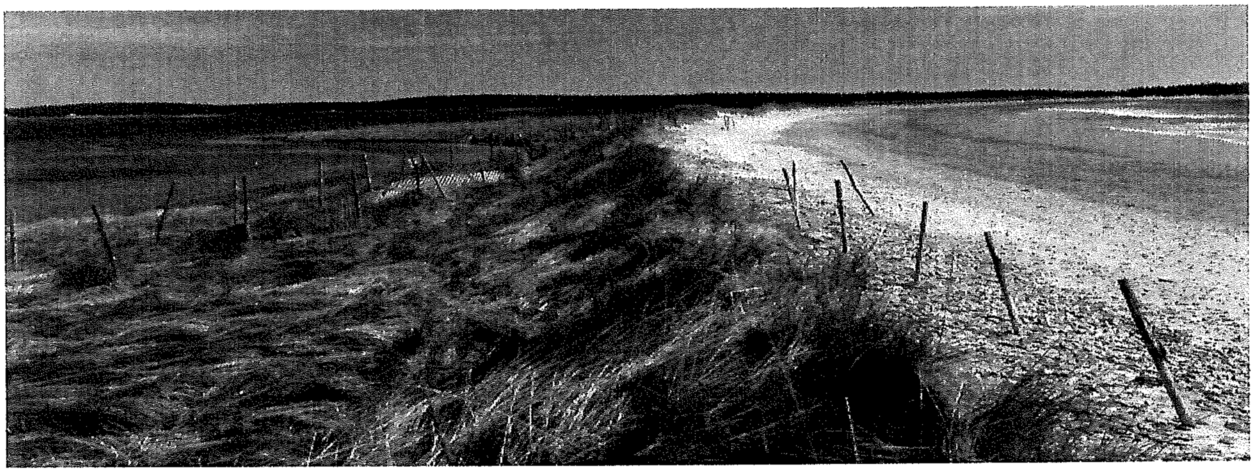
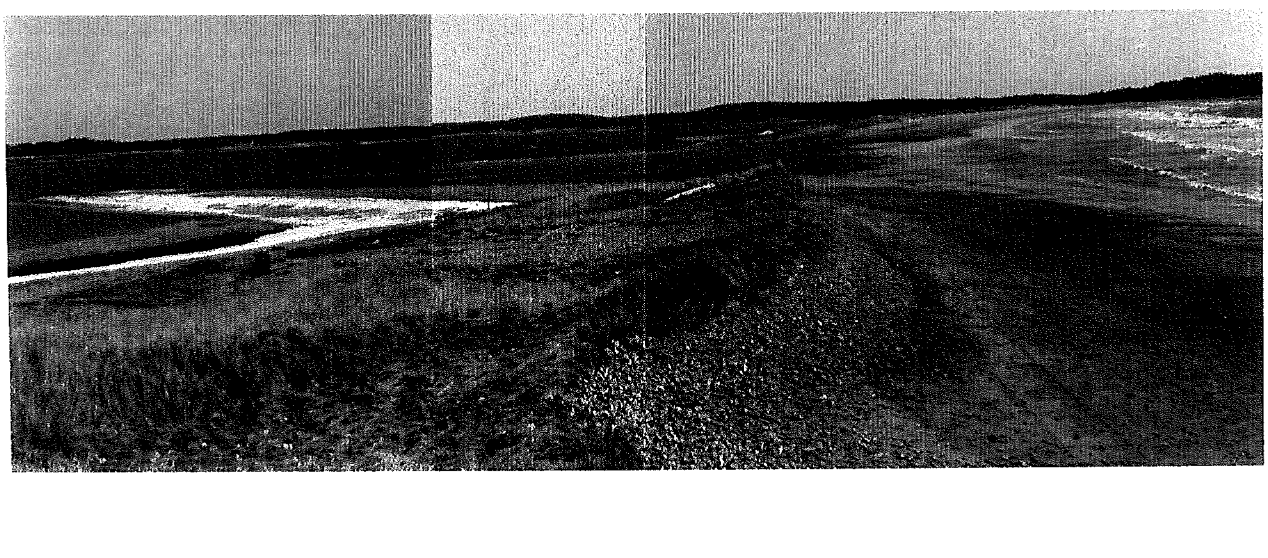
Geological Survey of Canada
Open File Report
3823

Barrier Breaches and Washover Features Martinique Beach, Nova Scotia

R.B. Taylor and D. Frobel





Natural Resources Canada
Ressources Naturelles Canada

Canada

Barrier Breaches and Washover Features Martinique Beach, Nova Scotia

R.B. Taylor and D. Frobel
Geological Survey of Canada
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

Geological Survey of Canada
Open File Report
3823

October 1999

Front Cover- The tendency, when a barrier beach becomes very narrow is for people to build structures such as sand fences to trap sediment and rebuild the dunes. In contrast the "natural" solution is for waves to cut through the dunes and widen and rebuild the beach farther landward. Wave overwash is one of the principle mechanisms for transferring the sediment landward from the seaward side of a barrier beach. Two views looking east along one of the narrowest parts of Martinique Beach, Nova Scotia, illustrate the above statements.

By April 1996 (upper photo) some dune building had been accomplished on the backshore before the sand fences were damaged by waves. However the dune recovery was insufficient to withstand the elevated water levels and wave overwash that occurred during a storm in late February 1998. Subsequent transport of sediment landward through a large wave washover channel (bottom photo March 1998) formed an extensive lobe of sediment (called a washover fan) which forms the foundation for the new barrier beach.

Introduction

Several storms struck the Atlantic coast of Nova Scotia in the winter of 1998, including the storm of February 25, when a local TV news program reported that waves had completely breached Martinique Beach and carried much of its soil landward. The newscast prompted widespread interest in the "loss" of the beach. As a consequence of the concerns about the stability of Martinique Beach, surveys of the new breach and several beach lines were completed in March 1998. Subsequent visits to the beach in March and August 1999 and a resurvey of the barrier breach in June 1999 provide an update on the impacts and natural evolution of the breach. Several older breaches are also described and their impacts on beach stability are compared with those of the 1998 breach.

Martinique Beach is located 50 km east of Halifax along the Atlantic coast between Petpeswick Inlet and Musquodoboit Harbour. The beach is 3.5 km long and joins Flying Point Island to the mainland (Fig. 1). Anchored between a series of rock outcrops such as at Whale Point, and the "mid-beach outcrop" the beach is characterised by a gradual sloping sand foreshore backed by a single primary dune ridge in the backshore. The dune increases in elevation from 3 m at the east and west end of the barrier to just over 5 m between beach lines 3 and the mid-beach outcrop east of line 5 (Fig. 1). On its landward side, Martinique Beach shelters the Musquodoboit River estuary and an extensive salt marsh.

Breach of February 1998.

The impacts of the February 25th, 1998 storm were most evident along the eastern part of Martinique Beach. Waves combed down the beach, cut a scarp along the base of the primary duneline and formed washover channels across the backshore where the duneline was lowest. The largest cut or breach through the dunes occurred at beach line 6 (Fig. 1, 2) where waves overwashed the beach reaching the estuary channel behind. On March 13, 1998 water was flowing through the washover channel at high tide but only a trickle of water flowed landward and seaward from the mouth of the breach at low tide (Fig. 2c). Surveys of the breach were completed on March 27, 1998, and June 11, 1999, one month and 16 months after the storm. Differential GPS surveys were completed using a Geotracer system 2000 in the real time kinematic mode. The base station for the surveys was established at Nova Scotia benchmark 10051 at Philip Head west of the beach (Fig. 1). Points were surveyed relative to the North American Datum 1983 (NAD 83) and plotted using the UTM (Universal Transverse Mercator) mapping projection (Zone 20). Elevations are relative to Geodetic datum.

Between March 13 and 27, 1998, waves continued to cut down the beach and seaward duneline and expand the width of the breach. By March 27, 1998 the barrier breach had expanded to 136 m wide at its mouth, i.e. at the seaward duneline, and extended 138 m landward to the main estuary channel (Fig. 3, 4). Within the breach, the main washover channel was 70 m wide. It cut down to mean sea level at the mouth of the breach and the channel bed sloped downward to - 0.7 m elevation where the washover fan intersected the estuarine channel (Fig. 4b). The channel was bounded on its sides by 1 m high levees which were built over top of the previously existing backshore deposits (Fig. 2, 3).
During spring high tide, the depth of water flowing through the channel varied from 0.9 m at the mouth to nearly 1.5 m at the washover fan (Fig. 4). Across the backshore, the channel bed

rbt/asc 98

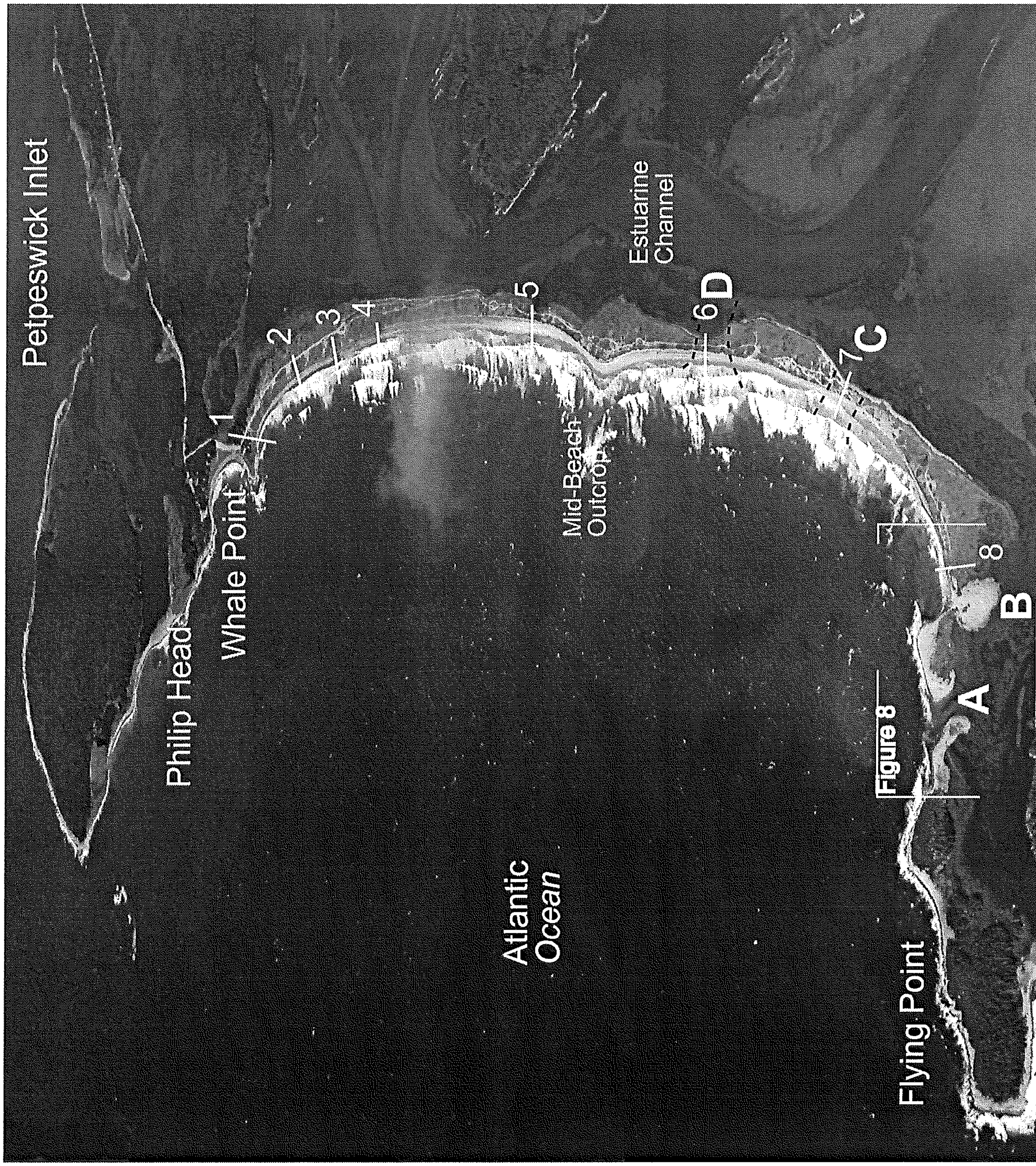


Figure 1. Aerial view of Martinique Beach taken from its east end, September 29, 1976, showing the location of beach survey lines (1 to 8) and breaches caused by wave overwash (A) before 1945 (B) 1974 to 1976; (C) 1977; and (D) 1998. Note the position of the estuarine channel that flows along the back barrier. (photo by R. Belanger, Bedford Institute of Oceanography).

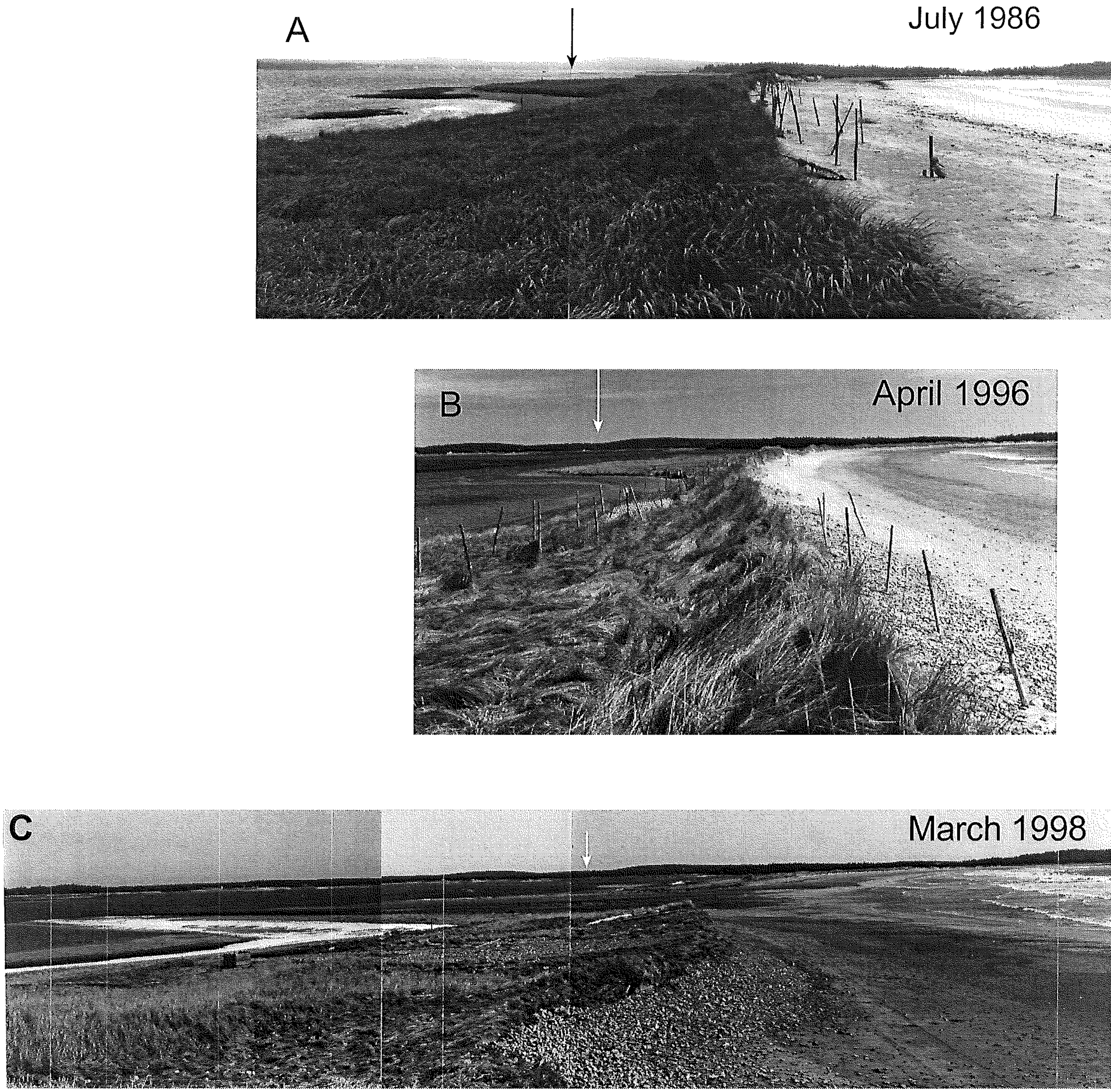


Figure 2. Ground photos taken at line 6 in: (A) July 1986, (B) April 1996, and (C) March 1998 after the formation of the breach (arrows are for visual alignment of same point). The wooden posts are all that remain of sand fencing which was used to encourage sand accumulation and widening of the beach during the 1980s. Note the increase in pebble cobble clasts at the base of the dune in 1996 and 1998.

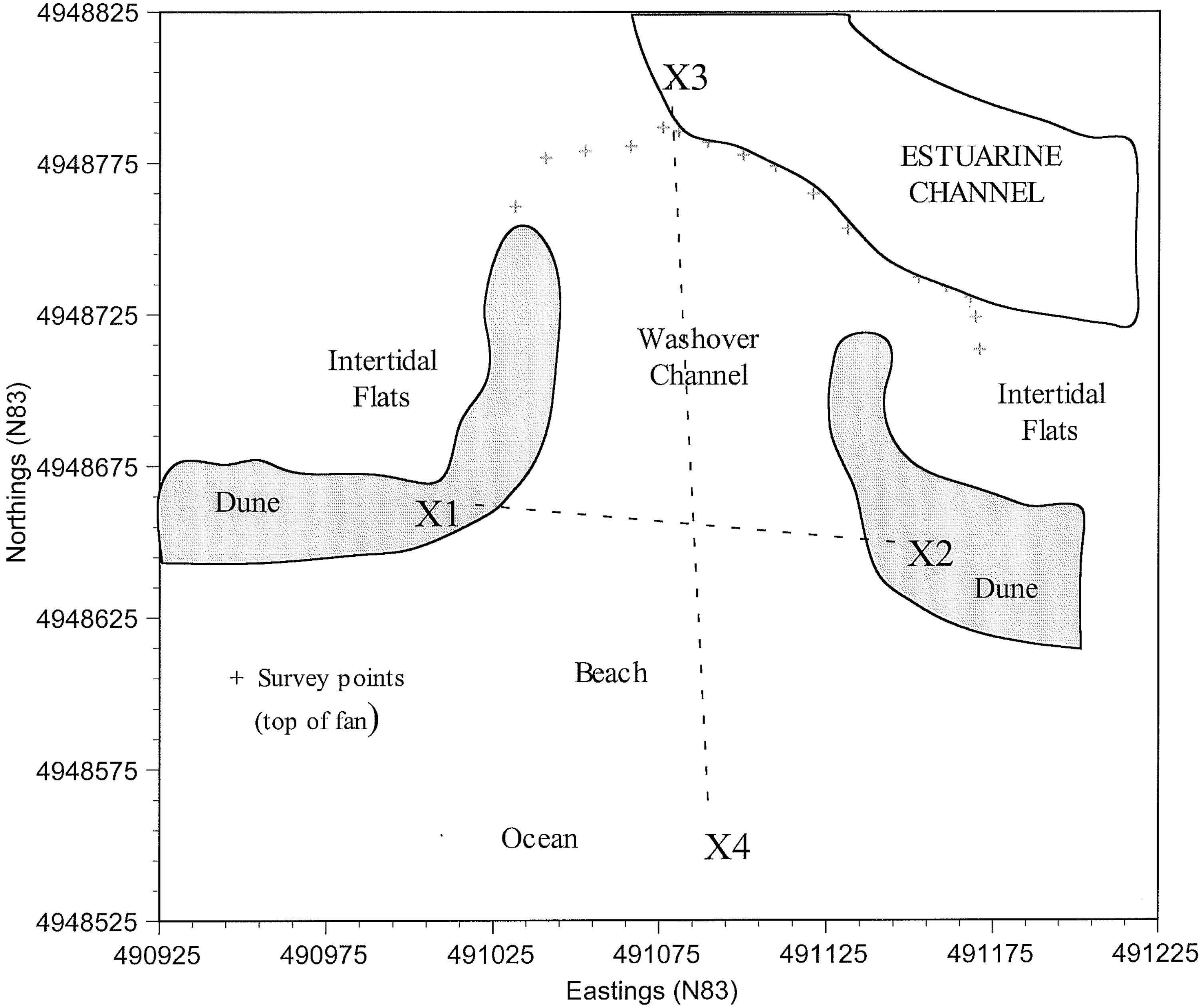


Figure 3. Plan map of the wave washover channel cut through the east end of Martinique Beach in February 1998. The map was surveyed on March 27, 1998 using differential GPS with a Geotracer system 2000. X1-X2 and X3-X4 mark the locations of profiles shown in figure 4.

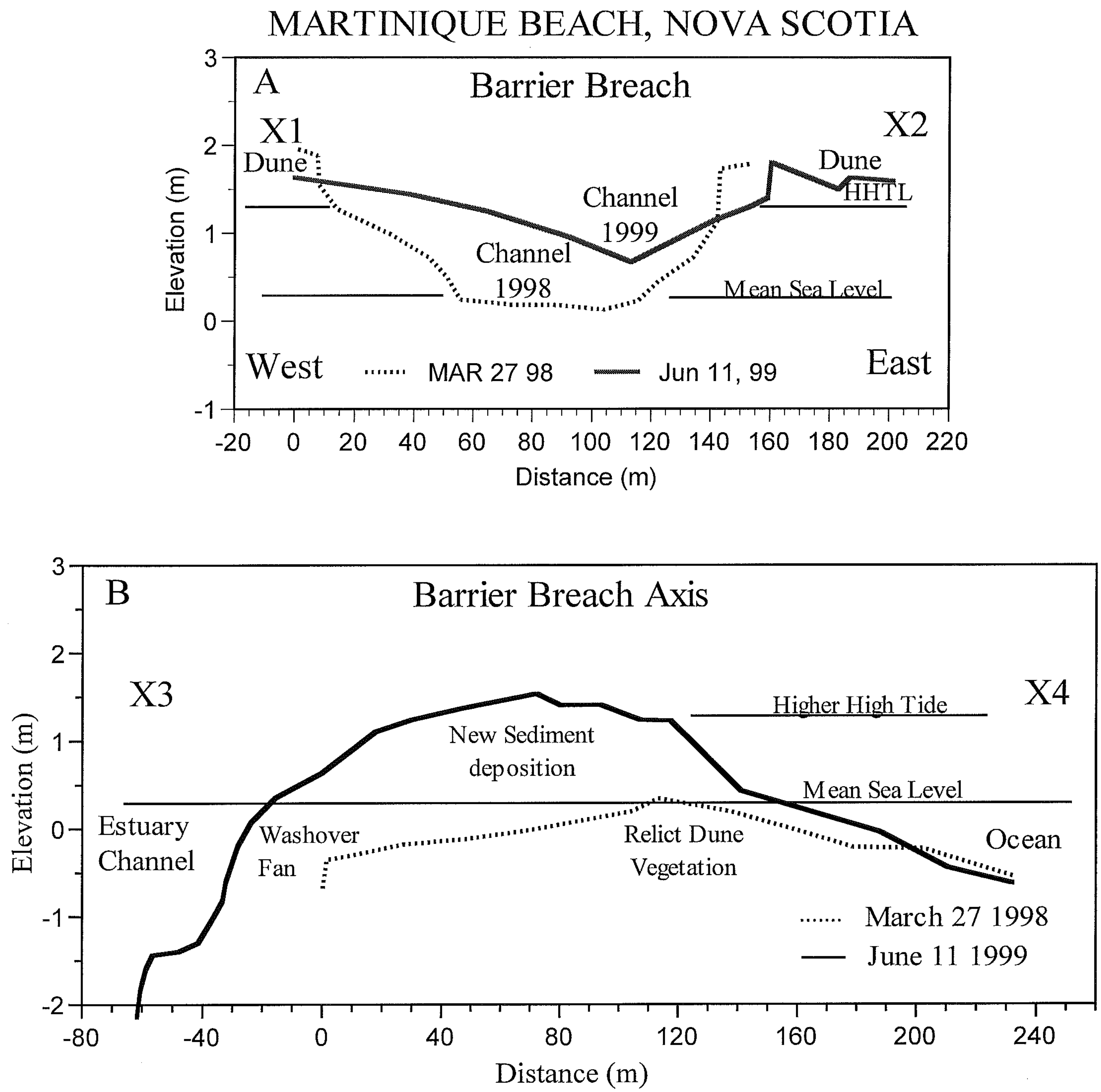


Figure 4. Cross-sectional views of the 1998 barrier breach: (A) across its mouth and (B) along its axis showing changes in its morphology between March 1998 and June 1999. The location of the profile lines is shown on figure 3.

consisted of well defined sandy megripples formed by strong tidal flows. Closer to the mouth of the channel, the bed consisted of mounds of relict dune vegetation, and a cover of sand and pebble.

Sediment eroded from the outer beach and dune was added to the washover fan which was building northward into the main estuary channel (Fig. 1, 3). Maximum depth of the estuarine channel was unknown but it was more than 2 m deep where the washover channel intersected it. The top edge of the washover fan was extremely unstable in March 1998 because sand was being deposited very rapidly and there had been little time for the new slope to consolidate and stabilize. Initially the unstable slope posed a possible hazard to curious onlookers who walked too close to the edge, but within a year the deposit was much firmer.

Aerial photos (Fig. 5) taken of the site in May 1998 by D. Dauphinee, Nova Scotia Department of Natural Resources showed the washover fan had extended westward, and the mouth of the breach widened. Despite the widening, sediment accumulation at the mouth had temporarily stopped wave overwash and flow from the ocean (E. Crowell, 1998, pers. com.). It is not known how long the channel remained closed. On March 1, 1999 there was some wave overtopping along the east side of the breach but no well defined tidal channel. Beach sands blown alongshore from the east were being deposited within the breach. In contrast, by early June 1999 there was a better defined tidal channel with water flowing through it at high tide.

In 16 months the mouth of the breach had widened by nearly 30 m and the seaward duneline west of the breach had been cut back by 10 to14 m and to the east of the breach the dunes were cut back 3 to12 m (Fig. 6). The original washover channel had infilled by 1.1 m at its mouth and 1.6 m farther inland (Fig. 4a). The main washover channel had shifted eastward. It was 0.5 m deeper than the western part of the breach but shallower than the 1998 channel (Fig. 7). By August 4, 1999, the mouth of the breach was again built up and tidal flow stopped. However the lower landward side of the breach was being flooded from the estuary.

At the back of the breach, the upper edge of the washover fan was extended 32 m farther northward and the toe of the fan was nearly 60 m north of its March 1998 position (Fig. 4b, 6). The eastern side of the washover fan had been extended by less than 10 m. The growth of the washover fan was greatest toward the west as sediment accumulated over top of older deposits that fringed the estuary channel (Fig. 5b). The gradient of the washover fan was 14 to 19 degrees (tan ϕ 0.258 to 0.350) along its eastern slope and the base of the fan was at an elevation of -1.9 m. Along the northern and western slope, the base of the fan appeared to be at -1.6 m but it may have extended farther into the estuary channel which was too deep to survey. An estimated 36,506 m^3 of sediment accumulated within the breach since March 1998 (Appendix 1). If we assume the original duneline lost was 136 m long, 15 m wide and 1.5 m thick, then 3060 m^3 of sediment was derived from the initial breakthrough. This volume is only 8% of the total sediment that has been transported into the breach. A large volume of sediment is being derived from erosion of the duneline east and particularly west of the breach.

Further changes in the breach observed in August 1999 included: a widening and better definition of washover channel along the western part of the breach (Fig. 6, between X1and X8); numerous

Figure 5. Aerial views of the 1998 breach showing its extension westward over shallow estuarine deposits and northward into the deeper estuary channel. Sediment accumulation at the mouth of the breach had temporarily stopped the flow of water through it. (Photos taken May 29, 1998, by D. Dauphinee, Nova Scotia Department of Natural Resources).

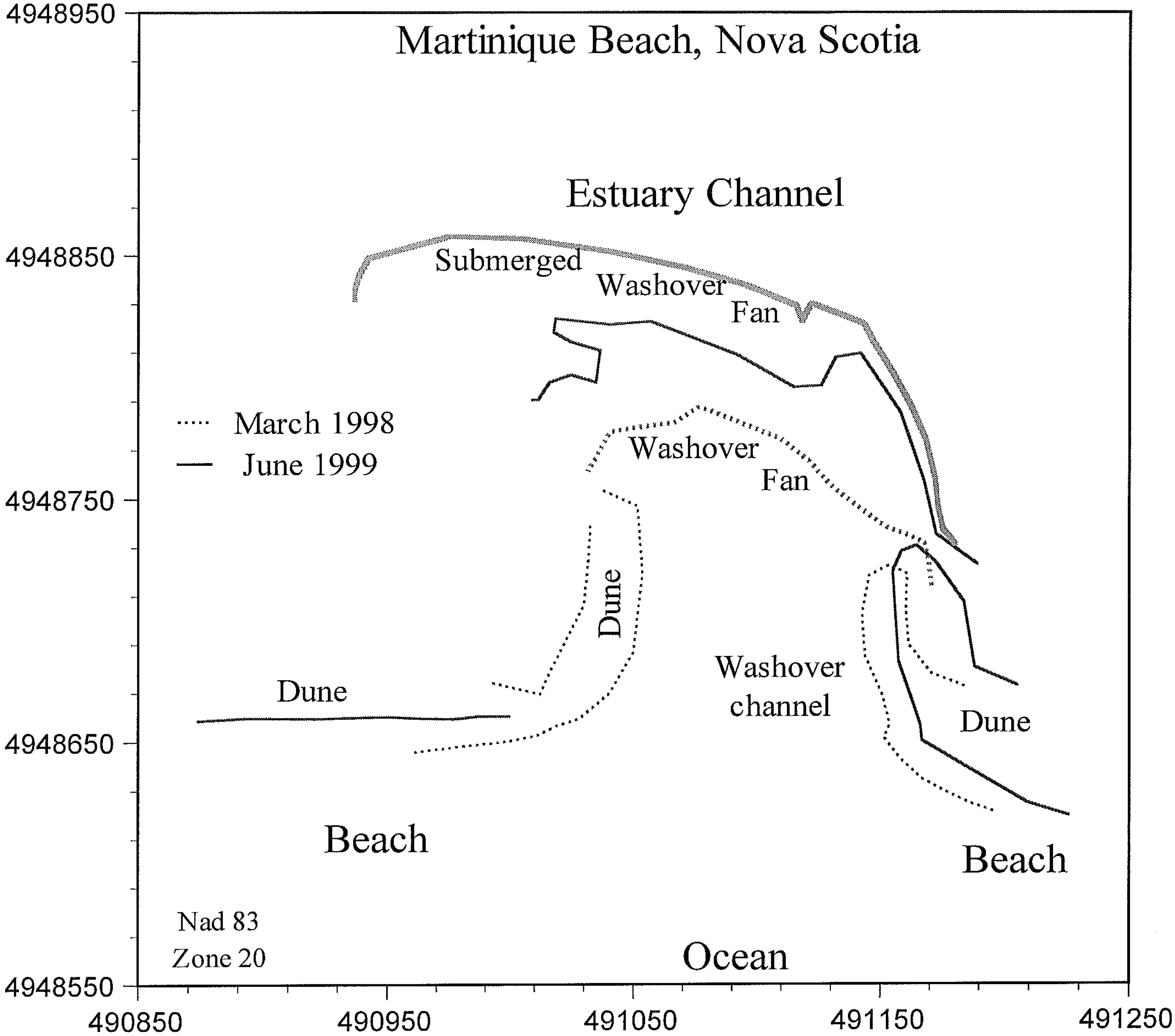


Figure 6. Plan map of the 1998 breach 16 months after its formation showing the widening of its mouth, the retreat of the seaward duneline and the extension of the washover fan. Surveys were completed on March 27, 1998 (dotted lines) and June 11, 1999(solid lines).

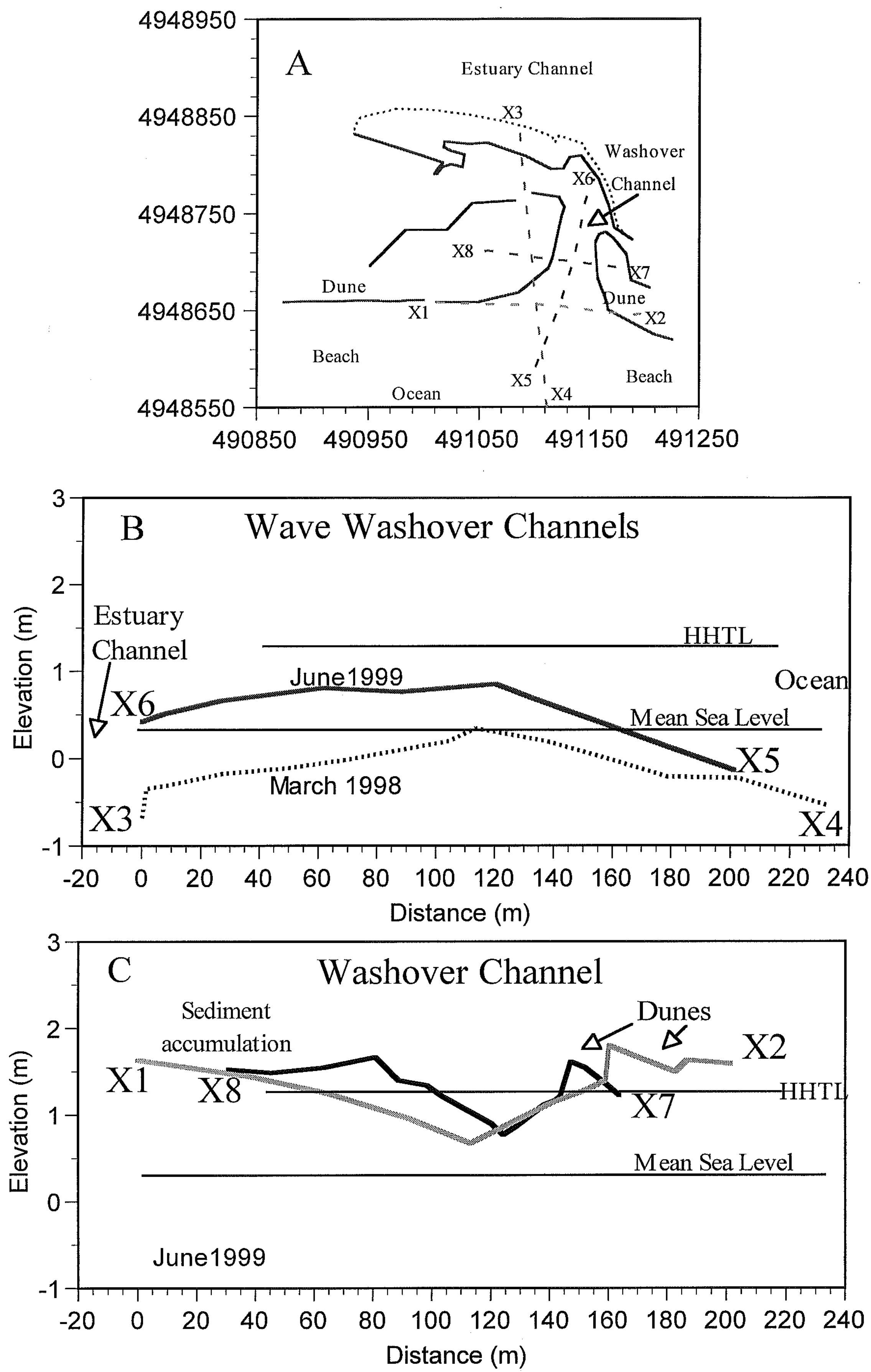


Figure 7. (a) Location of profiles surveyed in June 11, 1999 and profiles (b) showing the depth of scouring along the axis of the 1999 channel relative to the one observed in March 1998 and (c) cross-channel profiles at the mouth (X1-X2) and inner portion (X8-X7) of the breach. The profiles in 7c are aligned along a common UTM Easting.

small sand accumulations around logs, debris, and clumps of vegetation across the western channel and temporary closure of the breach from the sea by a sand berm. In contrast to the mid breach mound, which was higher and partially vegetated, the back of the eastern channel remained low and wet. Tidal flow in the estuary channel does not appear to have changed but there are no measurements to confirm whether this is true. Estuarine muds have been buried beneath the washover deposits which may adversely affect some biological communities.

East and west of the'98 breach the seaward duneline has become narrower and lower since March 1998. There has been increased wave overwash through the lower parts of the duneline and deposition of sediment across the low backshore. The estuary channel has begun to infill. Accelerated duneline retreat has been observed as far as west as the "mid-beach outcrop" (Fig. 1). Until June 1999 the duneline west of the breach had retreated faster than the duneline east of the breach, but by August 1999 duneline retreat east of the breach had accelerated. A positive aspect of the '98 breach was the formation of an extensive unvegetated sandflat which is favourable breeding habitat for shore birds such as the Piping Plover.

In March 1998 a potential barrier breach site was identified at a large dune blowout, at line 5 (Fig. 1). Two lines of sand fencing were extended across the blowout by Nova Scotia Natural Resources however little sand had accumulated by June 1999. By August 1999 additional fencing had been placed across two other blowouts between Line 5 and the "mid-beach outcrop" (Fig. 1). The sand fencing was installed by a Boy Scout troop from Sackville Nova Scotia under the supervision of a local resident and scout leader. The work was based on instructions from R. Bradley (Parks Division, N.S. Natural Resources) and materials were supplied by N.S. Natural Resources.

Older Barrier Breaches and Washover Features

A 1763 map of the Atlantic Neptune series (Taylor et al., 1985) shows an inlet separated Martinique Beach from Flying Point but the Church map of 1865 (Taylor et al., 1985) shows them joined. There is no other information about inlets or major cuts through the dunes until the advent of air photos. Since 1945 repetitive air photos have show that waves have washed over Martinique Beach at a number of places. In 1954 the air photos revealed that the western portion of the beach, including the pocket beach west of Whale Point, was building over a nearly continuous series of wave washover deposits. Dunes along the eastern part of Martinique Beach appeared more stable and were covered by pockets of more mature vegetation. There was a channel (Fig. 1, "A") cut through the pebble cobble barrier adjacent to Flying Point (Fig. 1, 8). This channel formed before 1945 but it is not known if it was once part of the inlet shown on the historical maps. Although it has changed in shape, depth and position, it still exists in 1999. In August 1999 water flowed through this channel at high tide to a drainage channel in the backshore.

The most significant changes along the eastern part of Martinique Beach began in the mid 1970s when washover fan "B" and breach "C" developed (Fig. 1). Washover fan "B" formed between 1974 and 1976. It covered a large extent of marsh (Fig. 8). Line 8, which was surveyed in 1986 and 1998, is adjacent to washover fan "B". The dunes presently extend to 3 m elevation and have

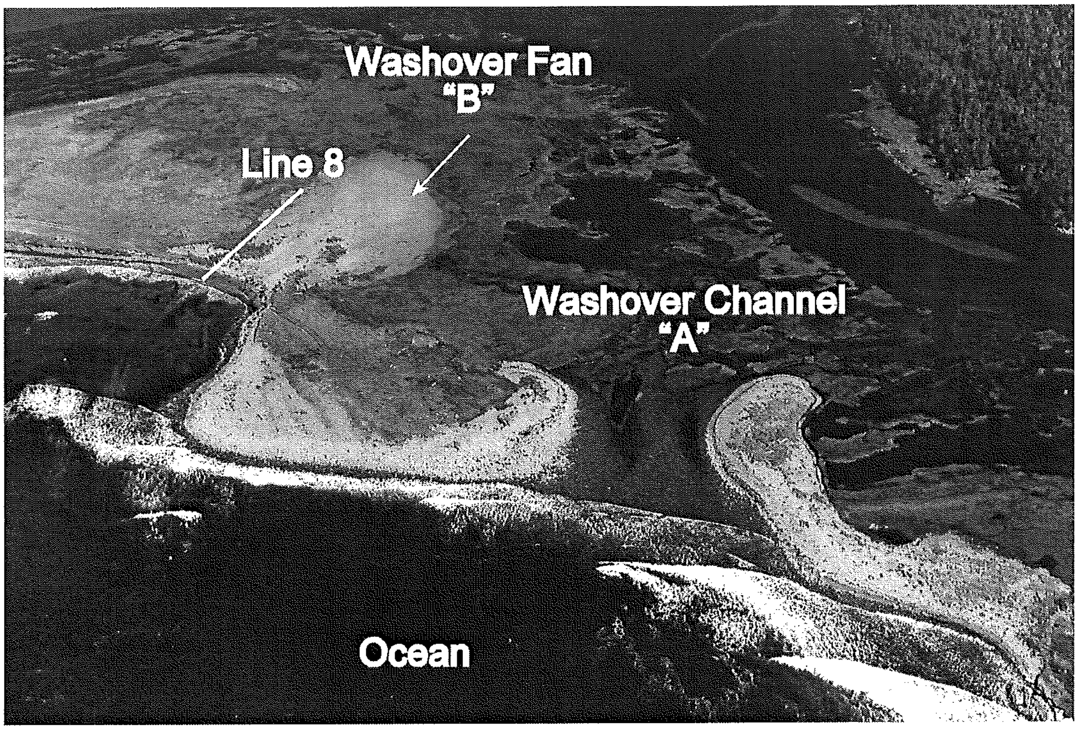


Figure 8. Aerial view of the east end of Martinique Beach, September 1976 showing an older channel (A) that cut through the pebble-cobble portion of the barrier before 1945, and a washover lobe of sand (B) that formed some time between 1974 and 1976 near line 8. The older channel(A), despite changing its shape and position slightly still exists in 1999. Water flows through the channel at high tide and into another backshore drainage channel.(Photo by R. Belanger, BIO).

prograded seaward as much as 3 m in the past 13 years. Sand deposition also has increased over the nearby gravel beach ridges allowing dune vegetation to spread eastward.

Breach "C" (Fig. 1, 9, 10) was initiated in 1977 and is probably the best documented of the older breaches (Taylor et al., 1985). There are no surveys available but from photos it appears that the breach was similar in size to the one formed in 1998. Several attempts were made to trap sand in the breach using christmas trees and sand fences. It took until late 1979 before water stopped flowing through the breach and sufficient sediment accumulated to allow new sand fencing to survive. By 1981 the breach was infilled by partially vegetated dunes that extended to elevations of 2.4 m (Fig. 9, 10a). If one assumes a width of 100 m the breach was infilled by roughly 3000 m^3. Sand levels remained high in 1986-87 and by April 1996 the seaward dune was being cut back and built higher (Fig. 10b). During the 20 years the dunes grew to an elevation of 3.5 m and to 4.1 m along their seaward edge (Fig. 9). In 1999 the duneline was 3 m farther seaward than in 1981, it contained 600 m^3 more sediment but it was already in a retreat phase. The duneline extended farther seaward in the late 1980s (Fig .9, 10b,c). Between 1981 and 1999 the beach had been cut down by 1.8 to 2 m (Fig. 9) which over a width of 100 m is roughly equivalent to 9000 m^3 of sediment. In March 1999 a significant volume of sand was being blown westward from the beach toward and into the '98 breach. It is possible that much of the beach lowering observed at line 7 occurred in response to the '98 barrier breach which has become a major sink for beach sediment.

What conditions led to the formation of the 1998 breach?

Despite the closure of the 1977 breach, the duneline farther west continued to retreat and become very narrow near the site of the 1998 breach (Fig. 2). A comparison of beach surveys at line 6 (site of the 1998 breach) in the mid-1970s and 1981 showed that the upper beach and seaward duneline had retreated an estimated 9 m (Taylor et al., 1985). Despite a well developed beach berm and higher sand levels in 1981, the base of the seaward duneline was scarped. By mid-1986 (Fig. 2a) the duneline had retreated another 6 m landward leaving only a 4 m wide dune ridge. Several attempts were made to trap sand and widen the dune using sand fences between 1981 and 1986. Fencing erected in the late 1980s (Chris Trider, pers com., 1989) trapped sediment and resulted in a higher dune ridge by 1996 (Fig. 2b) but it was still very narrow and much of the fencing had been destroyed by waves. Only posts remained of the seaward fences and pebble- cobble clasts had accumulated along the seaward base of the duneline by 1996. The appearance of gravel is the consequence of the landward movement of coarser clasts derived from the steepening and lowering of the lower beach face and in some cases the re-exposure of gravel following the retreat of the duneline. Pebble cobble had been observed in 1981 along the base of the dune east of line 7 (Fig.1). Between 1981 and 1986 the lower beach slope at line 6 was steepened and lowered by 0.4 to 0.7 m. There were no surveys to confirm whether the beach slope continued to lower after 1986 or whether its level fluctuated from year to year. Increased scouring of the duneline and the increased abundance of gravel along the upper beach (Fig. 2c) suggest there had been more periods of low, than high sand levels since 1986.

Although there were several storms during January 1998 when the breach may have begun, it is generally accepted that it was the storm of February 24, 25 1998 which formed the breach. On the evening of February 24, 1998 winds along the Atlantic coast of Nova Scotia were 44 to 59

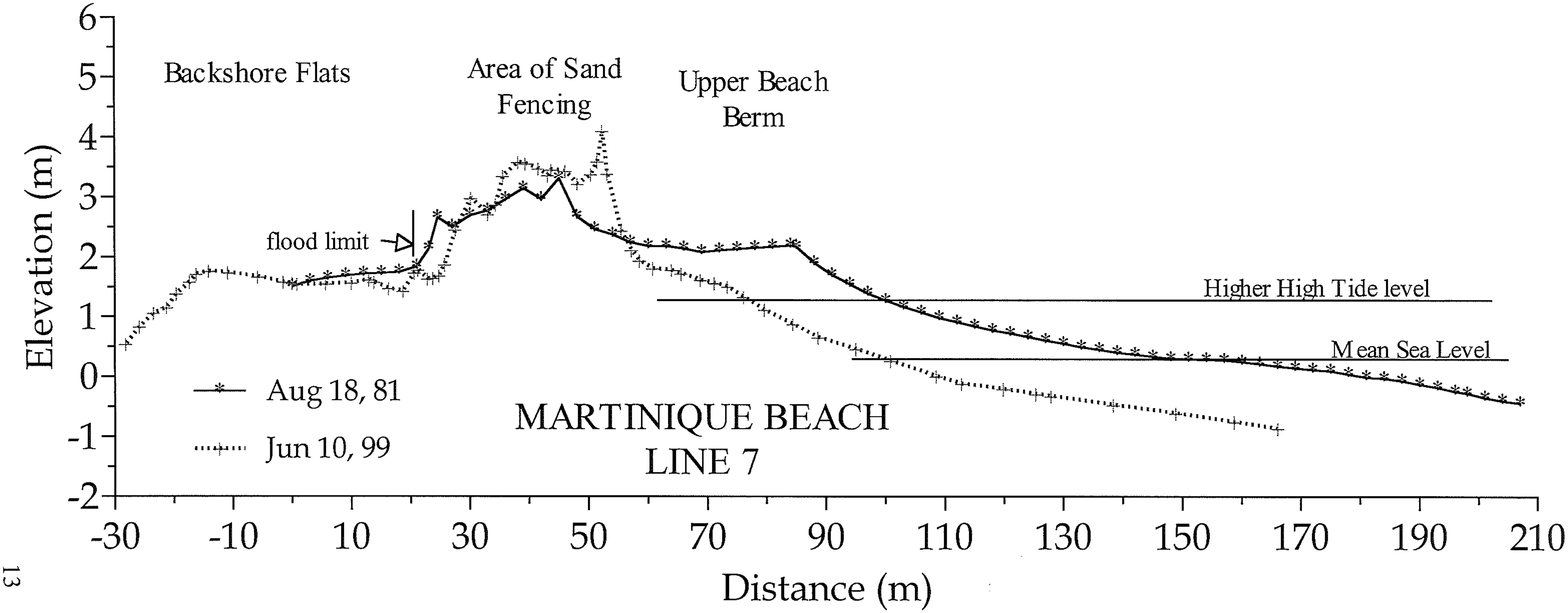


Figure 9. Cross-shore profiles of the 1977 barrier breach showing the extent of dune recovery in 1981 and 1999. During the early-mid 1980s higher sand levels along the upper beach provided a source of sediment for dune building. The duneline began to retreat landward by 1996 and possibly as early as 1987. Accentuated dune buildup at the seaward edge of the duneline is a product of dune transgression. In 1999, beach sediment was being transported by wind westward into the 1998 breach.

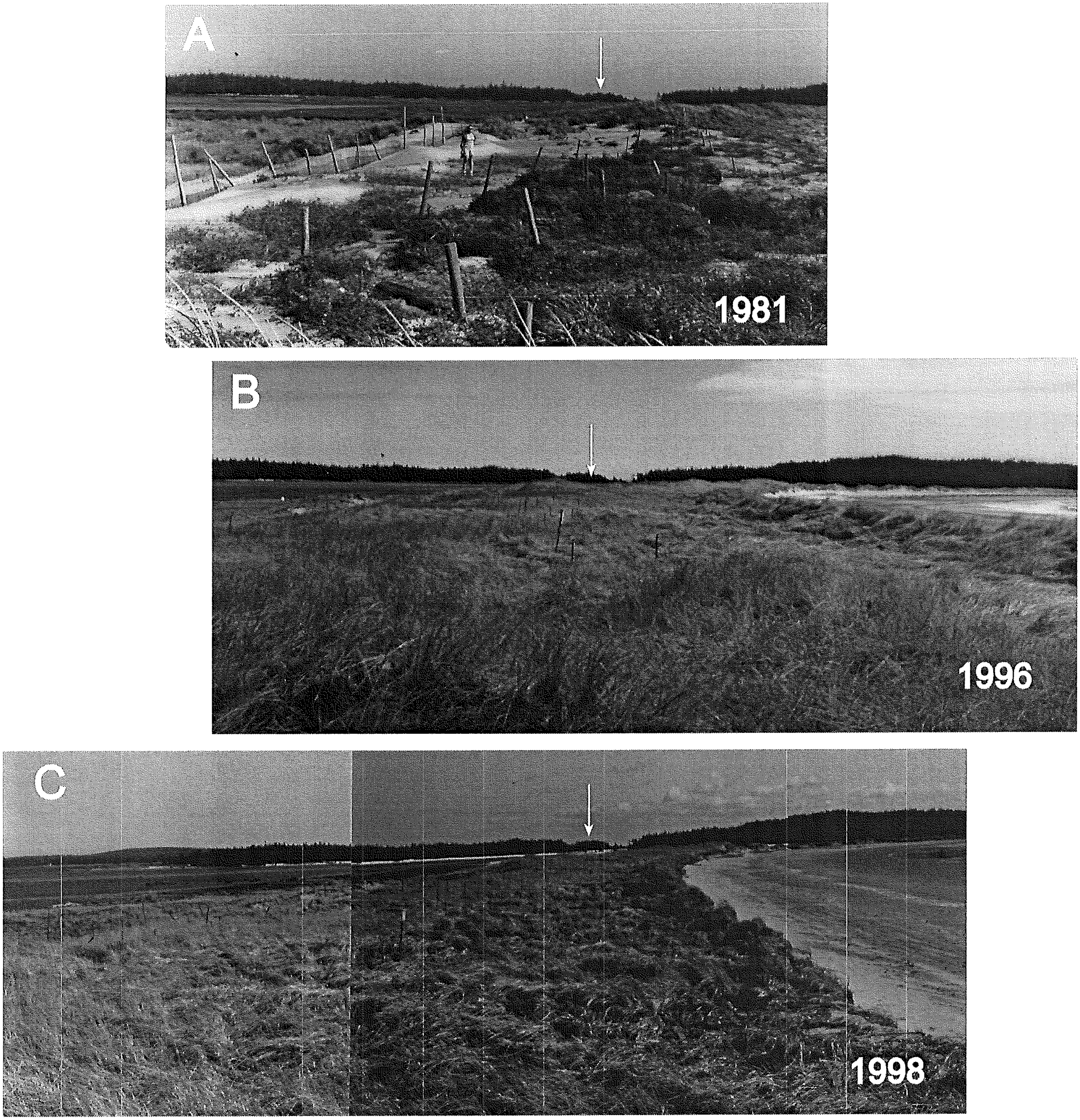


Figure 10. Ground views of the area of sand fencing established within the 1977 barrier breach (a) September 1981 when the dunes were only partially vegetated, (b) April 1996 with dense vegetation cover and natural building along the seaward edge of the duneline and (c) March 1998 with good vegetation cover but increased scouring along the seaward duneline. Arrow provides visual reference of same location on each photo.

knots and wave heights were reported to be more than 7 m off southwest Nova Scotia. The tide gauge in Halifax Harbour recorded a 0.52 m surge at high tide which produced a total water level of 2.1 m. A larger surge of 0.6 m occurred later but it was close to the next low tide. The surge abated as the winds dropped just before high tide early on the morning of the 25th and then water levels rose again to 2.39 m a few hours after high tide. Seas with significant wave heights of 8.1 m, maximum wave heights of 11.7 m and 14 second period were recorded at the Shearwater wave buoy. A positive surge of 0.3 to 0.4 m continued until at least February 27th. The weak state of the duneline, high water levels and waves were the causes of the breach. The amazing thing was that the breach had not occurred much sooner because the dune had been very narrow since 1996.

Response Strategies

In the early 1980s, Bowen and Boyd (1983) concluded that the eastern part of Martinique Beach was in a phase of breakdown whereas the beach west of the "mid-beach outcrop" (Fig. 1) was fairly stable. They believed that there was insufficient sediment to rebuild the dunes along the eastern end of the beach and it would continue to be overwashed and degrade.

Since the mid-1970s there has been an increased number of breaches, some duneline retreat and a transfer of sediment to the backshore. However, there has also been significant recovery and growth along some parts of the eastern duneline and with some assistance, closure of the largest breaches. It appears that the growth has been at the expense of erosion along other parts of the beach and duneline (Fig. 11). This suggests that although there is sufficient sediment to mend the duneline, there is insufficient material to maintain the whole duneline in its present position. Normally as the duneline retreats and sediment is transferred landward, the dunes reform as the backshore aggrades, however a deep estuary channel flows along the backbarrier shores of Martinique Beach. For the backshore to extend landward and aggrade, the channel will need to be infilled. This process which began with the 1998 breach, will reduce the availability of sand for dune building.

It is felt that the1998 breach was comparable, at least initially, in size to the 1977 breach. Both were significant events in the natural evolution of this beach, however the most recent breach will have a greater consequence on the barrier stability if the transfer of sediment into the estuary channel continues. Other areas of the backshore have already been widened by deposits transported through earlier breaches. The aerial view of Martinique Beach in September 1976 (Fig. 1) shows that the 1998 breach occurred at one of the narrowest parts of the beach, consequently it will require significant volumes of sediment to widen this part of the beach.

Two possible strategies for responding to these beach changes include: 1) do nothing and let nature take its course or 2) conduct limited dune restoration activities to slow down the natural retreat of the beach. Monitoring of beach conditions is also encouraged regardless of the strategy picked..

<u>1) Let Nature Take its Course-</u> The breach cut through the eastern part of Martinique Beach in 1998, was a natural process that has occurred in the past and will occur again in the future. Wave overwash is a method of transferring sediment landward, widening the backshore and building

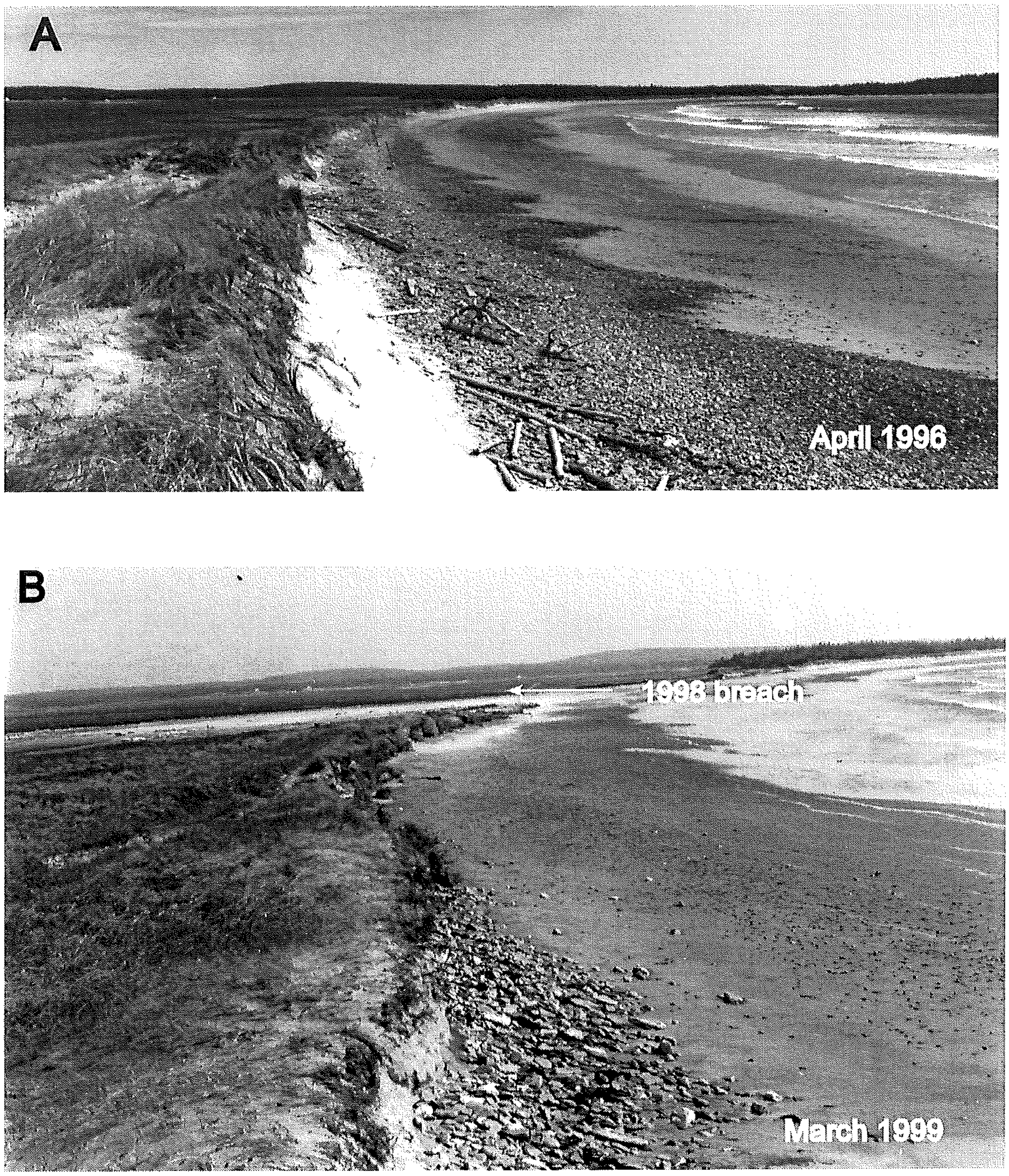


Figure 11. Views to the east toward the site of the 1998 barrier breach (a) in April 1996 and (b) March 1999. The 1998 breach formed in one of the narrowest parts of Martinique Beach and since its formation the duneline west of the breach has retreated 15 m leaving a low backshore vulnerable to increased wave overwash and the expansion of the 1998 breach further westward. The higher sand levels across the beach in 1999 compared to 1996 were partly attributed to the retreat of the duneline.

the foundation for the beach as it retreats landward during periods of decreased sediment supply and rising sea levels. In this case the landward transfer of sediment is facilitated by the low backshore. Although the duneline may intermittently mend itself, it is anticipated that, in the near future, the eastern portion of Martinique Beach will experience a faster rate of change which includes the formation of a series of washover channels, sandflats and small dunes as was observed along western Martinique Beach in the 1940s and 1950s. These changes do not pose a problem to park infrastructure but may result in natural changes in the biological communities living along the beach and in the wetlands behind.

West of the "mid-beach outcrop"(Fig. 1), where park facilities exist, changes in the duneline are anticipated to be slower, but they will accelerate after the barrier becomes detached from its "mid-beach rock outcrop" and sediment is more easily transferred eastward alongshore.

The retreat of Martinique Beach is inevitable in the longer term but the rate at which it retreats will depend on how the sediment becomes reorganized, i.e. whether the duneline becomes reestablished or the estuary channel is infilled. The continued transfer of sediment into the estuary channel will significantly decrease the availability of sediment for short term recovery of the duneline, but it may contribute to the long term recovery of the barrier. Dune restoration activities when used in conjunction with natural processes can facilitate the short term recovery of the present duneline but they will not solve the longer term beach retreat which is the natural response to rising sea level and a diminishing sediment supply.

2) <u>Limited Dune Restoration Activities-</u> Duneline recovery across the breaches can be accomplished within 3 to 5 years , as it was in the late 1970s, if restoration activities work with the natural processes. Restoration activities involve a three stage approach: a) trap sediment within the breach, b) raise the sediment levels, and c) stabilize the accumulated sediment. Closure of the '98 breach could be initiated and expanded from the higher areas of the breach such as just west of the main washover channel where the flats have already aggraded by more than 1 m. It is too early to establish fencing, however the placement of flotsam such as large logs across the breach surface or by erecting them vertically would facilitate the trapping of windblown sand, sea grass, kelp and other debris transported landward during future wave overwash events. Once the sand levels have built sufficiently to restrict wave overwash, short lengths of sandfence placed in an offset pattern could be established. Additional levels of fencing may be required to further raise the level of sand, or vegetation transplants could be established which would also facilitate the natural accretion of sediment. Once the sand levels are raised above higher high tide levels, marram grass should be planted to stabilize the sediment and foster the growth of new dunes.

Farther alongshore from the '98 breach the duneline is rapidly retreating. Wave overwash of the seaward dunes is occurring and the potential for the formation of new breaches is increasing. It might be timely to add a few short sturdy fence lines farther landward where the seaward duneline is already being overwashed. This action may help trap sediment across the lower backdune, as wave overwash increases and reduces the transfer of sediment into the estuary channel. However, care must be taken not to damage the present vegetation cover, or align the fences so that wind scouring of the backshore is accelerated. Irregardless of the strategy selected for dealing with the beach changes of 1998, future monitoring of the physical condition of Martinique Beach should be continued through cooperative efforts of the provincial and federal Departments of Natural Resources.

Acknowledgments
We wish to thank John Shaw and Dave Dauphinee for reviewing the manuscript and to Roger Belanger, formerly of Bedford Institute of Oceanography, photography group, and Dave Dauphinee, Nova Scotia Natural Resources, for permission to use their photos in figure 1, 8 and 5.

References
Bowen, A.J. Edmond, D.P. Piper, D.J.W. and Welsh, D.A. 1975. The maintenance of beaches; Technical Report , Institute of Environmental Studies, Dalhousie University, Halifax, N.S. 582 p.

Bowen . A.J. and Boyd, R. 1983. The Eastern Shore Beaches-Cow Bay, Cole Harbour, Conrads Lawrencetown, Martinique; Contract report prepared for Nova Scotia Department of Lands and Forests, 71 p.

Keeley, J. R., 1977. Nearshore currents and beach topography, Martinique Beach, Nova Scotia; Canadian Journal of Earth Sciences, V. 14, 1897-1905.

Munroe, H.D., 1982. Regional variability, physical shoreline types and morphodynamic units of the Atlantic coast of mainland Nova Scotia; R.B. Taylor, D.J.W. Piper and C.F.M. Lewis (eds); Geological Survey of Canada Open File Report 725, 25 p.

Taylor, R.B., Wittmann S.L., Milne, M.J., Kober, S.M., 1985. Beach morphology and coastal changes at selected sites, Mainland Nova Scotia; Geological Survey of Canada Paper 85-12, 59 p.

Taylor, R.B., Frobel, D., Forbes, D.L., and Parlee, K. , 1995. Coastal stability and the monitoring of physical shoreline changes in Nova Scotia; In: Proceedings of the 1995 Canadian Coastal Conference, Volume 2, Dartmouth, Nova Scotia, 829-843.

Appendix 1.

A) Volume of sediment deposited in the 1977 breach by 1981 and 1999
There are surveys across the 1977 breach site in 1976, 1981, 1987 and 1999 but there is no way to relate the position of the mid 1970 and 1981 surveys because the benchmarks were lost when the breach occurred in 1977. From photos it is apparent the dune was cut to base level so assuming a 100 m wide breach, sand accumulation within the new dunes was estimated at 3300 m^3 and only 3900 m^3 by 1999, however by that time the duneline was already retreating. This volume is similar to the volume of dune lost in 1998.

If only the beach change is measured, the loss of sediment seaward of the dunes between 1981 and 1999 was 90 m^3 assuming a 1 m width and it would be 9000 m^3 if the change was applied over a 100 m width. Some of this change may just reflect seasonal losses because the 1981 survey was taken in August at a time when sand levels are generally at their highest, whereas the 1998 survey was completed in June. Nevertheless at least some of this sediment has been transferred into the 1998 breach since its formation.

B) Volume of sediment deposited in the breach between March 27, 1998 and June 11, 1999
Area 1 west side of breach
The area of sediment between X3 and X4 using -2.0 as the base level between the two surveys was 717.38 - 447.31m2= 270.07 m^2. The area it represents is 108 m wide, east to west, therefore the total volume of sediment would be 108 X 270.1 =29,171 m^3.
If we assume the base of the washover fan is actually at -1.6 m then the volume of material would be 599.88-354.49 m^2 =245.4 m^2 which when multiplied by 108 = 26,503 m^3 .

Area 2 east side of breach
The area of deposition since 1998 was 155.5 m^2 - 35.05 m^2 =120.45 m^2.
The area represents a width of 60 m of breach so total volume of sediment deposited is
60 x 120.5 = 7230 m^3.

Total Volume of deposition is 7230+ 29276 = 36,506 m^3.
Minimum total volume of deposition would be 7230 + 26,503 m^3 = 33,690 m^3.
If we assume the initial duneline lost in the breach was 136 m long, 15m wide and 1.5 m thick the volume of sediment contributed to the backshore would be 3060 m^3 which is only 8 % of the estimated total volume.