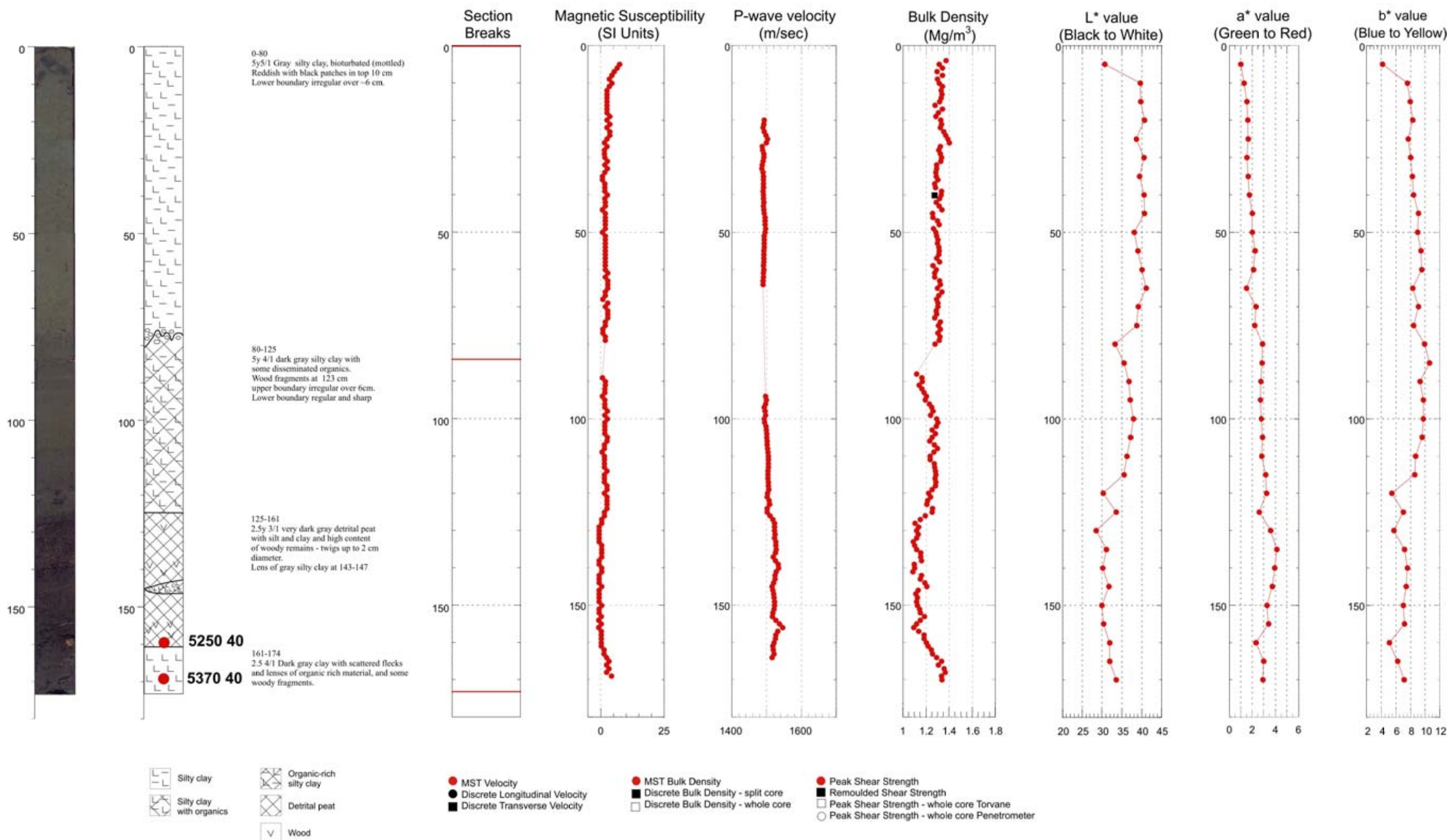
2003015 Gravity Core 076

46° 04.6099' N, 60°47.1502' W   Water depth 21m   TD 146cm



2003015 Gravity Core 077

46° 04.6118' N, 60°47.1516' W Water depth 23m TD 174cm



Appendix 2: Names of largest coastal barriers in the Bras d'Or lakes and their present phase of evolution

(Site numbers refer to Figure 44 in report)

Site No.	Geographic Name	Shore Morphology	Present * Phase of Evolution	Site No.	Geographic Name	Shore Morphology	Present * Phase of Evolution
1	Castle Bay	Barrier Beach	3	**43**	Red Point	Barrier Beach	4
2	Amagaudees Pond	Barrier Beach	3		McKinnon Harbour		
3	Dhu Point	Spit	4	**44**	Bens Beach	Barrier Beach	3
4	Indian Islands West	Barrier Beach	3 to 4	**45**	Gillis Beach	Barrier Beach	4
5	Indian Islands East	Tombolo	3	**46**	Jamesville East	Barrier Beach	6
6	Cossett Point W	Barrier Beach	3	**47**	Plaster Cove	Barrier Beach	3 to 4
7	Cossett Point	Spit	4	**48**	Grass Cove	Barrier Beach	3
8	Head East Bay N	Spit	6		MacRitchies Pond		
9	Head East Bay S	Spit	3	**49**	Maskells Harbour	Spit	3
10	no name	Barrier Beach	early 4	**50**	Burnt Point	Barrier Beach	3
11	MacDougall Point	Tombolo	6	**51**	Neil Island	Tombolo	4
12	Marble Point	Barrier Beach	4 to 5	**52**	Washabuck	Tombolo-paired	
13	Porphyry Point	Barrier Beach	4		Centre	northeast	3 to 4
14	Big Pond	Barrier -relict	5			southwest	3
15	Lochmore Harbour	Spit	4	**53**	Hazeldale	Barrier Beach	3
16	Lochan Fad	Barrier Beach	5	**54**	The Harbour	Spit	4
17	Irish Vale	Barrier -relict	5		Baddeck Bay		
18	Barachois Harbour	Barrier Beach	5	**55**	Poker Dans Pond	Barrier Beach	early 4
19	Evans Island North	Barrier Beach	3	**56**	MacKillop Pond	Barrier Beach	3 to 4
20	Evans Island South	Spit	5	**57**	MacDonald Point	Barrier-cuspate	3
21	Indian Island	Spit	4 to 5		Starks Pond		
22	Cape George Harbour	Spit	3 to 4	**58**	Black Island	Tombolo-paired	
23	Cape George	Tombolo-paired		**a**	Fraser Point	shoal	5
	a	Barrier Beach	4 to 5	**b**		Barrier Beach	3
	b	Barrier Beach	3	**59**	Coffin Point	Barrier Beach	3
24		Barrier- relict	5	**60**	Point Clear	Barrier-cuspate	3 to 4
25	MacMullens Pond	Barrier Beach	3		(Robenas Pond)		
26	Urquart Pond	Barrier Beach	4	**61**	McGreadyville	Spit	2
27	McLeod Point	Tombolo-paired		**62**	Barachois	Barrier Beach	4
	a	Barrier Beach	4	**63**	McLean Point	Barrier-relict	5
	b	Barrier Beach	4	**64**	Ironville	Barrier-cuspate	3
28	Dunphy Head	Spit	4 to 5	**65**	Neil Beach	Barrier-cuspate	5
29	West Bay	Spit	5	**66**	Dougall Point	Barrier-cuspate	3
	Settlement	Barrier-cuspate	3	**67**	Beaver Cove	Barrier -cuspate	3
30	MacDonalds Cove	Spit	2	**68**	McLean Beach	Barrier-cuspate	
31	MacKenzies Cove	Tombolo	3 to 4	**a**	Point		4
32	Brians Pond	Barrier-Beach	3 to 4	**b**			3
33	Pellier Island South	Spit	3 to 4	**69**	Shunacadie	Tombolo-paired	
34	Sheep Island	Barrier -Looped	3	**a**		east	5

Site No.	Geographic Name	Shore Morphology	Present * Phase of Evolution	Site No.	Geographic Name	Shore Morphology	Present * Phase of Evolution
35	Militia Point West 1	Barrier Beach	3 to 4	**b**		west	4
36	Militia Point West 2	Barrier Beach	3	**70**	Big Pond	Barrier Beach	4
37	Malagawatch Harbour	Barrier Beach	3		Shunacadie		
38	Johnson Cove 1	Barrier Beach	3	**71**	Long Beach Point	Barrier-cuspate	3
39	Johnson Cove 2	Barrier Beach	3 to 4	**72**	Goose Pond	Barrier-relict	5
40	Fiddle Head	Tombolo-paired	3 to 4	**73**	Christmas Island	Tombolo-relict	
	(Big Harbour)			**a**			3
41	Boom Island	Barrier Beach	4	**b**			4
	(Malagawatch)			**74**	Grand Narrows	Barrier Beach	late 4
42	Campbell Island	Tombolo-paired	3	**75**	Pipers Cove	Barrier Beach	3
				76	Benacadie west	Barrier Beach	3

*** Phases of Beach Evolution**

1 Initiation	4 Breakdown
2 Growth	5 Collapsed/Stranded
3 Established	6 Artificially constrained