State of Maine's Beaches in 2007

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INTRODUCTION

This report, the first of a biennial series that will be published in conjunction with the Maine Beaches Conference, summarizes qualitative morphologic characteristics and changes observed at Maine beaches that are monitored as part of the State of Maine Beach Profiling Project, termed herein as SMBPP (Maine Sea Grant Extension, 2003). This effort is in support of the goals outlined in *Protecting Maine's Beaches for the Future*: *A Proposal to Create an Integrated Beach Management Program* (Beach Stakeholder Group, 2006). The concept of monitoring Maine's beaches was endorsed by the Joint Standing Committee on Natural Resources of the Maine Legislature and a law was signed by Governor Baldacci in 2006 creating the Beaches Advisory Group and a biennial report to the Maine Legislature on many aspects of the State of Maine's beaches, including the geology described here.

The purpose of this geological program is to monitor beaches along the Maine coastline using a simple, cost-effective method that enables volunteers and local stakeholders to help collect and understand the coastal changes that impact their communities. The data help make beach management decisions and provide the basis for university research. Several scientific theses and research papers have been published using the results of the program (Hill and others, 2002), and the program was the basis for similar programs in other states (O'Connell, 2001). The SMBPP is funded and managed by combined efforts of the Maine Geological Survey (MGS) of the Department of Conservation, the University of Maine's Department of Earth Sciences, Maine Sea Grant, University of Maine Cooperative Extension, Southern Maine Community College, and the Maine Coastal Program at the State Planning Office with additional support from the National Oceanic and Atmospheric Administration's Office of Ocean and Coastal Resource Management. Significant time, personal equipment, and expenses are also contributed by a large team of citizen volunteers who conduct fieldwork monthly and record measurements in an electronic database.

As of 2007, the beach profiling program monitors 15 beaches within 9 different communities (**Figure 1**). Volunteers are currently monitoring a total of 59 different profile locations on a monthly basis. Some of these beaches have been monitored since inception of the program in 1999, while others have joined the program in subsequent years.

This report reviews general beach and dune characteristics, topography, and general shoreline change characteristics at each beach profile location on a year-by-year and seasonal (summer vs. winter) basis since the start of data collection and continuing through April 2007 (where data were available). *Results of this report are based only on beach profile data that were available for download from the Maine Shore Stewards Online Data Collaborative website (Maine Shore Stewards, 2007) as of the end of April 2007. Therefore, gaps may exist for data at some locations which have not been entered into the online database.*

Data collection methodology

The SMBPP incorporates the use of trained volunteers to collect monthly beach profiles that start at a known point (usually a point marked in the dune or in a seawall) and continue shore-perpendicular to roughly the low water line at select locations.

The SMBPP utilizes the Emery Method of beach profiling for data collection (Emery, 1961) (**Figure 2**). This method is a simple, quick, inexpensive, and relatively accurate way to determine the change in elevation (Y) over horizontal distance

(X). These data result in the creation of a beach profile that documents the topography of the beach and specific features at a given point in time (**Figure 3**). Volunteers record topographic data on a standardized data sheet (University of Maine, 1999), but also record notes on beach features along the profile, such as the presence of a scarp or edge of dune vegetation. Collected data are then entered online by volunteers into a database that is used to manage and view collected beach profile data. This database also allows for data download for additional analysis. This online database was the source of the data for this report.

At some locations, MGS has been able to use a Real Time Kinematic Global Positioning System (RTK-GPS) to survey the starting points for the beach profiles (Magellan Navigation, Inc., 2007). This enables the starting marks to be located in a three-dimensional (x, y, and z) framework of earth coordinates.

Spatial and temporal extent of data

The locations of beaches involved in SMBPP are shown in **Figure 1**. Generally, there are 2-4 profiling locations along each beach. Along each collected profile, topographic points are generally collected at approximately 3 m intervals from the starting point, usually a stake in the dune crest or mark on a seawall, seaward to the low-water line (see ***Data Collection Methodology***).

Volunteers have collected beach profile data intermittently in some cases since 1999 at some beaches. Most volunteer groups have entered applicable data into the online database through 2007 (and many with results from the 2007 Patriots' Day Storm), though many beaches also have gaps in data entry. In general, beach profiles are collected around the same time each month during times of low tide. Temporal datasets for each set of profiles are shown in Table 1.

Table 1. Spatial and temporal aspects of SMBPP data.

Beach Name	Town	Acronym	No. of profiles	Dates*	Mark surveyed
Willard	South Portland	WI	6	2001-2007	Yes
Higgins	Scarborough	HI	3	1999-2007	Yes
Scarborough	Scarborough	SC	4	1999-2007	Yes
Western/Ferry	Scarborough	WS	3	1999-2007	Yes
East Grand	Scarborough	EG	4	1999-2007	Yes
Kinney Shores	Saco	KS	2	1999-2007	Yes
Ferry (Saco)	Saco	FE	4	2000-2007	Yes
Fortunes Rocks	Biddeford	FR	4	1999-2006	No
Goose Rocks	Kennebunkport	GR	4	2002-2007	No
Goochs	Kennebunk	GO	4	2001-2006	Yes
Laudholm	Wells	LH	5	2003-2007	No
Drakes Island	Wells	DI	4	2001-2007	No
Wells	Wells	WE	4	2003-2007	No
Ogunquit	Ogunquit	OG	4	2001-2007	No
Long Sands	York	LS	4	2002-2007	Yes

* not all dates are continuous and may include breaks in months or years

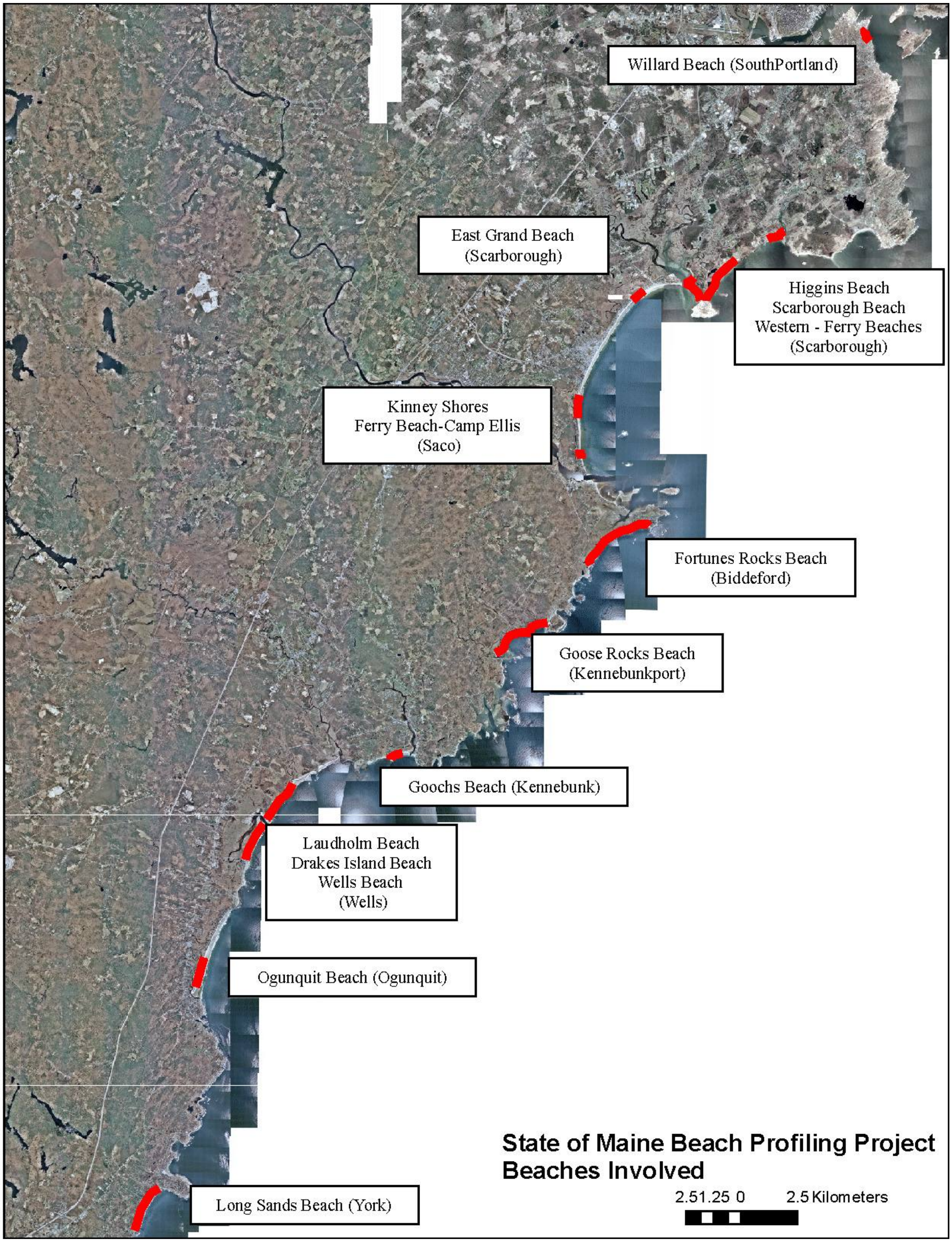

Figure 1. Location map of the coast of southwestern Maine showing the 15 beaches involved in the State of Maine Beach Profiling Project. The colored line along the coast shows the approximate geographic extent of profile coverage. The background image is courtesy of the Maine Office of GIS.

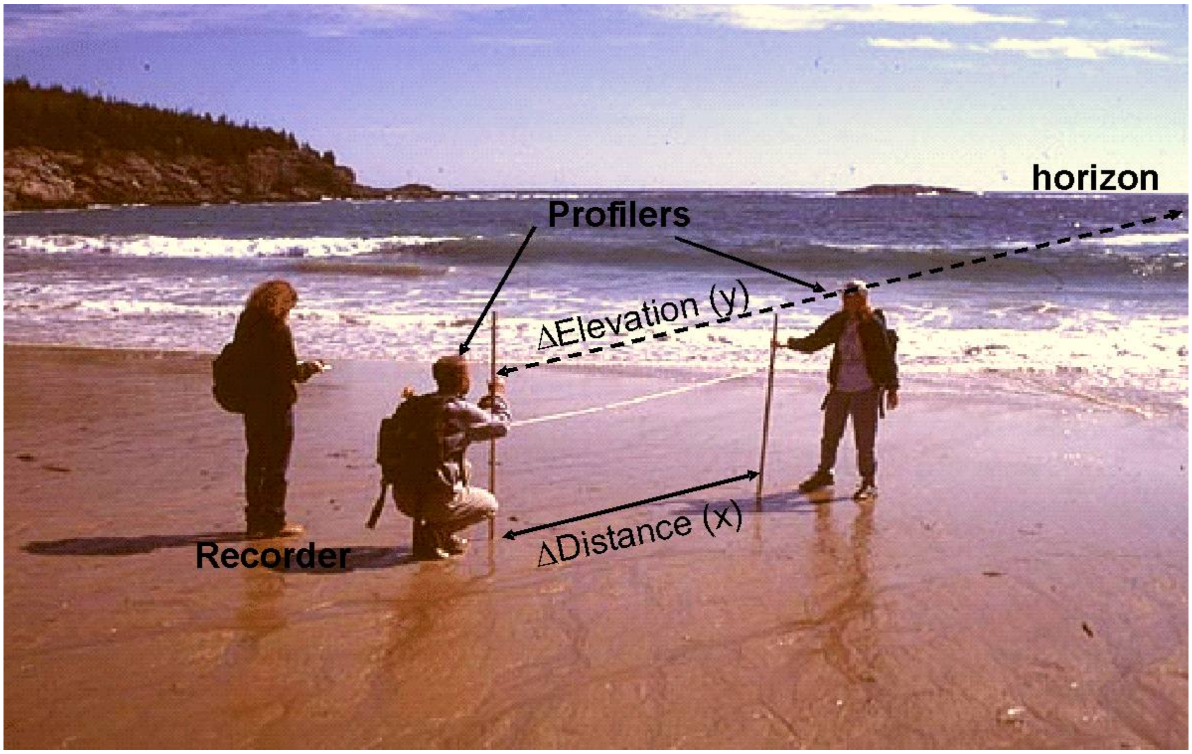

Figure 2. The Emery Method of beach profiling for data collection (Emery, 1961). The horizon and the lower of two graduated poles is used as a level to intersect the second pole to make a reading in the change in elevation (y) over a known distance (x). Field readings are taken and entered into a website for compilation.

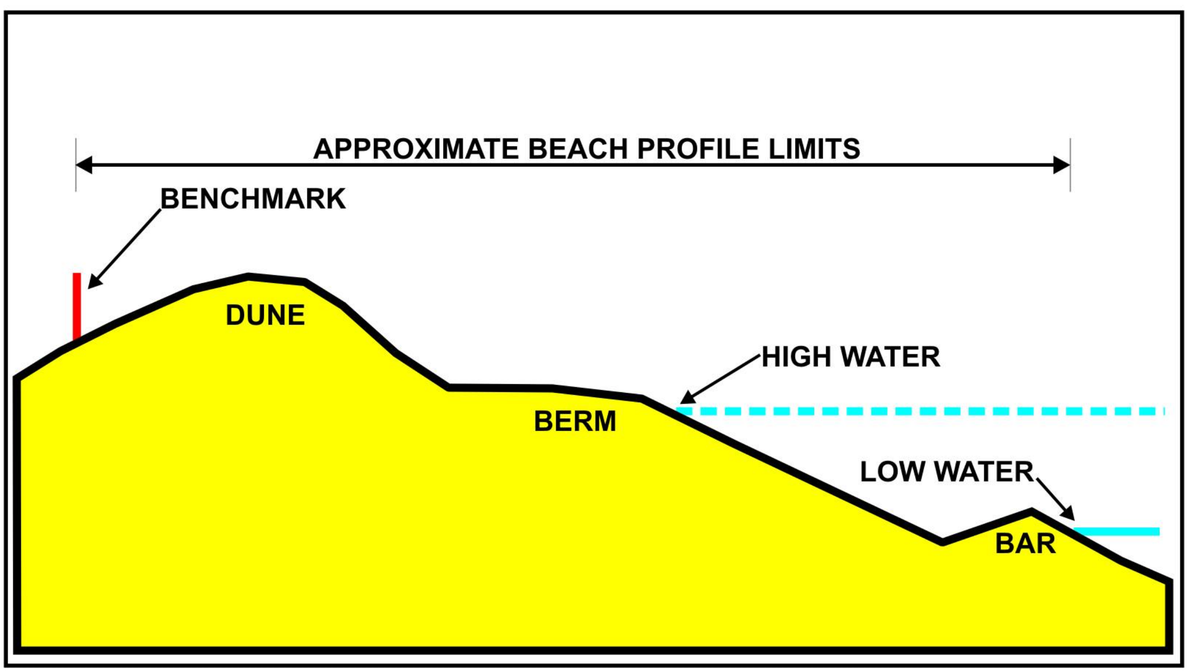

Figure 3. Data collected using the Emery Method is used to construct a beach profile. The profile is a transect from a starting point (a metal pin, post, or other fixed mark) on a dune or seawall toward the ocean. The profile measurements extend to the waterline at the time of the survey and are usually made at low tide.

The Beaches

Background geology and characteristics

The 15 different beaches involved in this monitoring program are each unique in terms of geology, morphology, development characteristics, and general locations of the beach profiles. Aerial images of the beach and the profile locations are shown at the start of each beach summary. Each section provides a short summary which describes the geology of each beach, including historic erosion rates (if available) and information on the locations of beach profile marks, if surveyed. Many of the beach geology descriptions have been adapted from Heinze (2001). Each beach is subsequently described in terms of generalized annual and seasonal changes.

Annual and seasonal beach profile changes

The shapes of annual and seasonal beach profiles are heavily dependent upon both long-term and short-term (storm-induced) erosion or accretion. Typically, annualized mean beach profiles remove short-term changes (variance) and provide a more stable longer-term representation of the beach profile shape.

The shapes of seasonal beach profiles are highly dependent on storm-induced episodes of accretion or erosion. For this study, winter months have been generalized to include the months November through April. During these months, there are more frequent storm conditions and beach profiles tend to erode dunes and lose sediment, resulting in a flatter profile and a larger deposit of sand offshore within a sandbar. Conversely, during summer months (characterized as May through October for this study) when wave conditions are generally calmer, beaches tend to build, or prograde, and beach profiles react by having more sediment on higher portions of the profile, resulting in a wider berm and better developed dunes.

To analyze annual beach changes (at each beach profile location) an annual mean beach profile was calculated for each year that data were available. The methodology used to create these profiles was as follows:

1. Available beach profiles were downloaded from the website database into Excel.
2. MATLAB programming software was used to format the data into matrices and analyze the data based on averaged annual and seasonal conditions.
3. To create mean profile data, the horizontal (x) axis data were used to create a standardized x-axis (i.e., spaced at 3 m intervals) based on the maximum length of the longest profile.
4. Available elevation (y) values at each 3 m interval along the x-axis were then averaged, thereby creating a mean profile.
5. Where points were not available (i.e., data were collected at 1 m mark instead of 3 m), the y-values were interpolated using a best-fit linear regression.

The technique employed to calculate the average profile shape along the length of the x-axis for each year did so using any available beach profile data; if 12 collected profiles extended to the same horizontal distance from the pin (x-axis), then all 12 were used to calculate the mean annual profile. For example, if data had a maximum horizontal length of the longest collected profile of 200 meters, the technique would use whichever profiles were available (i.e., 12 profiles, then 11 profiles, 8, profiles, 7 profiles, etc.) to calculate the mean y-value along the X-axis (**Figure 4**). The reason this method was employed was so that data would not be cut to the shortest profile in the calculation of the mean annual beach profile.

In order to quantify seasonal changes, all collected profiles from all available years were grouped into the two different seasons: summer (May to October) and winter (November to

April). For each season, a mean profile was calculated using the same methodology discussed above. Additionally, the maximum and minimum profile envelopes shown as dashed lines were calculated to show the maximum and minimum recorded variations around the mean profile shape. Also, plots showing the standard deviation the variance around the mean values were created and plotted against the standardized X-axis. This was done so that vertical seasonal variations of certain features, such as a sand dune or berm, could be quantitatively described.

This section will provide a qualitative summary description of the annual mean profile changes observed, along with the seasonal changes and characteristics deduced at each of the profile locations at each beach, for which data were available.

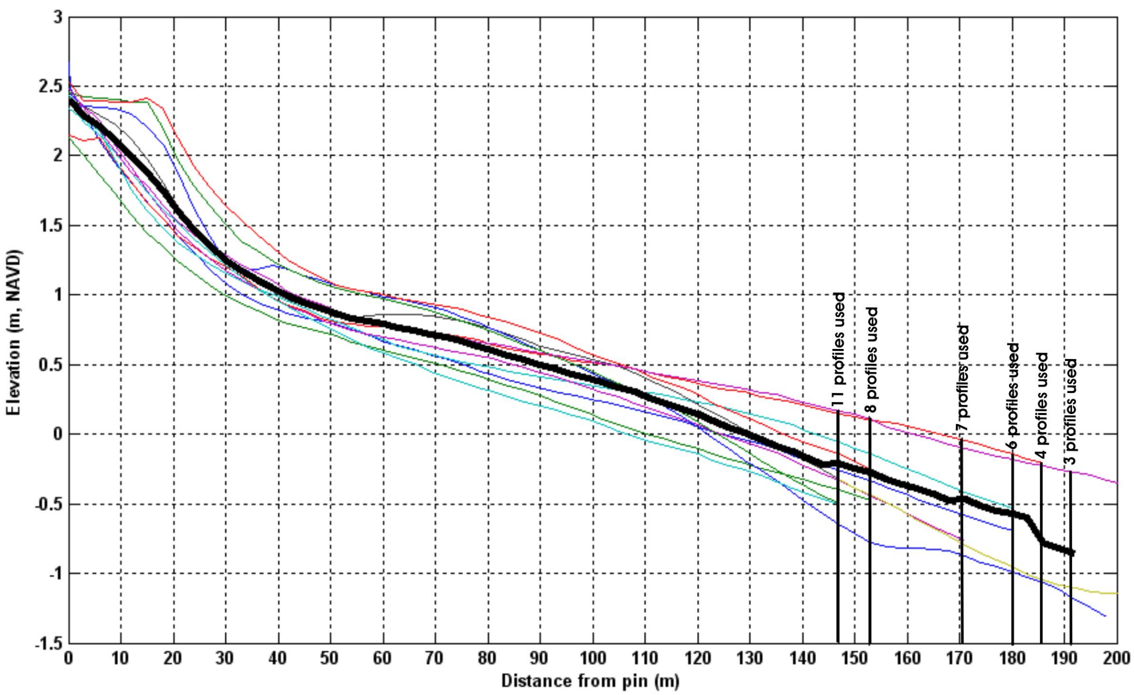

Figure 4. A composite sample graph of many beach profiles that are averaged to produce the solid black line as the mean annual profile. Less data are used in the average farther out (to the right) on the line so the mean shape is less smooth closer to the seaward end of the survey.

Willard Beach, South Portland

Background geology and characteristics

Willard Beach is a relatively small (<600 m) arcuate-shaped pocket beach bound by bedrock headlands and located within Simonton Cove in South Portland. It is moderately developed and the beach and dune are mostly in a natural state, with only about 15% of the shoreline being armored (Dickson, 2006b). Two studies of historical shoreline change have been completed for Willard Beach. A 1977 study found that the shoreline underwent periods of erosion and accretion, with erosion rates as high as 3 to 5 feet per year (Timson, 1977). The U.S. Army Corps of Engineers (1982) released a report which noted that the 6, 12, and 18-foot depth contour lines all moved inland from 1853 to 1941.

There are 6 beach profiles (WI1-WI6) along Willard Beach, starting at the southern end of the beach. Several marks have been added over the past few years, and data only exist through the online database for a few locations (**Figure 5**). MGS has surveyed all the starting points.

Annual and seasonal beach profile changes

Unfortunately, the majority of data collected for profiles at Willard Beach was not available through the online database, and therefore much has been omitted from this analysis. Data were available for WI1, WI3 and WI4, and are included herein. No data were available for WI2, WI5, or WI6. Subsequent data, once incorporated into the database, will be included in updated editions of this report.

At WI1, only data from 2000 were available. The averaged profile (**Figure 6**) shows a relatively prominent berm about 10 m in width, positioned at approximately the +0.5 m contour. This profile also represents the available seasonal data, since only 1 profile that was collected was available for analysis (June 2000).

At WI3, data were available for parts of 2001 and 2002. Mean profiles (**Figure 7**) show that the entire profile accreted from 2001 to 2002. Seasonal data (**Figure 8**) indicate that both the winter and summer profiles have a wide berm, with little change until 0 m NAVD (at 75 m from the mark), where the summer profile tends to have more sediment. Standard deviation data (**Figure 9a**) indicate marked variability at the 55 m mark in both summer and winter profiles, but notably summer (variations up to 35 cm). Offshore sand storage during winter (at 110 m) varies to about 35 cm vertically as well, indicating that the sediment that is lost from the beach berm area in the summer is stored offshore in the winter each season.

The beach at WI4 had data available from 2001 to 2002. Here, the profile appears to have lost some sediment at the base of the dune (at the 2.5 m NAVD elevation), but gained sediment down the rest of the profile (**Figure 10**). Seasonally, a slightly larger berm is evident in the summer, with both profiles having very small profile envelopes (**Figure 11**). Variability is minute; standard deviation values for both summer and winter are on the order of 10 cm or less (**Figure 9b**). This indicates seasonal stability of the profiles.

Data that were available for analysis show that the enclosed littoral system at Willard Beach undergoes typical seasonal changes (i.e., winter and summer profile shapes). Overall, the system is relatively stable, with sediment that is eroded from the dunes and profile during the winter returning in the summer months. Although it is not included herein, analysis of the beach was completed by MGS after the Patriots' Day Storm in 2007 (Slovinsky, 2007). This indicated substantial horizontal and volumetric losses along the dune and the beach. Subsequent profiling of the beach will help determine whether or not Willard Beach effectively recovers from this event.

Figure 5. There are 6 beach profiles (WI1-WI6) along Willard Beach, starting at the southern end of the beach. Several marks have been added over the past few years, and data only exist through the online database for a few locations.

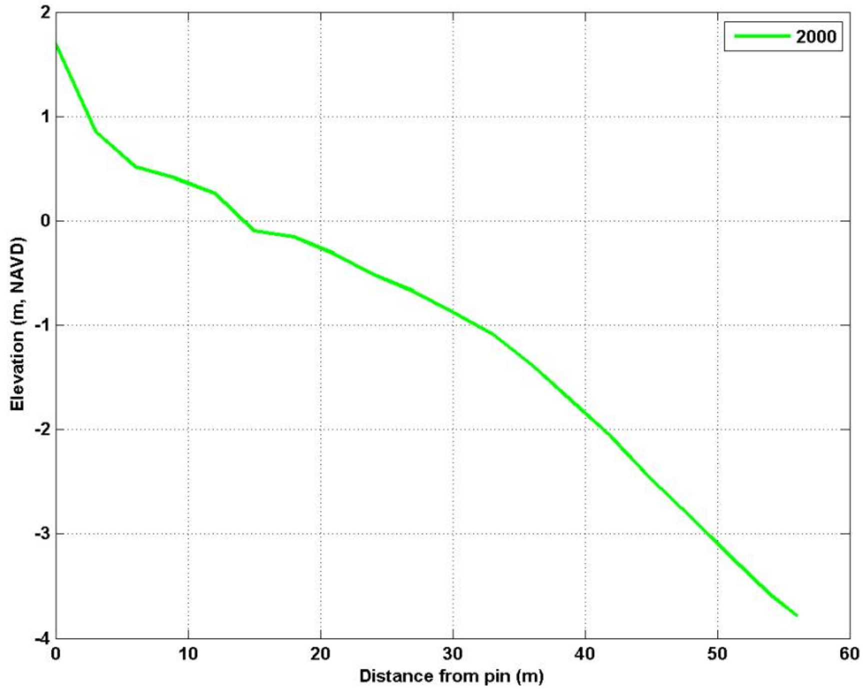

Figure 6. At WI1, only data from 2000 were available. The averaged profile shows a relatively prominent berm about 10 m in width, positioned at approximately the +0.5 m contour. This profile also represents the available seasonal data, since only 1 profile that was collected was available for analysis (June 2000).

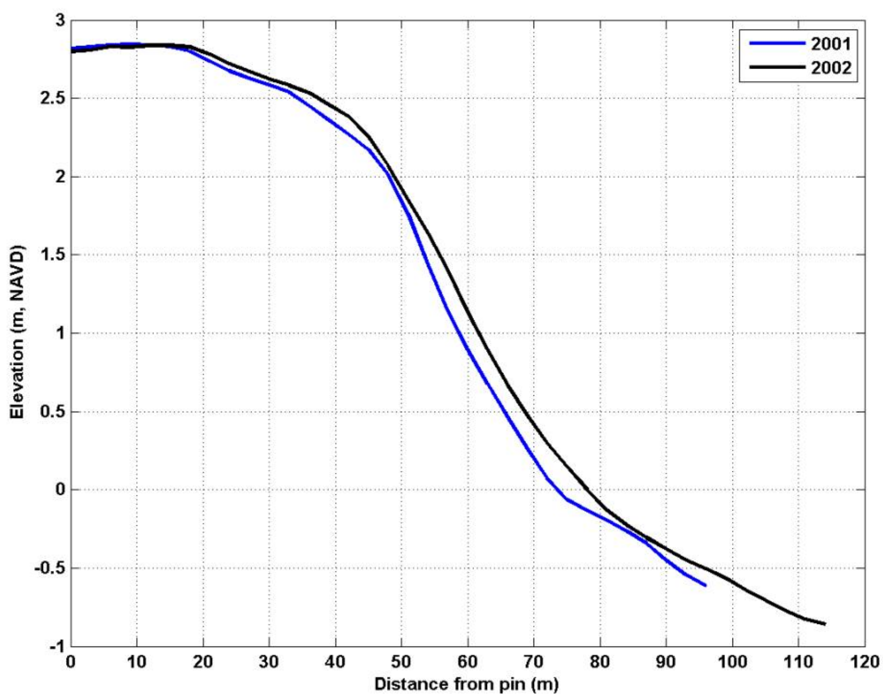

Figure 7. At WI3, data were available for parts of 2001 and 2002. Mean profiles show that the entire profile accreted from 2001 to 2002.

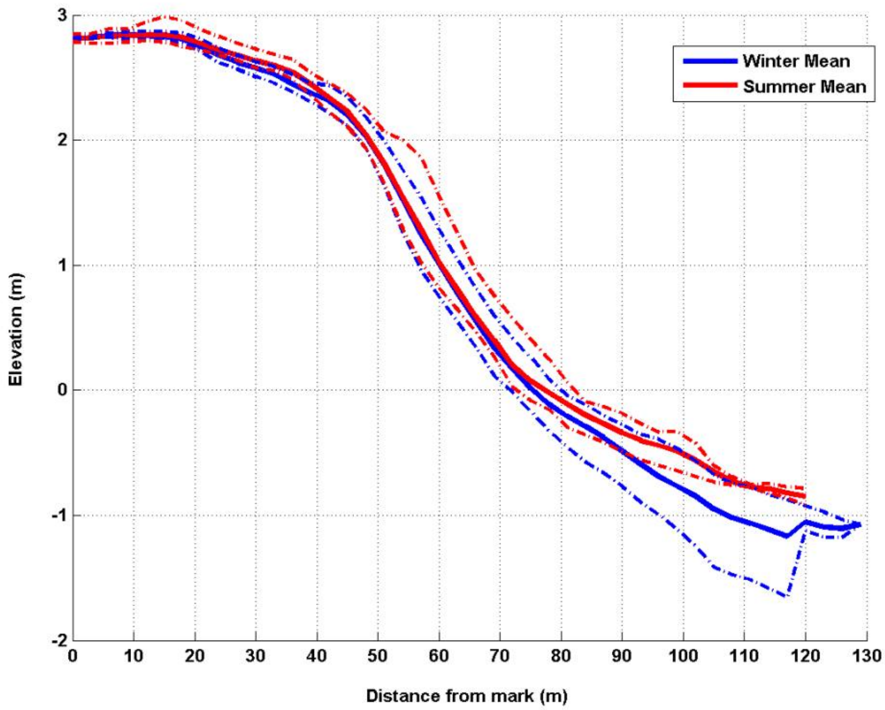

Figure 8. Seasonal data indicate that both the winter and summer profiles at WI3 have a wide berm, with little change until 0 m NAVD (at 75 m from the mark), where the summer profile tends to have more sediment.

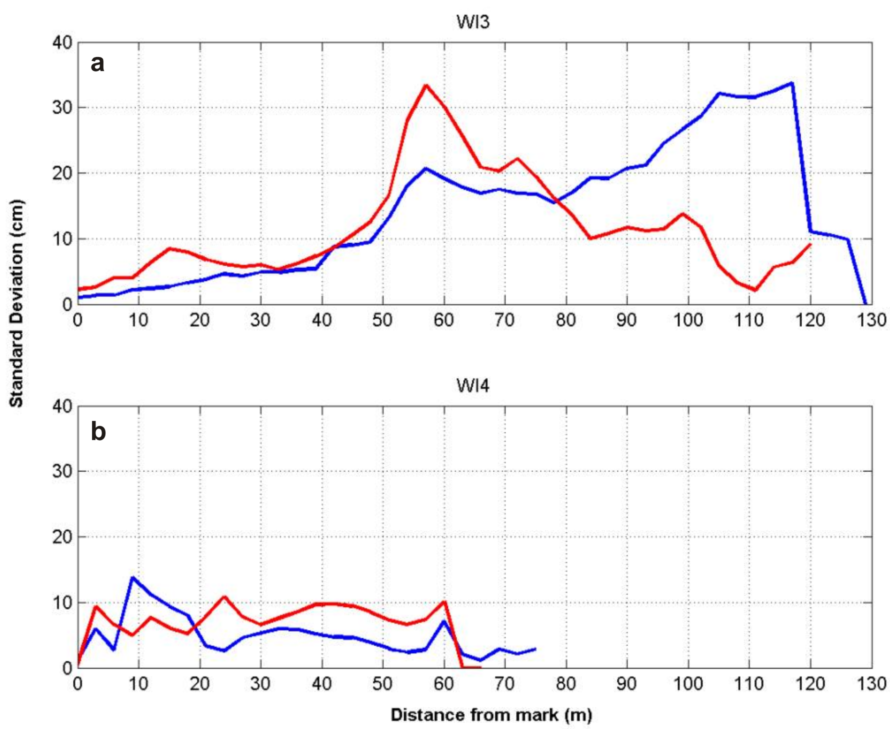

Figure 9. (a) Standard deviation data at WI3 (top, a) indicate marked variability at the 55 m mark in both summer (red) and winter (blue) profiles, but notably summer (variations up to 35 cm). Offshore sand storage during winter (at 110 m) varies to about 35 cm vertically as well, indicating that the sediment that is lost from the beach berm area in the summer is stored offshore in the winter each season. (b) At WI4 variability is small along the entire profile.

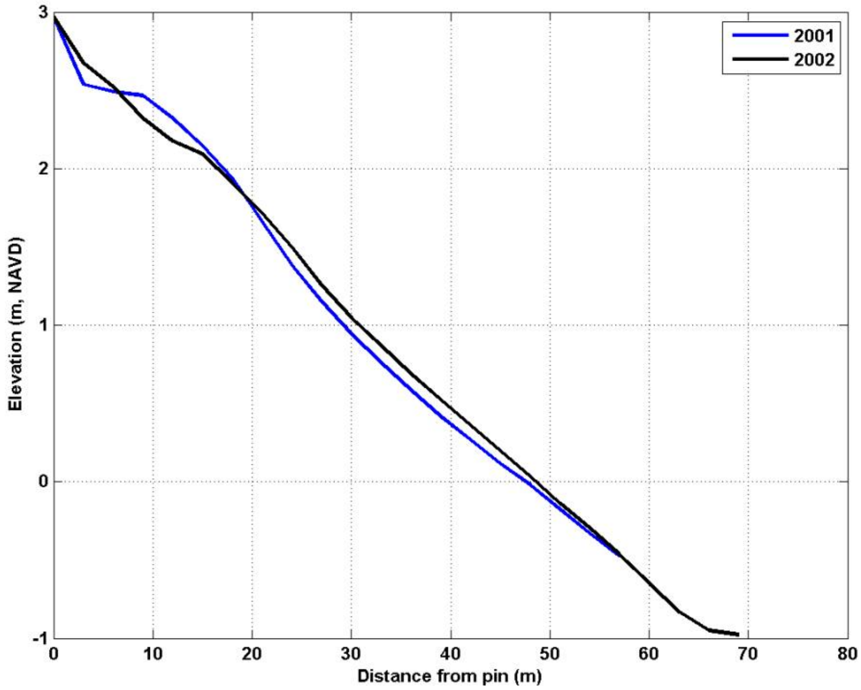

Figure 10. From 2001 to 2002 some sand was lost at WI4 from the base of the dune (around 10 m out on the line), but was gained on the rest of the profile.

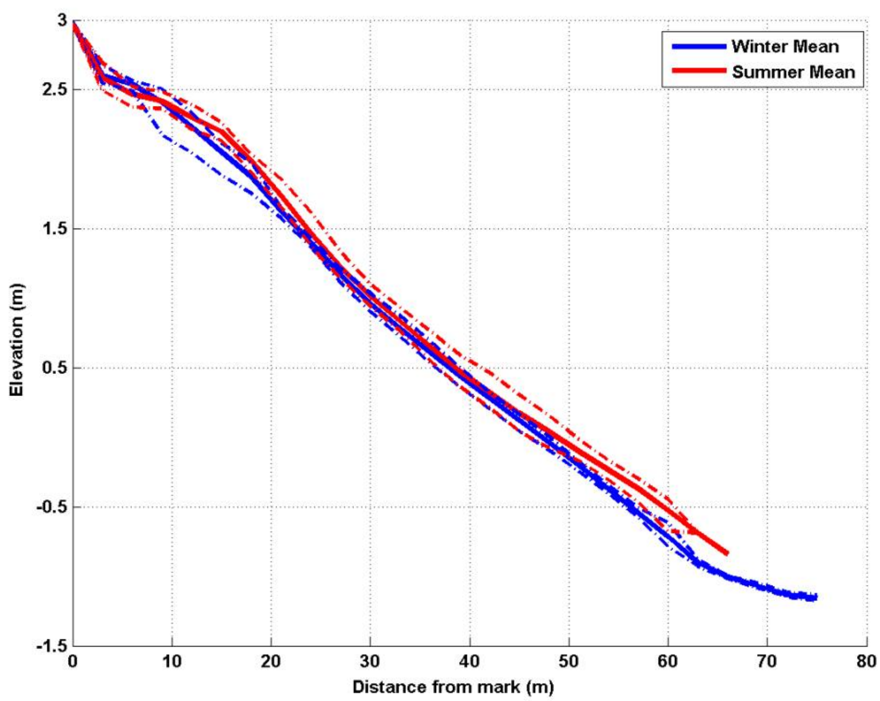

Figure 11. A slightly larger berm is present in the summer at WI4. Both profiles have very small envelopes of vertical variation.

Higgins Beach, Scarborough

Background geology and characteristics

Higgins Beach is an approximately 900 m long spit, bound by bedrock at its southwestern end and the Spurwink River at its northeastern end. Almost 70% of the shoreline is armored with seawalls, with the largest unarmored section comprising the spit adjacent to the Spurwink River. The Spurwink River tidal inlet is down drift from the beach, and the spit has continued to prograde since net sand transport is northeast toward the inlet. Generally, the beach receives no new sand supply so sediment removed from the beach is difficult to replace; a net loss of sand was documented by Timson and Lerman (1980) in the Higgins Beach Management Plan. The plan calculated shoreline recession rates from 1 to over 5 feet per year along the beach. Nelson (1979) determined an erosion rate of 1 to 1.5 feet per year over most of its length with greater variability at the spit end (Dickson, 2006a).

Higgins Beach has 3 beach profiles, HI1-HI3, from southwest to northeast. HI1 is located near the base of the concrete/riprap seawall at the Ocean Avenue/Bayview Avenue intersection. HI2 is located at the top of a seawall at the seaward end of Vesper Street. HI3 is located at the northeastern end of a wooden seawall fronting several homes off of White Sands Lane (**Figure 12**). The three beach profile benchmarks along Higgins Beach were surveyed by MGS in June 2006.

Annual and seasonal beach profile changes

For HI1, beach profile data were available for 1999, and 2001 through 2007. Overall, the beach monitored at HI1 is relatively stable and has undergone little change from 1999-2007, with the majority of the variability concentrated in the first 30 m (**Figure 13**). These variations are less than 0.5 m. The offshore portions of all profiles from about 100 m offshore and greater vary very little, less than 0.25 m. The 2001 and 2002 annualized mean profiles appear to hold the largest volume of sediment, while the 2007 profile (which accounts for the months of December-April) appears to hold the least amount of sediment. This is likely due to the seasonal bias (winter data only) for the 2007 collection period. HI1 shows typical seasonal variability for beach profiles in Maine (**Figure 14**). The summer profile has substantially more sand on the beach profile than the winter profile, with the winter profile being flatter and more sediment-starved. Profile envelopes show that HI1 can undergo changes on the order of about 0.5 m in summer, and almost a full meter in winter. Standard deviation values indicate that vertical berm fluctuations are mostly within the first 20 m of the profile and are values of about 30 cm or less (**Figure 15a**).

Aside from mean profiles from 1999 and 2001, which appear to have started at a different location than the remaining years, HI2 shows very little annualized change, especially in the nearshore (**Figure 16**). Farther offshore (120 m and greater), there is slightly more variability in the mean profiles. This may indicate that HI2 is also relatively stable, with the majority of changes occurring at the lower portion of the profile. HI2 also shows a distinct seasonal variability, with the mean summer profile showing a much more well defined berm (between 40-120 m from the pin) than the winter mean profile (**Figure 17**). For the summer mean, much of the profile variability is concentrated in the first 40 m of the profile. The winter mean profile shows more stability in the nearshore, with greater variability from the mean starting around 100 m offshore. This makes sense since sandbar variability should be greater in the winter than in the summer, since sediment is typically removed from the upper portion of the beach profile in the winter and stored in offshore bars. The calculated standard deviation values for summer and winter profiles show marked berm development in the summer, which varies about 40 cm vertically and is concentrated near the 20 m mark (**Figure 15b**).

HI3 shows dramatic variability on an annualized basis (**Figure 18**). This variability is a result of the influence of the beach spit's end and proximity of the profile location to the ebb-tidal delta of the Spurwink River. This area of Higgins Beach is called a sediment sink ; that is, this area typically receives sediment moving along Higgins Beach and becomes trapped in the ebb delta. Annual variability is marked; from a low in 2001, to highs in 2007, variability is on the order of 1 m or more, especially past the 50 m mark. Based on this data, it appears that this area of Higgins Beach is generally accreting. Seasonal variability at HI3 is not comparable with the other profiles (**Figure 19**). Profile envelopes show variability on the order of a meter or more for both seasons, and the summer and winter profiles do not show typical characteristics of the other profiles along Higgins Beach. The standard deviations show summer berm development much farther offshore, near the 40 m mark with vertical variations on the order of nearly 60 cm. Variations offshore in the summer profile reach nearly 80 cm vertically, while the winter profile is closer to 60 cm (**Figure 15c**).

The variations in the profiles along Higgins Beach may relate to the three different beach types found at each of the profile locations. HI1 is located at the base of a large rip-rap seawall; this wall is active at high stages of the tide that is, tidal water and wave activity is in contact with the seawall. This is reflected in less berm development and general low variability of the mean profiles, especially as compared with HI2. HI2, though it starts at a seawall, is located at a portion of the beach that has more sediment, undergoes more seasonal changes, and is not active during high tide phases. HI3 is heavily influenced by the spit end of Higgins Beach, which terminates at the Spurwink River ebb-tidal delta; this area undergoes large changes due to sediment movement and availability at the spit and ebb-tidal delta.

Figure 12. Higgins Beach has 3 beach profiles, HI1-HI3, from southwest to northeast. HI1 is located near the base of the concrete/riprap seawall at the Ocean Avenue/Bayview Avenue intersection. HI2 is located at the top of a seawall at the seaward end of Vesper Street. HI3 is located at the northeastern end of a wooden seawall fronting several homes off of White Sands Lane.

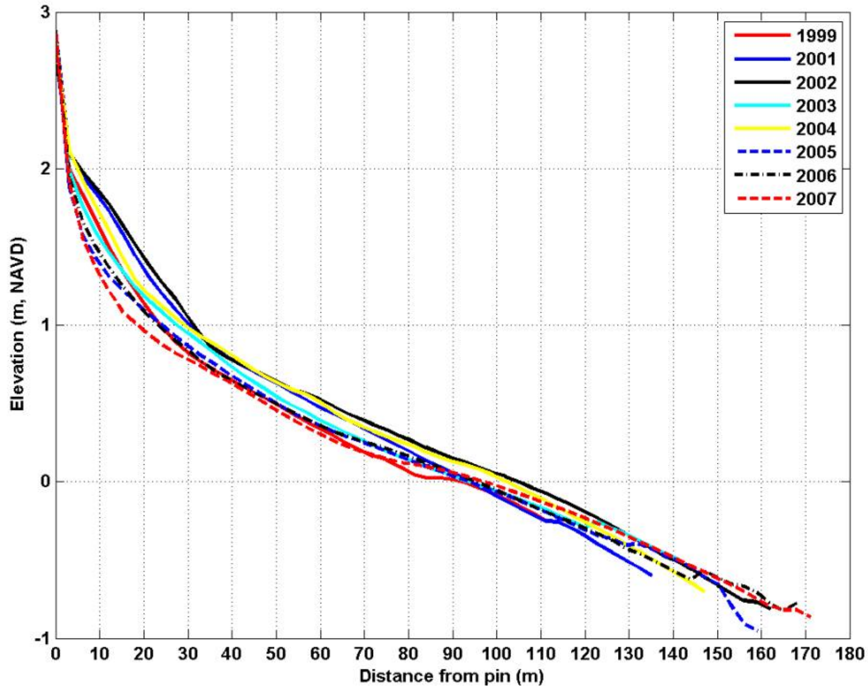

Figure 13. Profile HI1 appears relatively stable over 8 years. The greatest variability is over the first 30 m and closest to the riprap wall.

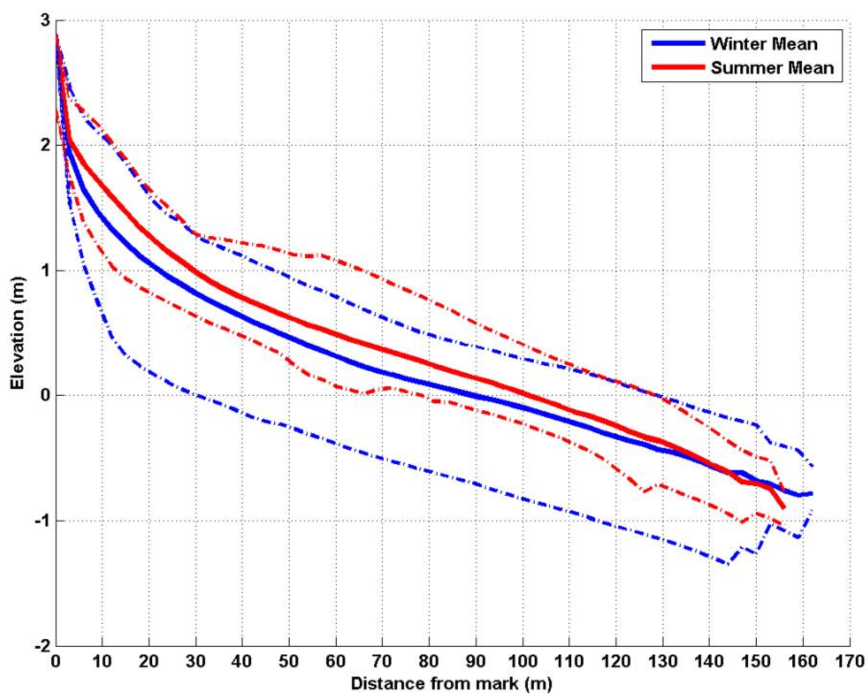

Figure 14. Seasonal variability at HI1 is typical with more sand on the beach in summer than winter. The summer envelope is smaller and about half the vertical size of the winter envelope. Winter erosion can easily be 0.5 m deeper than the deepest summer profile.

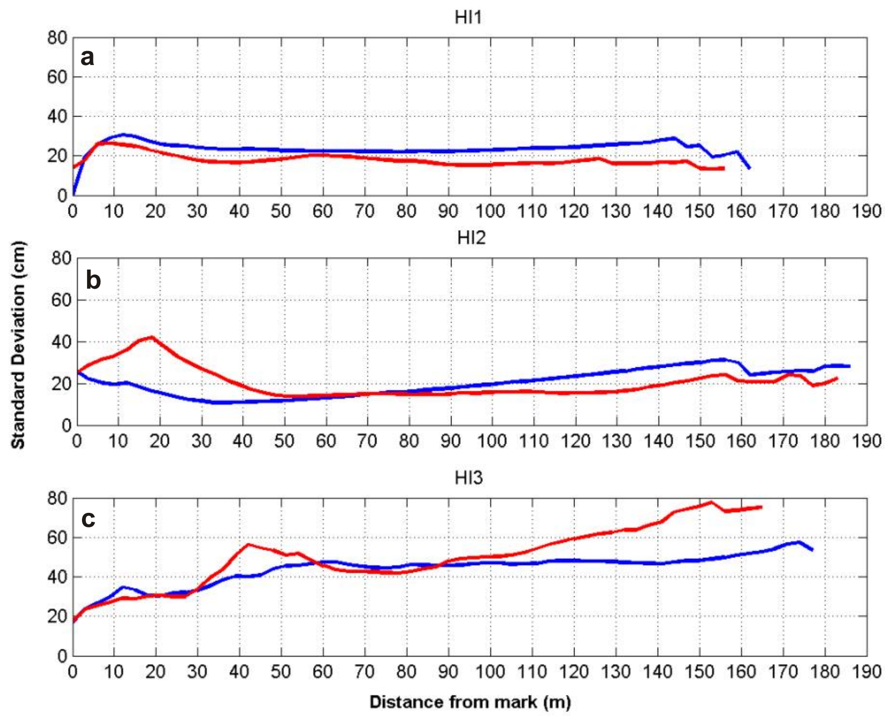

Figure 15. (a) Standard deviation at HI1 indicates that the berm area fluctuates 0.3 m or less and within the first 30 m of the profile. (b) At HI2 the summer berm height varies by as much as 0.4 m. (c) A wide dry beach at HI3 results in the greatest summer berm variability 40 to 50 m out on the profile line. The summer berm standard deviation is about 0.6 m.

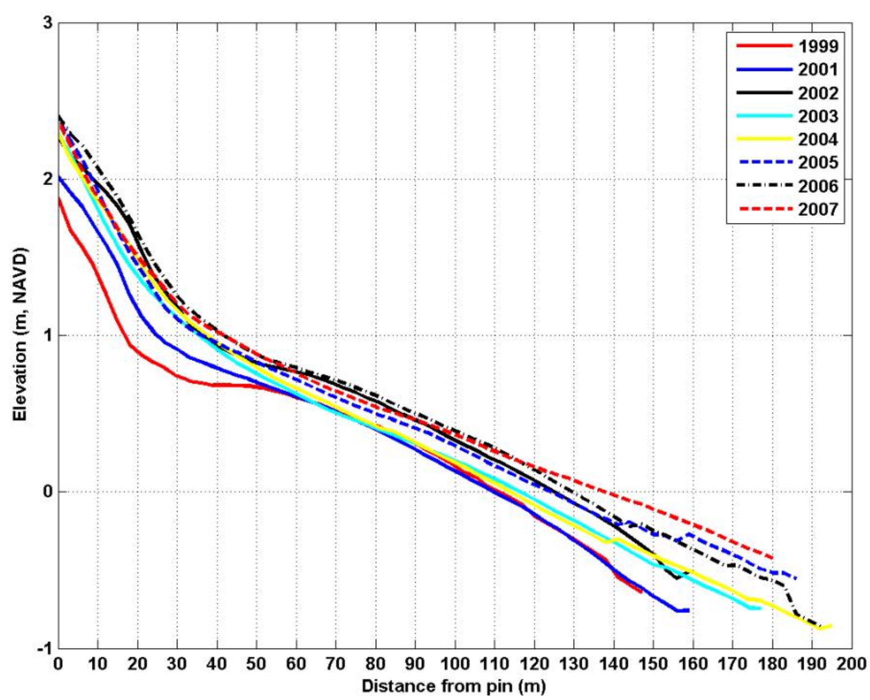

Figure 16. Annual variability at HI2 is very small. It appears that 1999 and 2000 transects were made from a different starting point than the rest.

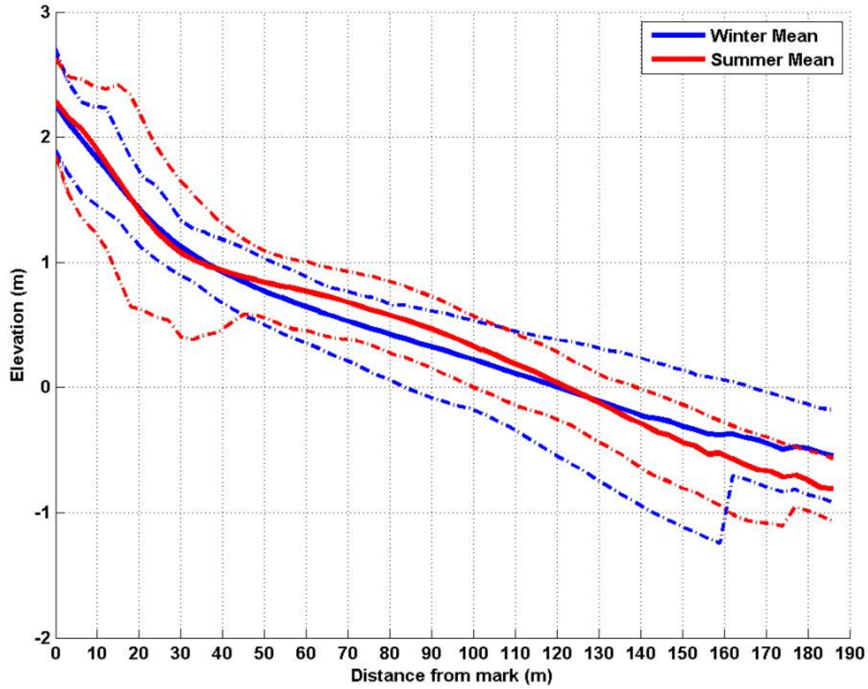

Figure 17. Seasonal variability at HI2 shows the winter and summer means are very similar. However, the summer berm envelope is very large compared to the winter envelope which has about half the vertical variation in the berm and upper beach profile.

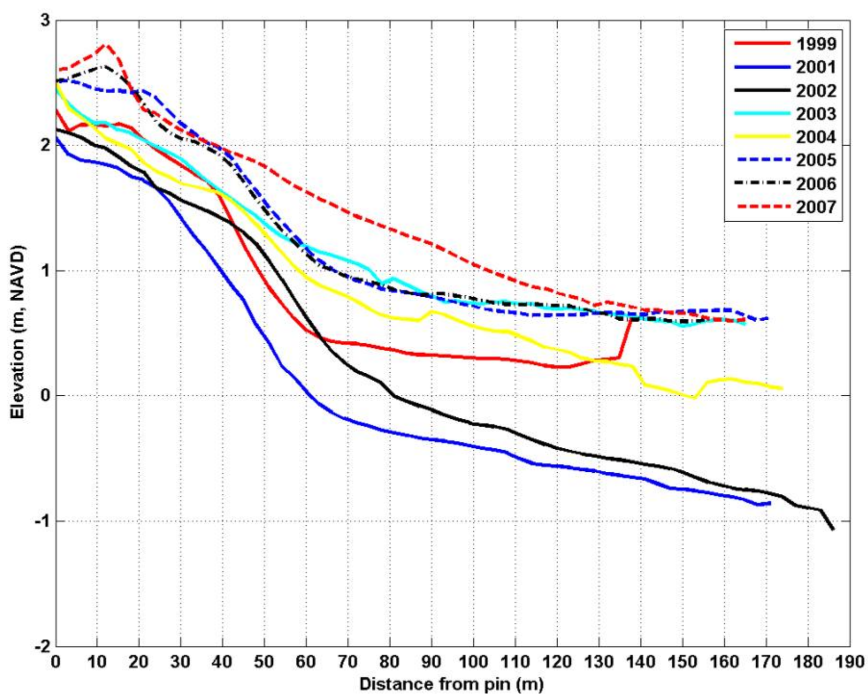

Figure 18. Profile HI3 shows a considerable vertical change in the mean annual profile over 8 years. From 2001 to 2007 the net trend has been a rise in the profile showing a buildup of sand of 1.5 meters on the profile from 60 to 170 m.

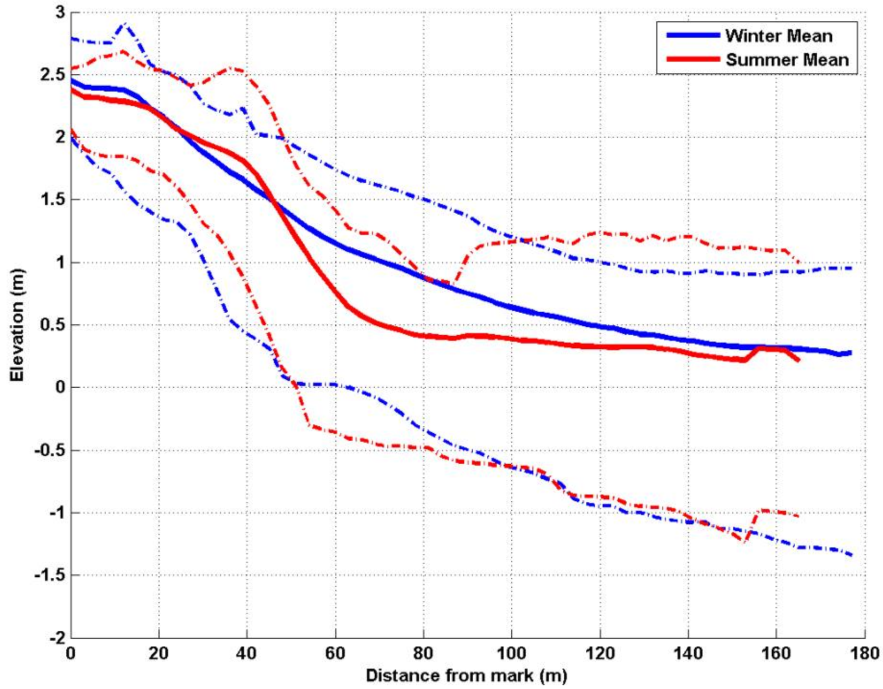

Figure 19. Seasonal variability at HI3 is larger than the other two sites and a meter or more of vertical change is possible in winter or summer.

Scarborough Beach, Scarborough

Background geology and characteristics

Scarborough Beach is an approximately 2200 m long beach located on the eastern side of Prouts Neck, anchored by bedrock at both ends. An offshore shoal shelters part of the beach from waves, thus creating a seaward-shaped bulge in the beach (Nelson, 1979). This effectively divides the beach into two distinct areas based on sediment characteristics: north of the bulge, the beach is dominantly sandy. South of this point, the beach is composed of a mix of cobbles, sand, and gravel.

Historically, Scarborough Beach is relatively stable to slowly eroding. Occasionally, old salt marsh peat is exposed in the surf zone. This indicates that the beach was once an open barrier with a back barrier lagoon and salt marsh (Nelson and Fink, 1980). Over time, the dunes have retreated up and over the old salt marsh, along with the beachface.

Scarborough Beach has 4 measured beach profiles, SC1-SC4. SC1 and SC2 are located on the northeastern side of the main dune walkover, while SC3 and SC4 are located on the southwestern side of the walkover. All transects start behind the crest of the frontal dune (**Figure 20**). The beginning marks were surveyed by MGS in June 2006.

Annual and seasonal beach profile changes

Beach profiles along Scarborough Beach all start behind the frontal dune crest. Data at SC1 were available for 1999-2000, and 2004-2007. It appears that the beach at SC1 generally went through some accretion from 2004-2006, and erosion during 2007 (**Figure 21**). This is likely due to the fact that the 2007 data include only data from winter months (ending in April 2007 with the Patriots' Day storm). Annualized profiles from 2004-2006 show very little overall variability, with changes on the order of less than 0.2 m. Seasonally, SC1 does not appear to vary much (**Figure 22**). Both the mean profiles for summer and winter are about the same, and the profile envelopes only vary slightly from each other. They do, however, indicate that profiles during both seasons can have changes on the order of up to about 1 to 2 m in elevation. Standard deviation values indicate that the majority of nearshore vertical changes are less than 40 cm for both summer and winter. In winter, the variations increase markedly offshore, up to about 75 cm (**Figure 23a**). This is consistent with winter bar formation.

Annualized mean data at SC2 show that sediment was lost from the profile between 1999-2000 and 2005-2006 (approximately 1 m vertically along the profile, **Figure 24**). It appears that a portion of the dune was lost during this time as well. The annual profile for 2007 shows additional loss of about 1 m between 2006-2007, likely due to influence from the winter data collected in 2007 and the Patriots' Day storm. Profile SC2 shows slightly more of the typically seen seasonal variability that is, a more developed berm and more sediment on upper portions of the profile in the summer months versus the winter months (**Figure 25**). The winter seasonal profile shows greater envelope variability, up to about 3 m, while the summer profile appears to not change as much. Both summer and winter profiles have large standard deviations, on the order of 75 cm, which indicates that the profile is highly variable (**Figure 23b**).

For SC3, the mean profile from 1999 appears to have started at a different location; therefore it is difficult to compare to the other annualized data from 2000 onwards (**Figure 26**). In general, there is consistent loss of sediment from the overall profile from 2000-2007, though there appears to be some growth of the sand dune. 2007 again had the least sediment in the profile, likely due to the winter bias of the data. Seasonal data (**Figure 27**) indicate that the summer profile, as could be expected, contains more sediment out to about 100 m, and that sand is typically lost from this portion of the profile in the winter. The large envelope and standard deviation associated with the summer data may be caused by the inclusion of 1999 data, which was collected during the summer months from a different benchmark. Envelope variability for the winter data is on the order of 1 m, with vertical standard deviation data approaching 50 cm (**Figure 23c**).

Annualized data for SC4 indicate that the overall profile has lost sediment over time, especially from about 20 m from the pin and seaward (**Figure 28**). There was stability between 2005-2006 in the upper portion of the profile (to about 35 m offshore), and then sediment gain in the outer portions. From 2006 to 2007 the entire profile underwent erosion. SC4 displays little seasonal variability (**Figure 29**), in both the mean profile shapes and the profile envelopes. It seems that slightly more extreme maximum and minimum values occur in the winter data (over 1 m), while the summer envelope of values appears to be on the order of 1 m or less. Standard deviation data for both are quite similar along the profile, but highly variable, with the majority of variability on the order of around 50 cm or less (**Figure 23d**).

Data at Scarborough Beach indicate that the beach undergoes typical seasonal changes and that the beach is generally stable. However, some of the profiles indicate a steady landward transgression of the beach, mostly in response to larger storm events.

Figure 20. Scarborough Beach has 4 measured beach profiles, SC1-SC4. SC1 and SC2 are located on the northeastern side of the main dune walkover, while SC3 and SC4 are located on the southwestern side of the walkover. All transects start behind the crest of the frontal dune.

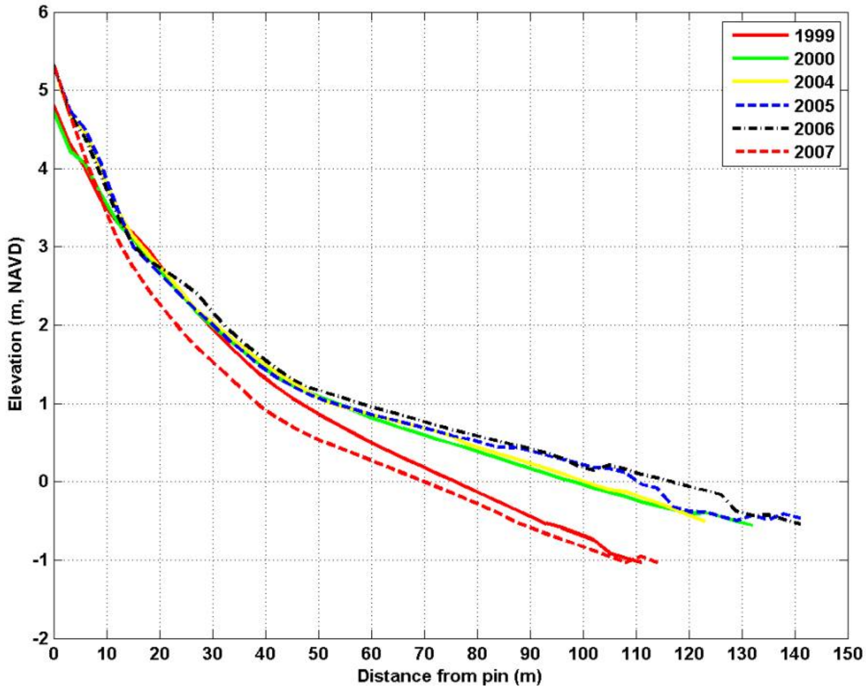

Figure 21. Annual variability at SC1 shows some accretion from 2004 to 2006 followed by erosion in 2007 to a depth below the 1999 starting profile.

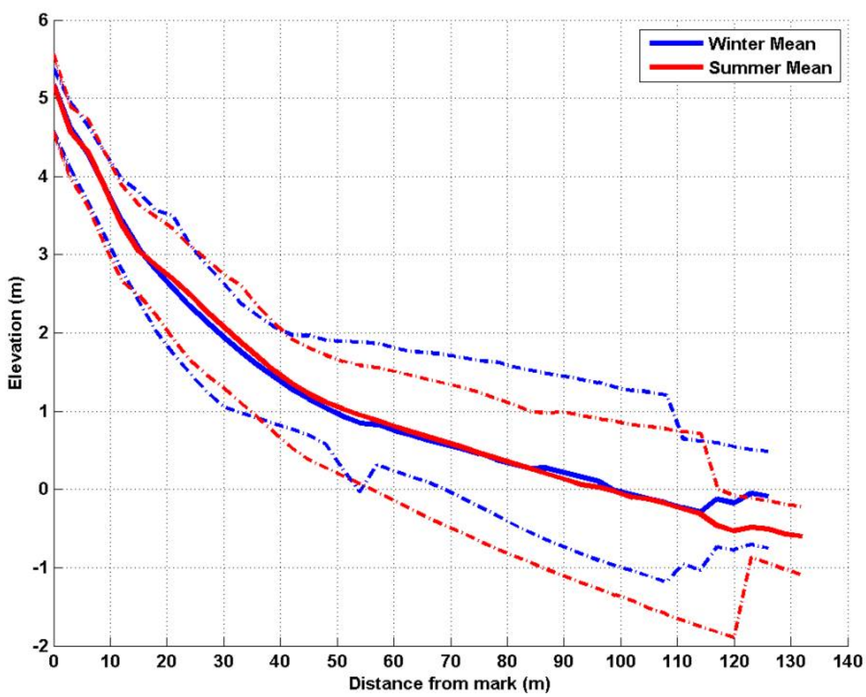

Figure 22. Seasonal variability at SC1 shows very similar winter and summer mean profiles. The envelopes are also generally similar throughout most of the profile distance.

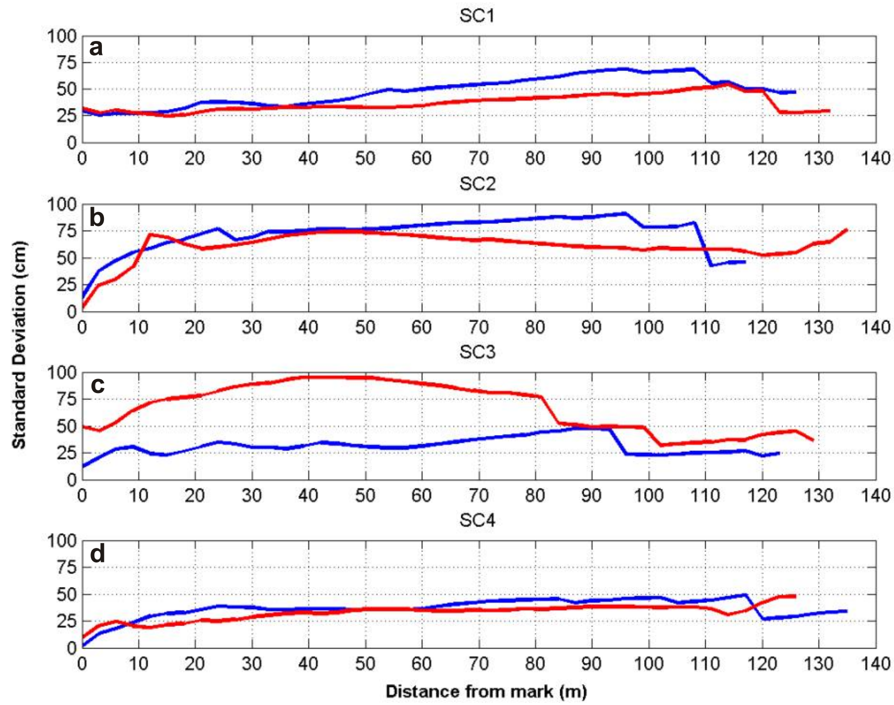

Figure 23. (a) Standard deviation at SC1 shows the greatest variability in elevation occurs in the offshore portion. This is most likely due to shifting positions of sand bars. (b) At SC2 the standard deviation is about 0.7 to 0.8 m of elevation throughout most of the profile. (c) At SC3 the large summer standard deviation may be an artifact of including the 1999 data in the calculation. The winter standard deviation is about half that of SC2. (d) At SC4 the standard deviation is about 0.5 m throughout most of the profile length.

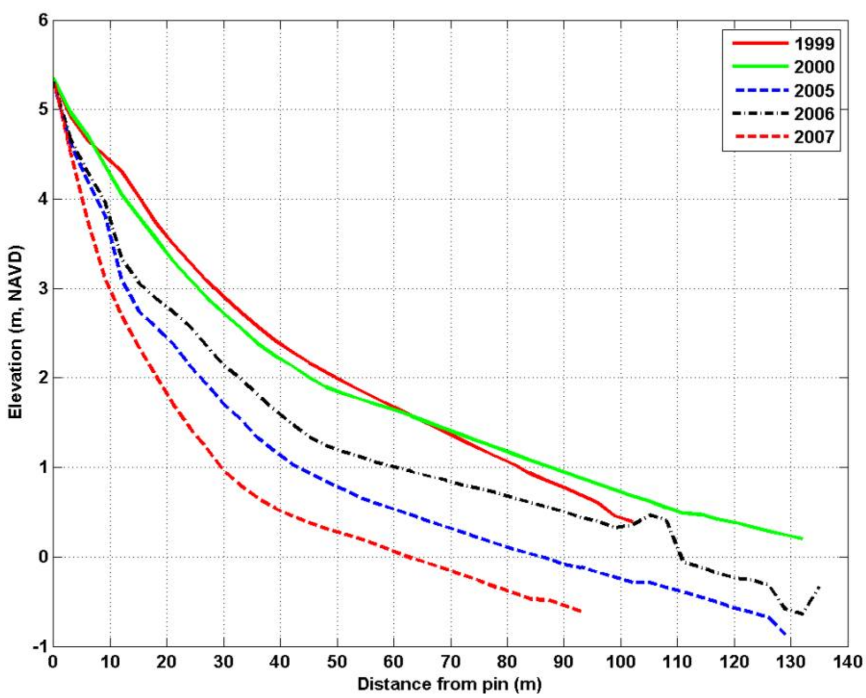

Figure 24. At SC2 annual variability is greater than at SC1. From 1999 to 2000 and 2005 to 2006 about 1 meter of sediment was lost and the dune appears to have receded. From 2006 to 2007 the mean profile lowered about a meter - some of which may be due to the 2007 Patriots' Day Storm.

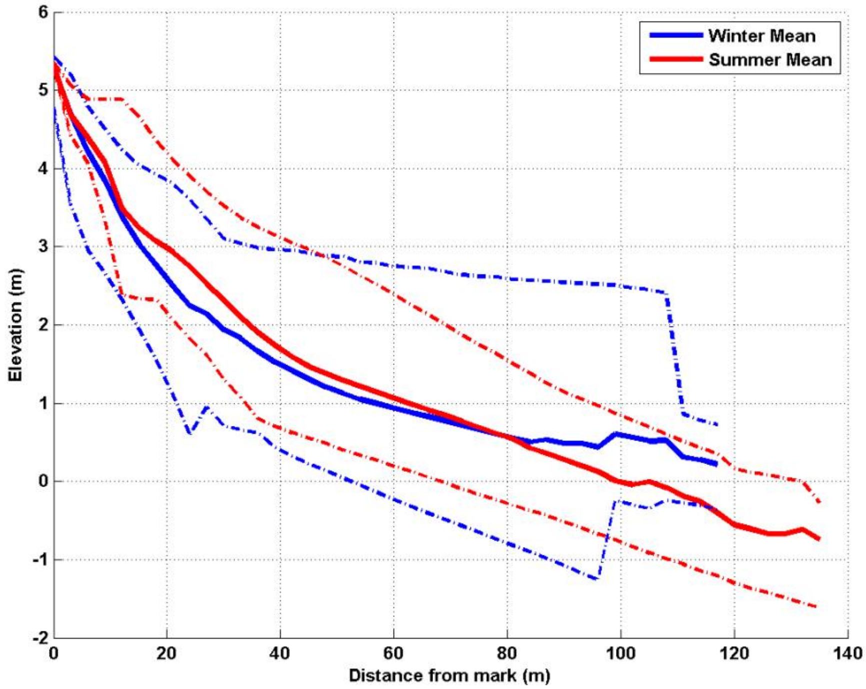

Figure 25. Seasonal variability at SC2 shows the expected influence of the summer berm on the upper profile with greater variability than in winter. The outer profile has greater winter variability consistent with seasonal sand bar migration.

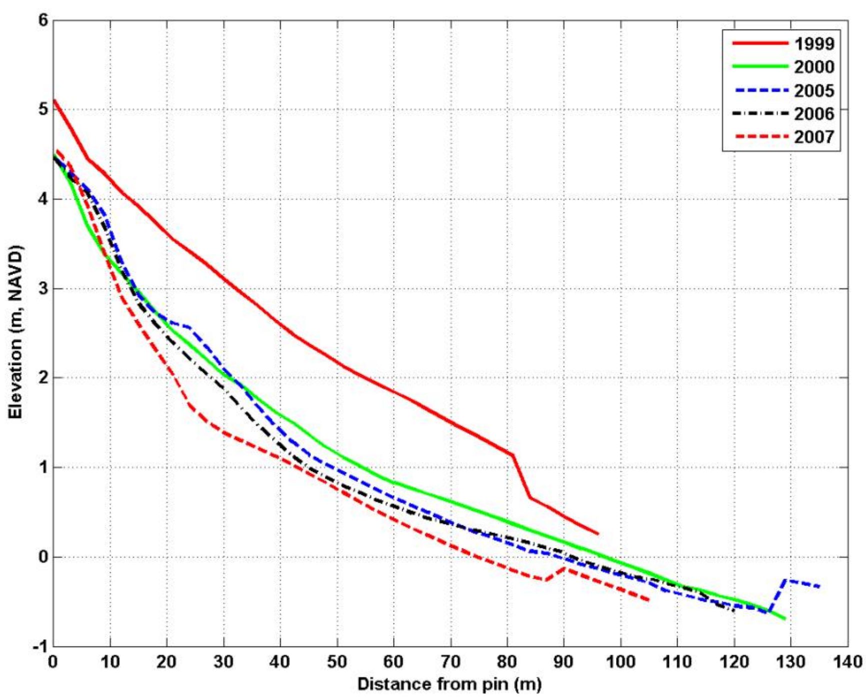

Figure 26. The beach at SC3 appears to start at 1999 in a different location than the rest of the years. From 2000 to 2007 there is consistent loss of sediment on the profiles, but not as dramatic as on SC2. The overall profile shape is similar through the years.

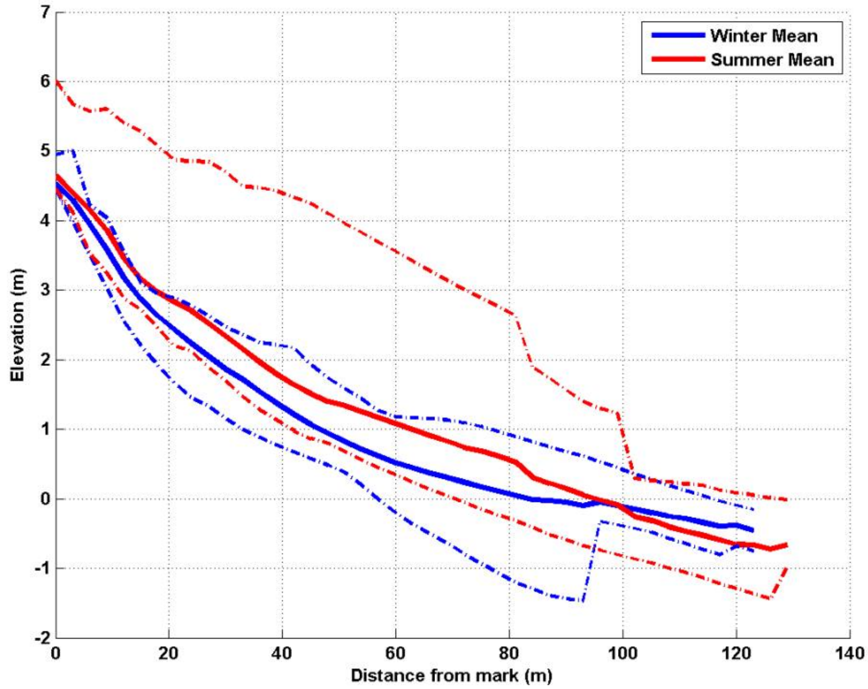

Figure 27. At SC3 seasonal variability shows an expected behavior with loss on the upper profile in winter compared to summer.

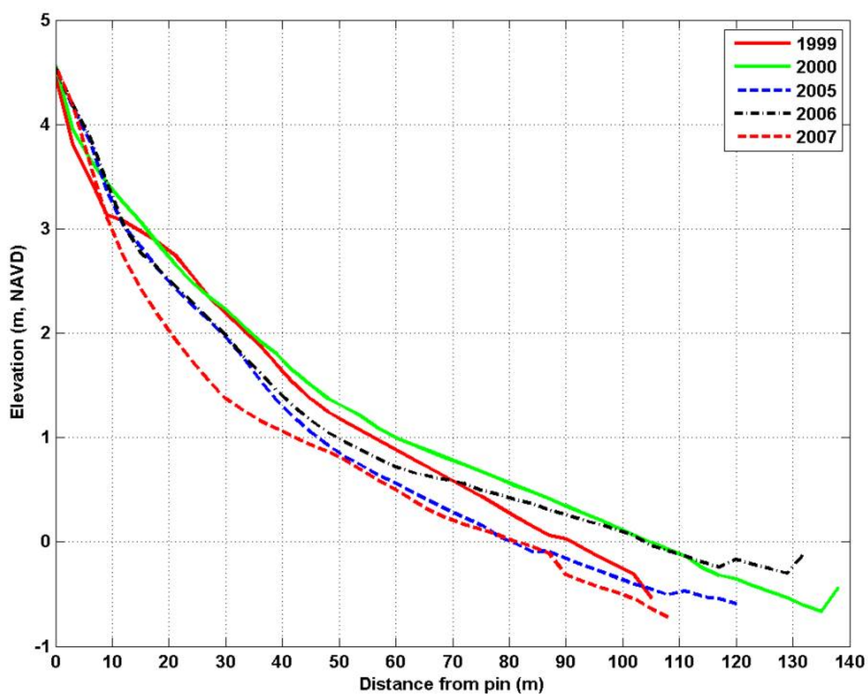

Figure 28. The profiles at SC4 show the trend seen at SC3 with a lowering of the mean annual profile from 1999 to 2007. By 2007 the profile has reached its lowest level with a vertical loss of 0.5 to 1 meter of beach elevation over 8 years.

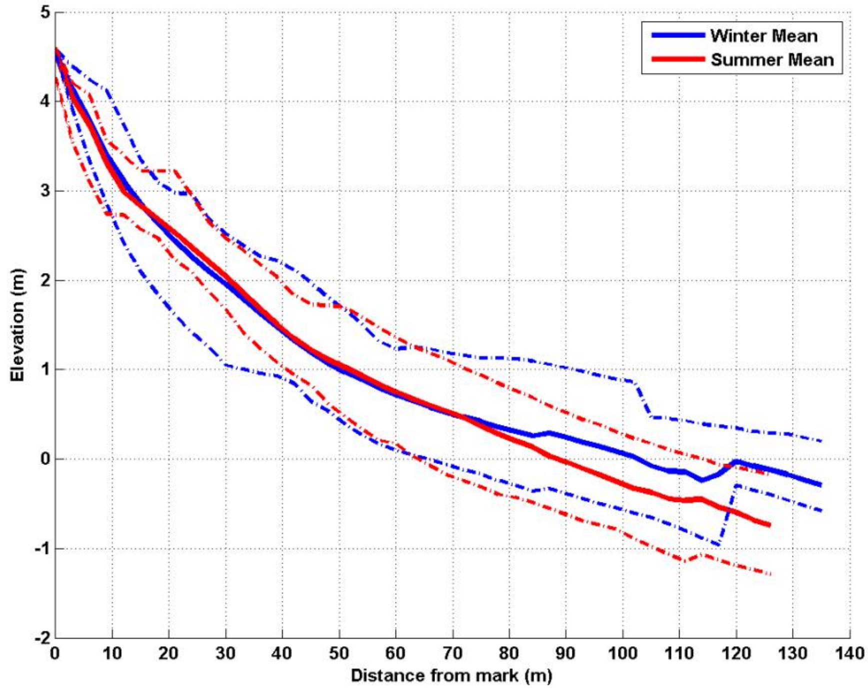

Figure 29. Seasonal variability at SC4 is minimal as at SC1. As expected, the winter has the greater range in elevation from highest to lowest levels.

Western Beach and Ferry Beach, Scarborough

Background geology and characteristics

Western Beach is a roughly 1 km pocket beach, oriented northwest-southeast and located on the western shore of Prouts Neck, adjacent to the Scarborough River. It is bound by Prouts Neck to the southeast and Ferry Rock to the northwest. Ferry Beach curves almost circularly from Ferry Rock to Black Point, another bedrock outcrop to the north (Nelson, 1979). Ferry Beach is partly a pocket fringing beach and partly a pocket barrier beach. Both beaches are located at the mouth of the Scarborough River. A forest and a golf fairway are found behind Western and Ferry Beaches.

Historically, the shorelines of both Ferry Beach and Western Beach have been stable (Nelson and Fink, 1980). Numerous paleo-dune ridges, cross-cutting one another, suggest a complex history of episodic erosion and accretion at Western Beach. Studies by Nelson (1979) and Timson (1989; 2003) indicated general accretion along Western Beach until the late 1970s. The channel for the Scarborough River was stabilized by the USACE in 1962. It appears that, as a result of the stabilization, Western Beach underwent progradation until about 1978. MGS postulates that this was most likely caused by the abandonment of sand shoals on the east side of the stabilized channel, which over time migrated to the northeast by wave action and welded onto Western Beach, until the sediment was depleted (Slovinsky, 2006).

Western Beach, since 1978, appears to be undergoing a period of recession since the sediment that fed its shoreline is not being replenished by regular shoal bypassing events, inhibited by the main channel of the Scarborough River. Shoal bypassing has continued to a limited extent, evidenced by the regular shoaling of the main channel. Records of dredging at the Scarborough River indicate that large amounts of sediment are being removed from the system through maintenance dredging, thus not allowing the majority of sediment to successfully bypass the inlet and weld onto the Western Beach shoreline. The sand shoals that are currently reaching Western Beach (that are not removed by dredging), are not of a sufficient volume to sustain a stable or prograding shoreline. Western Beach has undergone dramatic erosion since the 1980s, and has received sediment through a beach nourishment project in 2005.

Western Beach and Ferry Beach have a total of 4 beach profiles, WS1-WS4, with 2 profiles (WS1 and WS2) located along Ferry Beach and 2 along Western Beach (WS3 and WS4) (**Figure 30**). WS4 was lost and not relocated. Several of the beach profiles (WS1 and WS3) along Western Beach and Ferry Beach were surveyed by MGS in June 2006. In February 2007, MGS resurveyed the profiles and established a new network of profiles. WS1 and WS3 will be renamed as WS5 and WS7, respectively. A new WS6 will be in the vicinity of WS2, and WS8 will be located farther southeast on Western Beach. The next update and analysis of profiles will include these new locations.

Annual and seasonal beach profile changes

The beach profiles at Western and Ferry Beach start behind the frontal dune crest. Data collected along Western and Ferry beaches in Scarborough were quite confusing due to the number of times it appears that front and back stakes were used, and changed position. The analysis of the data broke each profile (WS1-WS3) down into a front stake (FS) and back stake (BS).

Data were collected at the WS1 front stake (FS) between 1999-2001. Through the data collection period, the mean profiles show consistent sediment loss along the profile from about 15 m from the pin and farther seaward, with the gain and development of a slight berm at around the 10 m mark (**Figure 31**). Seasonal data from WS1FS indicate that the summer and winter profile shapes are very similar out to about the 15 m mark (elevation of about 2 m); past this, the summer profile is more voluminous (**Figure 32**); however, standard deviation data indicate that the winter profile past this point is more variable (up to 40 cm), while the summer profile is more stable, with variations up to about 20 cm (**Figure 33a**).

For WS1BS, a data set between 2001 and 2006 was collected. Analysis indicates that the profile has been variable, but eroded during the overall time period (**Figure 34**). Between 2001-2002, the profile gained sediment; from 2002-2003, it remained stable to slightly accretive. From 2003-2004, the profile lost a significant volume of sediment along the majority of its length; maximum loss appears to be on the order of 0.5 m. Between 2004-2005, the profile gained some sediment, and then lost sediment between 2005-2006. On a seasonal basis, data indicate that WS1BS underwent typical summer and winter changes, with the summer mean exhibiting more sediment along the profile than the winter mean (**Figure 35**). Maximum and minimum profile envelopes indicate that up to 1.5 m of variability in the profile shapes has occurred. Based on standard deviation data, both profiles can be variable vertically (almost up to 60 cm), with maximum variability at 20 m offshore, and around 45 m offshore (**Figure 33b**).

Data at WS2FS were collected between 1999-2000; the horizontal length of the data set is very short. The mean profiles indicate a loss of approximately 0.5 m of sediment along the length of the profile over the two years (**Figure 36**). Seasonal data indicate the expected differences in summer vs. winter profile shapes (**Figure 37**). Summer berm development, evidenced in the standard deviation data, is highly variable, up to 60 cm (**Figure 33c**).

WS2BS annualized mean data show steady accretion along the entire profile, with the buildup of a dune crest at around 12 m from the pin (gaining about 0.5 m in elevation). Farther offshore, the profile gained much more sediment (**Figure 38**). The most marked change was between 2004-2005, with over 1 m of accretion. This may be due to the migration of sediment into this area

Figure 30. Western Beach and Ferry Beach have a total of 4 beach profiles, WS1-WS4, with 2 profiles (WS1 and WS2) located along Ferry Beach and 2 along Western Beach (WS3 and WS4). The fourth profile, WS4, was lost and has been discontinued. WS2 and WS4 are approximately located on the figure.

due to the beach nourishment project completed in December 2005. The accretion continued into 2006. Surprisingly, the winter profile for WS2BS shows more sediment volume along the profile than the summer profile (**Figure 39**). This may be attributed to the influence of the beach nourishment, since the nourishment project was completed during the winter of 2005, this might skew the winter data. Variability for summer and winter data is relatively low until about 15 m, when vertical variability reaches about 50 cm; seaward of this, variability steadily increases for both summer and winter data, with winter standard deviation values peaking at 100 cm (1 m) at about 38 m from the mark, and summer values approaching 140 cm (1.4 m, **Figure 33d**).

Data at WS3FS were collected between 1999-2003. Mean profiles show a relative stability to slight accretion along the overall profile length (**Figure 40**). Seasonal profile comparison indicates a slightly more sediment-rich profile during the summer, and slightly greater variability than the winter (**Figure 41**, **Figure 42a**).

WS3BS data were collected from 2003-2006. There was little change between 2003-2004, then substantial accretion between 2004-2005, likely due to the influence of nourishment (**Figure 43**). There was some erosion between 2005-2006. Seasonally, WS3BS shows little variation until around 80 m from the pin (**Figure 44**); here, the winter profile appears to have slightly more sediment. Standard deviation data indicate a variable dune and berm during the summer (with vertical changes up to 40 cm), with winter variability being much less, on the order of 20-25 cm (**Figure 42b**).

Data at WS4 were collected from 1999 through 2001; the mark was never surveyed by MGS before it was lost. Profile data indicate that the shoreline underwent erosion between 1999-2000, with slight recovery in 2001, though a large offshore bar that was present in 1999 did not reappear (**Figure 45**). Seasonal data indicate generally that the winter profile held more sediment than the summer profile shape (**Figure 46)**. Standard deviation data showed relatively high (up to 40 cm) variability along both summer and winter profiles alike (**Figure 42c**).

Profiles along Western and Ferry Beaches are heavily influenced by the flood- and ebb-tidal formations associated with the Scarborough River. The river, which is flood dominated, tends to store large amounts of sediment within the flood-tidal shoals, adjacent to Ferry Beach. Beach and dune growth (and erosion) is episodic, dependent upon the movement of these shoals. Anthropogenic influence in the form of beach nourishment also has an impact on the shapes of the profiles, especially along Western Beach proper. The nourishment material, over time, should end up in the flood-tidal delta of the river, where sediment is sequestered. Erosion of Western Beach proper will likely continue unless sediment is delivered to the beach at a rate equal to that of the natural shoal bypass rate at the Scarborough River (a good estimate of this is the rate that the dredged river channel shoals).

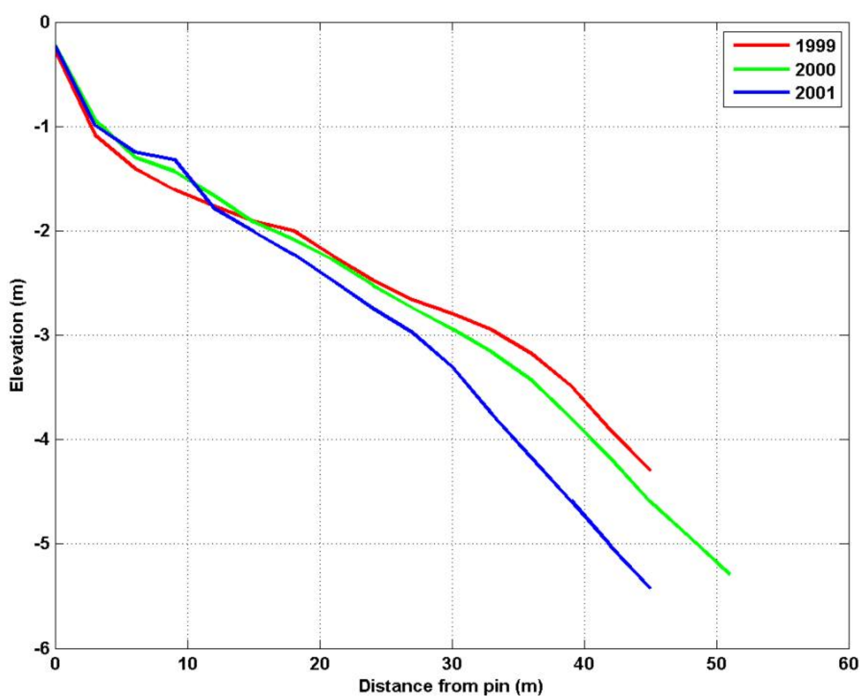

Figure 31. Annual profiles from the front stake (FS) at WS1 show an overall loss of sand from the beach from 1999 to 2001.

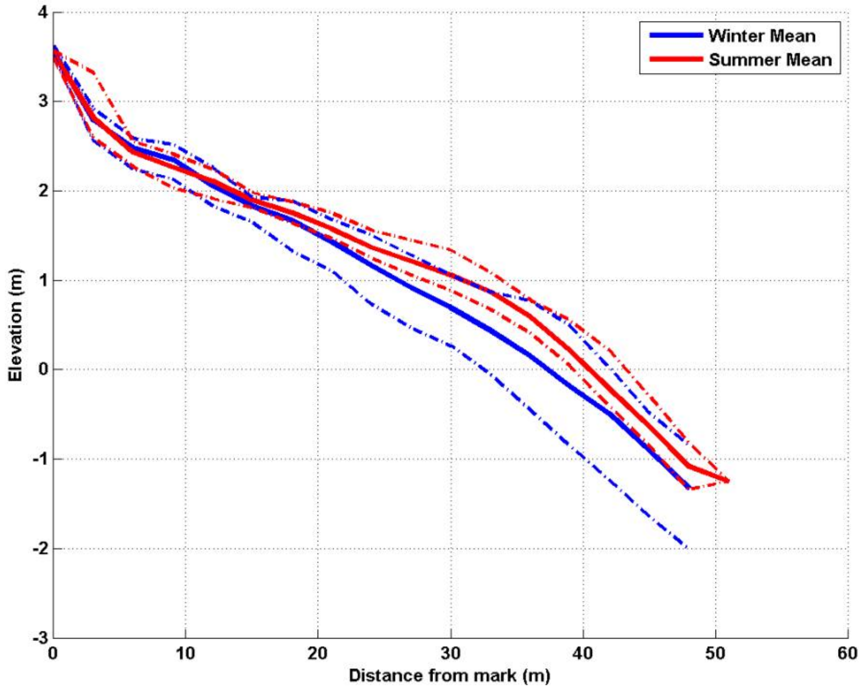

Figure 32. At WS1FS the summer and winter beach is similar along the upper profile, but more sand is on the lower profile in the summer.

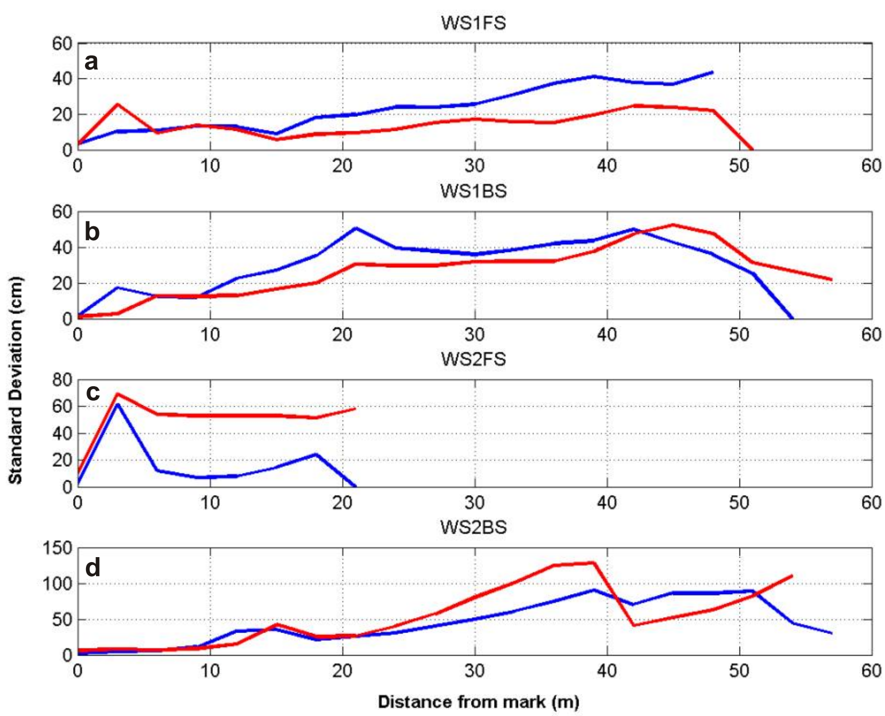

Figure 33. (a) The profile variability at WS1FS increases with distance offshore. The winter profile tends to be more variable than the summer profile. (b) At WS1BS the pattern continues as in WS1FS above. (c) At WS2FS the higher standard deviation in summer can be attributed to berm formation. (d) Variability at WS2BS is low on the upper profile in both seasons and, as expected, higher on the outer profile where there is more influence of beach nourishment and tidal currents of the Scarborough River.

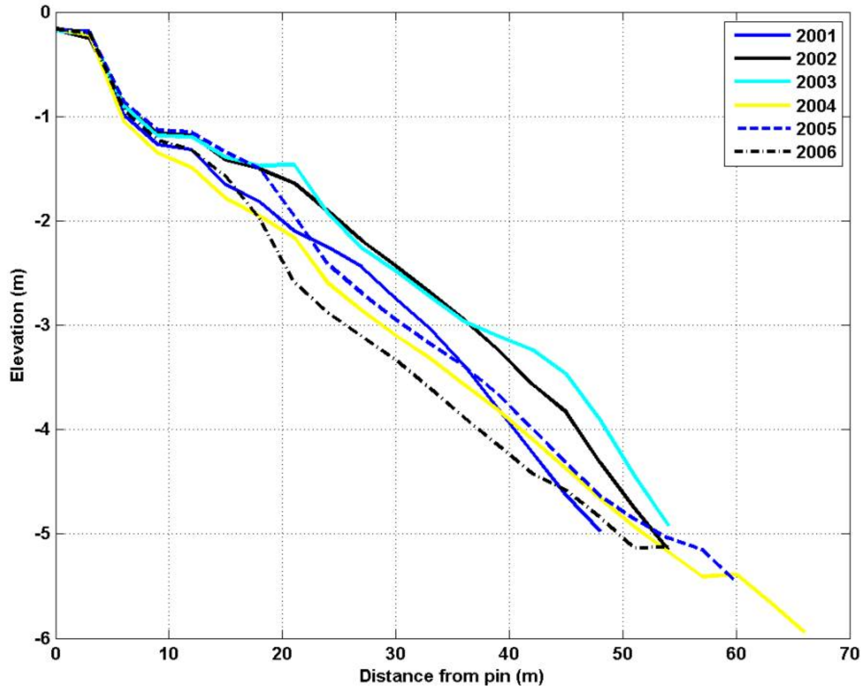

Figure 34. Profile WS1BS has data from 2001 to 2006 with nearly a meter of elevation change over the years. The 2006 profile is the lowest recorded.

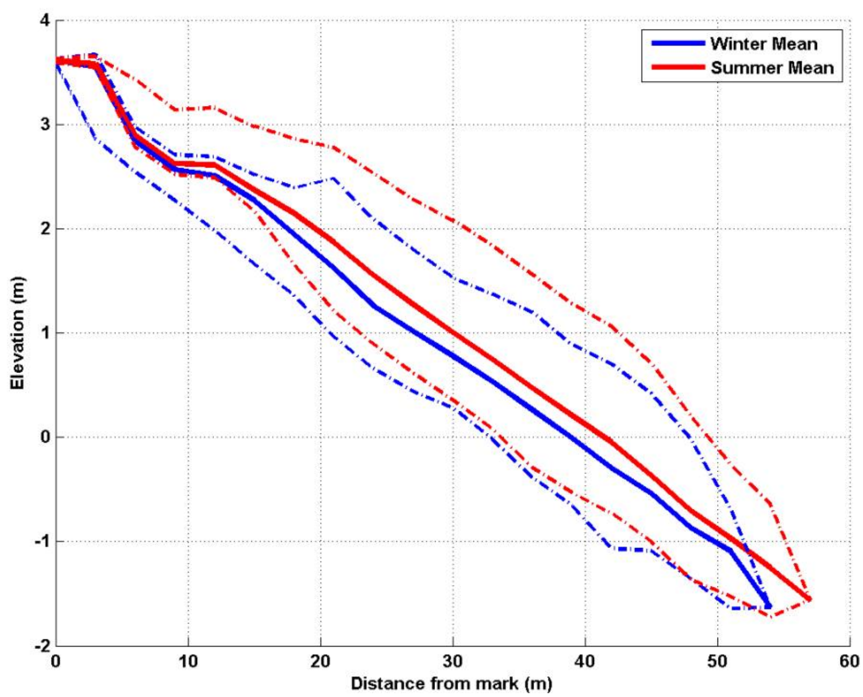

Figure 35. The seasonal comparison at WS1BS shows the summer beach has more sand than in winter, typical of many beaches.

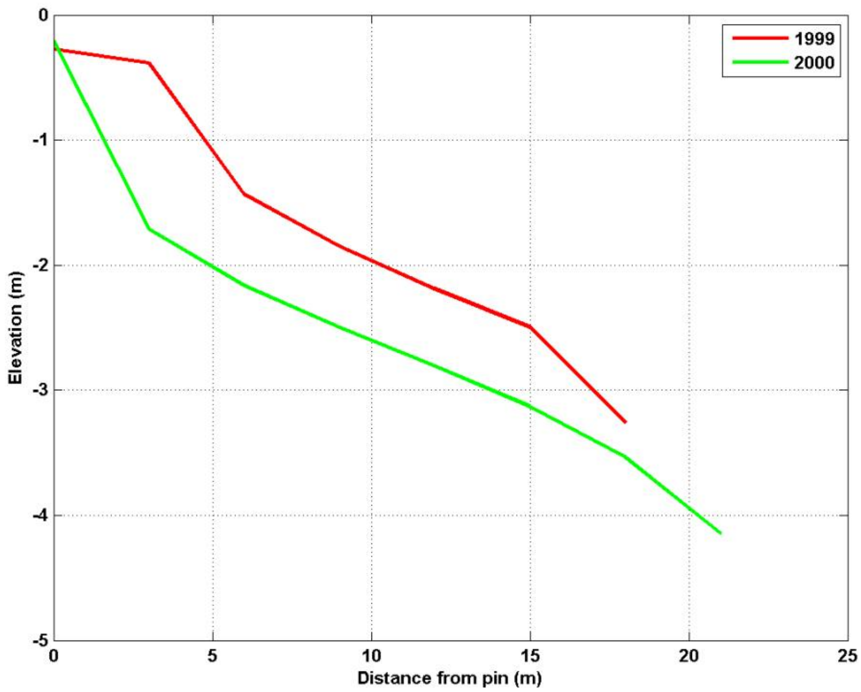

Figure 36. Annual profiles at WS2FS from 1999 to 2000 show a loss of about 0.5 m of sand from the beach across the full profile.

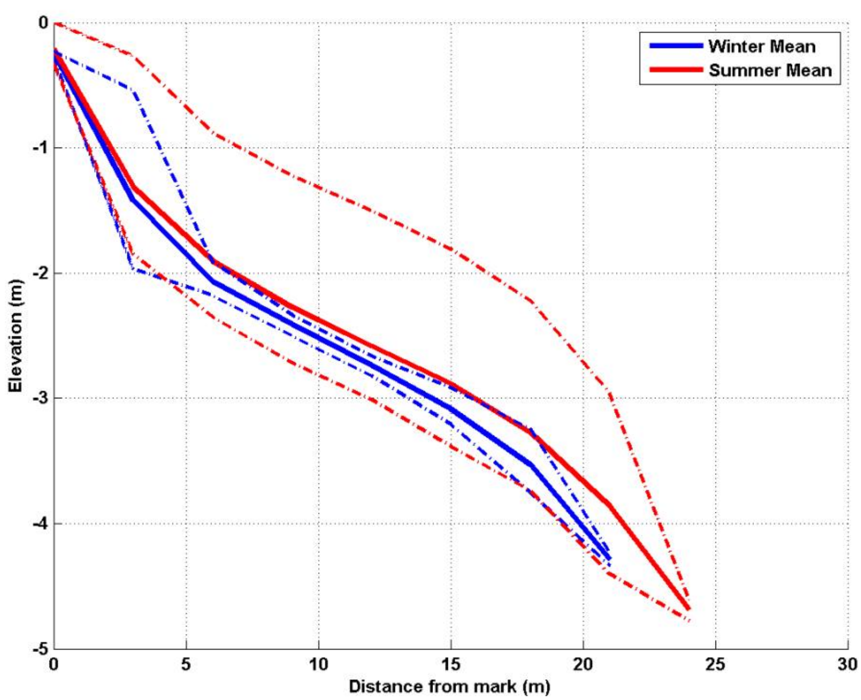

Figure 37. As expected, the profile at WS2FS has a slightly higher elevation in summer than in winter.

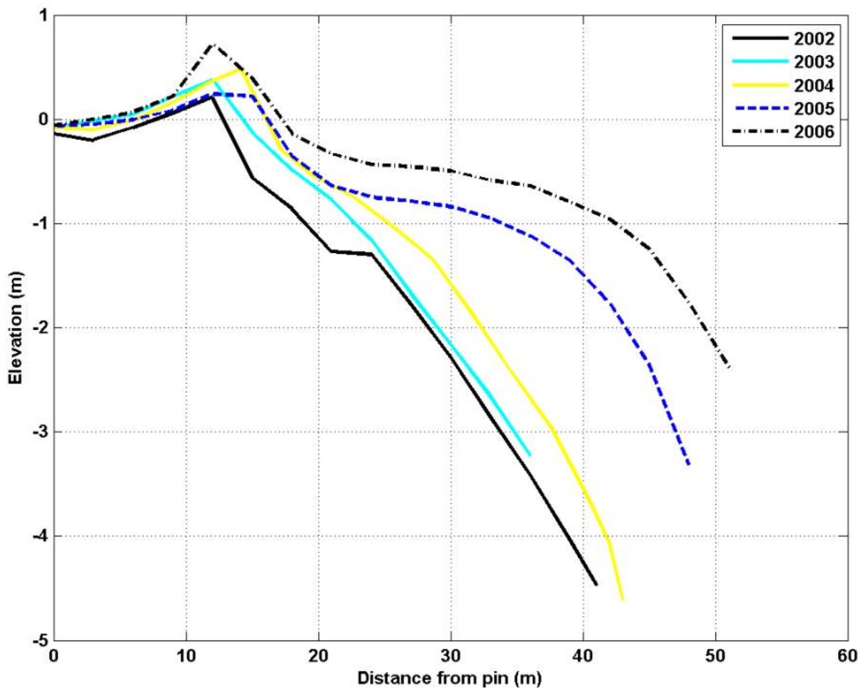

Figure 38. Annual profiles at WS2BS from 2002 to 2006 show a trend of beach and dune building. River channel dredging and beach nourishment late in 2005 probably facilitated the growth of the beach through 2006.

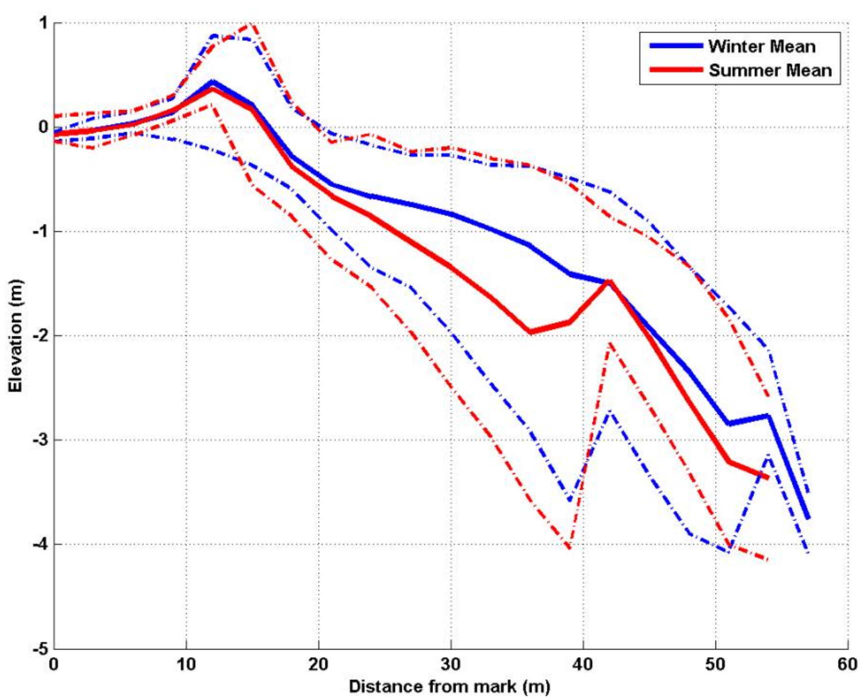

Figure 39. The high average winter profile compared to the summer at WS2BS may be due to the addition of beach nourishment sand in the winter of 2005-2006. The envelope of profile variability gets very large on the outer profile next to the Scarborough River.

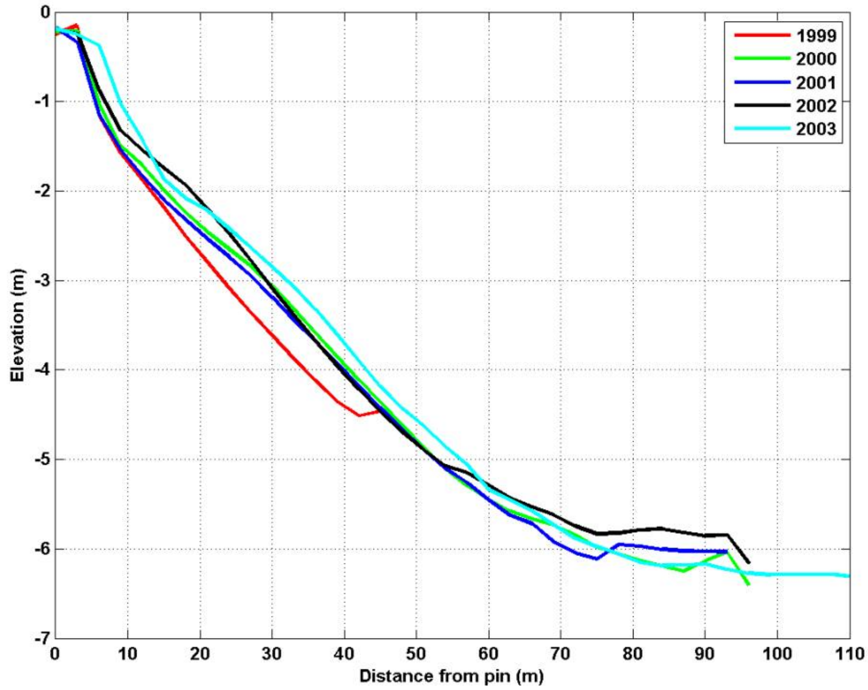

Figure 40. At WS3FS there was relative stability from 1999 to 2003.

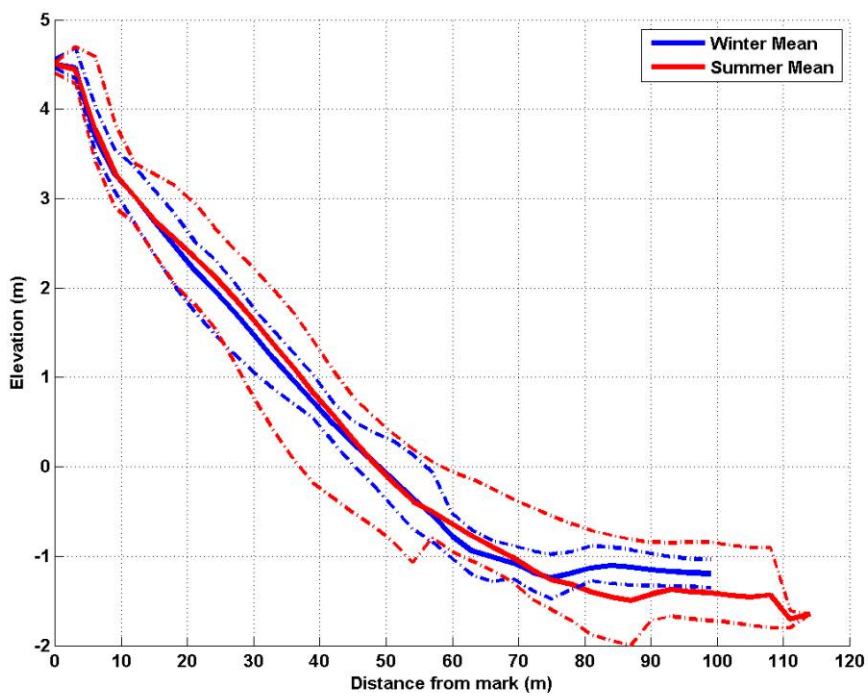

Figure 41. In the summer at WS3FS there was only slightly more sand on the beach than in winter. The winter envelope of variability is less than the summer.

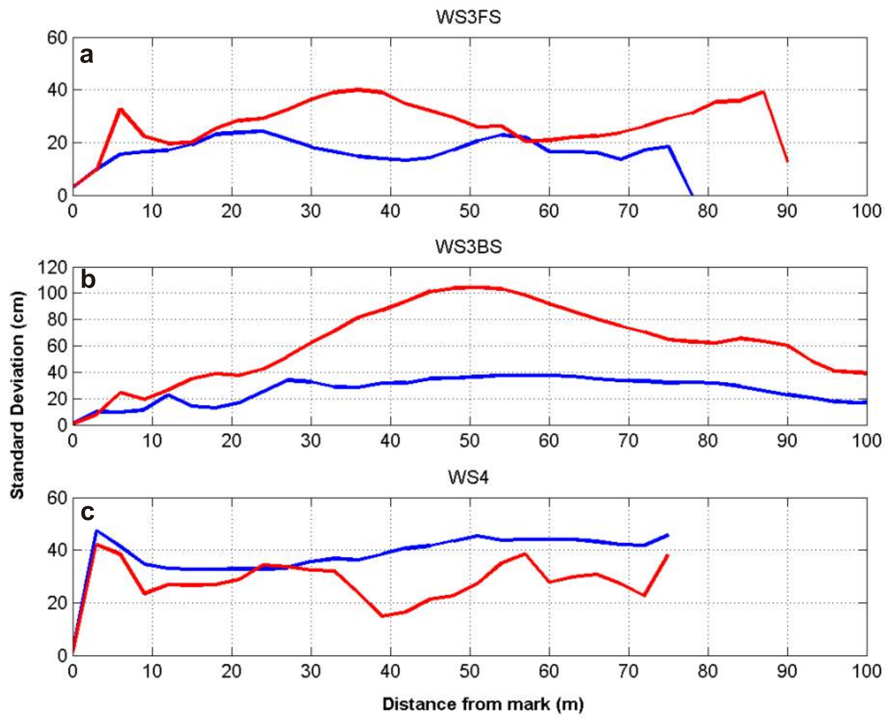

Figure 42. (a) At WS3FS the standard deviation is larger in summer than winter. (b) At WS3BS this pattern continues with as much as a meter of variability in the middle of the profile. (c) At WS4 the standard deviation is greater in winter than in summer but both are quite high across the full profile.

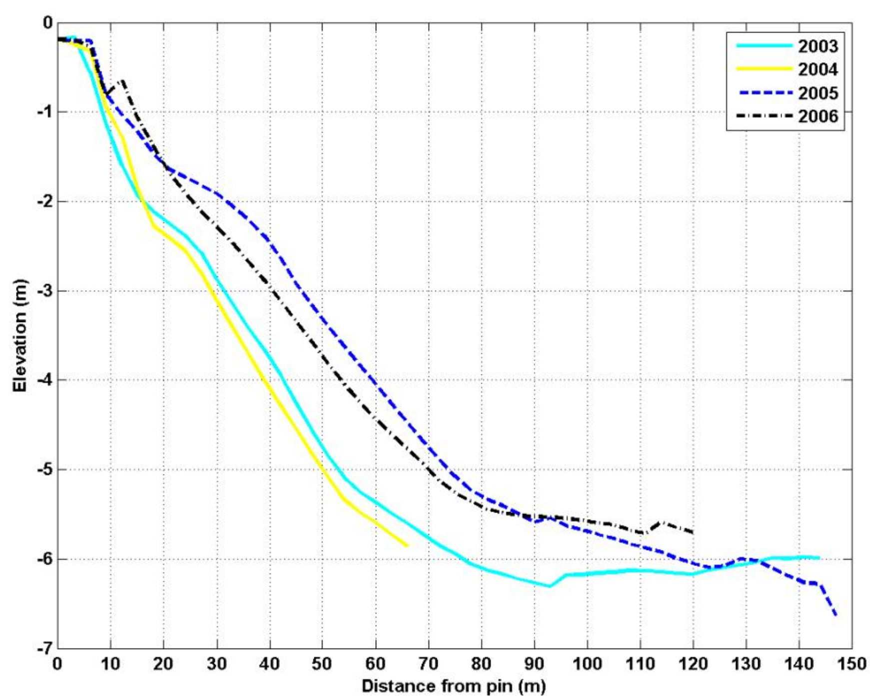

Figure 43. Annual profiles at WS3BS from 2003 to 2006 show the influence of beach nourishment that began in December 2005. Over much of the profile about 0.5 m of nourishment appears to have been lost across the middle of the profile from 2005 to 2006.

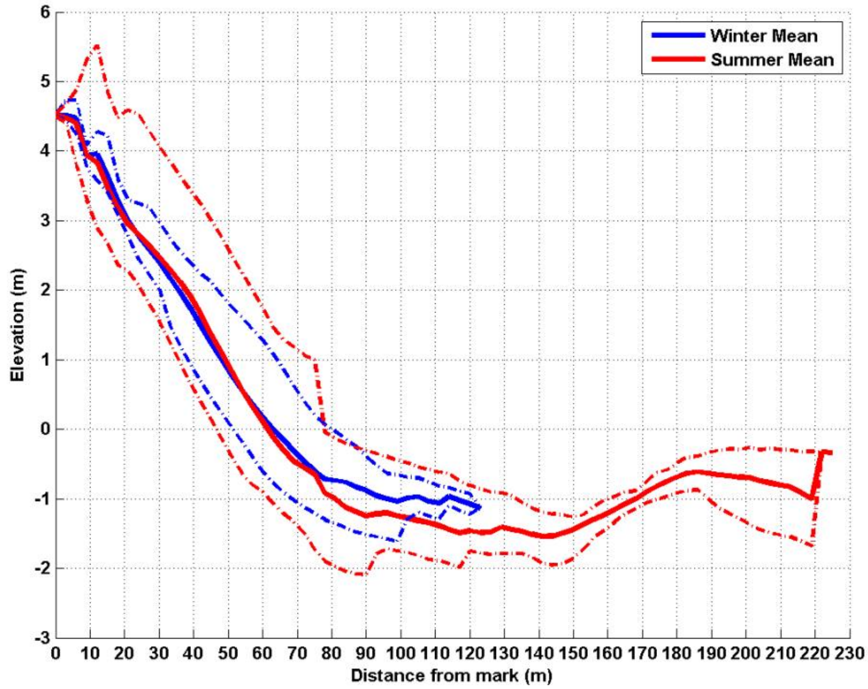

Figure 44. Winter and summer means have very similar shapes at WS3BS with greater variability in the profile envelope in summer.

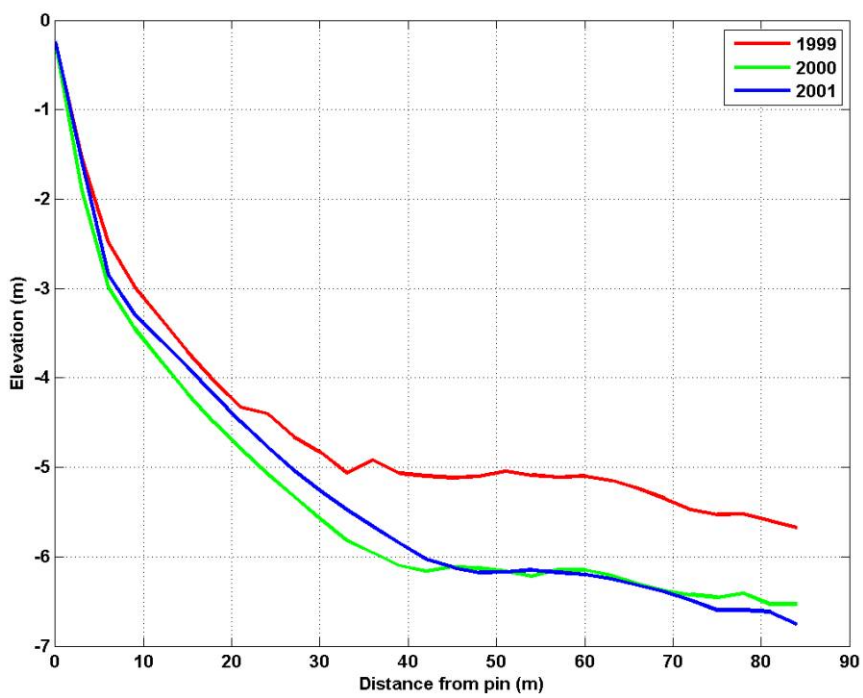

Figure 45. Profile WS4 experienced erosion from 1999 to 2000 with slight recovery in 2001. Erosion on the low-tide terrace (beyond 40 m) resulted in the vertical lowering of the beach by about a meter.

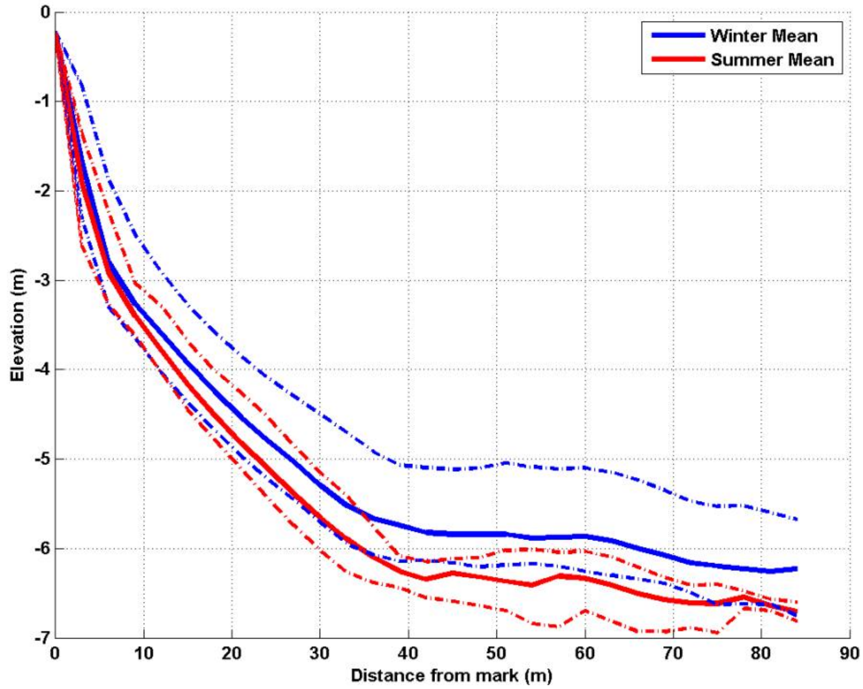

Figure 46. Unlike many locations, WS4 appears to hold more sand on the profile in winter than in summer.

East Grand Beach, Scarborough

Background geology and characteristics

East Grand Beach is located along contiguous beach from Old Orchard Beach north to Pine Point, and is a highly developed stretch of arcuate shoreline located at the central to northern portion of the expansive Saco Bay beach system. This region stretches northwards from the Goosefare Brook tidal inlet in the south and includes the communities of Ocean Park, Old Orchard Beach proper, and Surfside (all part of Old Orchard Beach), and East Grand Beach and Pine Point (in Scarborough). The shoreline along Old Orchard Beach is relatively stable to accretional (Nelson, 1979; Slovinsky and Dickson, 2003). Along the central section of Ocean Park and Old Orchard Beach are artificial frontal dunes that contain buried sewer pipelines that service the dune neighborhoods. This dune was developed as part of a dune management plan in the 1980s (Timson and Denison, 1986) and has succeeded in stabilizing much of the Old Orchard Beach dunes. Much of the shoreline along Old Orchard Beach is armored, though many seawalls are now located landward of vegetated dunes due to a positive shoreline change rate. The apparent shoreline accretion in this segment of Saco Bay is due, in part, to dune restoration and management so the apparent shoreline change used in this report is a function of the management action.

The Little River Inlet, closed sometime between 1859-1868 as a consequence of railway line construction, used to form the Old Orchard Beach-Scarborough town line, as well as the York-Cumberland County boundary. At this point, it appears that the beaches of Old Orchard Beach are relatively stable (Kelley and others, 1995; Kelley and others, 2005; Slovinsky and Dickson, 2003).

There are no SMBPP volunteer profiles within Old Orchard Beach itself; East Grand Beach has 4 measured beach profiles, EG1-EG4. All 4 profiles are located adjacent to each other, starting with the northeasternmost, EG1, located within the dune just south of 9th Street. EG2 is located just seaward of 11th Street, while EG3 and EG4 are located consecutively to the southwest (**Figure 47**). Starting locations were surveyed by MGS in June 2006.

Annual and seasonal beach profile changes

Beach profiles along East Grand Beach all start from behind the frontal dune crest. East Grand beach profiles form a continuous dataset from 1999-2007, one of the only locations to do so. At EG1, inspection of the mean profile shapes indicates a well developed dune that has migrated landward slightly and gained elevation consistently over the data collection period (for example, in 1999 the dune crest was located at 40 m from the pin and 2.8 m in elevation; by 2007, the crest was located at 24 m from the pin at an elevation of 3.5 m (**Figure 48**). This indicates that the dune is migrating landward through the process of overwash, and that enough sediment is available for the dune to gain elevation. The winter and summer mean profiles are extremely similar in terms of overall shape and variability based on envelope and standard deviation data (**Figure 49**). The berm appears to vary between 25-35 cm vertically, at a position between 20-40 m from the mark (**Figure 50a)**.

Similar to EG1, mean annualized profiles at EG2 show dune growth and landward migration from 1999 (at 35 m offshore and 2.8 m elevation) to a maximum during 2004 (22 m from pin and 3.7 m), with a slight loss in dune elevation from 2004-2007 (**Figure 51**). Consistent with many other locations, the 2007 overall profile contains less sediment, except for the 2003 profile. There is little difference in the summer and winter mean profile shapes, though the winter profile exhibits a much larger minimum and maximum envelope (**Figure 52**). Standard deviation variability is larger for the winter profile, up to 50 cm vertically, over a large horizontal area, between 30-110 m from the mark (**Figure 50b**).

Like the other profiles at East Grand Beach, EG3 underwent similar changes to the dune crest landward movement and a gain in elevation, with the 2007 profile exhibiting the highest dune elevation (at 3.2 m compared with 2.6 in 1999). Generally, there has been little change to the profile past 50 m from the pin (**Figure 53**). Seasonally, there is little difference between the summer and winter mean profiles, though the summer profile exhibits a slightly greater volume of sediment along the berm (**Figure 54**). The maximum variability based on profile envelopes and standard deviations (**Figure 50c**) is about the same for summer and winter, about 25 cm of vertical variation on average.

Annualized profiles at EG4 (**Figure 55**) show changes similar to the other 3 profiles; that is, the landward migration and growth of the frontal dune crest. The dune crest, between 1999-2007, migrated about 5 m inland and gained approximately 0.5 m in elevation. The 2003 mean profile was again the leanest, similar to the other EG profiles. Seasonal data (**Figure 56**) indicate that the EG4 summer profile exhibits slightly more sediment along portions between 30-120 m from the mark. There is little seasonal variation of the dune shape, and the profile variability envelopes are quite similar, though farther offshore, the variability based on standard deviations increases to near 50 cm vertically (**Figure 50d**).

The profiles at East Grand Beach appear to be relatively stable, though steady landward migration of the dune crest is apparent in the data. However, the dune crest is gaining in elevation as it migrates landward, indicating enough of a sediment supply to facilitate such processes. This indicates a healthy, yet somewhat transgressive, beach system.

Figure 47. East Grand Beach has 4 measured beach profiles, EG1-EG4. All 4 profiles are located adjacent to each other, starting with the northeastern most, EG1, located within the dune just south of 9th Street. EG2 is located just seaward of 11th Street, while EG3 and EG4 are located consecutively to the southwest.

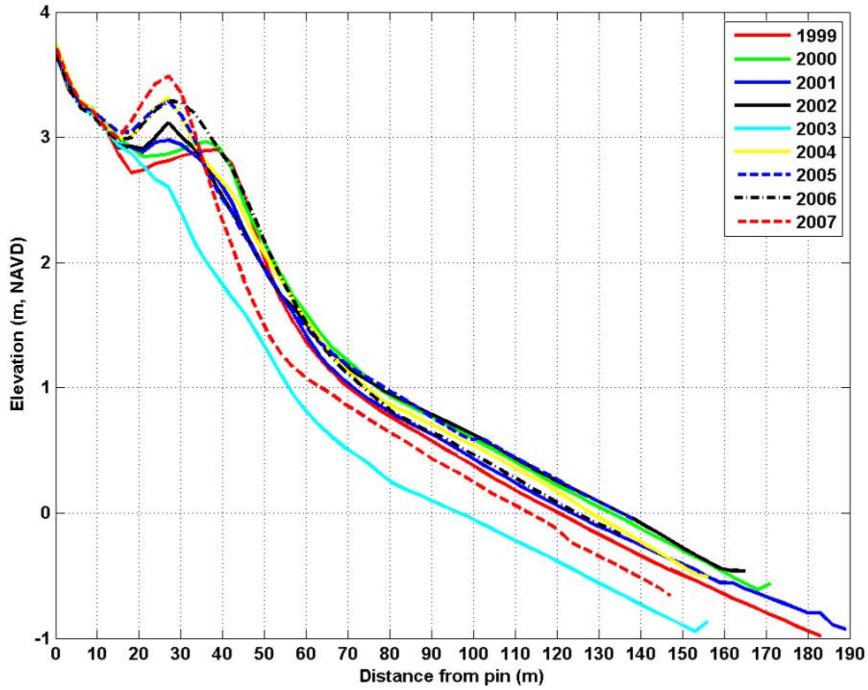

Figure 48. At East Grand Beach (EG1) a very continuous data set documents the growth and slight landward migration of the frontal dune ridge from 1999 to 2007 and a general trend of seaward accretion of the beach until 2006.

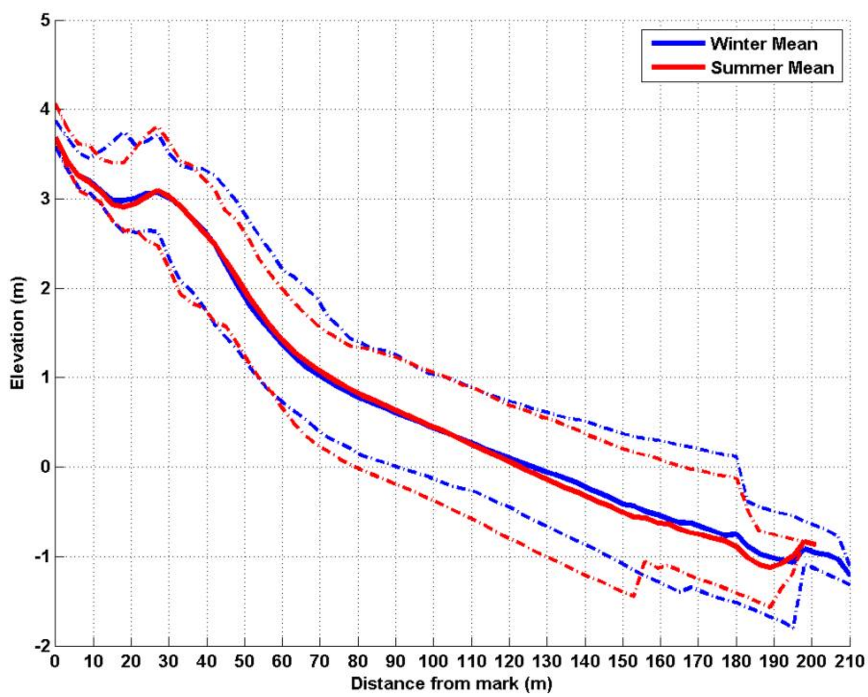

Figure 49. Seasonal differences at EG1 are very small and, on average, the profile shape appears the same year-round.

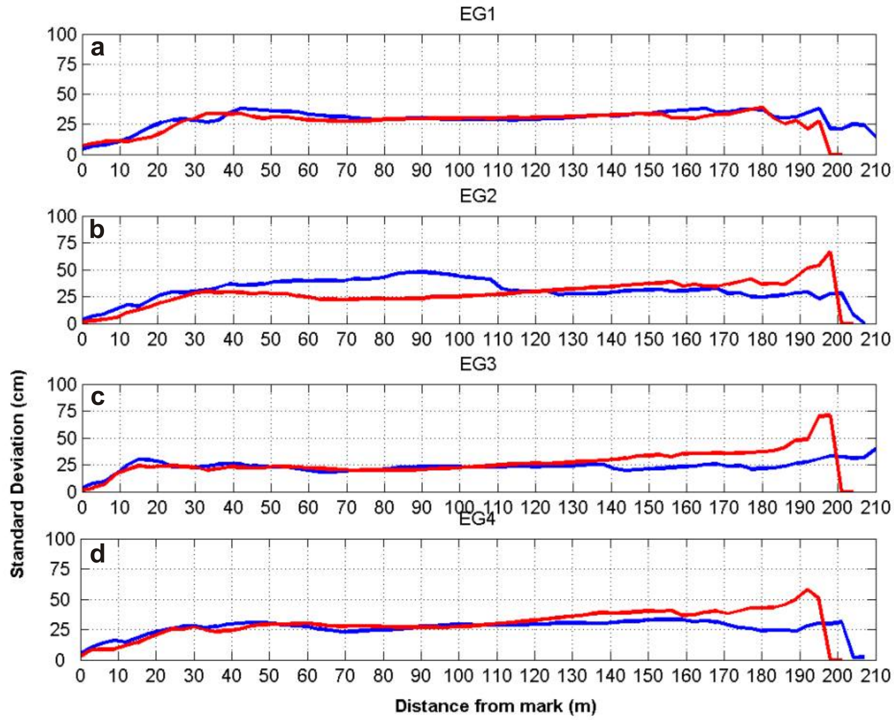

Figure 50. Winter and summer profiles and variability at EG1 (a) are also very similar as indicated by the standard deviation values . EG2 (b), EG3 (c), and EG4 (d) all show similar standard deviations and no large winter-summer difference with a common value of 0.25 m for most of the profile length.

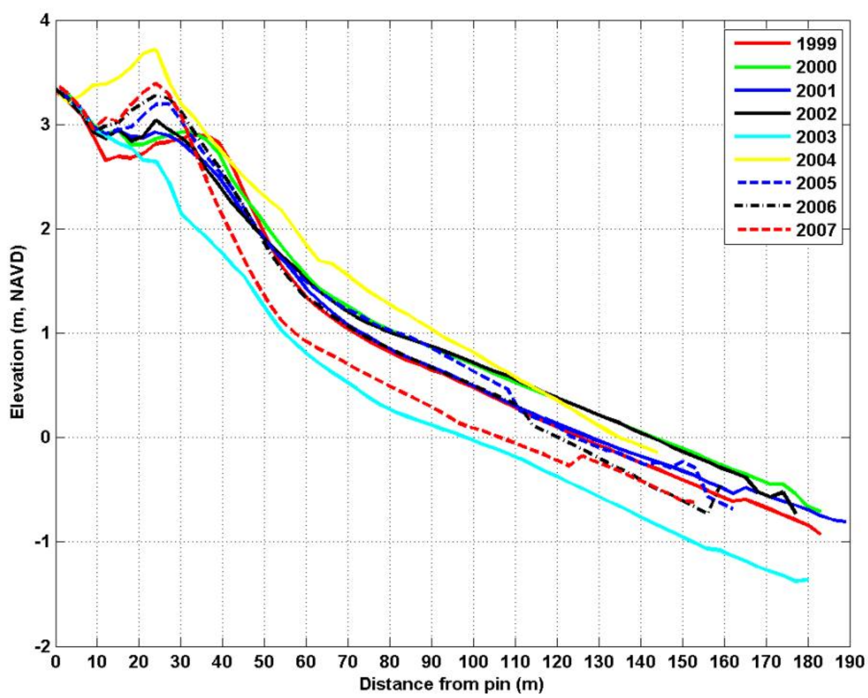

Figure 51. Profiles at EG2 are similar to EG1 and document a net trend of dune growth and profile buildup from 1999 to 2006. Erosional episodes in 2003-2004 and 2006-2007 mark the lowest levels of the beach over 8 years. Recovery after 2004 was to previous levels.

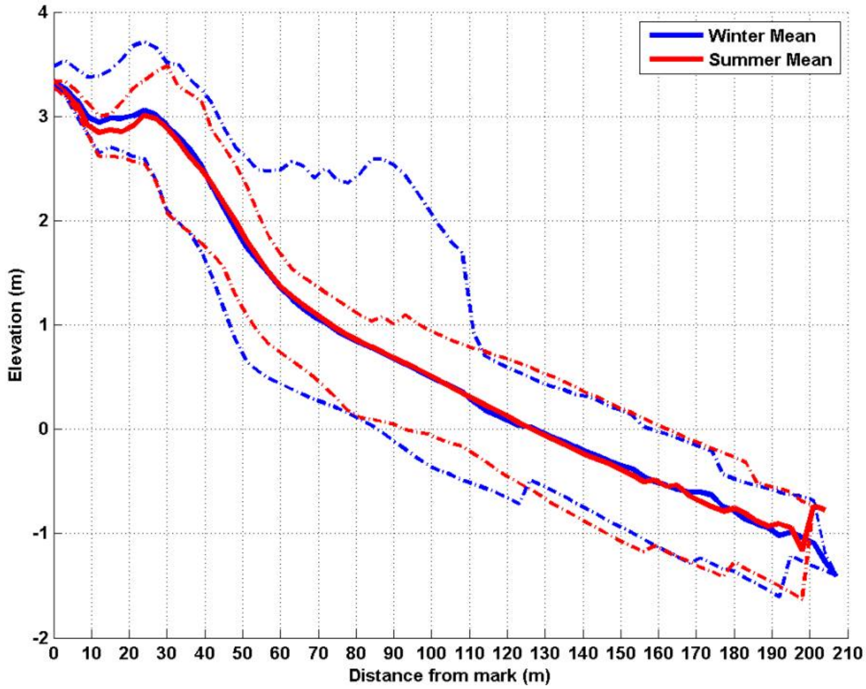

Figure 52. The winter and summer mean profiles at EG2 are very similar and mimic EG1. The winter envelope shows greater change than the summer envelope.

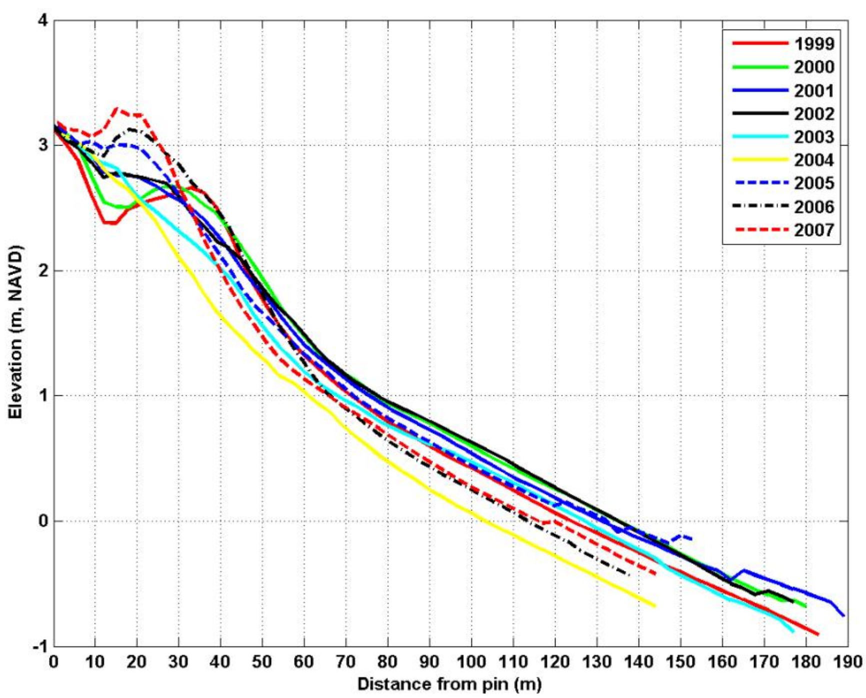

Figure 53. EG3 also exhibits landward dune crest movement while it built to a higher elevation. The greatest changes were in the dune rather than on the beach.

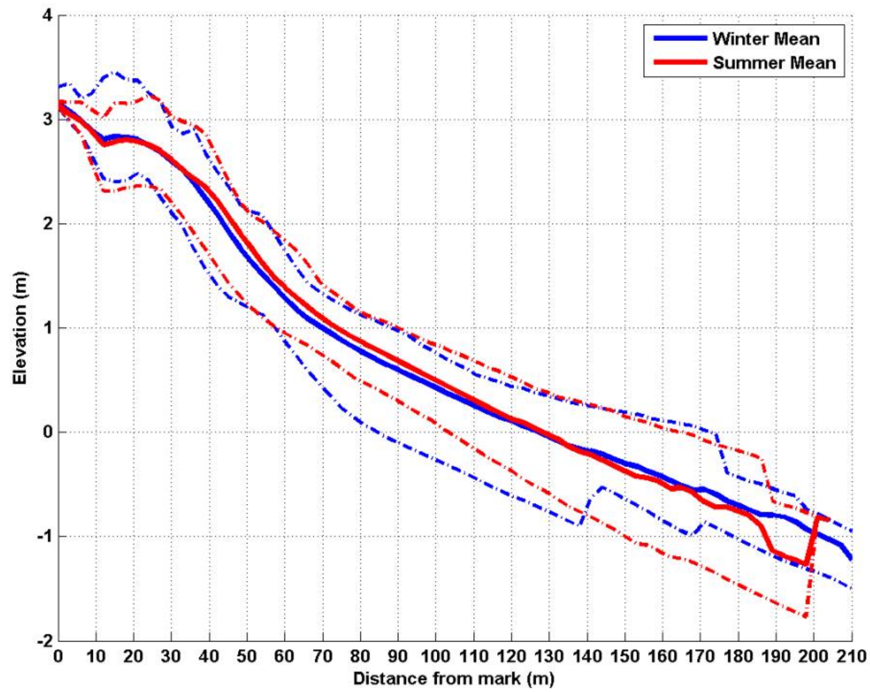

Figure 54. Seasonal means at EG3 are similar to one another and both show little difference in the envelopes of all the profile data.

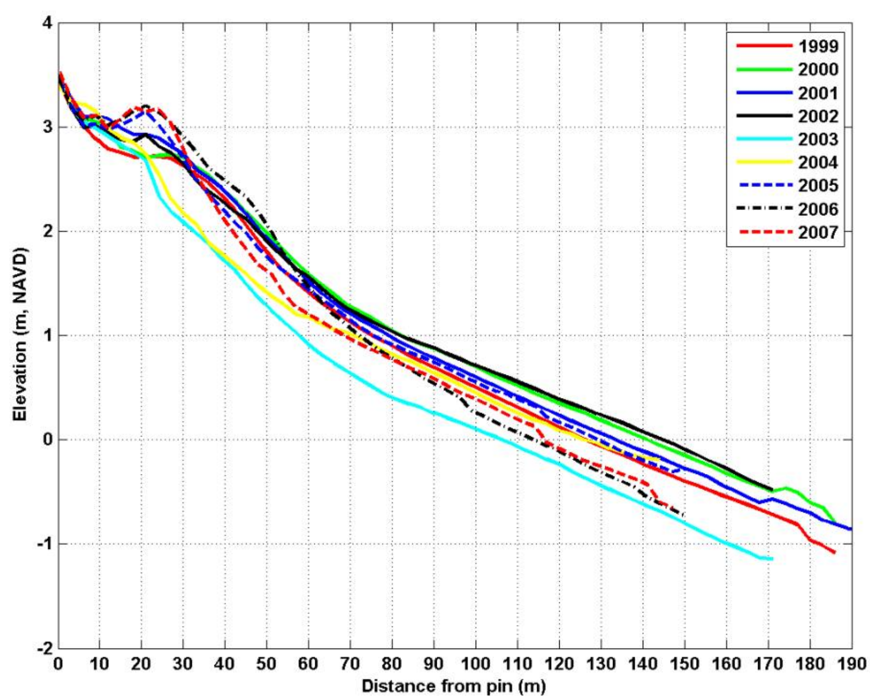

Figure 55. At EG4 the data also support a landward movement of the dune ridge. Being farther south, the ridge is smaller and not as well defined as it is to the north. Here also, 2003 and 2004 were lean years on the profile. In 2007 the data do not show as much erosion (relative to earlier years) as the profiles farther to the north (EG1-EG3).

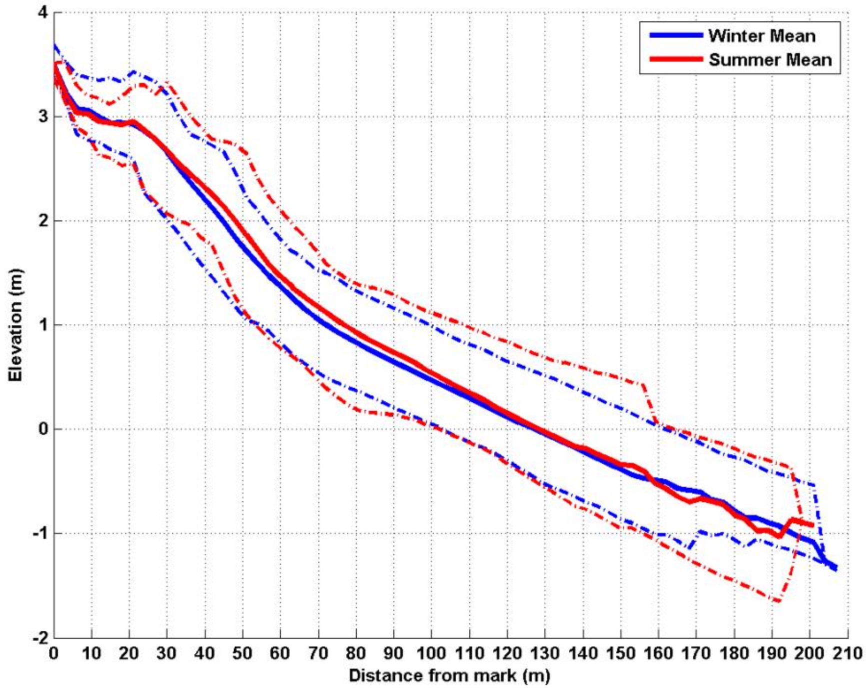

Figure 56. As at the other EG profile sites, the winter and summer mean profiles at EG4 are very similar. This location shows a slight tendency to have a little more sand on the profile in the summer season.

Kinney Shores, Saco

Background geology and characteristics

The beaches of Kinney Shores are part of a north-south trending barrier spit that constitutes the northern end of the southern barrier complex in Saco Bay, terminating at Goosefare Brook. The shoreline along this stretch is considered to be somewhat stable to slightly erosive. Areas of shoreline stability may relate to nearshore outcrops that develop salients and help dissipate wave energy (Slovinsky and Dickson, 2003). Field research and inspection of aerial photographs have located relict sand spits in the Goosefare Brook marsh system (Farrell, 1972; van Heteren and others, 1996). These features represent past shoreline positions and a seaward progradation of the shoreline. Historical aerial photos indicate that Goosefare Brook was unstable, and at one point its main channel was located farther to the south.

Kinney Shores has 2 measured beach profiles, KS1 and KS2. KS1 is located within the dune just south of the southern terminus of Oceanside Drive. KS2 is located in Bayview, at the top of a seawall east of Shore Avenue (**Figure 57**). The starting points were surveyed by MGS in June 2006.

Annual and seasonal beach profile changes

Beach profiles at Kinney Shores start within a seawall (KS1) and behind the frontal dune crest (KS2). Kinney Shores beach profile data include the years from 1999 to 2007. Annualized mean profile data for KS1 (**Figure 58**) indicate that the beach underwent berm accretion from 1999 to 2005, with the fullest berm in 2005, then erosion from 2005-2007, though there was slightly more sediment on the upper portion of the profile (between 2.5 and 4 m in elevation) in 2006. Seasonal data at KS1 (**Figure 59**) indicate a slightly more voluminous berm for the summer mean profile, and slightly more sediment stored farther offshore (between 0 and 1 m) for the winter mean profile. Based on standard deviation data (**Figure 60a**), the berm also appears to be in slightly different locations from summer to winter; in summer, the berm varies by about 60 cm, with its crest at the 30 m mark. In winter, the berm varies vertically around 55 cm, with its crest at the 25 m mark.

Similar to KS1, KS2 annualized data (**Figure 61**) showed general accretion, though it appears that the accretion continued from 1999 through 2006, with loss of the berm and volume along the profile between 2006-2007; this most likely is attributable to the influence of the winter data of 2007. KS2 seasonal data (**Figure 62**), like that of KS1, show a more inflated berm for the summer mean compared to the winter mean profile, and again, more sediment stored farther offshore for the winter mean profile. The berm at KS2 has greater vertical variability; standard deviation values are around 80 cm during the summer and about 65 cm during the winter (**Figure 60b**). The berm's horizontal location appears relatively stable, at about 40 m from the pin.

Profiles at Kinney Shores appear to be stable to accretive, and undergo typical seasonal changes.

Figure 57. Kinney Shores has 2 measured beach profiles, KS1 and KS2. KS1 is located within the dune just south of the southern terminus of Oceanside Drive. KS2 is located in Bayview, at the top of a seawall east of Shore Avenue.

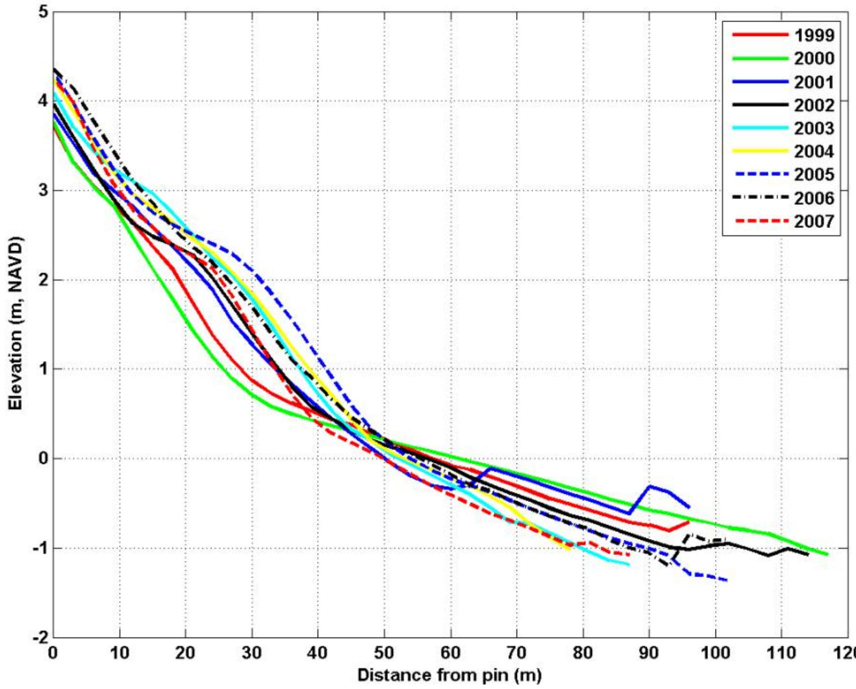

Figure 58. Kinney Shores profile KS1 starts at a seawall and has a long and complete series of data from 1999 to 2007. Average annual profiles show 1999 and 2000 as the lowest years and 2005 a relatively high year in terms of beach and berm elevation. From 2005 to 2007 the beach has experienced erosion.

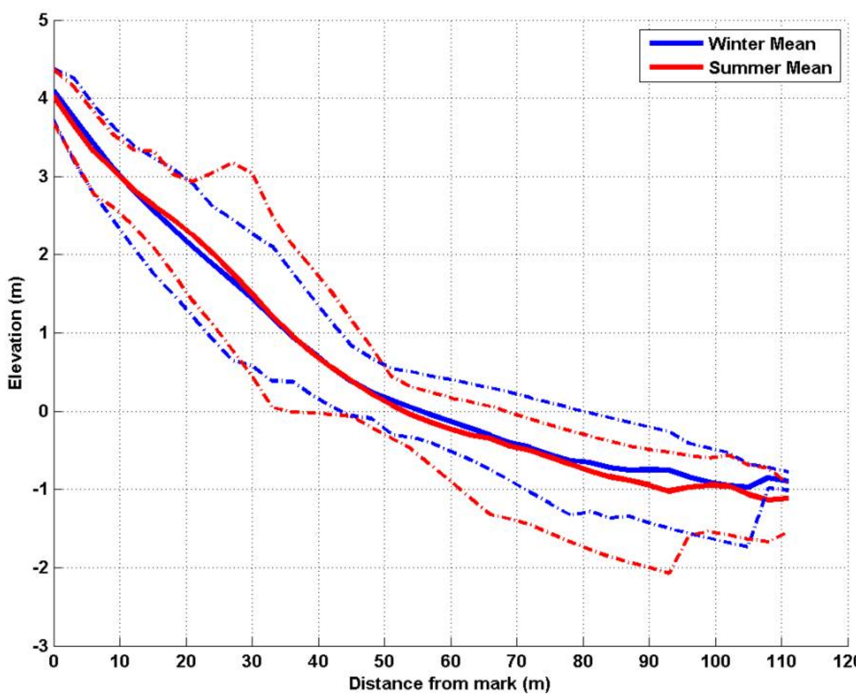

Figure 59. Seasonal differences in the KS1 profile are minimal as shown by the average winter and average summer profile positions. As expected, the summer berm (around 20-30 m distance) shows a slightly higher mean and a higher elevation in the envelope of profiles than in the winter.

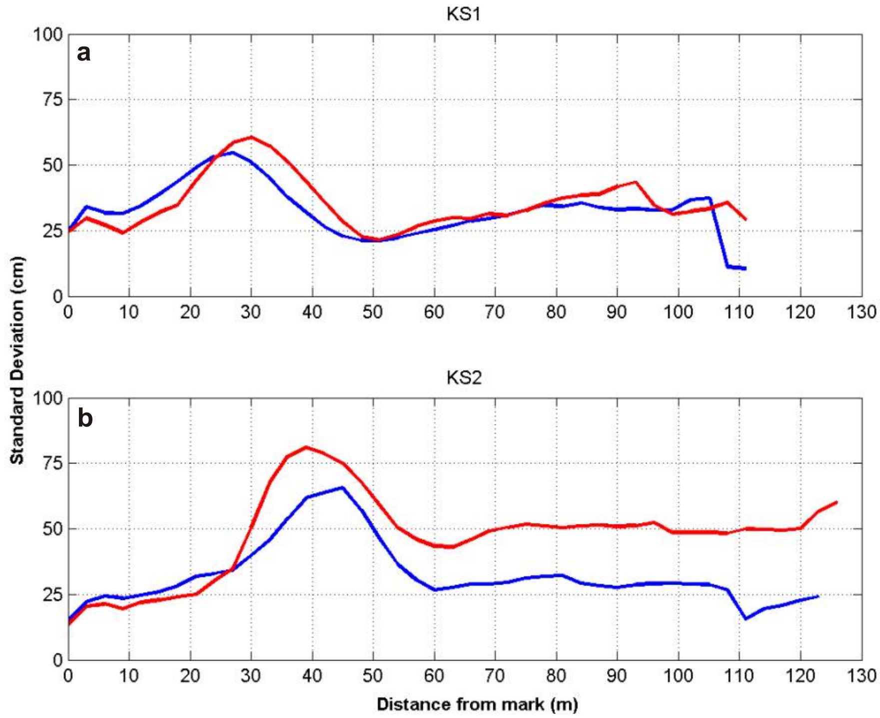

Figure 60. (a) Standard deviation data for KS1 show the variability associated with the berm to be slightly farther seaward in summer than in winter. This is consistent with summer growth in the berm. (b) Data at KS2 show summer variability across the profile line from the berm position seaward is greater than that in winter. Compared to KS1, the berm elevation changes more.

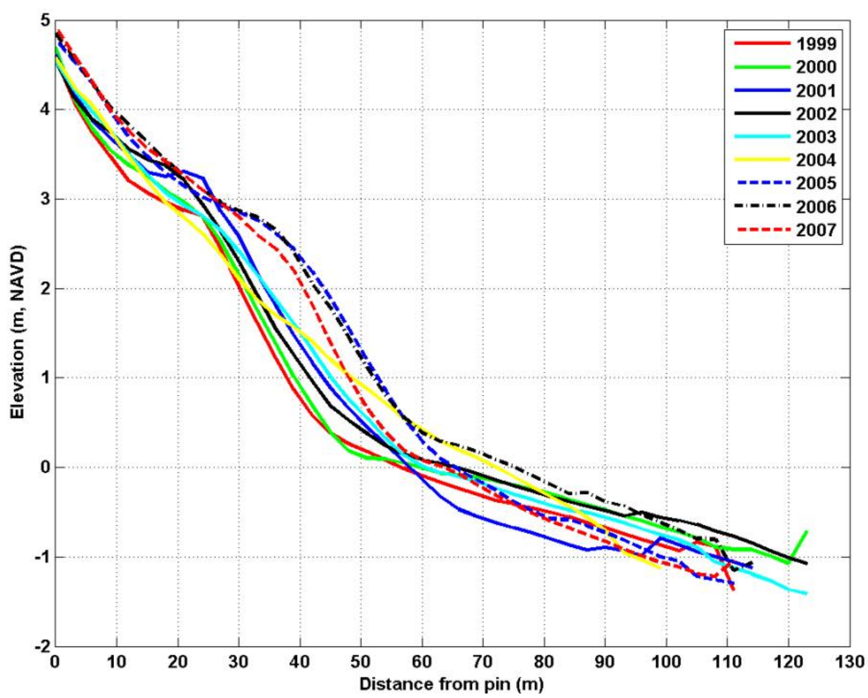

Figure 61. Kinney Shores profile KS2 starts in a dune and average annual profiles show general accretion from 1999 to 2006. From 2006 to 2007 shows some loss of the berm and a lowering of the low-tide terrace on the outer profile.

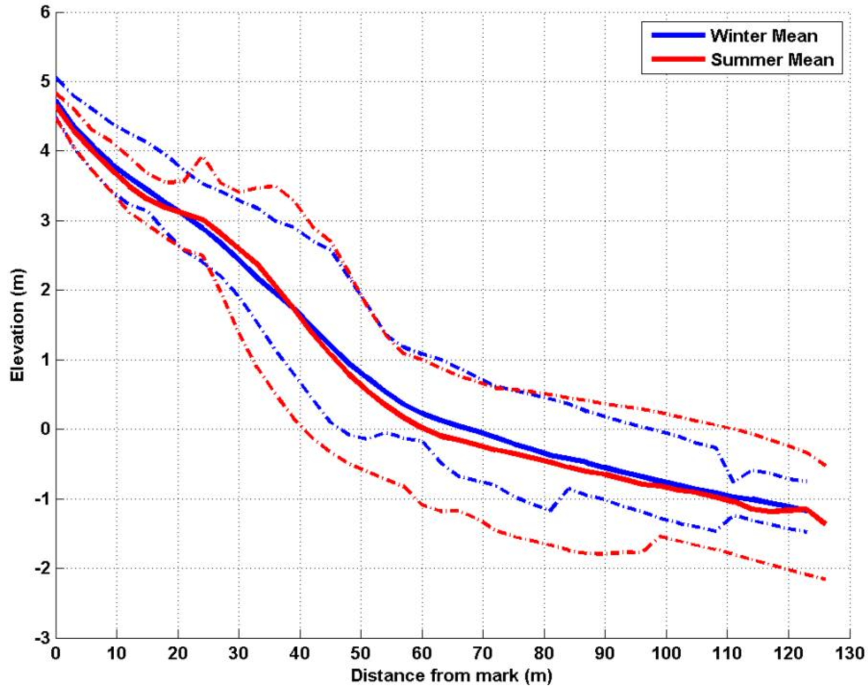

Figure 62. At KS2 the summer profile has a slightly larger berm and variability at the berm location than the winter profile. Both winter and summer profiles are generally alike. As expected, the winter profile is slightly straighter compared to the summer profile.

Ferry Beach, Saco

Background geology and characteristics

The beaches of Ferry Beach and Camp Ellis are part of a north-south trending barrier spit that constitutes the southern barrier complex in Saco Bay, terminating at the Saco River. The shoreline along this stretch is highly erosive at the southern end. Areas of shoreline stability may relate to nearshore outcrops that develop salients and help dissipate wave energy (Slovinsky and Dickson, 2003). Ferry Beach and severely eroding Camp Ellis make up the southern extent of the Saco barrier in the south. Ferry Beach and Camp Ellis Beach are located adjacent to the northern jetty of the Saco River.

The Saco River, stabilized in 1865, historically provided the majority of sediment to the bay (Kelley and others, 1995; Kelley and others, 2005; Slovinsky and Dickson, 2003). Directly after stabilization by the construction of jetties on both sides of the inlet, the shorelines adjacent to the Saco River prograded in response to ebb tidal shoal abandonment, until about 1900 (U.S. Army Corps of Engineers, 1955). After this time, the shoreline has continued to erode due to a decrease in available sediment to adjacent beaches caused by jetty construction and damming, wave reflection and propagation wave effects along the northern jetty, diversion of available sediment farther offshore by the jetties, and the construction of seawalls along the majority of Camp Ellis Beach (Slovinsky and Dickson, 2003). Ferry Beach appears to be eroding, on average, about 0.3 meters (1 foot) per year, with the limits of erosion extending approximately 1,800 meters (6,000 feet) north of the jetty.

Ferry Beach has 4 measured beach profiles, FE1-FE4, with various different locations (i.e., front stake and back stake) for each due to the instability of the shoreline. The profiles are clustered within the dune system on the north (FE1 and FE2) and south (FE3 and FE4) sides of Ferry Park Avenue, near the Ferry Beach Ecology School (**Figure 63**). The starting points were surveyed by MGS as located in the field in June 2006.

Annual and seasonal beach profile changes

The beach profiles at Ferry Beach all start landward of the frontal dune crest. However, Ferry Beach faces acute erosion problems; thus, the beach profile starting point locations have changed numerous times since data collection began, making a set elevation and contiguous analysis much more difficult. Thus, at this point, none of the surveyed elevations have been applied to the data. Data available from the website were also sporadic, with numerous years missing.

Profile FE1 was broken down into FE11 and FE12. FE11 contains data from 2000, 2001, 2003, and 2005, while FE12 has data from 2001-2003; there may be additional beginning points as well. It is extremely difficult to ascertain overall changes at FE11, since it appears that the starting point in 2000-2001 (a front stake) was different than those for 2003 and 2005 (a back stake). There appears to have been slight erosion of the profile between 2000-2001, and more substantial sediment loss and subsequent landward dune migration and slight elevation loss between 2003-2005 (**Figure 64**). Due to the number of changes in the benchmarks of the starting points, seasonal changes were not analyzed at FE11.

Annualized data for FE12 (**Figure 65**) showed loss of sediment along the profile from 2001-2002, and then loss of dune between 2002-2003, with the addition of sediment along the offshore portion of the profile (between 8 m and 40 m from the mark). No seasonal or standard deviation data were developed for FE12 due to the inability to relate the number of benchmarks used accurately with the data.

Similar to FE1, profiles at FE2 were collected at several different starting points, a front stake (FS) and a back stake (BS), during different years of data collection. The beach at FE2FS (**Figure 66**) saw general accretion from 2000-2002, then substantial accretion from 2002-2003 (or possibly the starting point changed). From 2003-2005, the entire profile lost elevation. Seasonal profiles (**Figure 67**) indicate little difference between the summer and winter profiles or their envelopes. Standard deviation data (**Figure 68a**) indicate that the winter and summer beach at FE2FS is quite variable during both seasons, varying between 50-75 cm vertically along a large portion of the profile (between 10-50 m from the mark).

The profiles at FE2BS, which were collected from 2005-2007, indicate that the beach underwent little change from 2005-2006 overall; however, in 2007, the dune was eroded by several meters, though there was slight accretion along the berm portion of the profile, between 35 and 55 m from the mark (**Figure 69**). Seasonal data indicate that there is generally a higher, more developed and stable frontal dune crest in the summer, while the crest is lower and more variable in the winter (**Figure 70**). During the summer, a slightly more prominent berm appears. Standard deviation data indicate that there is relatively little variability in the summer profile elevations, with only slightly more variability in the winter at the dune crest, and farther offshore, up to 40 cm of vertical variability (**Figure 68b**).

At FE3FS, the profile underwent accretion from 2000-2001, stability from 2001-2002, large amounts of accretion from 2002-2003 (unless the starting point changed), and slight erosion from 2003-2005 (**Figure 71**). The erosion was concentrated at the dune and lower portions of the profile, from 15 m from the starting mark and greater. Seasonally, the winter profile shows a slightly better developed dune, and more sediment storage in the offshore (**Figure 72**). There does not appear to be much of a berm in either season. Seasonal variability, based on the standard deviation data (**Figure 68c**), indicates that the beach undergoes relatively major changes in both the winter and

Figure 63. Ferry Beach has 4 measured beach profiles, FE1-FE4, with various different locations (i.e., front stake and back stake) for each due to the instability of the shoreline. The profiles are clustered within the dune system on the north (FE1 and FE2) and south (FE3 and FE4) sides of Ferry Park Avenue, near the Ferry Beach Ecology School.

the summer, in the dune area (on the order of 50 cm), and into the offshore, up to about 75 cm of vertical variability, especially in the winter. This may be indicated by the erosive nature of the beach during the winter season.

Annualized profiles at FE3BS were collected from 2005-2007. The beach underwent slight accretion at the dune between 2005-2006, and then loss of dune elevation on the order of 0.5 m from 2006-2007 (**Figure 73**). The portions of the profiles farther offshore seem to have changed little. The winter and summer mean profiles are about the same, though slightly more volume of sediment appears in the berm area of the profile in the summer mean profile (**Figure 74**). Standard deviation data (**Figure 68d**) indicate that the summer beach is relatively stable, with variations less than 20 cm along the profile. Winter variability is markedly increased at the dune (changes above 40 cm), and in the offshore, where variations are also on the order of 40 cm. This may indicate that erosion of the dune during winter leads to offshore storage of sediment during the same time period.

Profile FE4 had several different benchmarks over the years, the first from 2000-2003 (labeled as FE4FS), and the second from 2005-2007 (labeled as FE4BS). Annualized mean data for FE4FS (**Figure 75**) show that the beach underwent accretion from 2000-2001; this accretion continued in 2002. In 2003, the dune and berm underwent erosion from the dune to about the 20 m mark, and accretion occurred seaward of this. Seasonally, FE4FS (**Figure 76**) displayed more sediment in the dune and the berm in the summer than the winter. According to standard deviation data (**Figure 68e**), the summer profile exhibits greater variability, up to almost 75 cm at the location of the berm.

Data for the beach at FE4BS (data from 2005-2007) showed that the dune and beach underwent dramatic erosion complete loss of the frontal dune crest and its elevation, from 2005 to 2006 (**Figure 77**). This erosion was approximately 4-5 m horizontally and almost 0.5 m vertically. This was likely due to the May 2005 northeast storm. Analysis of seasonal data (**Figure 78**) and standard deviation data (**Figure 68f**) for FE4BS shows that the summer profile varies very little, while the winter profile varies greatly (up to 100 cm) in dune elevation and position and along the profile.

The profiles at Ferry Beach exhibit a marked difference seasonally; summer typically tends to see a slightly more developed dune crest and berm, while winter shows an erosive profile, with substantial loss in the frontal dune and berm, with little recovery to pre-winter conditions (though it appears a new summer shape follows the next season. This area is heavily eroded during winter storm events, with dune removal on the order of 3 to 6 meters (10-20 feet) during substantial events (i.e., 2005 northeasters and Patriots' Day storm). The fact that profile starting locations have been moved so many times is indicative of the erosive nature of this stretch of beach.

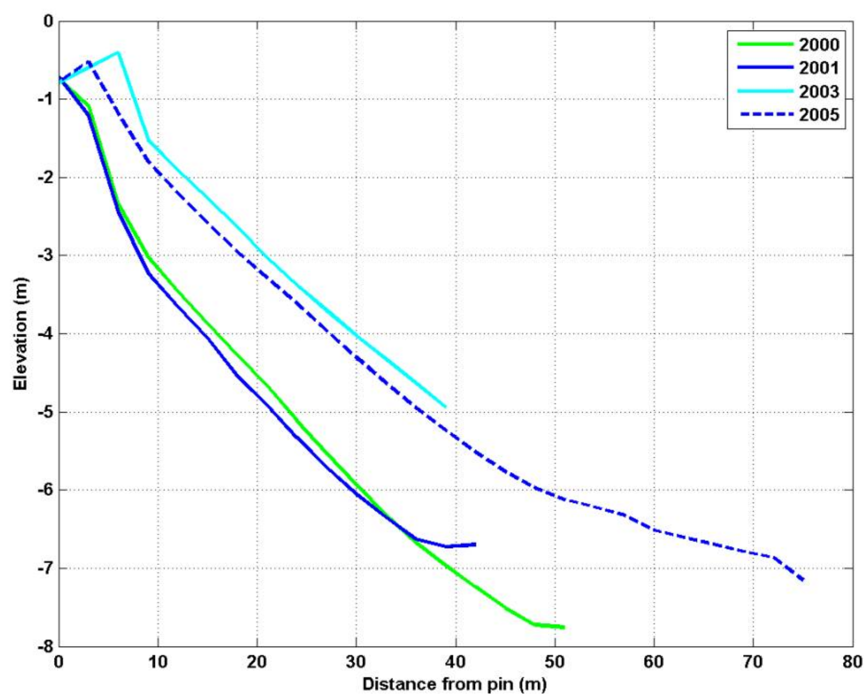

Figure 64. Annual profiles at FE11 include two separated data sets due to relocation of the starting pin. From 2000 to 2001 the beach lost sand across the entire profile. In the second interval, 2003 to 2005 more sand was lost resulting in a landward shift of 0.2 to 0.3 m horizontally. Due to different starting points, seasonal changes were not calculated at FE11.

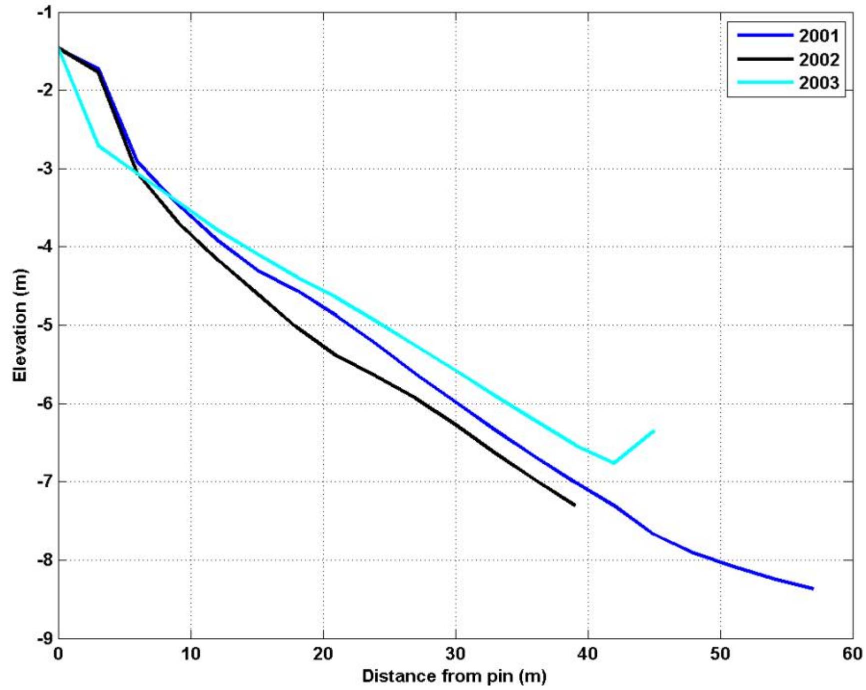

Figure 65. Annual profiles at FE12 from 2001 to 2003 (the interval of years missing in the previous graph). Sand was lost off the profile from 2001 to 2002 and the dune experienced a loss from 2002 to 2003 while the offshore profile built up.

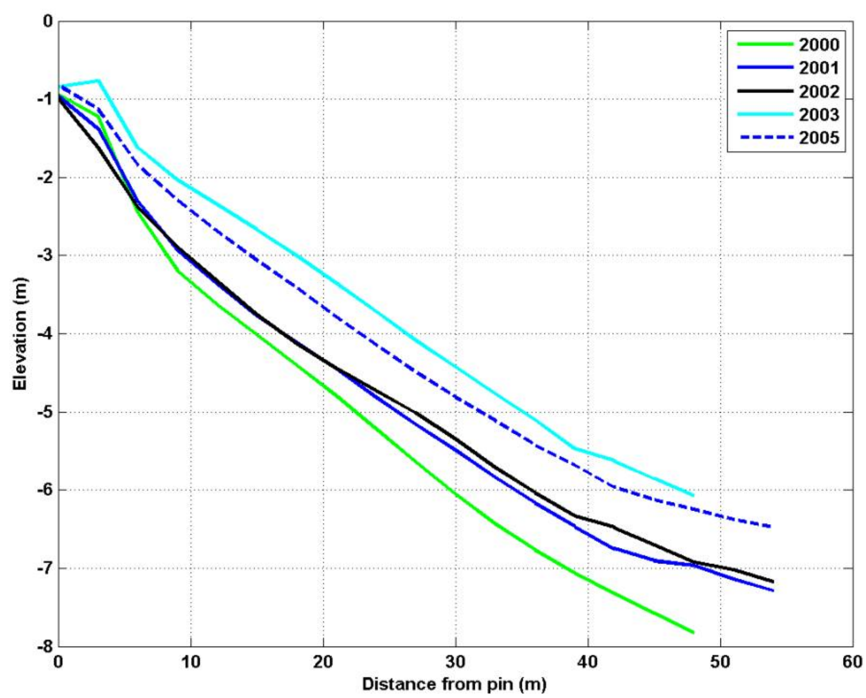

Figure 66. Annual profiles at FE2FS saw general accretion from 2000 to 2002 with either more accretion or a new starting point by 2003. Erosion with a vertical loss of about 0.5 m dominated the profile from 2003 to 2005.

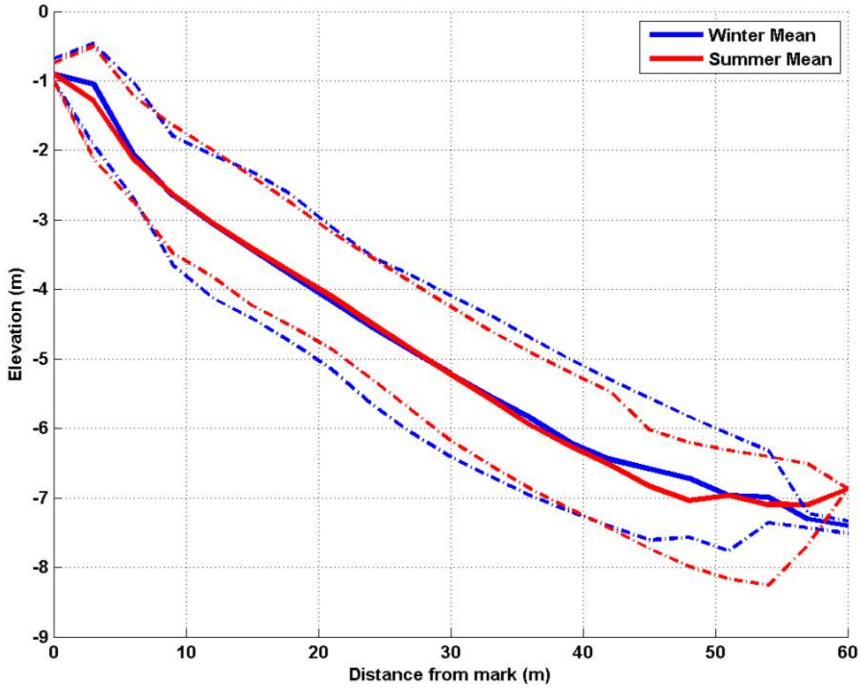

Figure 67. Seasonal profile shapes at FE2FS are very similar from winter to summer with a steep, rather linear beach and similar envelopes of maximum and minimum profile elevations.

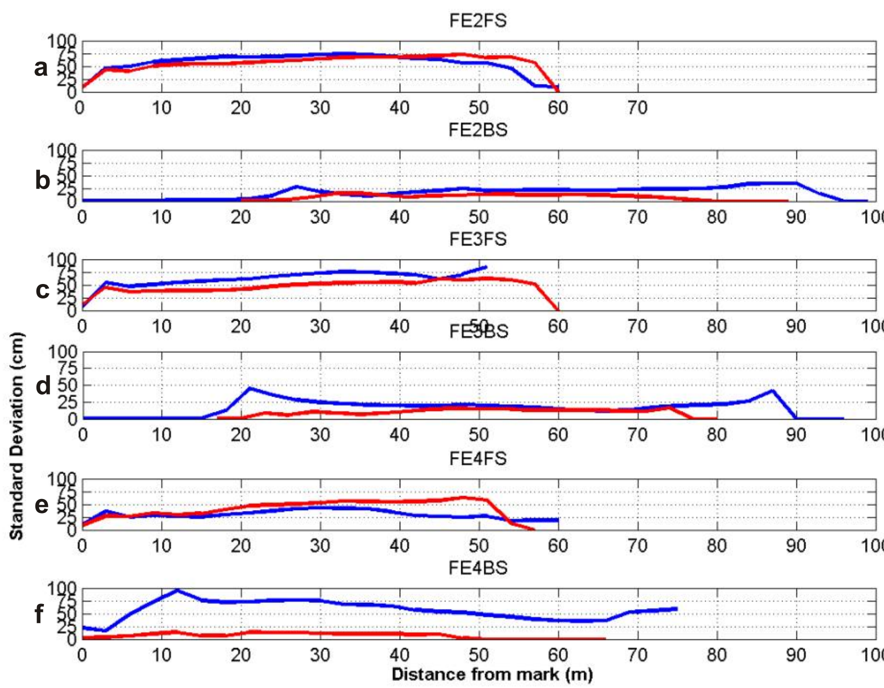

Figure 68. Standard deviation data at FE2FS (a) show 0.5 to 0.75 m of vertical variability in both summer and winter seasons. At FE2BS (b) the summer-winter variability is smaller than for FE2FS but the winter dune crest elevations show slightly more variability than in summer. Standard deviation data at FE3FS (c) show a 0.5-0.75 m change in winter beach elevation, slightly more than in summer. At FE3BS (d) the summer beach appears to vary little in elevation while the winter beach exhibits about 0.4 m of variability in the dune and offshore portions of the profile. The greatest variability at FE4FS was in the berm area during winter (e). Standard deviation data at FE4BS (f) show elevation changes on the order of 0.2 to 0.4 m. in both winter and summer seasons.

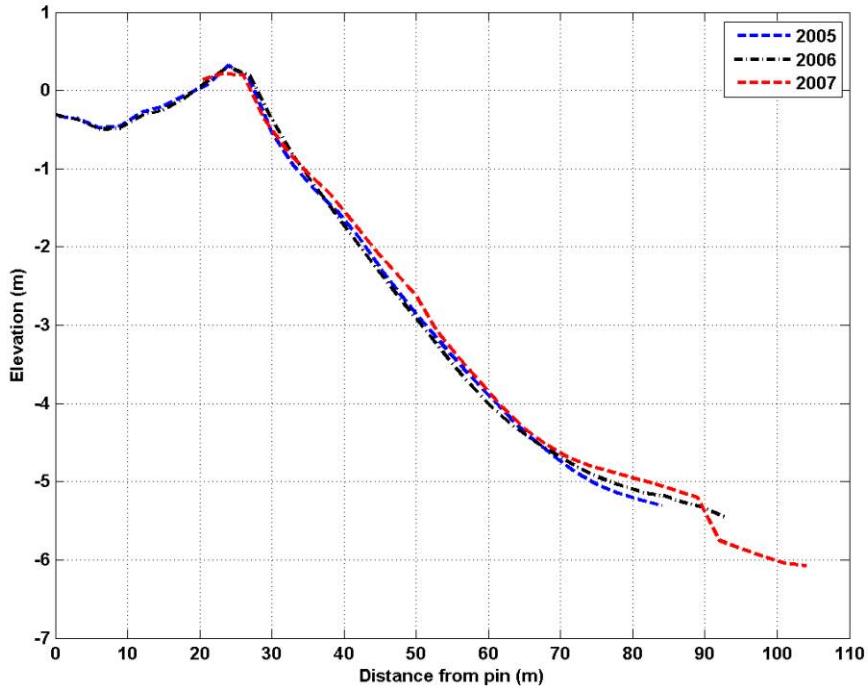

Figure 69. Annual profiles at FE2BS show a generally higher and more stable frontal dune. From 2005 to 2007 the beach was relatively stable. In 2007 the dune eroded and the berm gained a small amount.

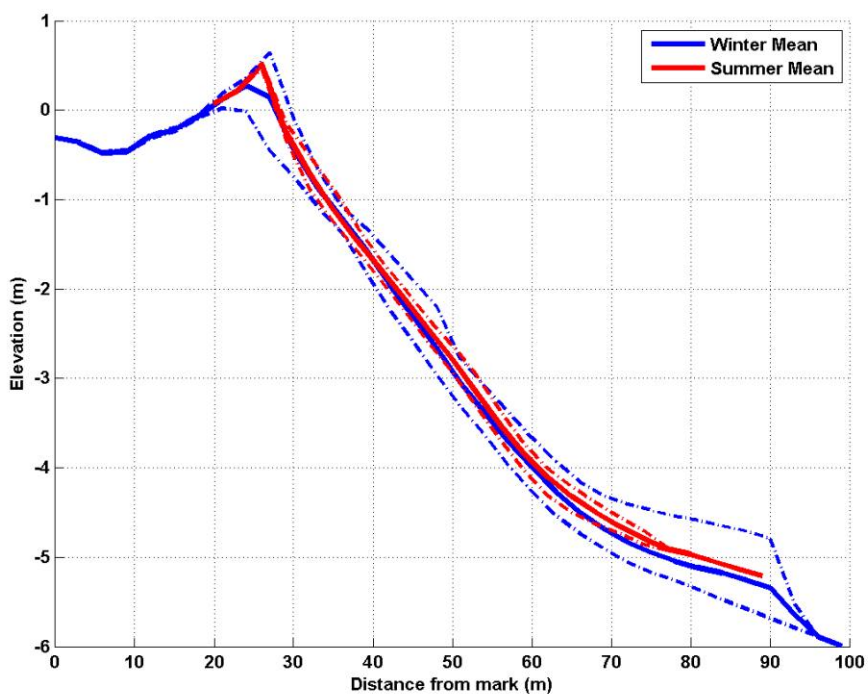

Figure 70. Seasonal profile shapes at FE2BS show generally similar winter and summer beach conditions. A higher frontal dune crest can exist in summer and the crest becomes more variable in elevation in the winter.

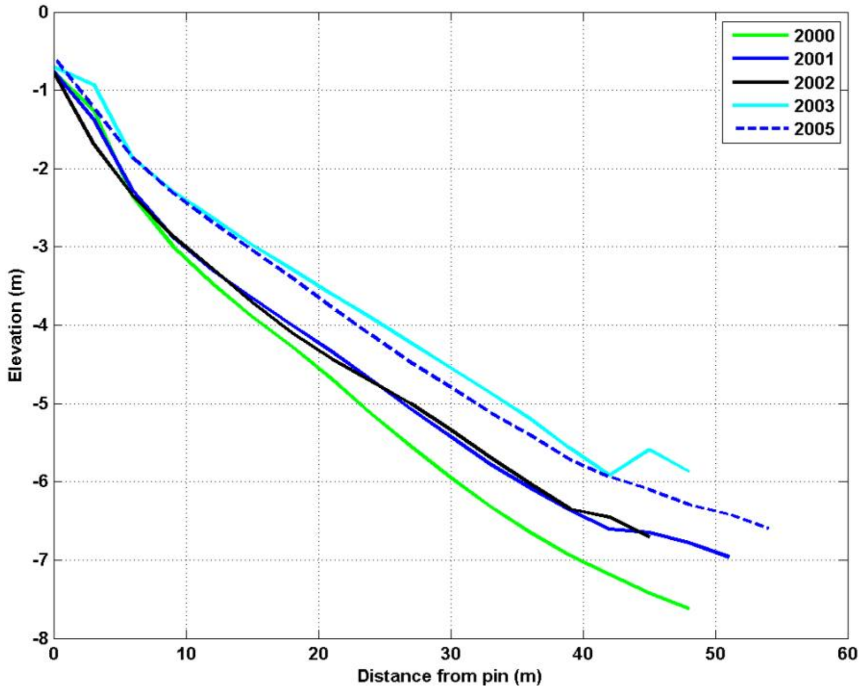

Figure 71. Annual profiles at FE3FS experienced accretion from 2000 to 2001 and stability from 2001 to 2002. The growth in 2003 is likely an artifact of a new starting location. From 2003 to 2005 the profile eroded, particularly on the lower half.

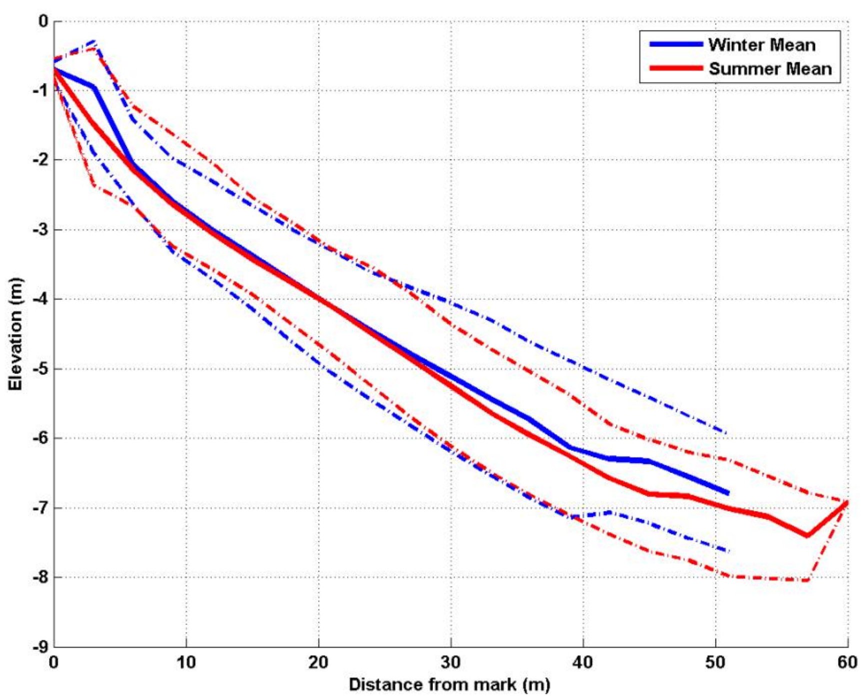

Figure 72. Winter and summer mean profiles at FE3FS are similar through the middle section but show a better developed dune in winter and winter sand storage offshore.

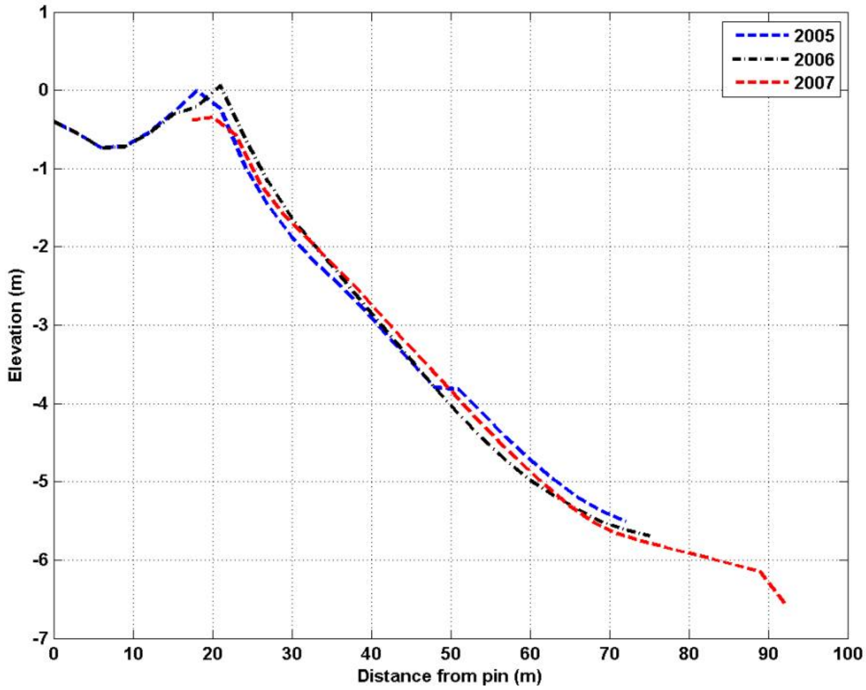

Figure 73. Annual profiles at FE3BS from 2005 to 2007 show slight dune accretion from 2005 to 2006 and then dune lowering of 0.5 m by 2007. The outer profiles are generally similar in shape over the 3 years.

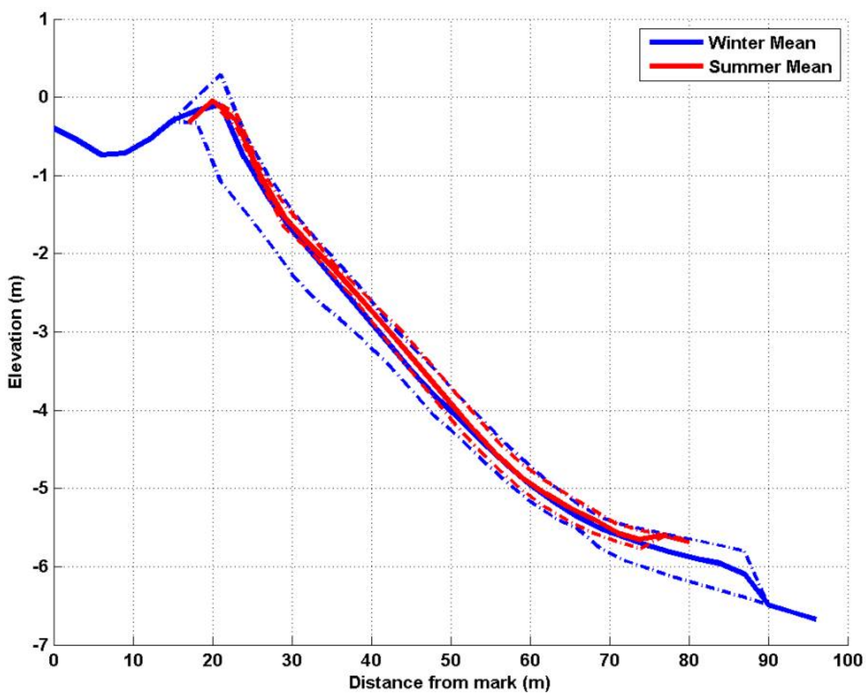

Figure 74. Seasonal mean profiles at FE3BS are very similar with a little more sand in the summer berm area. The envelope of profile variation is very tight in both winter and summer.

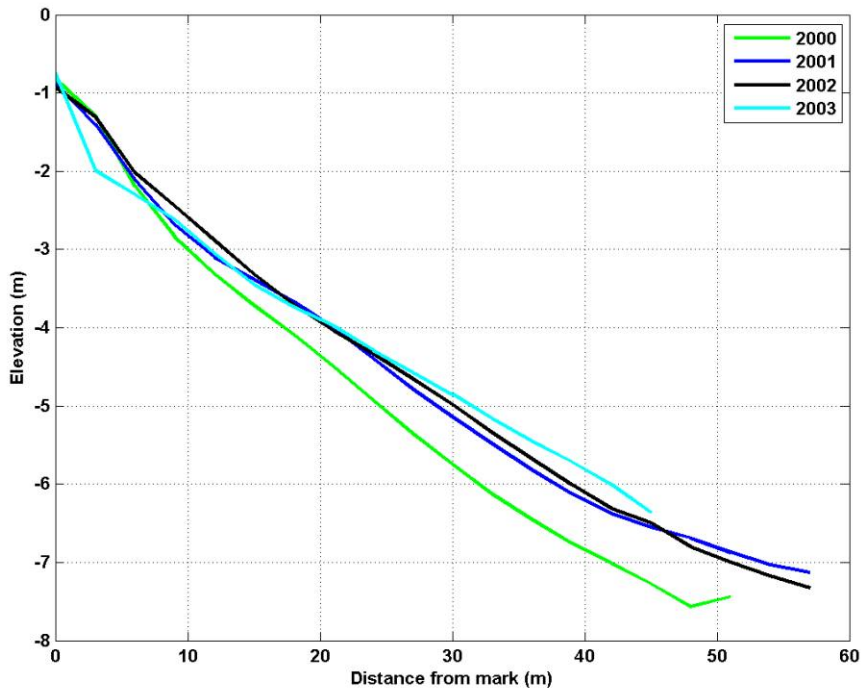

Figure 75. Annual profile data at FE4FS show general accretion from 2000 to 2002. In 2003 the dune and berm experienced net sand loss while there was some sand gain on the outer profile in this interval of time.

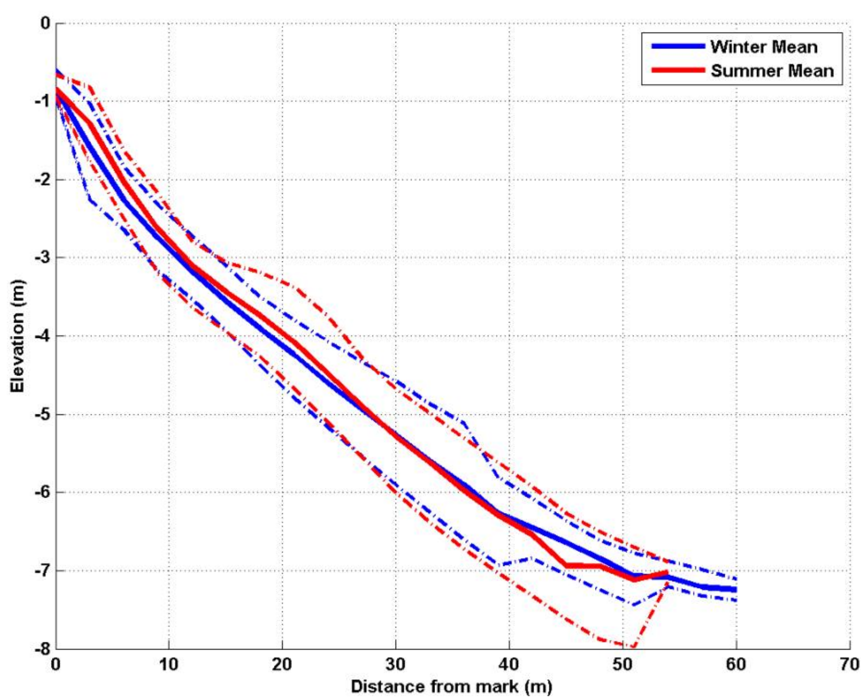

Figure 76. At FE4FS the dune had more sand in the summer than in the winter, contrary to some of the other nearby locations.

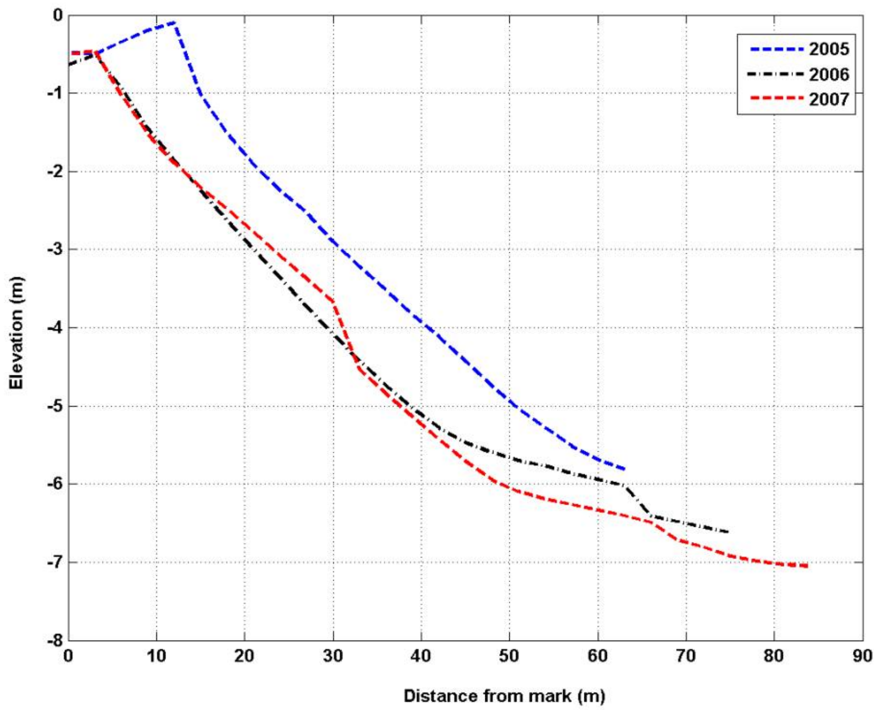

Figure 77. Annual beach profiles from 2005 to 2006 at FE4BS show dramatic loss of the frontal dune crest and an overall lowering of the profile's highest elevation. This amounted to a landward shift of the profile of 4 to 5 m and a lowering of the beach by about 0.5 m.

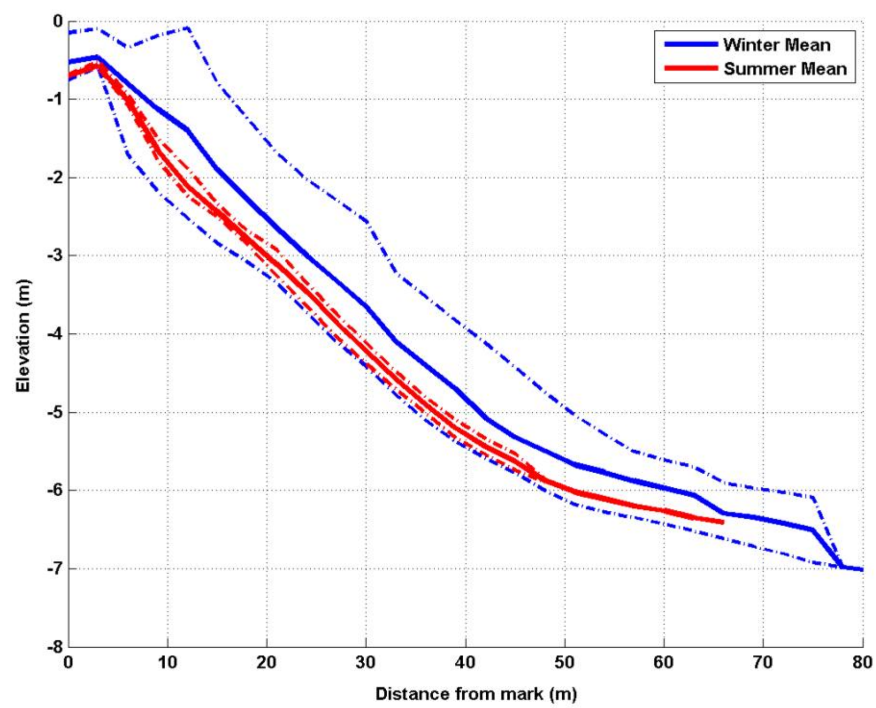

Figure 78. Seasonal data at FE4BS show a higher winter mean with greater winter variability in beach elevation. Summer beach profiles are consistently similar.

Fortunes Rocks Beach, Biddeford

Background geology and characteristics

Fortunes Rocks Beach is located on the southeastern side of Fletcher Neck, part of Biddeford Pool. Biddeford Pool consists of two transgressive barriers that connect bedrock islands to the mainland. Hulmes (1980) documented long-term erosion along Fortunes Rocks and Mile Stretch Beach. Seawalls front most of the southern portion of Fortunes Rocks Beach and, consequently, Nelson (1979) was unable to determine a rate for shoreline change. Along the natural shoreline, Nelson measured recession of about 1.6 feet per year. This beach appears to have chronic sand loss and net shoreline recession and or active seawalls along the frontal dune ridge (Dickson, 2006a).

Fortunes Rocks has 4 measured beach profiles, FR1-FR4. The overall beach is shown in **Figure 79**. The starting marks for the profiles have not been surveyed by MGS as of April 2007.

Annual and seasonal beach profile changes

The beach profiles at Fortunes Rocks Beach start behind the frontal dune crest and also within seawalls. Beach profile data were collected at the Fortunes Rocks locations from 1999-2006. At FR1, annualized changes showed little distinct patterns of general accretion or erosion (**Figure 80**). The beach appeared to be stable from 1999-2001, with accretion from 2001-2002 resulting in the most volumetrically sediment-rich profile in 2002. From 2002-2003, the profile underwent some loss, especially from about 25 m offshore seaward. In 2004, the beach was at its leanest shape. By 2005, the profile was similar in shape to the profile from 2001, with slightly more sediment stored offshore. Some erosion of the upper portion of the profile occurred between 2005-2006. Seasonally, the beach at FR1 (**Figure 81**) shows a typical summer shape, with more sediment stored in the berm area than the winter profile. Standard deviation data (**Figure 82a**) indicate that the berm at FR1 is relatively stable, changing its position laterally little between summer and winter. The berm appears to be positioned at about 30 m from the mark, with vertical variability on the order of 40 cm.

It appears that data collected at FR2 are from two different marks one was used from 1999-2002, and a second (behind the dune) from 2003-2006. The beach at FR2 accreted from 1999-2002, and this trend continued from 2003-2005 (**Figure 83**). In 2006, the dune appears to have been eroded slightly, and the berm appears to have lost much of its sediment volume. On a seasonal basis, FR2 (**Figure 84**) exhibited somewhat similar profile shapes, with slightly more volume of sediment in the berm in the summer profile. The profile envelopes are nearly identical, and the standard deviation values are quite similar as well. The berm, positioned between the 30-40 m marks, appears to vary vertically on the order of about 50 cm (**Figure 82b**).

The beach at FR3 showed steady accretion from 1999-2002, and a well developed berm in 2002. By 2003, the berm had been eroded (**Figure 85**). Erosion continued into 2004. In 2005, slight accretion occurred on the uppermost portion of the profile (between 0 to 2 m below the pin), with sediment loss from about 45 m from the pin seaward. In 2006, the dune appears to have accreted, while there was additional sediment loss in the middle portion (berm) and offshore portions of the profile. Seasonally, FR3 data (**Figure 86**) indicate a more developed berm during the winter rather than the summer, with more slightly more sediment stored offshore in the winter. The winter berm varied vertically by about 60 cm, and was located around the 25 m mark. The summer berm varied only around 40 cm. However, the summer data indicate large amounts of variation on the order of 50-60 cm over a large stretch of the profile in the offshore, between 55 and 120 m from the mark (**Figure 82c**). This may indicate that FR3 sees volumes of sediment pass offshore during the summer months as sediment is moved along the beach.

Data at FR4 indicate that the beach was stable from 1999-2001, then accreted from 2001-2005, with the most volume in the profile in 2005 (**Figure 87**). In 2006, the upper portion of the profile (from about 2 m below the pin and higher) lost sediment, while the remainder of the profile remained relatively stable. Overall, the profile gained sediment from 1999-2006. Seasonal data (**Figure 88**) indicate that the summer profile tends to hold more sediment along the dune and upper portion of the profile, with the winter profile having slightly more sediment volume in the offshore portion. Standard deviations (**Figure 82d**) indicate that there is more variability along the entire profile in the summer (up to 50 cm) than the winter. The berm at this profile is located much closer to the pin (10 m), as opposed to the other profiles along Fortunes Rocks Beach.

Profiles along Fortunes Rocks Beach indicate variability from year to year, but general stability over the time period of data collection. Seasonally, the profiles vary as expected.

Figure 79. Fortunes Rocks has 4 measured beach profiles, FR1-FR4. The starting marks for the profiles have not been surveyed by MGS as of April 2007. The 4 locations are approximately located on the figure.

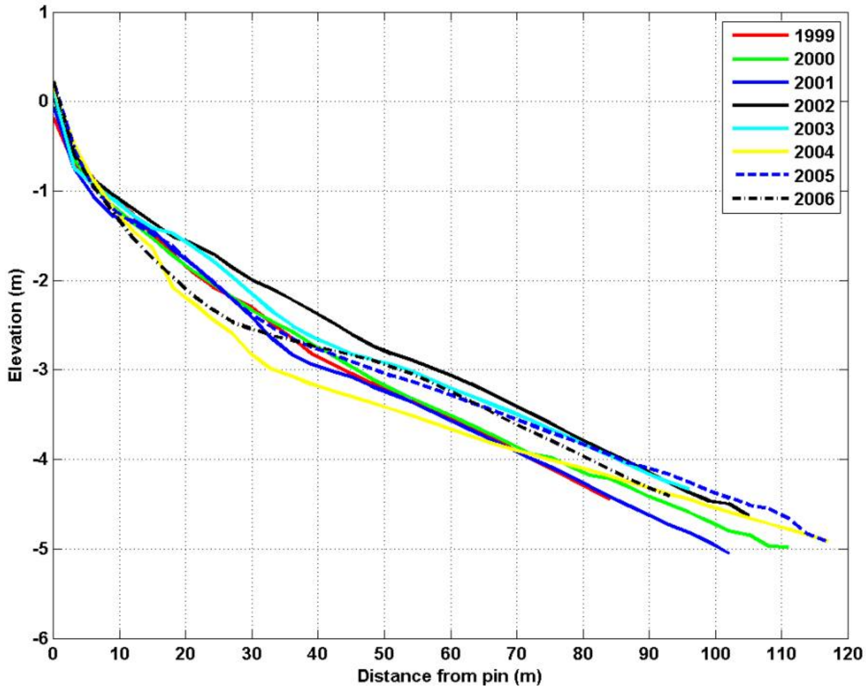

Figure 80. Annual beach profiles at FR1 from 1999 to 2006 show no strong erosion or accretion trends, but annual elevations can be 0.5 to 1 m different from the previous year.

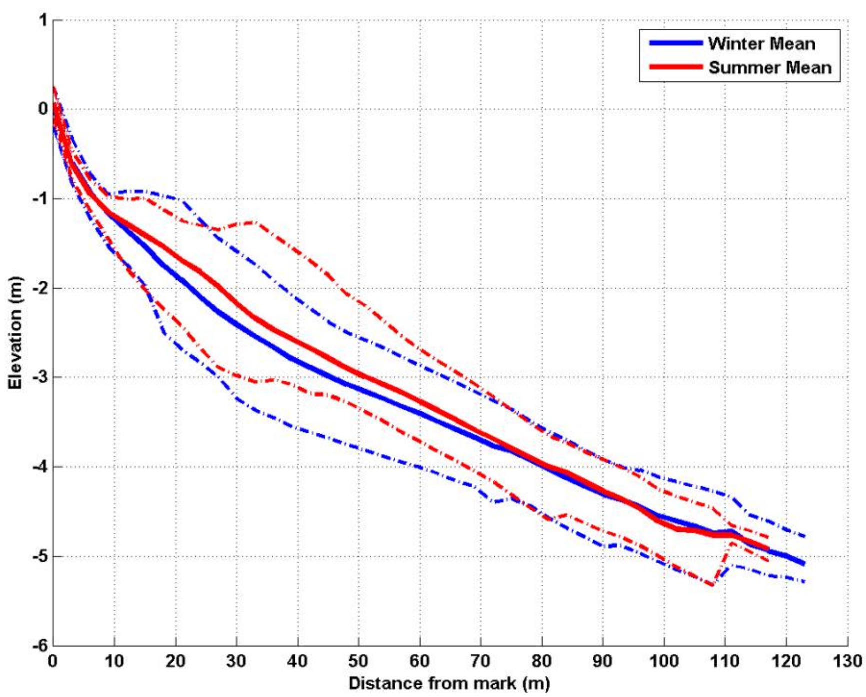

Figure 81. Seasonally, the beach at FR1 shows a typical summer shape with a larger berm than in winter. As expected, the envelopes of maximum and minimum profiles show greater summer variation in beach elevation compared to winter.

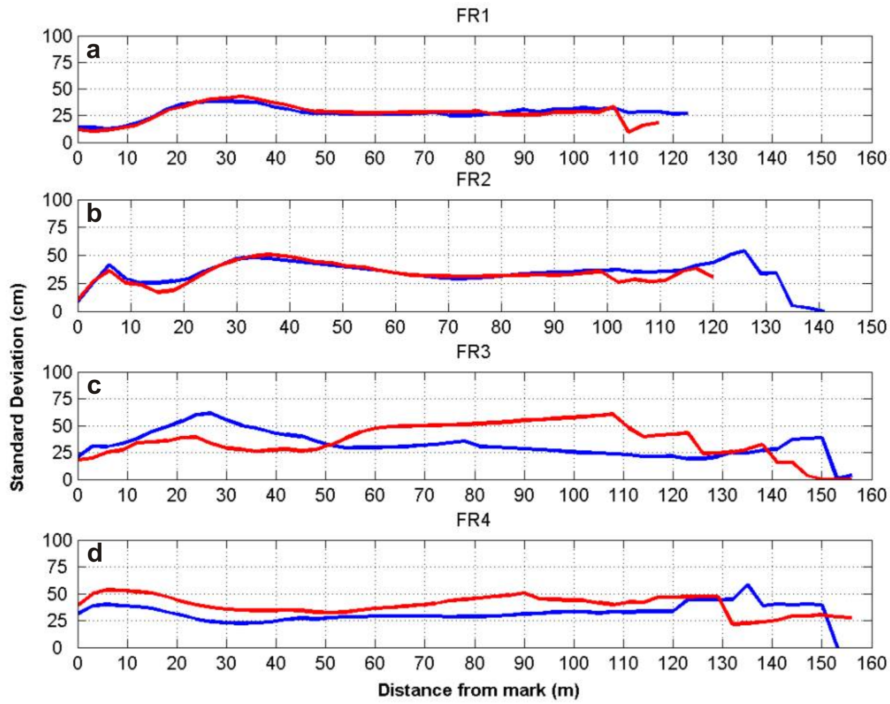

Figure 82. Standard deviation at FR1 (a) shows the berm location is relatively stable from winter to summer. At FR2 (b) the berm elevation varies by some 0.5 m (between 30 and 40 m distance). At FR3 (c), a variable winter berm is apparent, while offshore variability is greater in summer. Data at FR4 (d) show that the summer profile exhibits greater variability along its entire length than the winter profile.

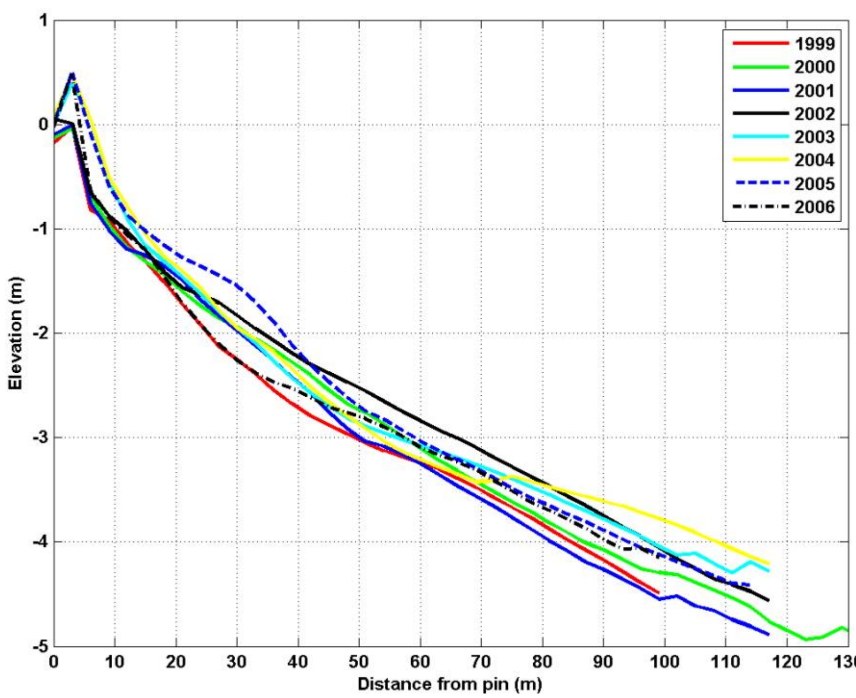

Figure 83. Annual profiles at FR2 suggest one location was used from 1999 to 2002 and another behind the dune crest was used from 2003 to 2006. From 1999 to 2002 the beach accreted and from 2003 to 2005 this trend continued. In 2006 the dune appears to have had some slight erosion.

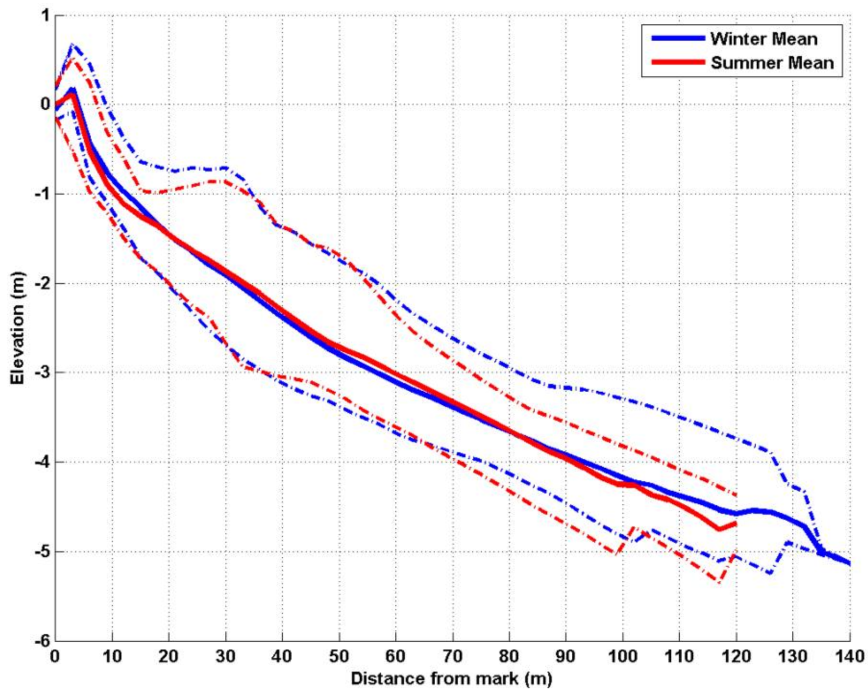

Figure 84. The winter and summer means appear similar overall at FR2 with slightly more sand in the summer berm. The envelopes are very similar also.

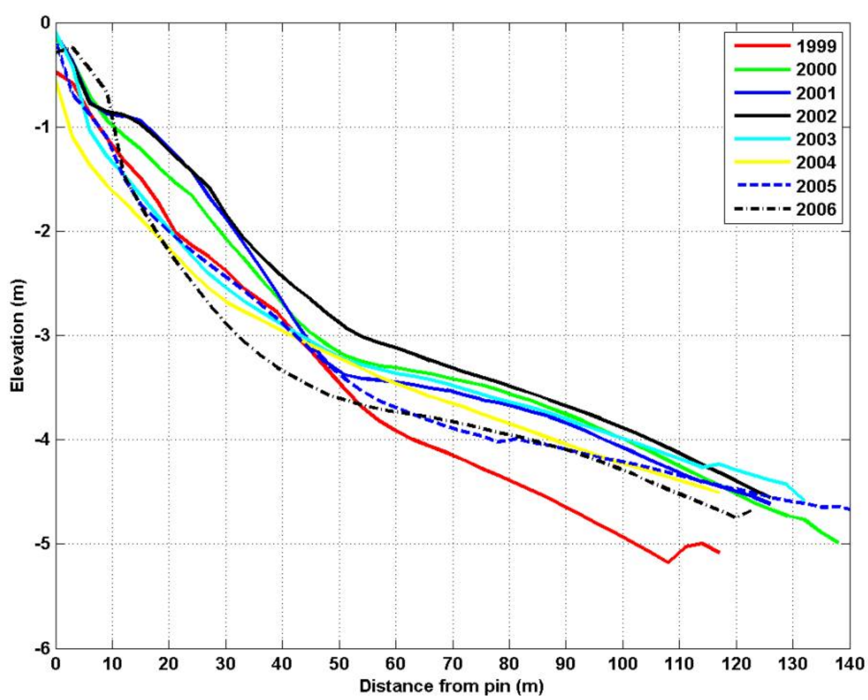

Figure 85. The annual profiles at FR3 show steady accretion from 1999 to 2002. A berm developed in 2002 but was not as large in 2003 and erosion continued into 2004. 2005 had a high berm and 2006 saw more accretion including some 2006 dune growth in the upper profile but loss in the lower profile.

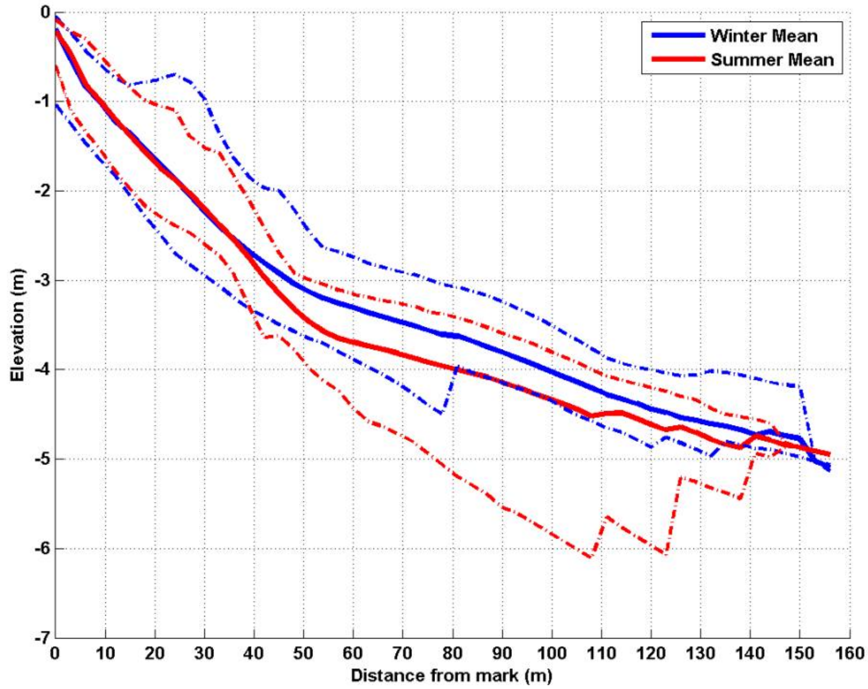

Figure 86. Seasonally, FR3 has a better-developed berm in summer and more sand stored offshore in winter. This summer-winter pattern is expected.

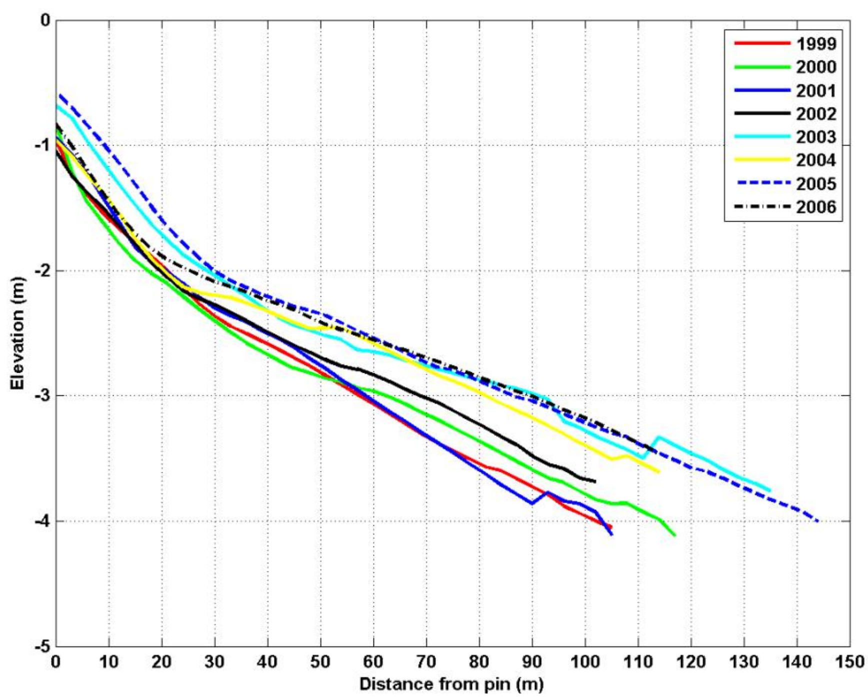

Figure 87. Annual means at FR4 show the beach was relatively stable from 1999 to 2001, and then it accreted from 2001 to 2005. In 2006 the upper profile lost sand while the rest remained relatively stable. Overall there was a net gain in sand over the 8 years.

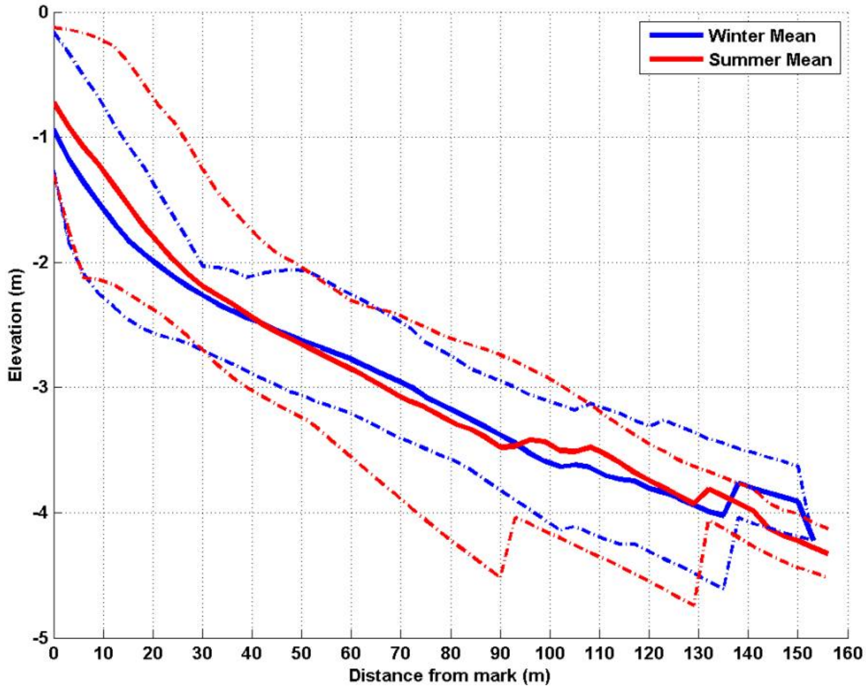

Figure 88. Seasonally, the summer profile at FR4 holds more sand along the dune/riprap wall and the offshore holds more sand in the winter. This seasonal shift is expected.

Goose Rocks Beach, Kennebunkport

Background geology and characteristics

Goose Rocks Beach is an approximately 3 km long sandy pocket beach that stretches southwest-northeast and is bound by two tidal inlets, the Little River to the northeast and the Batson River to the southwest. The shoreline along the beach is quite arcuate, mainly due to wave refraction around offshore islands and shoals. Dynamic beach spits are located at both ends of the beach, adjacent to the tidal inlets. Southwest of the sand beach is a headland with mixed sand and gravel beaches on Nessler and Marshall Points. According to Nelson (1979), the historical limit of erosion is landward of many homes within the dune system. Approximately 60% of the shoreline along Goose Rocks Beach is armored (Beach Stakeholder Group, 2006). There are no new significant sources of sand to replace sediment transported into the tidal inlets or eroded from the beach and carried to offshore sand bars (Dickson, 2006a).

Goose Rocks has 4 measured beach profiles, GR1-GR4. The overall beach is shown in **Figure 89**. The starting points have not yet been surveyed by MGS.

Annual and seasonal beach profile changes

Beach profiles at Goose Rocks Beach start behind the dune crest and also within seawalls. Profiles at Goose Rocks Beach tend to be very flat and long (out to about 500 m from the pin) and variable, mostly due to the sheltered area and influence of offshore islands and shoals. Continuous data were collected from 2002 through 2007. The beach at GR1 is adjacent to the Batson River ebb-tidal delta, and reflects this variability in the profile shapes (**Figure 90**). There is no contiguous pattern of either erosion or accretion, with changes being highly variable. There was general accretion along the profile from 2002-2003, with continued buildup of sediment adjacent to the seawall and berm into 2004, though some volume of sediment was lost on the middle portion (between 100 and 240 m from the pin). From 2004 to 2005 there was sediment loss along the entire profile. The beach fronting the dune/wall continued to recede into 2006, though more sediment appeared in the central portion of the profile. By 2007, the beach fronting the seawall stabilized, and additional accretion took place in the central portion of the profile. Seasonal mean data (**Figure 91**) show that there is generally little change from winter-summer, though the winter profile shows slightly more sediment nearer to the seawall. Profile envelope variability indicates that both seasons are somewhat variable, with values between the minimum and maximum envelopes on the order of 1 m. Standard deviation data (**Figure 92a**) show that the berm has more variability (55 cm) in the winter than the summer (45 cm). The berm's position appears to stay the same, around 20-35 m from the pin.

GR2 is much shorter in length than GR1. It appears that the profiles at GR2 collected in 2002-2003 may have started from a different location than the remaining years (**Figure 93**). If not, then the beach underwent accretion from 2002-2004. A berm, present in the 2002 profile at the 25 m from the pin mark (at an elevation of 1.5 m below the pin), was eroded by 2003. Data from 2003-2007 indicate that the beach changed little over this period of time and is relatively stable. On a seasonal basis (**Figure 94**), GR2 displays the typical sediment-rich summer berm, with sediment loss in the nearshore and growth of a sandbar farther offshore in the winter. Based on the mean seasonal shapes, berm fluctuation appears to be about the same for summer and winter. This is confirmed by standard deviation data (**Figure 92b**), which show changes on the order of about 40 cm for both seasons. The position of the berm appears to remain about the same.

The beach at GR3 appears to have been relatively stable between 2002-2004, then underwent a period of erosion in 2005 (this being the most erosive profile of the data, **Figure 95**). In 2006, the berm appears to have recovered, and this trend continued into 2007. Like GR2, GR3 shows a seasonal bias (**Figure 96**), with more sediment in the berm area during the summer, and more sediment in the bar area during winter. Profile envelope variability appears to be about the same for winter and summer, though the summer berm appears to reach a slightly higher elevation. Standard deviation values (**Figure 92c**) for the berm are greater in the summer profile. It seems the greater vertical variability is located farther from the mark at GR3 (around 40-50 m from the pin) than GR2 (25-30 m).

Profiles collected at GR4 are located near the Little River, and thus, are longer like the profiles from GR1. From 2002-2004, there was erosion of the berm area, with some growth offshore (**Figure 97**). From 2004-2005, the berm began recovery while the offshore portion of the profile remained stable. 2006-2007 saw continued berm growth, with little changes in the offshore. Seasonally, the summer profile (**Figure 98**) exhibits more sediment adjacent to the dune and berm than the winter profile. Standard deviation data (**Figure 92d**) indicate that the berm fluctuates vertically almost 70 cm in the summer, and 60 cm in the winter. Variability is greater than 40 cm along the majority of the profile, and increases to nearly 80 cm offshore, likely attributable to sandbar migration adjacent to the Little River.

Profiles along Goose Rocks Beach are influenced by the bounding rivers, and offshore, wave-sheltering outcrops and islands. The beach has been variable, with loss, especially in 2005, though it appears that the beach has the ability to recover from such loss. Seasonal variability is typical.

Figure 89. Goose Rocks has 4 measured beach profiles, GR1-GR4. The starting marks for the profiles have not been surveyed by MGS as of April 2007. The 4 profiles are approximately located on the figure.

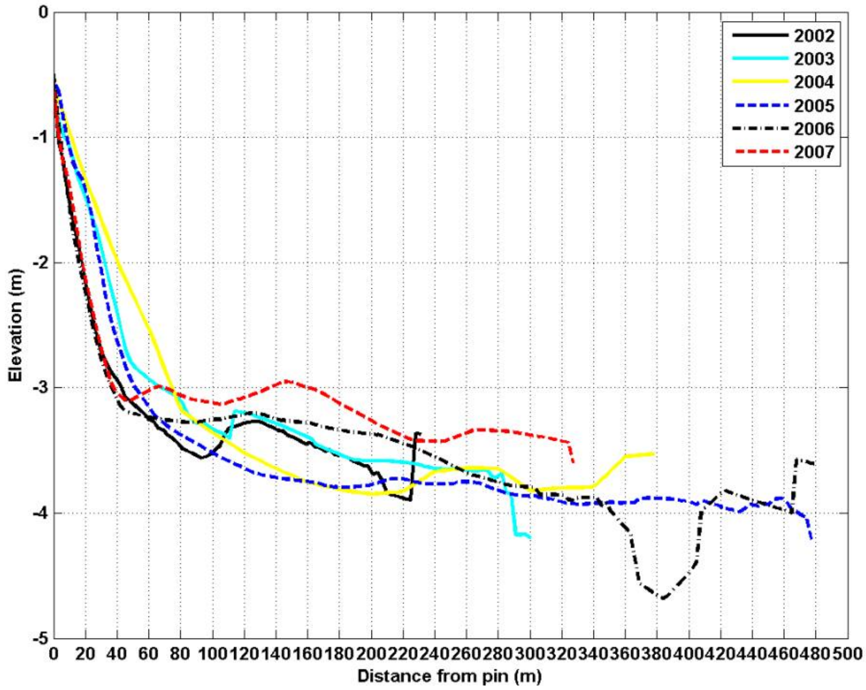

Figure 90. Annual mean profiles at GR1 near the Batson River show the dynamic shifting of sand bars on the low-tide terrace. On the upper profile the beach widened from 2002 through 2005, but in 2006 and 2007 returned to the 2002 position.

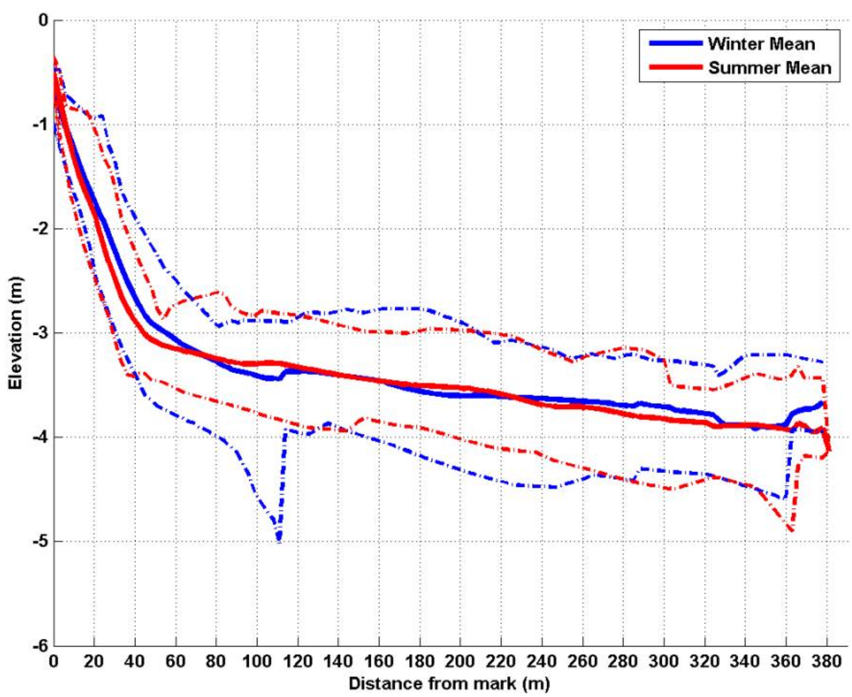

Figure 91. The seasonal comparison at GR1 shows that the winter and summer beaches are very similar in shape. The envelope of profile variation in height is over a meter in most locations.

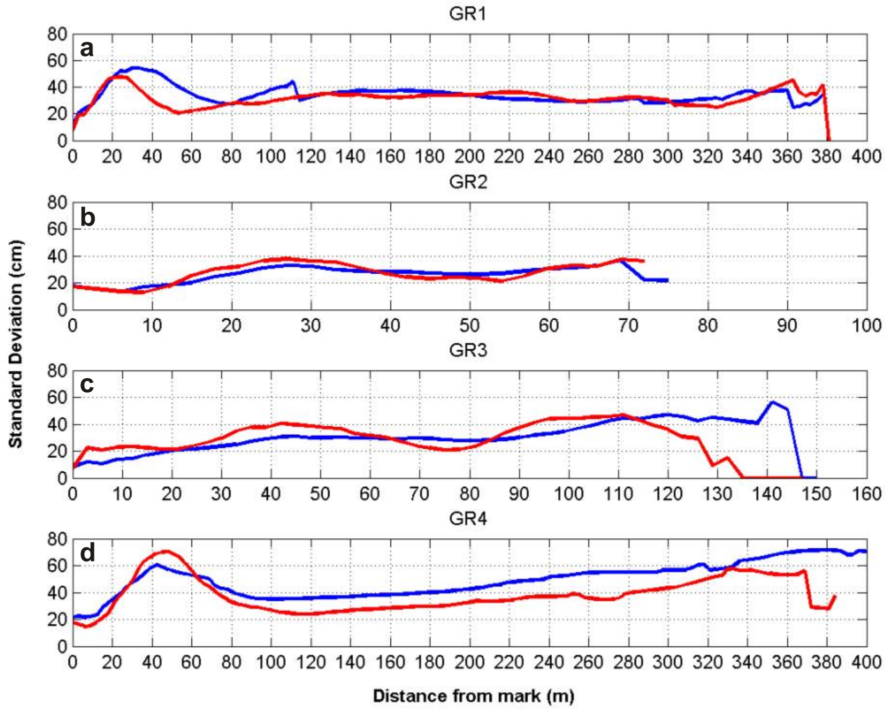

Figure 92. Standard deviation of the profiles at GRI (a) shows the most variability on the upper beach profile (20-60 m) with more movement in winter compared to summer. At GR2 (b) summer and winter berm fluctuation is very similar and the profile responds similarly in both seasons. At GR3 (c) there is some variability across the profile in the standard deviation. The summer berm position shows higher variability in elevation than in the winter. At GR4 (d) the berm fluctuates more in summer (0.7 m) than winter (0.6 m) and, like GR1 this may be due to the influence of the adjacent tidal channel.

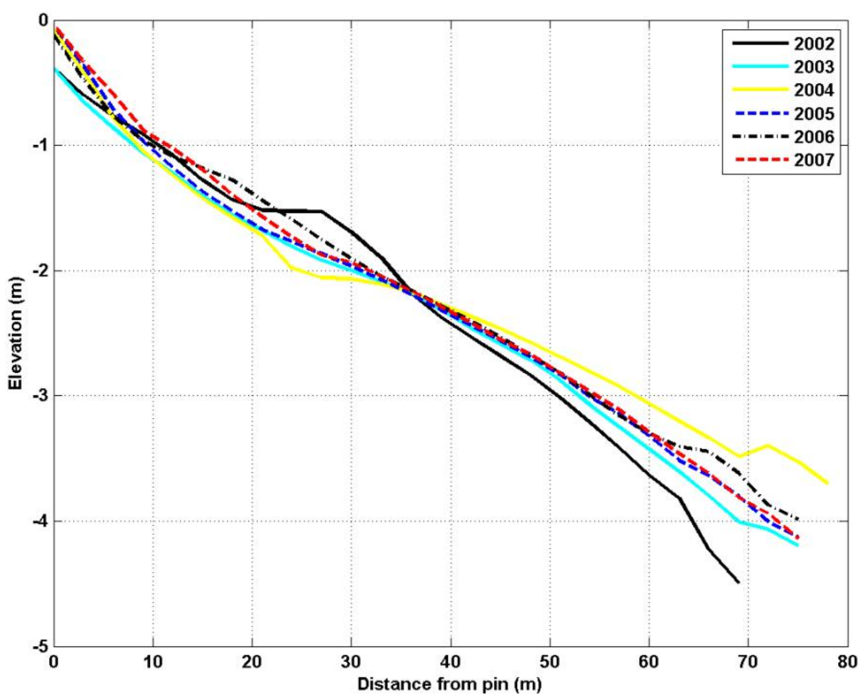

Figure 93. At GR2 the mean annual profiles show a very linear and more constant beach that at GR1 due to the lack of influence of the Batson River sand bars. The starting point seems to have moved in 2003. From 2003 to 2007 the beach changed very little in elevation and appears quite stable.

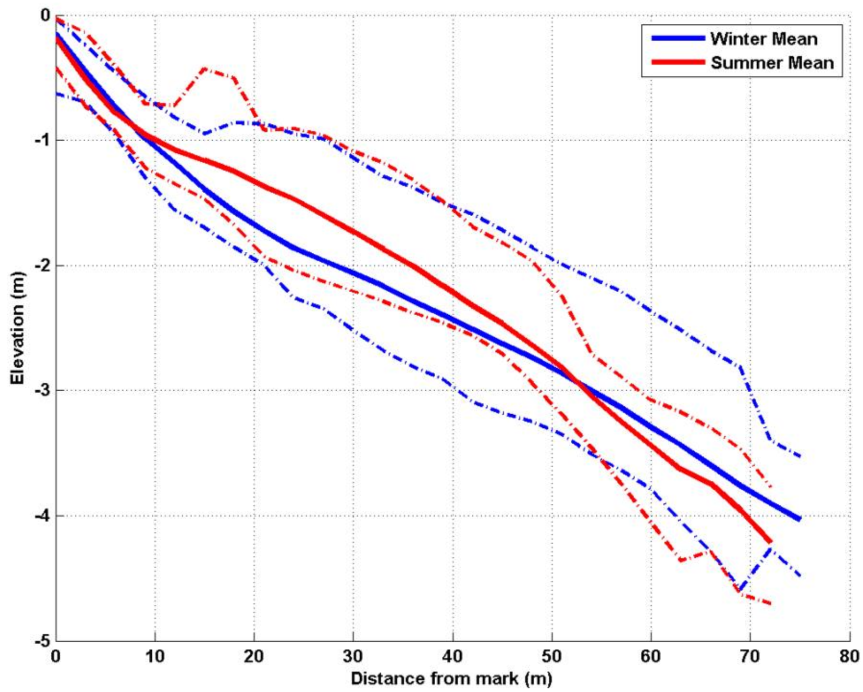

Figure 94. Seasonally, GR2 shows the typical summer berm and higher beach profile in the central section. In the winter sand bar formation on the lower profile raises the winter mean above that of the summer. The envelope of profile elevations shows there can be well over a meter of vertical change on most of the profile.

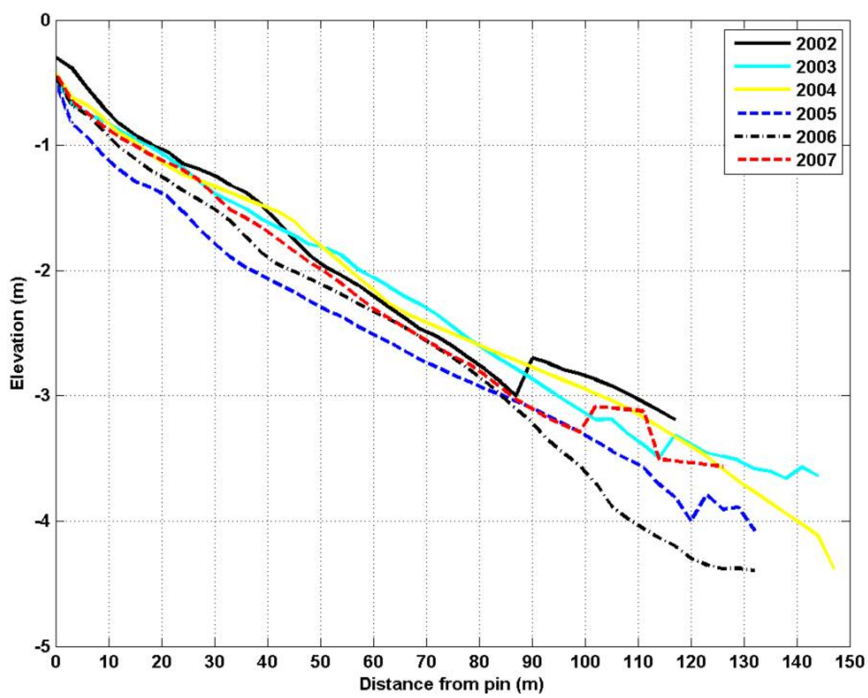

Figure 95. The mean annual profiles at GR3 show a relatively stable beach from 2002 to 2004. In 2005 the lowest profile erosion occurred along the upper beach. The following two years (2006-2007) show recovery from the erosion to a level seen in 2003.

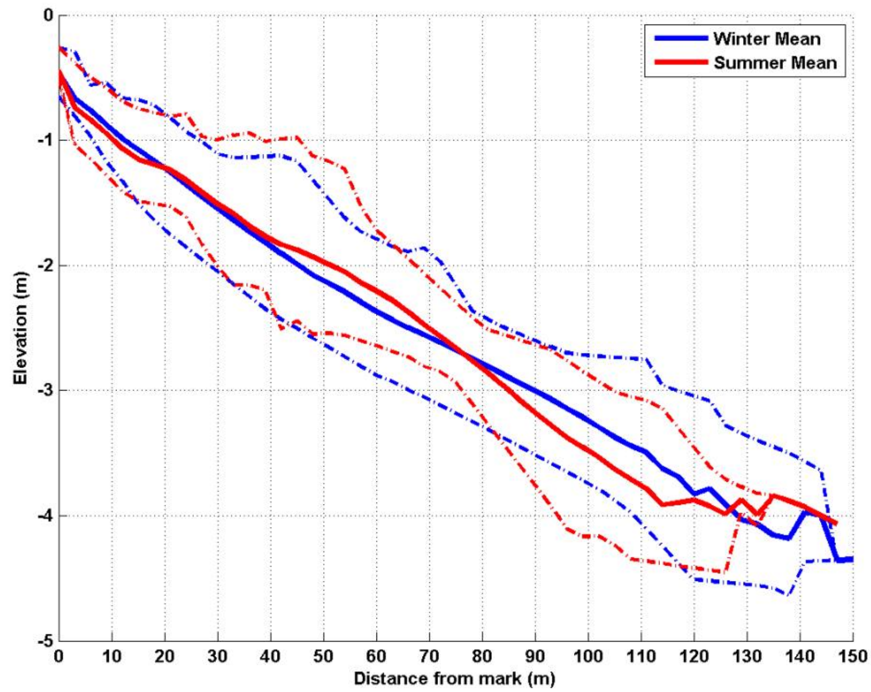

Figure 96. GR3 shows a pattern like GR2 with more summer sand on the berm and more sand offshore in a bar location in the winter. This is the expected profile change and it is driven by seasonal variability in wave energy. The envelope of profile variation is in excess of a meter, similar to GR2.

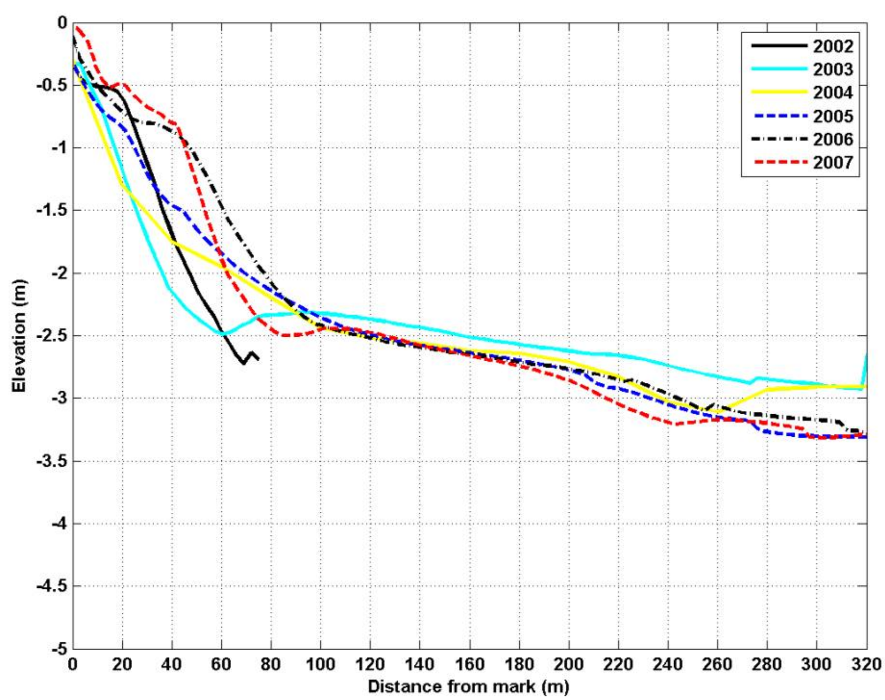

Figure 97. Profile GR4 is near the Little River and shows a long and flat low-tide terrace on the profile. Above the terrace, the beach width has been variable since 2002. The berm area eroded from 2002 to 2004, but recovery occurred from 2004 to 2006. By 2007 some of the profile below the berm began to show erosion while the low-tide terrace remained stable.

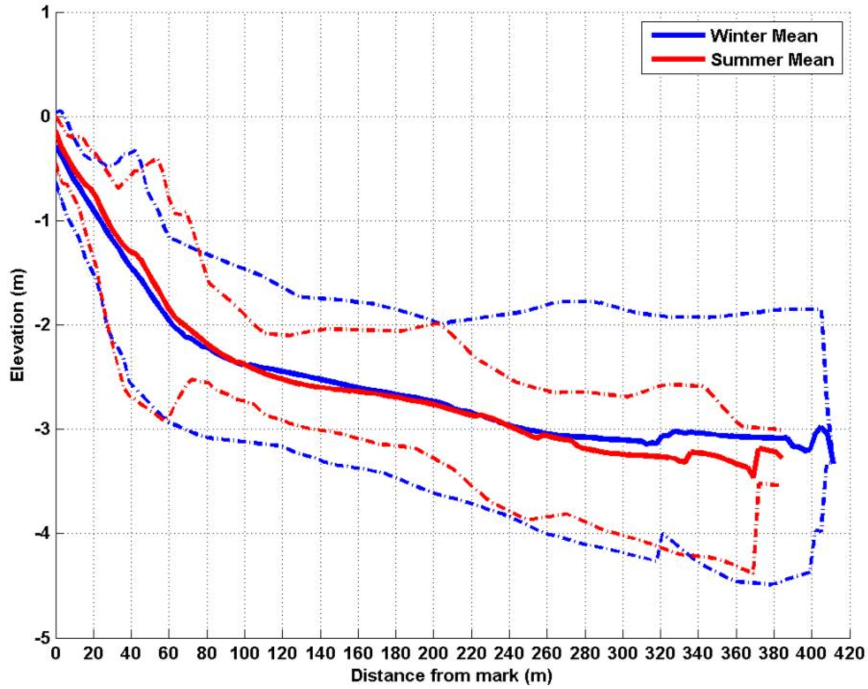

Figure 98. Seasonally, GR4 has a similar profile in winter and summer, but there is slightly more sand on the upper profile in summer. In winter the low-tide terrace holds more sand, as is expected during the stormy months.

Goochs Beach and Middle Beach, Kennebunk

Background geology and characteristics

Goochs Beach is an approximately 1.3 km long east-west trending pocket barrier located adjacent to the mouth of the Kennebunk River and bounded by bedrock headlands of Oaks Neck and Old Fort Point. Approximately 90% of Goochs Beach is fronted with a wooden seawall (Beach Stakeholder Group, 2006), though a very small active frontal dune is located adjacent to a jetty at the river mouth. The beach profile is generally flat and low and, due to the lack of sand exchange with most of the dune system and repeated wave action on the seawall, has a minimal summer berm. Middle Beach, west of Goochs Beach, is a mixed sand and gravel beach fronted with a large concrete seawall. No historical shoreline change measurements are available since this beach has been engineered since air photos were first taken (Dickson, 2006a).

Goochs Beach has 3 measured beach profiles, GO1-GO3, with a single profile located at the eastern end of Middle Beach (GO4). All profile starting points are located on the seawall. GO1 is located within the wall just south of Peninsula Drive, while GO2 is located just east of Surf Lane. GO3 is located in the wall just west of where Beach Avenue approaches the ocean and turns parallel to the seawall. GO4 is located within the seawall at the eastern end of Middle Beach, directly off of Beach Avenue (**Figure 99**). The starting points for these profiles were surveyed by MGS in July 2006.

Annual and seasonal beach profile changes

Profiles along Goochs and Middle Beach all start along a seawall, with the first point being the level of sediment below the wall. Overall beach profile data collection began in 2001 and has been continuous through 2007. The beach at GO1 was relatively stable to slightly accretive from 2001-2002, and erosive from 2002-2003 (**Figure 100**). In 2004, the beach gained sediment at its upper portions nearest the seawall - and also in the berm area. There were only slight changes in 2005-2006, mainly a slight increase in the berm elevation. In 2007, data biased by only the winter months, the mean profile indicated that sand elevations were lowest of all years except for a portion of the 2003 profile, along the berm, which was flat and not well developed. Seasonally, GO1 (**Figure 101**) shows relatively little change in the upper portion (berm area) of the profile (from about 1m and above). The berm here appears to be about 10 m in size during the summer. Standard deviation data (**Figure 102a**) show that the berm at GO1 varies about 30 cm vertically; in fact, variation along the entire profile is on the order of 30 cm, and increases to between 35-40 cm in the offshore, for both summer and winter.

The beach at GO2 underwent little change between 2001-2002. Between 2002-2003, almost the entire middle portion of the profile (to about 0 m in elevation) eroded (**Figure 103**). Erosion continued into 2004, though there was some elevation in gain in the upper portion of the berm. In 2004-2006, the middle portion of the profile recovered some sediment volume. The winter of 2007 eroded the entire profile dramatically, removing about 0.3 m of sediment along the entire length of the beach profile. GO2 exhibits a distinct difference in the summer versus winter profiles, with more sediment volume along almost the entire profile in the summer (**Figure 104**). Though overall profile envelope variability appears to be the same, the summer profiles appear to typically achieve a higher elevation than winter. Standard deviation values (**Figure 102b**) are about the same for both profiles overall around 20 cm or less, indicating that the profile is quite stable. The winter data show a small area of vertical variability during the winter located at the 10 m mark.

There was accretion between 2001-2002 at GO3 (**Figure 105**), with slight erosion back to 2001 profile shape in 2003. Erosion continued in 2004, lowering the portions of the profile below 1.5 m. Some recovery occurred in 2005-2006. Consistent with other profiles, 2007 resulted in substantial lowering and erosion of the overall profile. Seasonal data at GO3 (**Figure 106**) show a distinct summer versus winter profile difference, with the entire summer profile being more sediment rich than the winter one. Both profile envelopes are similar, though it seems the winter profile has a bit more variability. The standard deviations along the winter and summer profiles are quite similar, though the winter appears to be a slight bit more variable, on the order of 20 cm vertically (**Figure 102c**).

The gravel beach at GO4 appears to have gone through slight accretion between 2001 and 2002, especially at the berm area (**Figure 107**). 2003 saw some erosion of the upper portion of the beach profile from about the 1.2 m to 3 m contour lines. From 2003-2004, the berm recovered. There was general beach stability through 2005, with the mean profile very similar to the 2004 shape. In 2006, the upper portion of the profile underwent accretion, while the lower portion underwent erosion. The 2007 annualized shape is the leanest, showing the most erosion from all the years data were collected. Seasonal data (**Figure 108**) indicate that GO4 undergoes some berm variability during the summer months. This berm fluctuates about 20-30 cm for both summer and winter (slightly more in the summer), and is located at the 10 m mark according to standard deviation data (**Figure 102c**).

Data indicate that Goochs Beach, in general, is somewhat stable. However, it is heavily influenced by storm events, such as the Patriots' Day storm, which removed large volumes of sediment from the profile.

Figure 99. Goochs Beach has 3 measured beach profiles, GO1-GO3, with a single profile located at the eastern end of Middle Beach (GO4). All profile starting points are located on the seawall. GO1 is located within the wall just south of Peninsula Drive, while GO2 is located just east of Surf Lane. GO3 is located in the wall just west of where Beach Avenue approaches the ocean and turns parallel to the seawall. GO4 is located within the seawall at the eastern end of Middle Beach, directly off of Beach Avenue.

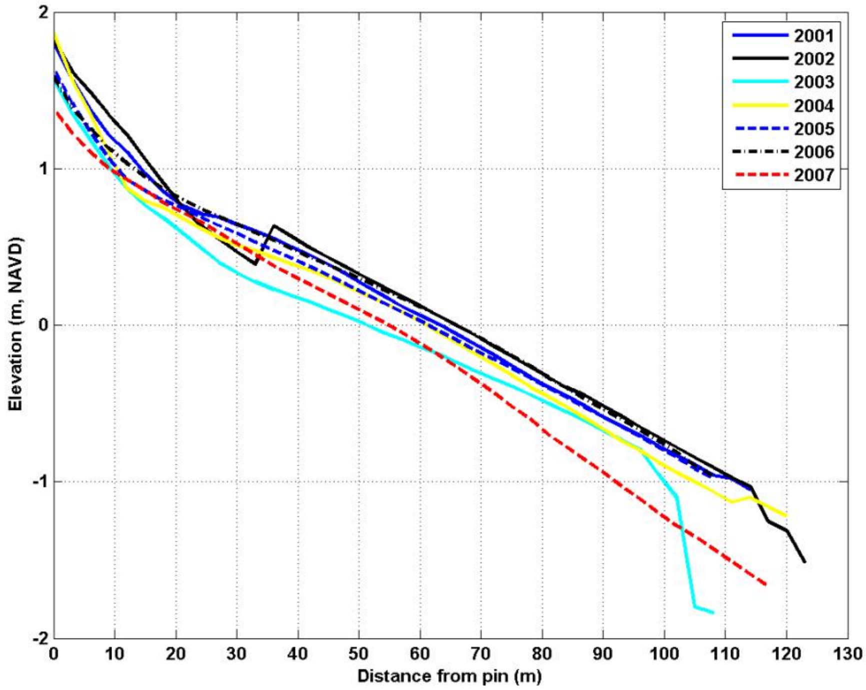

Figure 100. Mean annual profiles for GO1. The beach appears to be relatively stable, being most erosive in 2003 and 2007.

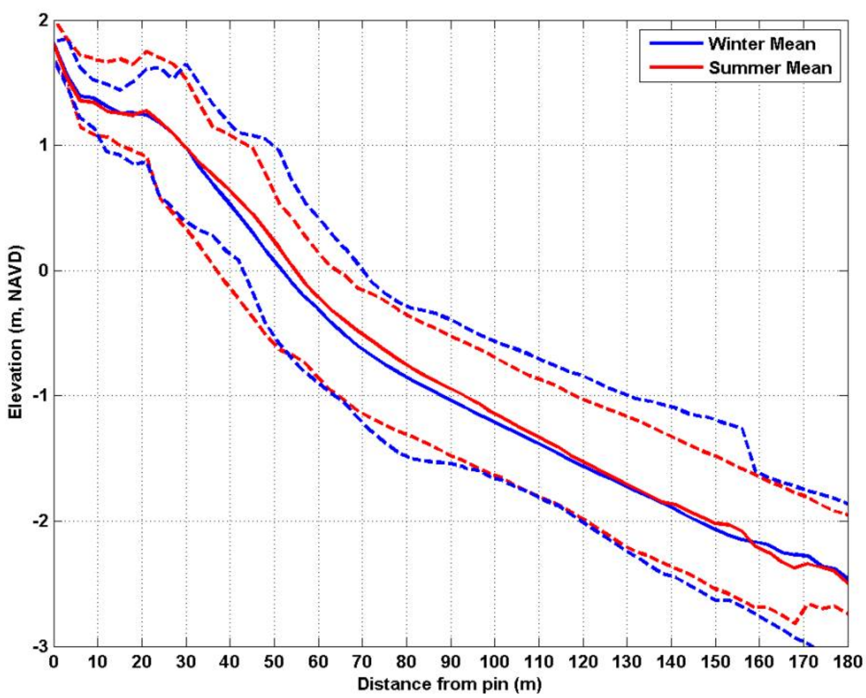

Figure 101. Mean seasonal profiles for GO1. The summer profile exhibits a more sediment-rich shape, with a more defined berm.

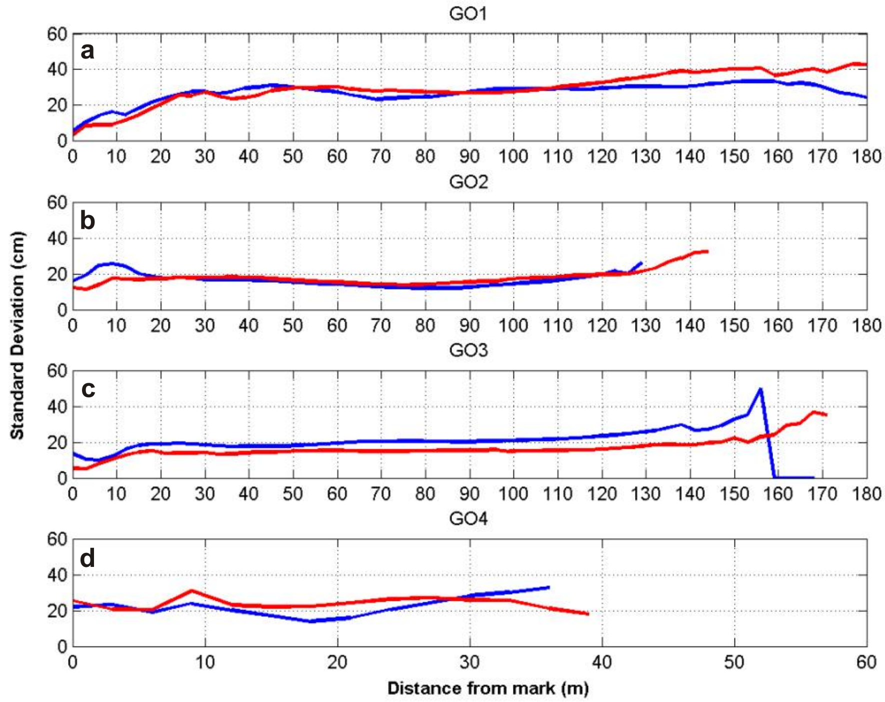

Figure 102. (a) Standard deviation data for mean seasonal profiles at GO1. The profile appears to be somewhat variable in summer and winter. (b) Standard deviation data for GO2 indicate that the profile is seasonally stable, with only slightly more variability along the upper portion in the winter. (c) Standard deviation data for GO3 show that both profiles are relatively stable, with slightly greater variability in the winter. (d) Standard deviation data for GO4 show a distinct berm formation that is visible at the 10 m mark.

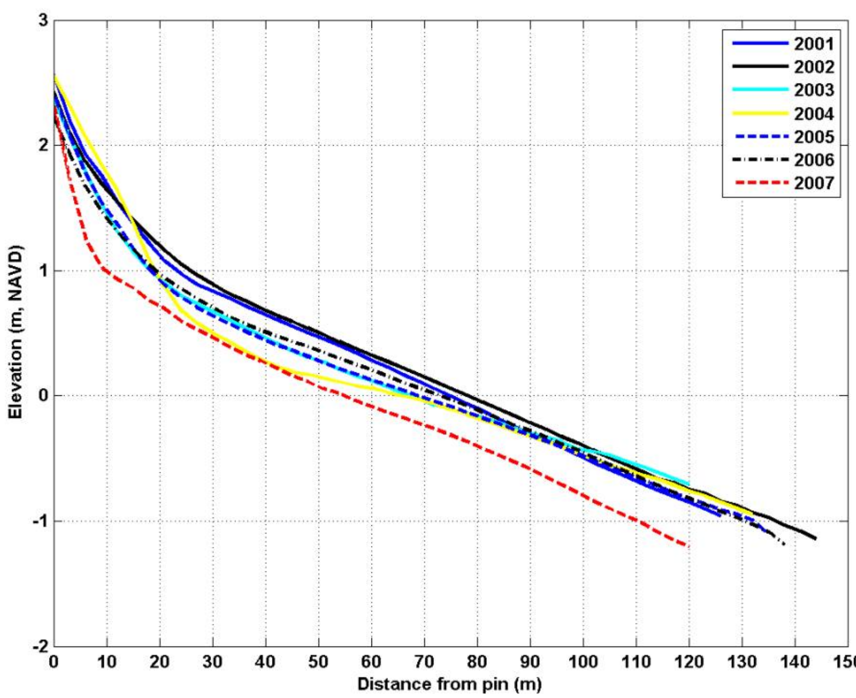

Figure 103. Mean annual profiles for GO2. The beach had the most sediment in 2002 and was most erosive in 2007.

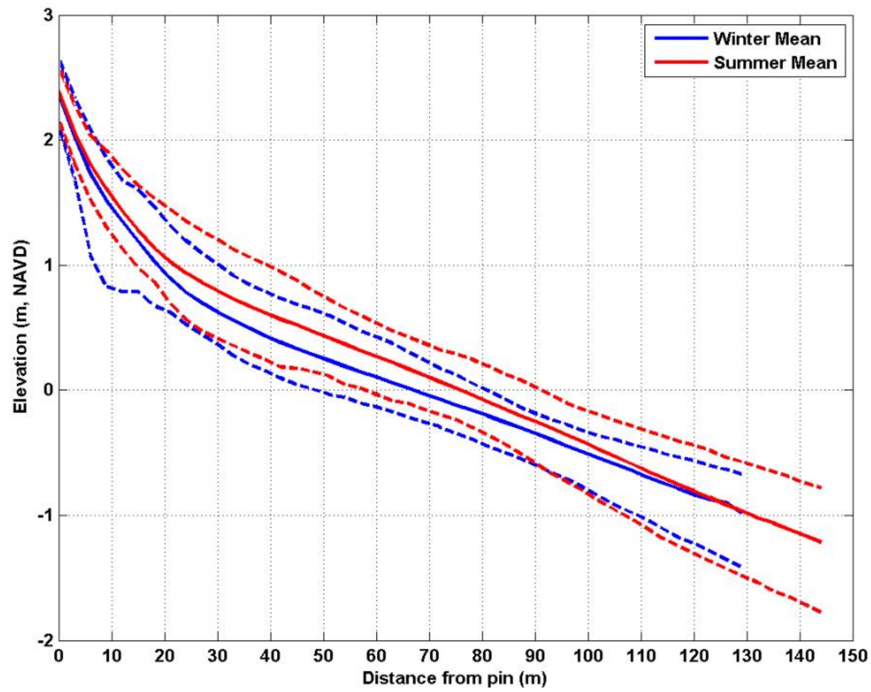

Figure 104. Mean seasonal profiles for GO2. The summer profile has a greater volume of sediment than the winter profile.

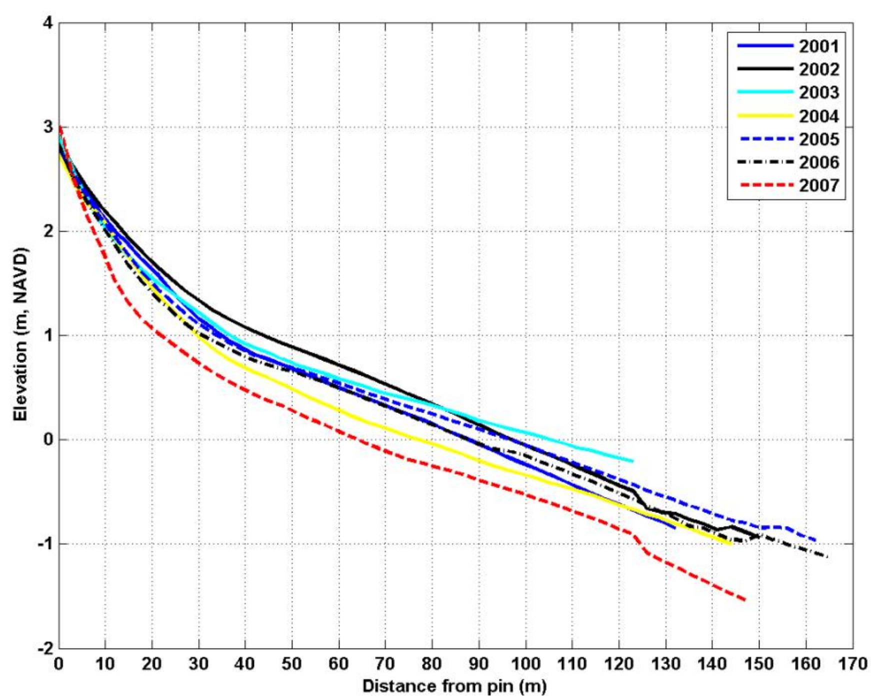

Figure 105. Mean annual profiles for GO3. Typical of the other profiles, the beach at GO3 underwent annual variability, with 2007 being the most erosive.

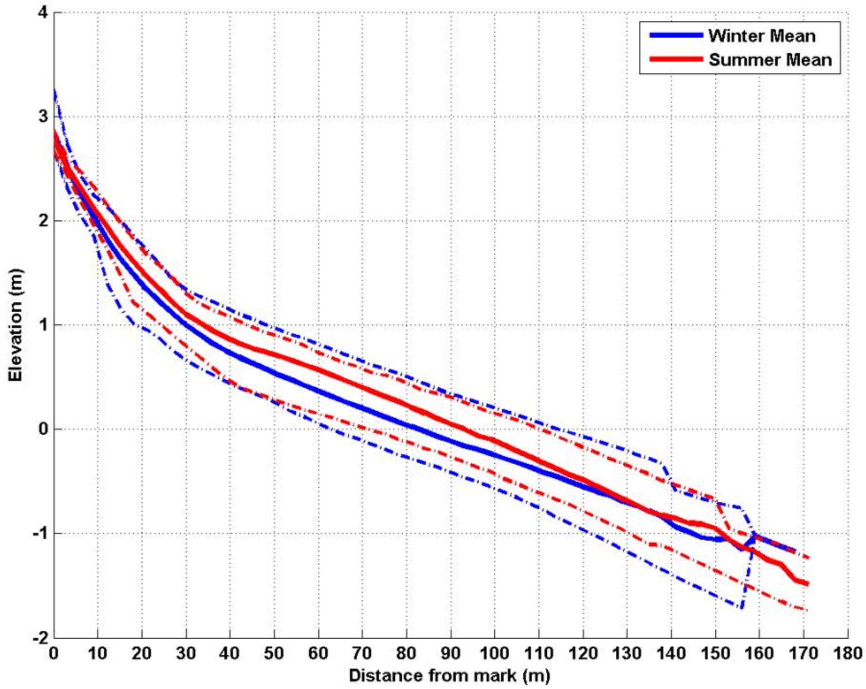

Figure 106. Mean seasonal profiles for GO3. The summer profile has consistently more sediment along its length than the winter profile.

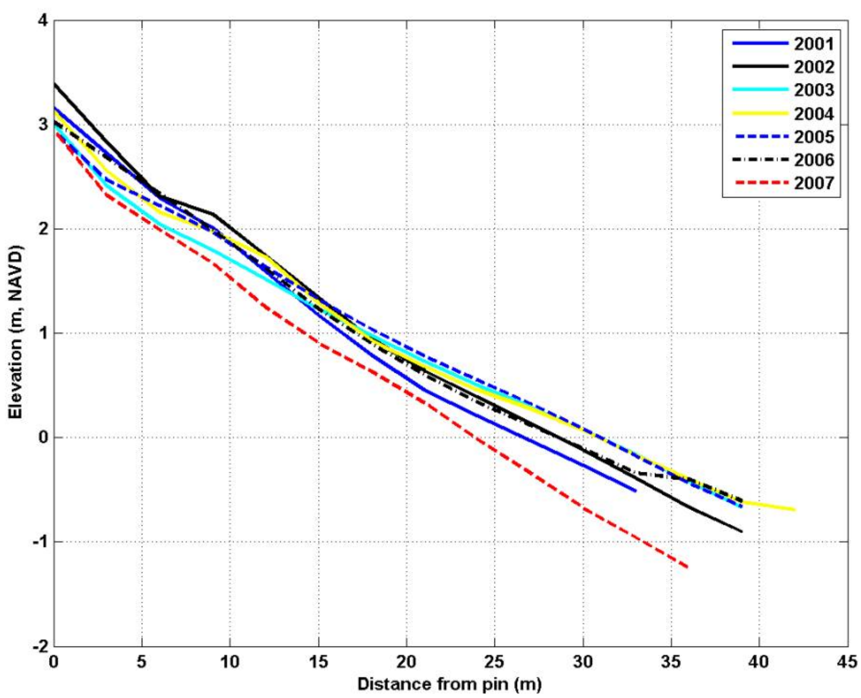

Figure 107. Mean annual profiles for GO4 show that the profile was generally richest in 2002 and most erosive in 2007, with variability in the other years.

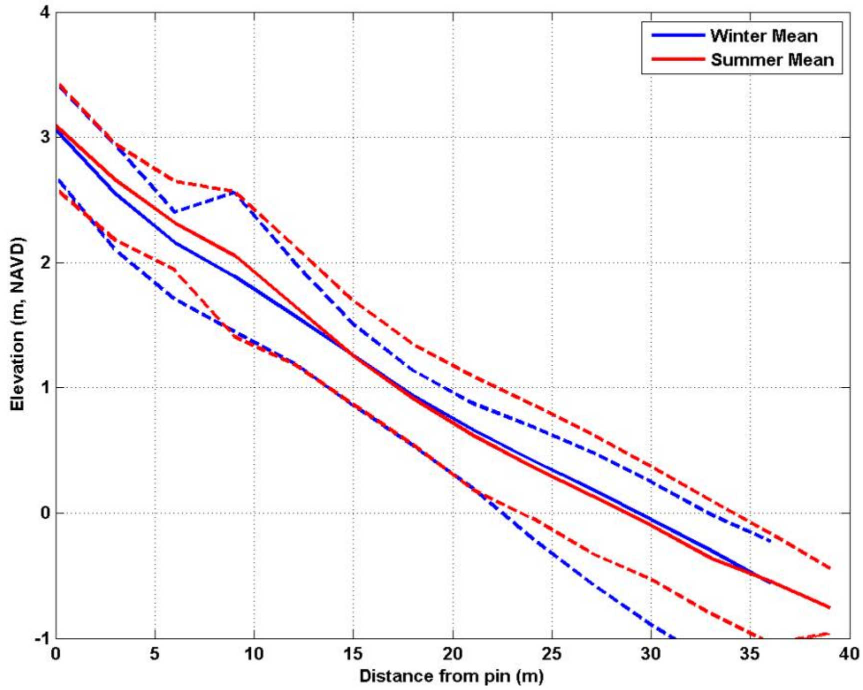

Figure 108. Mean seasonal profiles for GO4 indicate that berm fluctuation on the order of 20-30 cm occurs during both summer and winter.

Laudholm Beach, Wells

Background geology and characteristics

Laudholm Beach forms a barrier complex that stretches approximately 2.1 km from the federal jetty at the Webhannet River northeast along Drakes Island Beach to the inlet of the Little River. Laudholm Beach is 0.7 km long and terminates at its northeastern end at the Little River as a spit. It is only slightly developed at its southwestern end, while the remainder is undeveloped and unarmored. Extensive back-barrier salt marshes exist landward of Laudholm Beach.

Laudholm Beach is unarmored and has continued to migrate in a landward direction. MGS estimates an approximately 15 m offset between the crest of the frontal dune along Laudholm Beach and the crest of the seawall along Drakes Island (Dickson, 2006a).

Laudholm Beach (**Figure 109**) has 5 measured beach profiles, LH1-LH5. None of the points have been surveyed by MGS as of this report.

Annual and seasonal beach profile changes

Profiles collected at Laudholm Beach generally start behind the frontal dune. At LH1, two locations were utilized to initiate profiling; the first for data collected in 2001-2002, and the second for data from 2003-2007 (**Figure 110**). The beach saw dramatic erosion from 2001 to 2002, with the complete removal of a frontal dune crest. In 2003, a new benchmark was initiated. Erosion occurred along the majority of the profile between 2003-2004, though the dune crest itself appears to have gained slightly in elevation. From 2004-2005, additional erosion occurred, mostly of portions of the profile below 1 m below the pin elevation. 2006 saw erosion of the dune crest and a slight accretion in the offshore (beyond 60 m from the pin). In 2007 additional accretion occurred along the majority of the profile, but predominantly offshore, seaward of the 60 m mark. There is little difference between the summer and winter mean profile shapes until about the 60 m mark here, the winter profile exhibits better bar formation and offshore sand storage (**Figure 111**). The 60 m mark may signify some type of ravinement (erosion) surface that inhibits additional landward sediment transport. The winter envelope of variability is also much greater almost 2 m. Standard deviation data (**Figure 112a**) show that the winter profile has much more variability, between 40-50 cm, along a large portion of the profile (20 m to 110 m) than the summer profile, which has variability between 20-40 cm along this stretch.

At LH2, data were available for 2003 through 2007. Relatively substantial erosion occurred between 2003 and 2004, while little changes occurred between 2004 and 2005 (**Figure 113**). The 2006 annualized shape indicates little change in the dune and berm, while there was substantial volumetric change in the offshore, starting at around 50 m from the pin. In 2007, the dune and berm was eroded slightly on the order of 1-2 m, and there was some additional storage of sediment in the offshore. Seasonally, LH2 exhibits typical summer vs. winter profile shapes, with a better developed berm in the summer profile, and more storage offshore in the winter profile (**Figure 114**). Based on the standard deviation data, the summer profile is much more variable than the winter (**Figure 112b**). Winter fluctuation along the entire profile is on the order of 20 cm or less, while the summer variability ranges between 20-40 cm.

The beach at LH3 also had data available for 2003-2007. Similar to LH2, the beach in this area saw substantial erosion along its entire length, from about the 1 m below the pin mark from 2003-2004 (**Figure 115**). The 2005 mean profile shows that additional erosion occurred, though the dune area remained stable. In 2006, erosion of the berm area continued, while the remaining portions of the profile remained stable. In 2007, the dune appears to have accreted slightly, while the remainder of the profile changed very little. The seasonal comparison of profiles for LH3 indicates greater berm development for the summer profile, while profile envelope minimum and maximums appear to be greater for the winter profile (**Figure 116**). Standard deviations again indicate, similar to LH2, that the summer variability is much greater than winter along a large portion of the profile (20-140 m from the mark, **Figure 112c**).

Data were available only from 2003 to 2006 for LH4. Similar to the other profiles, the beach eroded substantially from 2003-2004 (**Figure 117**). Little change, aside from a slight addition of sediment to the berm, occurred in 2005. The berm eroded to its lowest point in 2006, with the majority of the erosion concentrated in the landwardmost 70 m of the profile. Seasonal data (**Figure 118**) indicate better berm development, within the first 45 m of the profile, for the summer profile, while the winter profile shows more sand storage offshore, past the 65-70 m mark. Standard deviation data (**Figure 112d**) show relatively large (50 cm) vertical fluctuations of the berm during the summer at the 45 m mark, while during the winter, the berm only varies around 20 cm.

Profile location LH5 was added in 2006. Overall, it exhibited little change between 2006 and 2007, though there appeared to be a bit of recession in the berm area of the profile, between 1

Figure 109. Laudholm Beach has 5 measured beach profiles. The starting marks for the profiles have not been surveyed by MGS as of April 2007. The 5 profiles are approximately located on the figure.

and 3 m below the pin (**Figure 119**). Some sediment accreted in the form of nearshore bars farther offshore. Seasonally, LH5 exhibits a distinct difference from other profiles (**Figure 120**). The winter shape has more sediment volume in the berm, and farther offshore than the summer mean shape. Standard deviation data (**Figure 112e**) show a slight bit more variation in the berm elevation (almost 40 cm) in the winter, versus around 20 cm in the summer. These characteristics may relate to the proximity of LH5 to more abundant gravel and peat deposits on the profile compared to the others that have sand over more of the profile.

Laudholm Beach has experienced some severe periods of erosion of the frontal dune and the berm is often composed of gravel and cobbles in the winter. Variability of the profiles seaward of the dune is somewhat atypical due to the mixed grain sizes of sand, gravel, and cobbles. The larger sediment sizes are sorted and transported more in the winter than in the summer hence some of the profile variability in winter is due to the higher wave energy. Summer sand often covers the cobble surface on the central portions of the profiles as sand bars migrate ashore from beyond the extent of profiling.

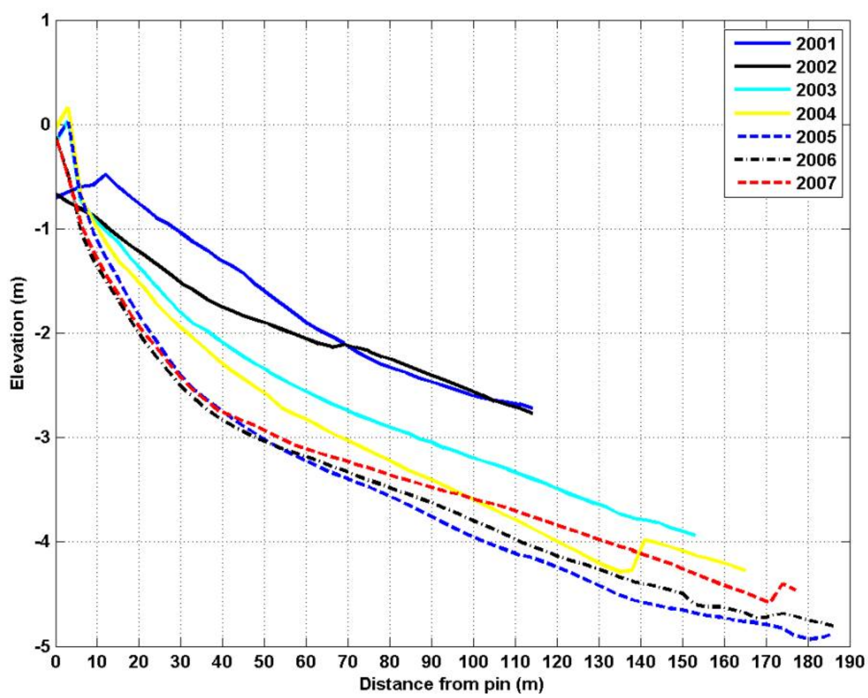

Figure 110. Mean annual profiles for LH1 indicate that two separate benchmarks were used. Erosion occurred from 2001-2004, then the profile stabilized somewhat in 2005-2007, though sediment was lost at the dune.

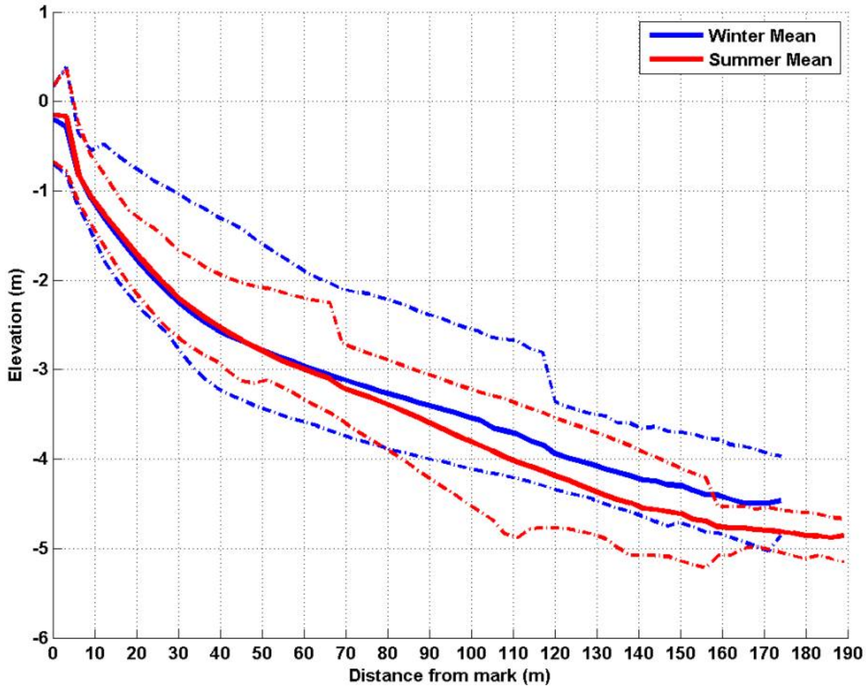

Figure 111. Mean seasonal profiles for LH1 show that the summer profile is only slightly better developed, and that more sediment is located offshore in the winter.

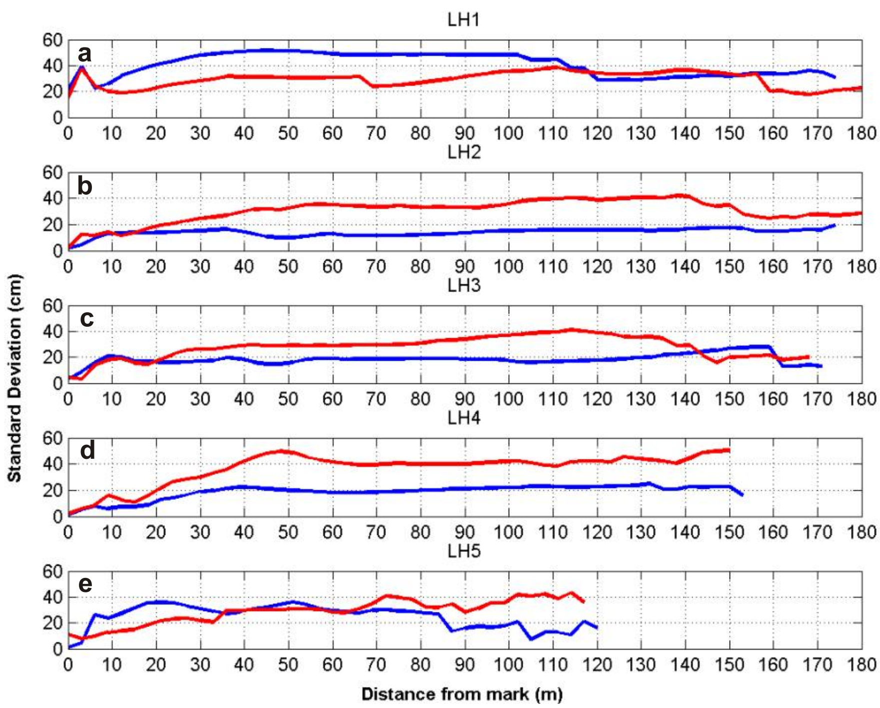

Figure 112. (a) Standard deviation data for LH1 indicate that both summer and winter profiles are variable, though the winter profile has markedly more variability than the summer. (b) Standard deviation data for LH2 show that variability along the profile in the summer is greater than during the winter. (c) Standard deviation data for LH3, like LH2, show that summer variability is greater than the winter. (d) Standard deviation data for LH4 indicate large vertical variability in the summer berm. (e) Standard deviation data for LH5 show slightly higher variability in the berm during the winter than the summer.

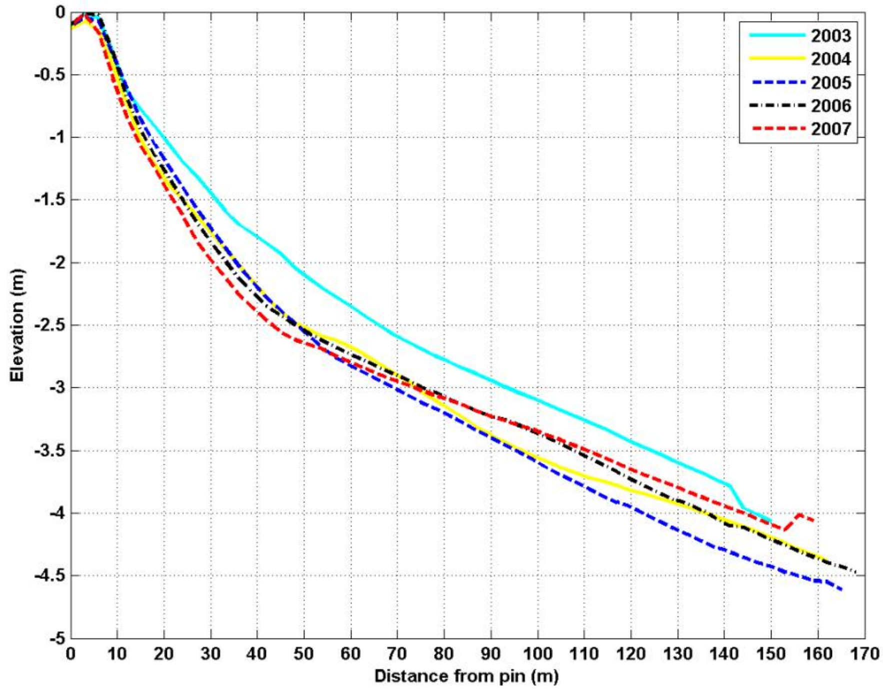

Figure 113. Mean annual profiles for LH2 indicate that the profile was most accretive in 2003 and most erosive in 2007. It appears to be generally erosive.

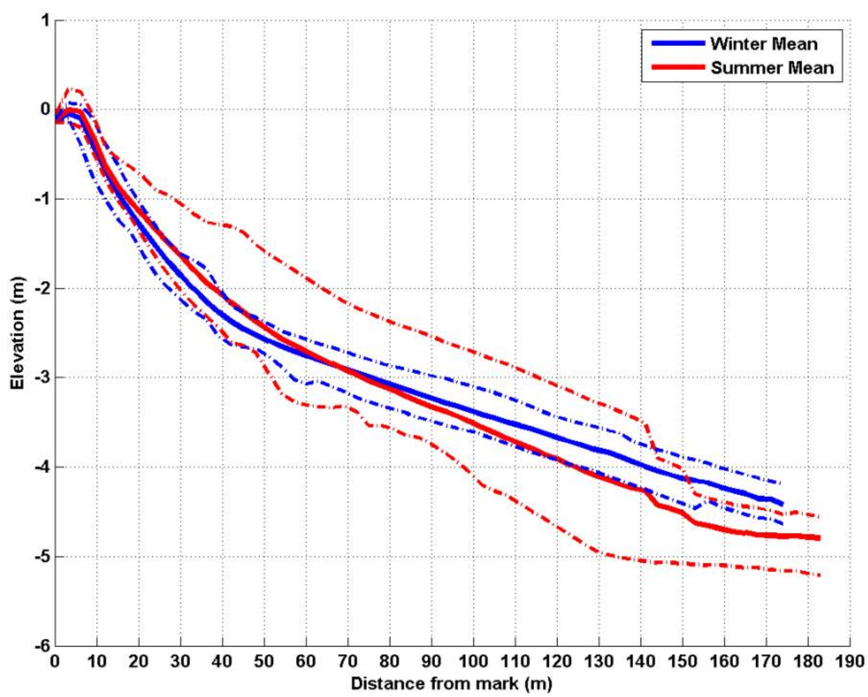

Figure 114. Mean seasonal profiles for LH2 show that the summer generally has a better defined berm, with more sediment storage offshore in winter.

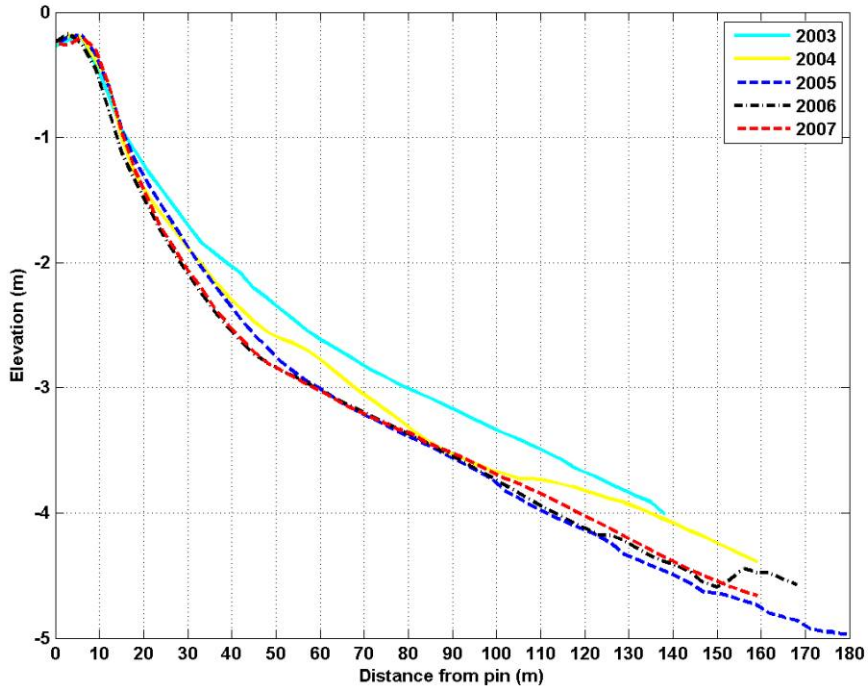

Figure 115. Mean annual profiles for LH3. The profile has generally undergone erosion through the study period.

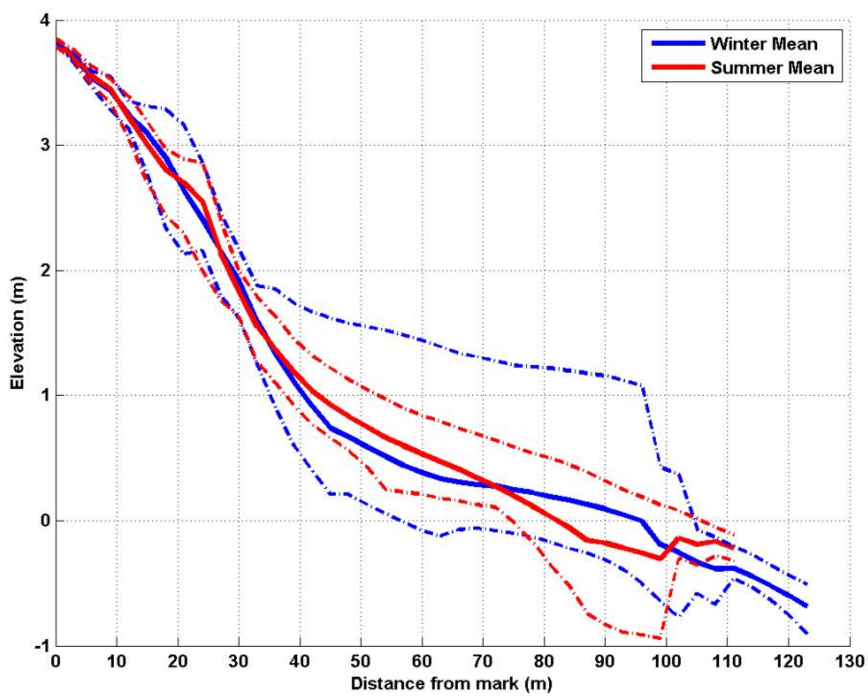

Figure 116. Mean seasonal profiles for LH3 show better berm development during the summer, with bar formation apparent in the winter.

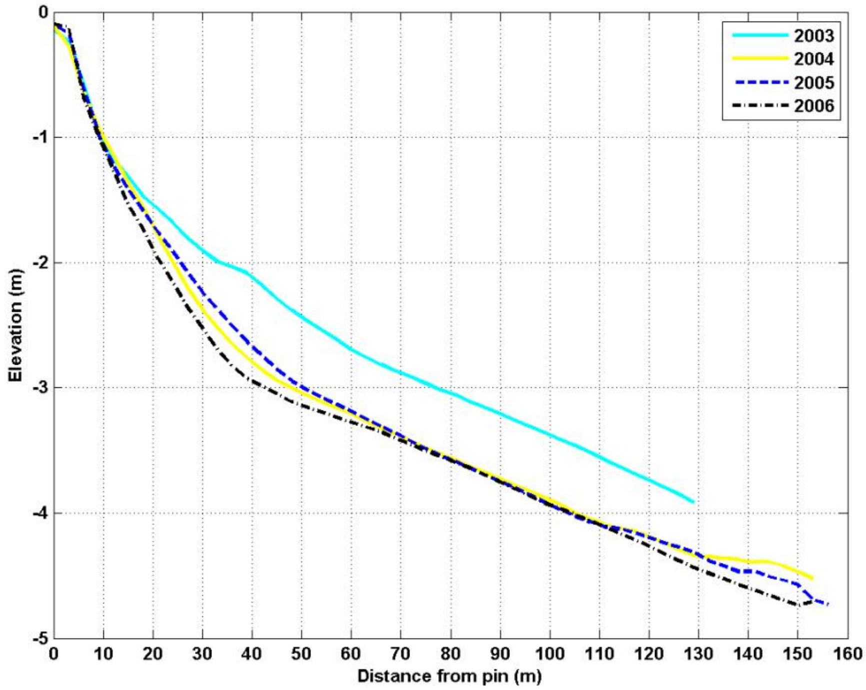

Figure 117. Mean annual profiles for LH4 show general erosion during the study period.

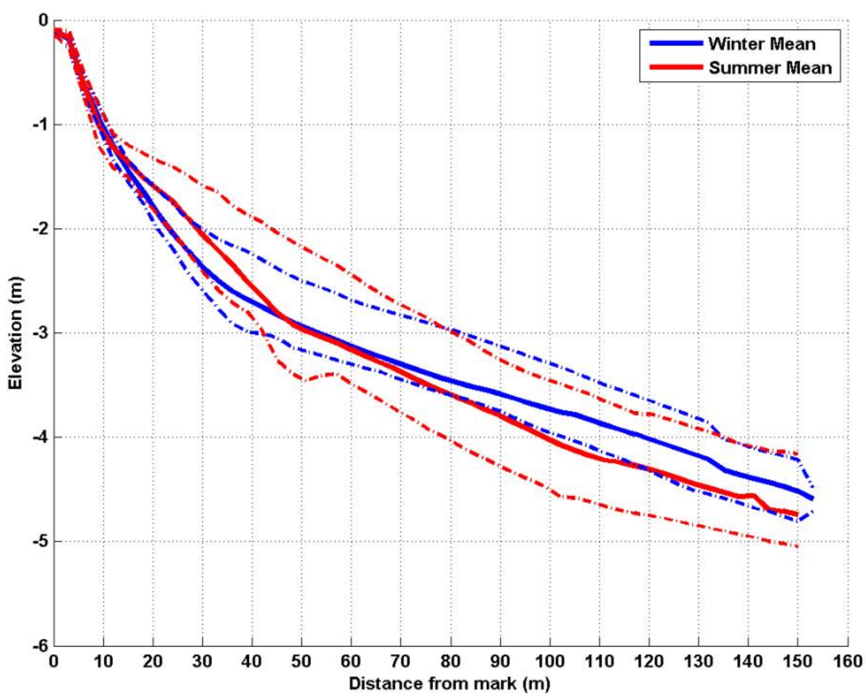

Figure 118. Mean seasonal profiles for LH4. A distinct berm is apparent in the summer profile, while offshore sediment storage appears in the winter.

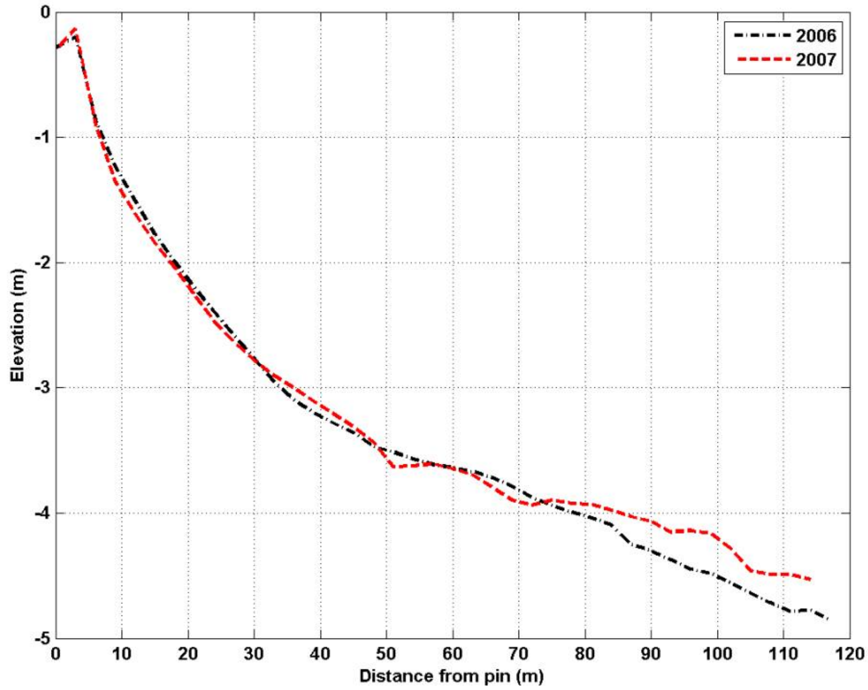

Figure 119. Mean annual profiles for LH5 show general stability between 2005-2006.

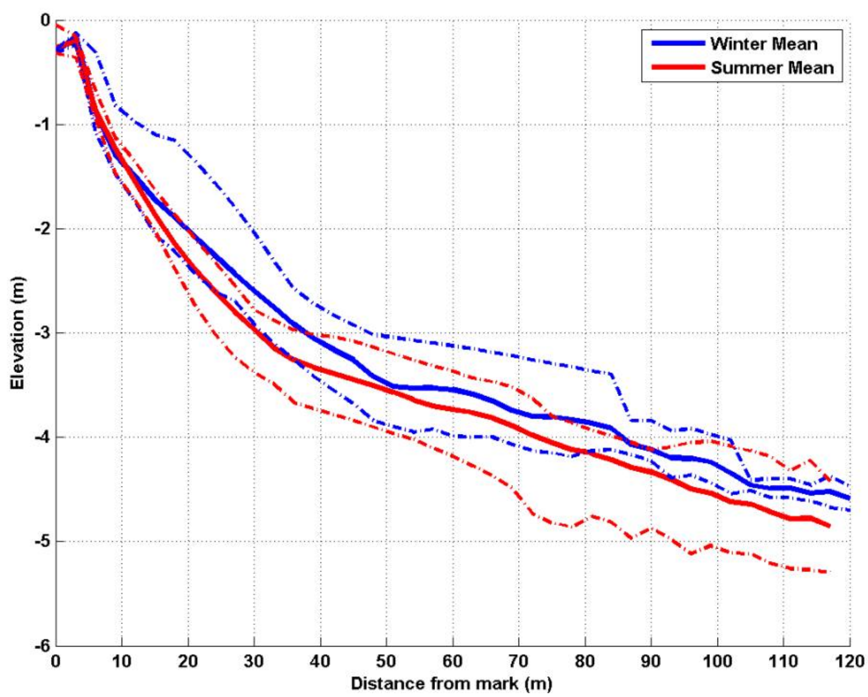

Figure 120. Mean seasonal profiles for LH5 show abnormally more sediment in the upper portions of the profile in the winter rather than the summer.

Drakes Island Beach, Wells

Background geology and characteristics

Drakes Island Beach and Laudholm Beach form a barrier complex that stretches approximately 2.1 km from the federal jetty at the Webhannet River northeast to the inlet of the Little River. Drakes Island Beach, located adjacent to the jetty, is approximately 1.4 km in length, and is highly developed with a seawall along 70% of the beach (Beach Stakeholder Group, 2006). Laudholm Beach, which terminates at its northeast end at the Little River as a spit, is only slightly developed at its southwestern end, while the remainder is undeveloped and unarmored. Extensive back barrier salt marshes exist along both beaches.

Shoreline change along Drakes Island Beach has remained relatively unchanged in a horizontal sense due to the presence of seawalls (Dickson, 2006a).

Drakes Island (**Figure 121**) has 4 measured beach profiles, DI1-DI5. The starting points for each profile have not yet been surveyed by MGS.

Annual and seasonal beach profile changes

Drakes Island is predominantly fronted by seawalls, except for the beach area adjacent to the jetties at the Webhannet River, which is fronted by relatively expansive dunes. Data available for DI1 were from 2001-2003 and 2005-2007. Annualized profile data for 2001-2002 showed dramatic accretion along the entire profile (**Figure 122**). It is possible that this is a remnant influence of the beach nourishment project that was completed in the winter of 2000 (Dickson, 2001). The 2003 profile indicates that the beach continued to prograde along its entire length. By 2005, the beach appears to have eroded slightly, starting at about 50 m from the pin, while the upper portion of the berm appears to have grown slightly. In 2006 the entire profile continued to accrete; this trend surprisingly continued in 2007. Overall there is little difference in the seasonal profile shapes, with the winter berm tending to be slightly higher than the summer (**Figure 123**). The standard deviation data (**Figure 124a**) indicate that the summer berm is relatively variable, with up to about 60 cm of vertical variation occurring. Winter data indicate that variability is on the order of 40 cm or less.

The beach at DI2 underwent similar accretion from 2001-2002, with the development of a substantial berm and volume of sediment in the offshore. In 2003, the beach appeared to be about the same, with slight erosion near the 50 m mark (**Figure 125**). By 2005, erosion was apparent in the upper and lower portions of the profile. In 2006, the lower portion of the profile, from 50 m seaward, underwent accretion. The upper portion of the profile also gained some volume. In 2007, almost the entire profile appears to have gained sediment. The seasonal differences at DI2 (**Figure 126**) appear to be more typical, with a slightly more developed berm associated with the summer profile, and more sediment located offshore in the winter profile. The summer profile envelope shows more variability in the elevation of the berm than the winter profile. Standard deviation data indicate slightly more variability in the berm elevation on the order of 30 cm while winter data show little variability along the entire profile (**Figure 124b**).

Annualized changes at DI3 were characterized by analysis from two different profile locations; DI3FS (front stake), at which data were collected from 2001 to 2003, and DI3BS (back stake), where data were collected from 2005-2007. The 2001 annualized profile at DI3FS exhibited a slight berm, which was lost by 2002, in addition to additional sediment loss along the rest of the profile (**Figure 127**). In 2003, the berm had receded farther, but accretion occurred along the remainder of the profile, starting at about 20 m from the pin. When data collection was continued at DI3BS in 2005, it appears that the beach underwent accretion in the successive years, through 2007 (**Figure 128**). The most accretion occurred at the profile's mid-point, at about the 70 m from the pin mark. Overall accretion between 2005-2007 reached about 0.5 m. Seasonal changes at DI3FS (**Figure 129**) indicated more prominent berm formations and sediment offshore in the winter profile rather than the summer profile. Seasonal data from DI3BS (**Figure 130**) generally showed the same characteristics, though a slightly more prominent berm (albeit small) was noted. Standard deviation data for all stakes were combined, and show that the profiles during summer and winter generally underwent little variability (20 cm or less) (**Figure 124c**).

The beach at DI4 appears to have had slightly more sediment on its upper portion, adjacent to the seawall/dune in 2001 than in 2002. Accretion occurred in 2002 along the lower portions of the profile, however, from about 20 m from the pin seaward (**Figure 131**). The 2003 mean profile showed continued accretion on the lower portion of the profile. It appears that the beach underwent erosive episodes between 2003 and 2005, with lowering of the overall profile elevation along its entire length. In 2006, the beach accreted back to approximately the 2003 profile levels. Seasonally, DI4 exhibited characteristics of a more sediment-rich summer beach profile, with the average beach elevation of the summer profile being approximately 0.2 m higher

Figure 121. Drakes Island has 4 surveyed beach profiles, DI1-DI5. The starting marks for the profiles have not been surveyed by MGS as of April 2007. The 4 profiles are approximately located on the figure.

than the winter profile (**Figure 132**). Interestingly, the summer profile maximum envelope exhibits the ephemeral presence of a significant bar offshore, at the 80 m from the pin mark, a characteristic more typical of the winter profile. Standard deviation data for DI4 (**Figure 124d**) indicate significant offshore sediment variability during the summer (up to 60 cm of vertical variation, between 80-105 m from the mark) and the winter (near 60-70 cm) with the variability being farther offshore, near the 120 m mark.

It appears that the jetties along the Webhannet River help trap sediment that is migrating to the south, along Drakes Island Beach. This is occurring mostly in the winter months, and may be responsible for some of the reverse seasonal trends seen along the Drakes Island profiles.

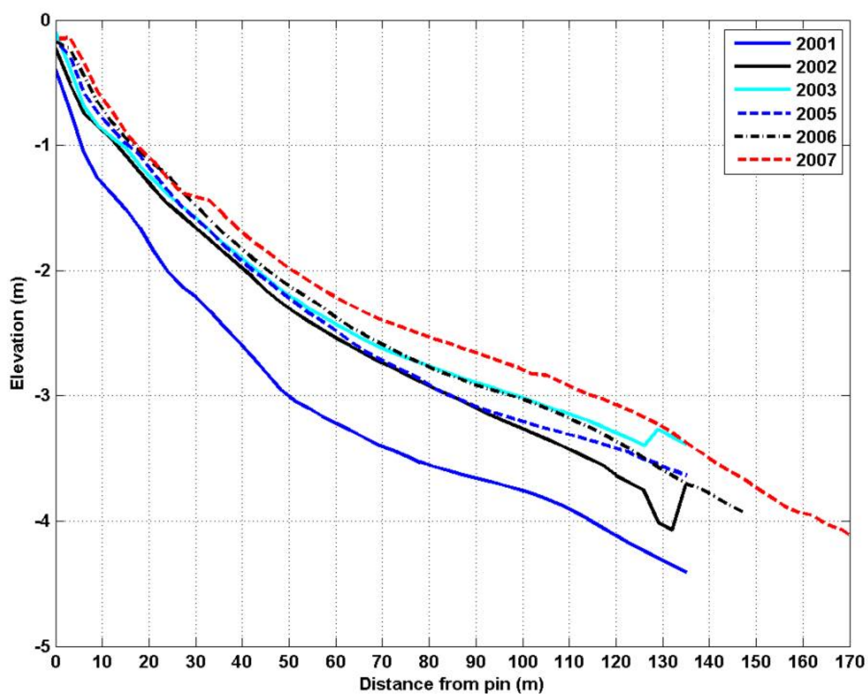

Figure 122. Mean annual profiles for DI1 indicate that the beach underwent accretion through the study period, especially between 2001-2002.

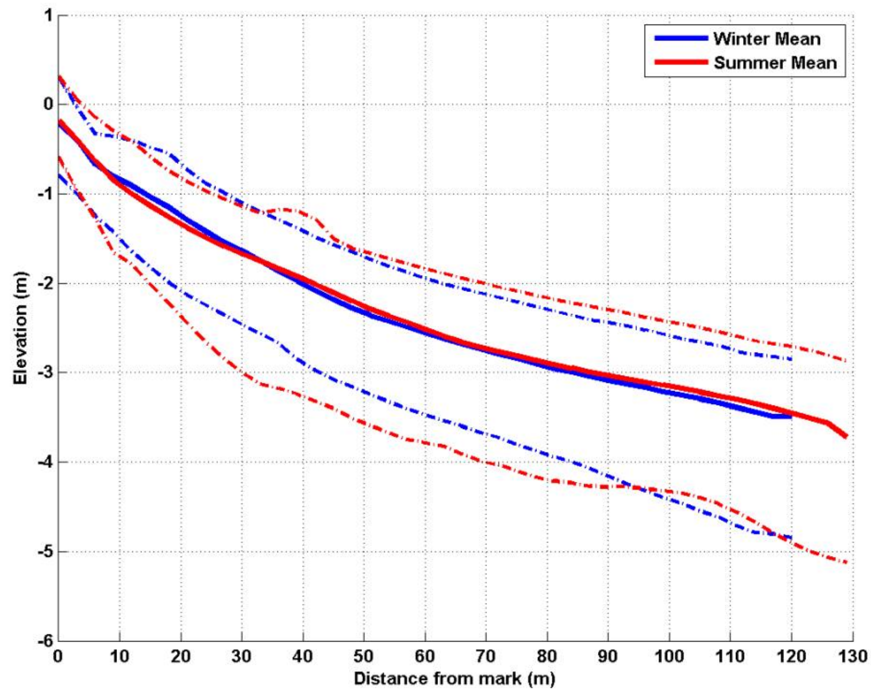

Figure 123. Mean seasonal profiles for DI1 show relatively little difference between the summer and winter profile shapes.

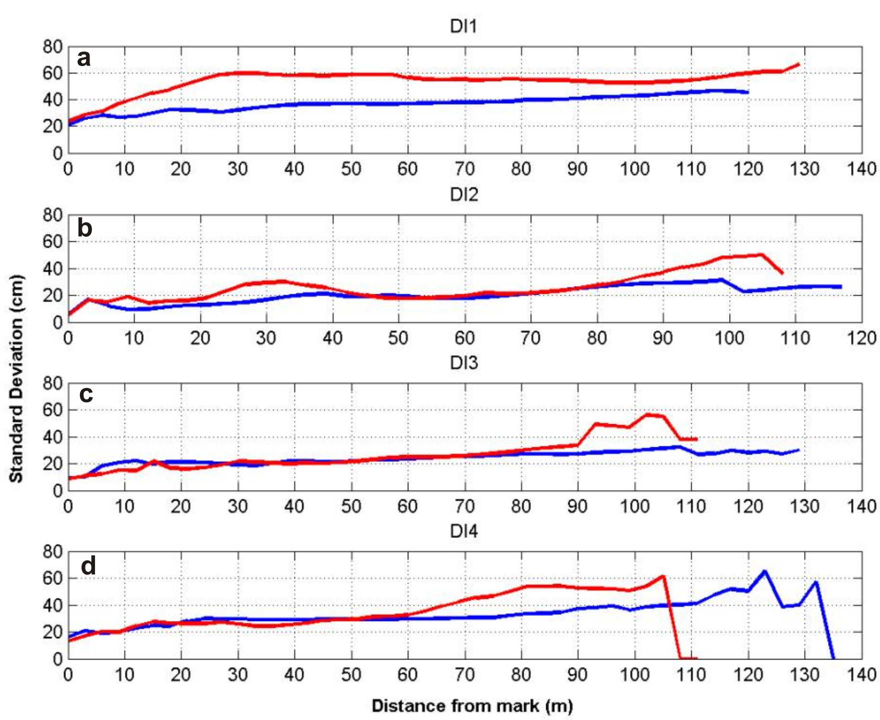

Figure 124. (a) Standard deviation data for DI1 indicate large amounts of summer variability, especially in the berm. (b) Standard deviation data for DI2 indicate slightly more variability in the berm in the summer than the winter. (c) Combined standard deviation data for the different benchmarks at DI3 show that the profile generally undergoes little seasonal variability. (d) Standard deviation data for DI4 indicate significant offshore variability in summer and winter.

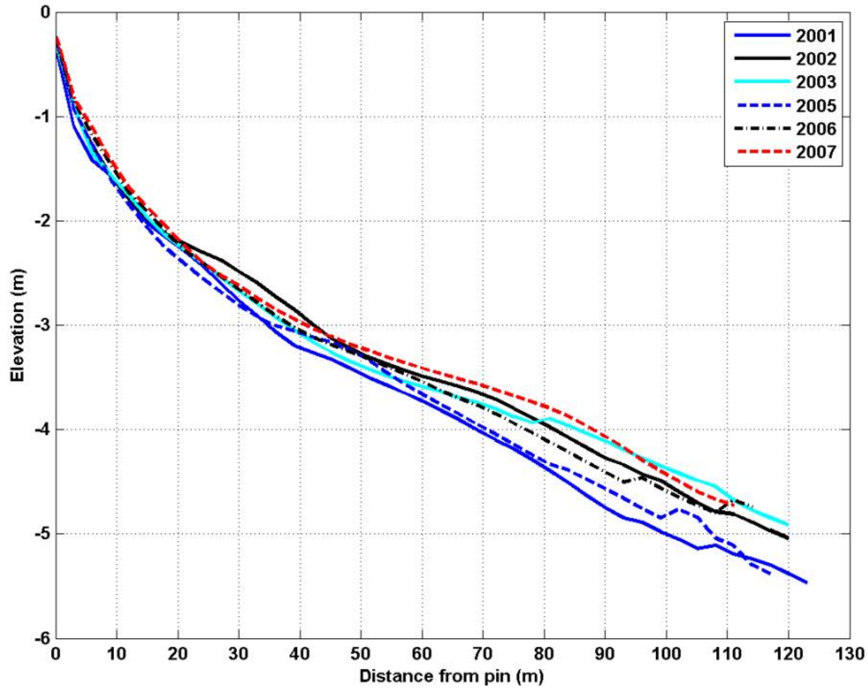

Figure 125. Mean annual profiles for DI2 show that the upper portion of the profile changed little, aside from berm loss, and that the majority of annual variability occurs farther offshore.

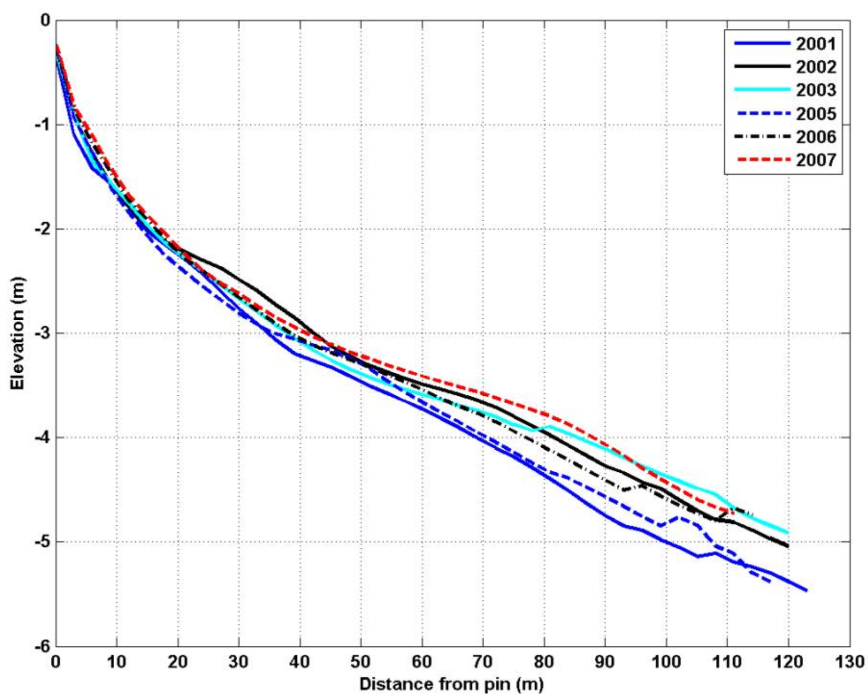

Figure 126. Mean seasonal profiles for DI2 indicate that during the summer, a more defined berm forms, while during the winter, sediment storage offshore increases.

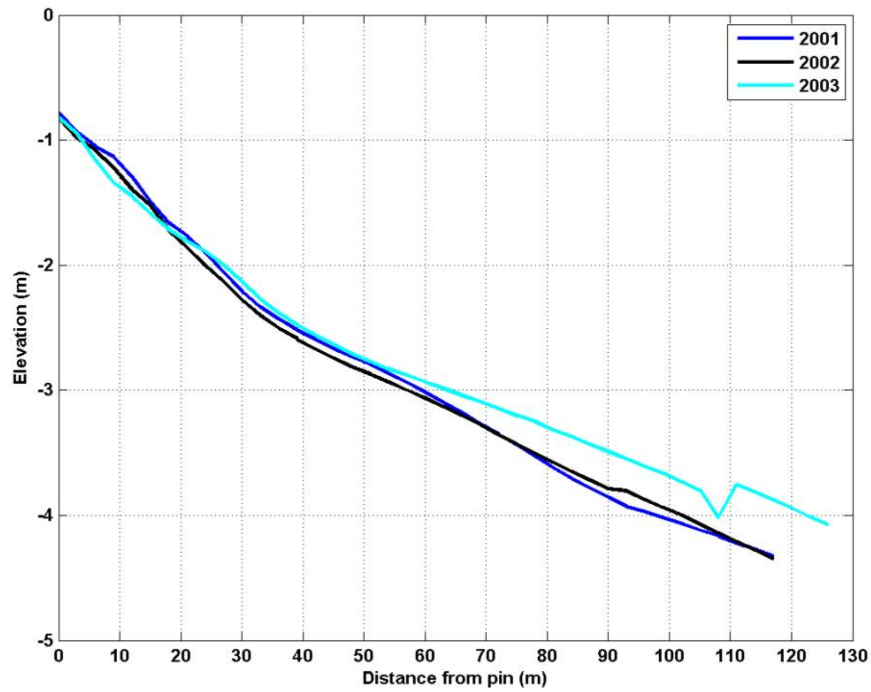

Figure 127. Mean annual profiles for DI3FS show that between 2001 and 2003, the berm receded, while the amount of sediment offshore increased.

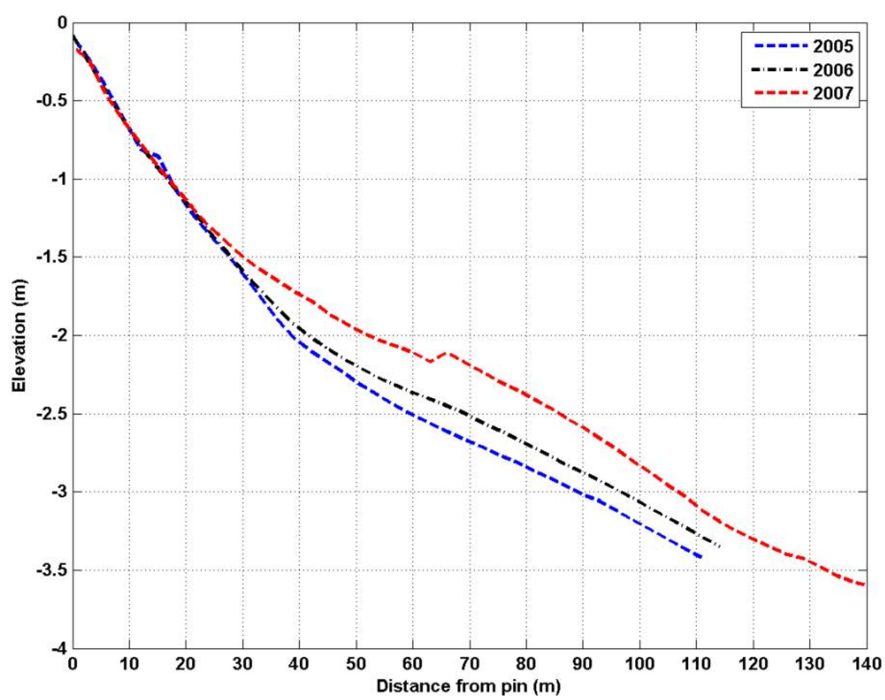

Figure 128. Mean annual profiles for DI3BS show that the upper portion of the profile remained markedly stable between 2005-2007, with relatively large amounts of accretion farther offshore.

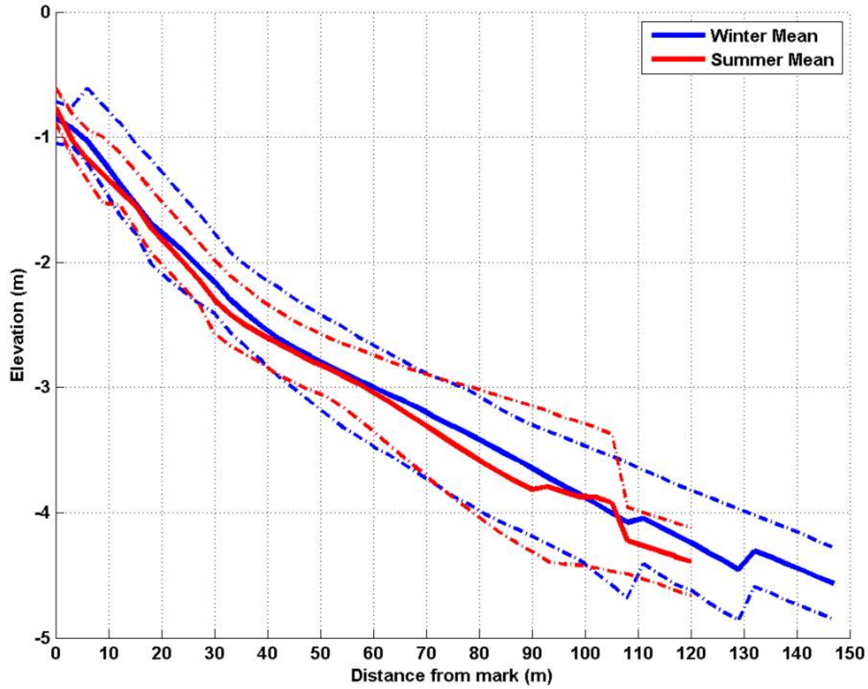

Figure 129. Mean seasonal profiles for DI3FS show that during the winter, more sediment is located on the upper portion of the profile in a series of berms, and offshore, than in summer.

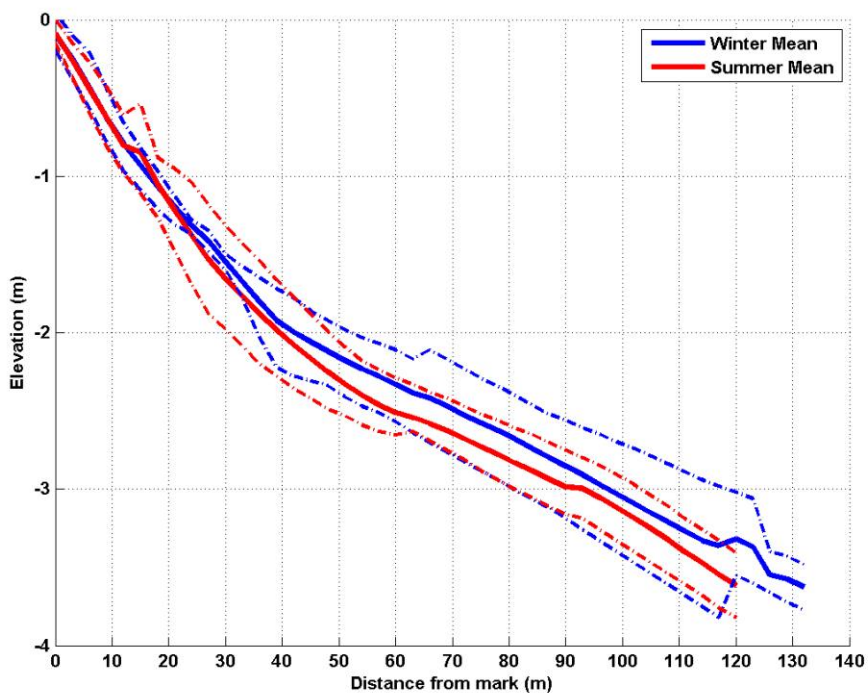

Figure 130. Mean seasonal profiles at DI3BS show that during the winter, more sediment appeared to be located along the profile than during the summer.

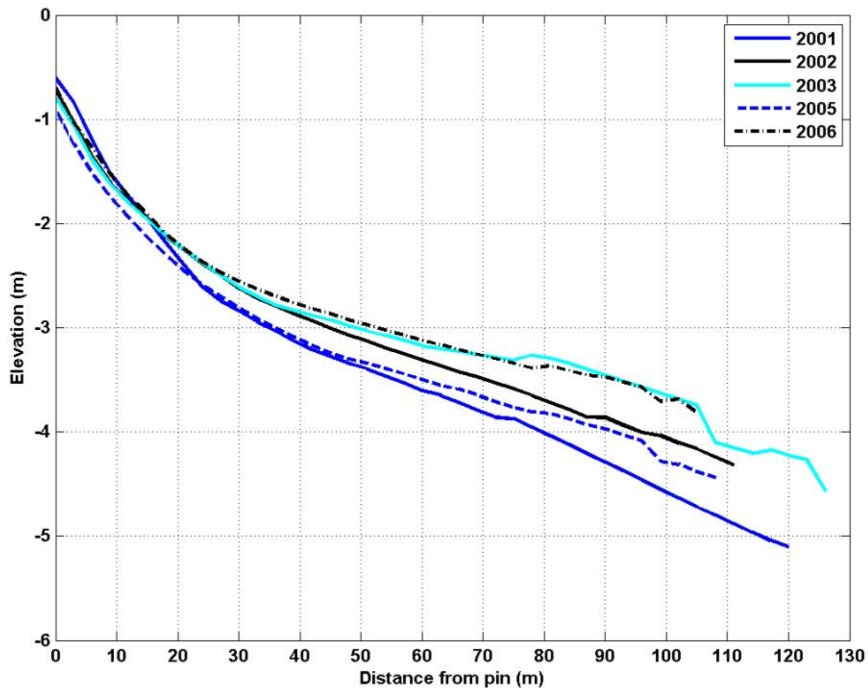

Figure 131. Mean annual profiles from DI4 show that the beach underwent accretion between 2001-2003, erosion between 2003-2005, and accretion in 2006.

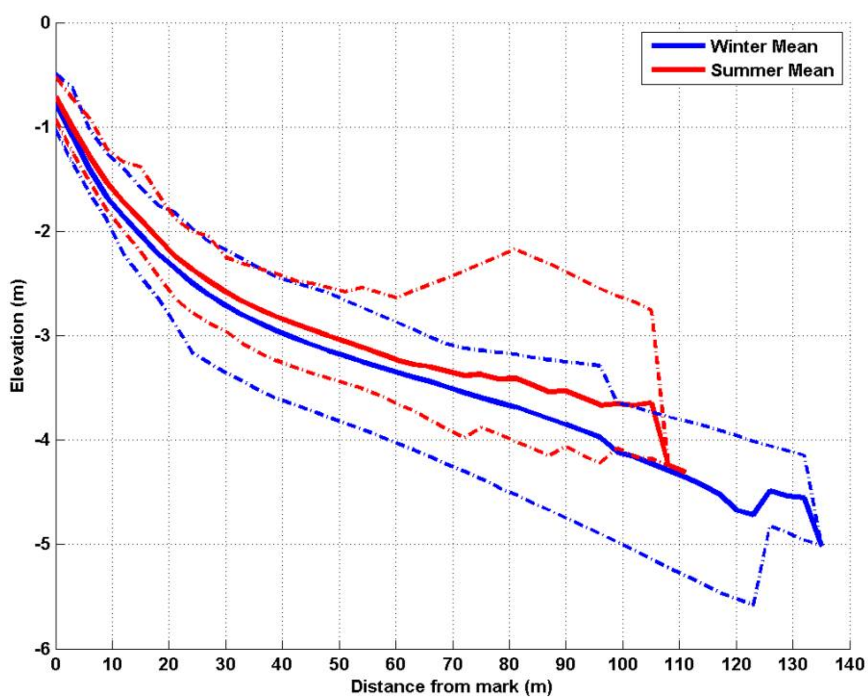

Figure 132. Mean seasonal profiles for DI4 indicate that the summer profile typically has a greater volume of sediment along the entire profile.

Wells Beach, Wells

Background geology and characteristics

Wells Beach is a highly developed barrier beach that extends from its northern terminus at the Webhannet River southward to the rocky headland of Moody Point. The beach here has undergone general erosion, aside from an area of accretion adjacent to the jetty at the Webhannet River. Jetties were constructed in the 1960s in order to stabilize the entrance to the river; in so doing, a sediment trap was created that tends to accumulate sediment on either side of the jetty.

Moody Beach is an approximately 1.9 km long stretch of barrier that trends northeast-southwest. It is bound in the north by the bulbous headlands of Moody Point, and its southern end continues into the contiguous stretch of Ogunquit Beach. Together, Moody Beach and Ogunquit Beach comprise one of the longest continuous barrier spits in Maine. Currently, Moody Beach is not part of the SMBPP volunteer monitoring.

Wells Beach has 4 measured beach profiles, WE1-WE4. The overall beach is shown in **Figure 133**. None of the starting marks had been surveyed by MGS at the time of report preparation.

Annual and seasonal beach profile changes

Data at the Wells Beach profiles were available for the years of 2003-2007. The annual mean profiles for the data collection period from WE1 exhibit marked variability. What appears as a significant accretion along the dune and berm between 2003-2004 (**Figure 134**), with dramatic deepening of the profile and sediment loss starting at the 30 m mark (roughly 3 m below the pin) is a result of the lack of a fixed starting pin on the seawall. The 2005 mean profile is quite similar to the 2003 profile shape. The profile starting point moved between 2006 and 2007 so the apparent 1-1.5 m of elevation gained along the entire profile from 2005-2006 is an artifact of different starting points. An additional 0.5 m of elevation occurred in 2007. This much change is possible, due to sand transport in the longshore drift around Casino Point. Seasonal data (**Figure 135**) indicate that DI1 tends to have a much more sediment-rich berm in the summer rather than the winter. Both seasonal profile envelopes indicate large possible variations of over 1 m. Standard deviation data (**Figure 136a**) indicate that the winter profile has slightly more berm fluctuation (up to almost 60 cm) than the summer profile, concentrated at about the 40 m mark.

The beach at WE2 underwent erosion along its entire length from 2003-2004 (**Figure 137**); this continued into 2005, which exhibited the lowest elevations of all profiles collected. The 2006 mean profile indicates that accretion occurred along the majority of the profile, while the 2007 profile exhibited erosion back to the 2005 profile level (out to about 40 m from the pin), then slightly less erosion along the remainder of the profile. Based on available seasonal data (**Figure 138**), WE2 exhibits the typical summer vs. winter profile shape, with more sediment in the upper portions of the profile during the summer rather than the winter. The berm elevation is higher in the summer as well. The profile envelopes and standard deviations indicate greater variability in the entire profile in the summer rather than the winter. Summer berm variability, based on seasonal data, appears to be greatest at about the 40 m mark, with up to about 50 cm of vertical change (**Figure 136b**).

Profile data at WE3 included 2003 and 2005-2007. Again, the 2003 profile had the largest volume of sediment, while the 2005 profile exhibited the leanest, most erosive features (**Figure 139**). Profile recovery occurred in 2006 and 2007, though the profile never came close to reaching its 2003 elevations. Seasonal data (**Figure 140**) show a well developed summer berm that flattens with winter. Profile envelopes show relatively dramatic berm variations are possible during the summer. Standard deviation data (**Figure 136c**) indicate that the largest summer deviations occur around 40 m offshore, likely the position of the berm, which fluctuates on the order of 40 cm. The largest variations in winter data tend to occur offshore (120 m and greater from the pin), fluctuating over 50 cm.

Unlike WE1-WE3, the beach at WE4 was not at its fullest in 2003. Between 2003 and 2005, the beach underwent accretion at the uppermost portion of the profile (within 10 m from the pin), and in the berm area, between 20-30 m from the pin (**Figure 141**). The lower portions of the profile did undergo erosion. From 2005-2006, the areas of accretion that occurred previously were eroded, but accretion occurred along the profile from about 35 m and seaward from the pin. The entire profile appears to have accreted in 2007. Seasonal data (**Figure 142**) indicate a typical summer vs. winter profile relationship, with much greater volumes of sediment in the berm area during the summer, and more sediment offshore in the winter. Standard deviation data show that the berm does not fluctuate significantly during the summer (generally 25 cm or less), though variability of elevation in the winter appears to be much greater (about 50 cm). In fact, the entire profile appears to be much more variable in the winter rather than the summer, indicating seasonal stability (**Figure 136d**).

Generally, the beaches at Wells underwent significant erosion in 2005, with slight recovery in 2006 and 2007. The jetties at the Webhannet River appear to significantly influence the profile shapes that are more proximal to the structures, since they trap any sediment that is migrating in a northern direction, towards the river mouth.

Figure 133. Wells Beach has 4 measured beach profiles, WE1-WE4. The starting marks for the profiles have not been surveyed by MGS as of April 2007. The 4 profiles are approximately located on the figure.

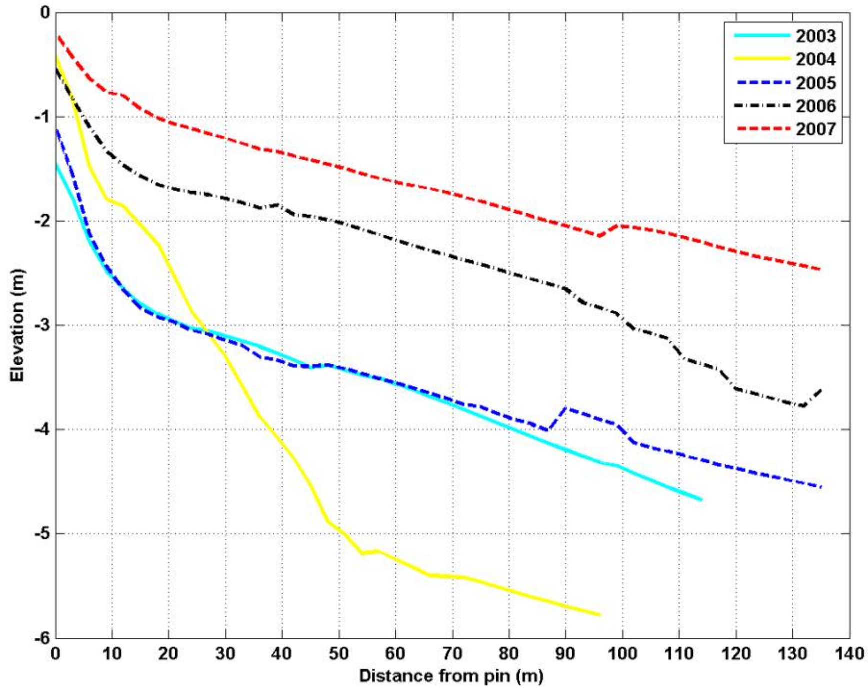

Figure 134. Mean annual profiles for WE1 showed stability between 2003-2005; it is difficult to gauge profile changes since the starting point changed between 2005-2006. Accretion occurred between 2006-2007.

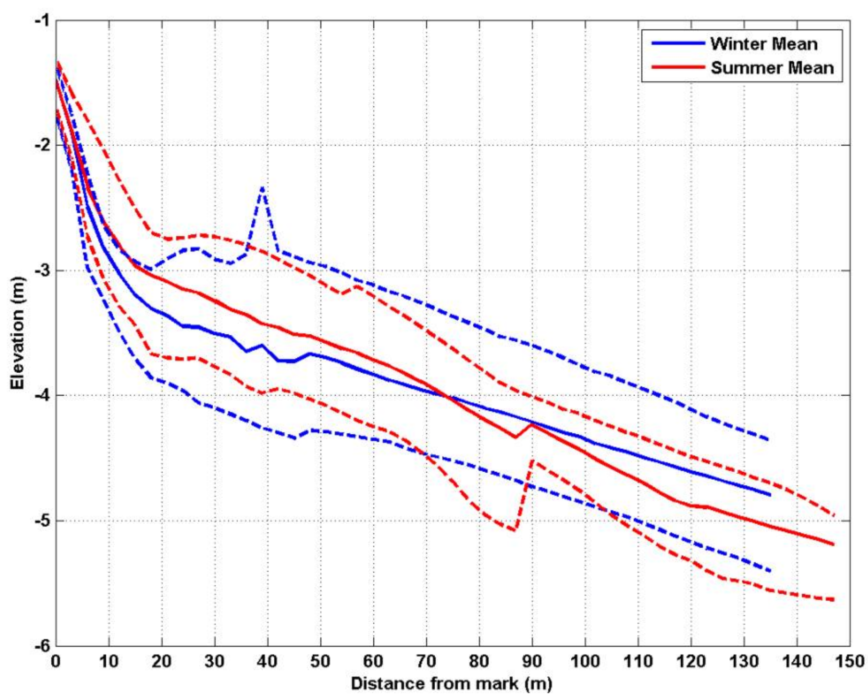

Figure 135. Mean seasonal profiles for WE1 show that the profile has a better developed berm in the summer rather than the winter.

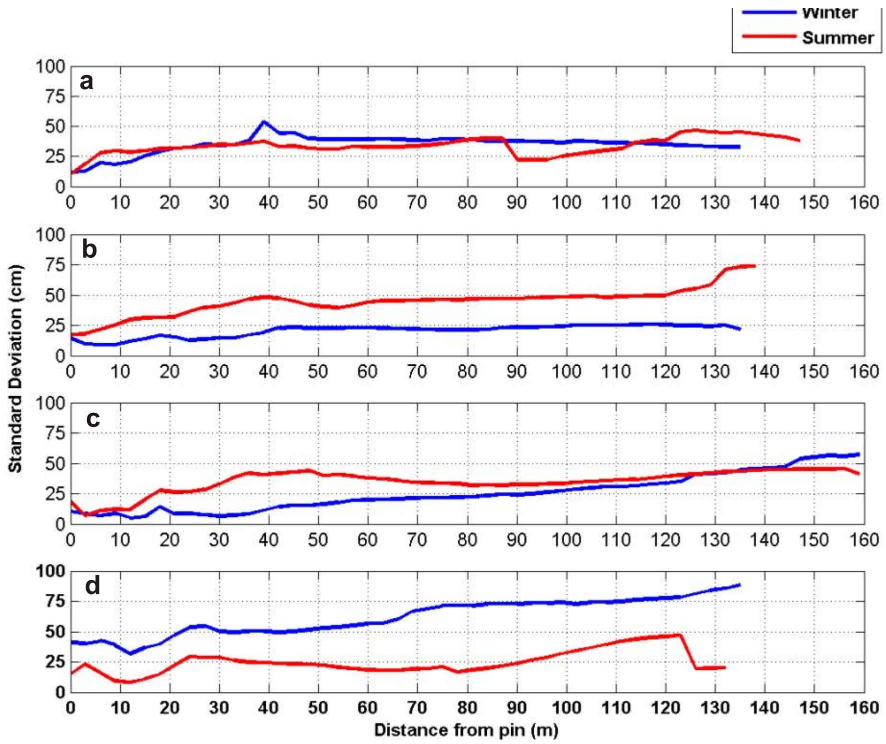

Figure 136. (a) Standard deviation data for WE1 indicate that the winter berm has slightly more variability than the summer shape. (b) Standard deviation data for WE2 show that the summer profile has much more variability than the winter profile, with a well defined berm. (c) Standard deviation data for WE3 indicate that the largest seasonal fluctuations occur in the summer and at the berm position of the profile. (d) Standard deviation data for WE4 show that the winter profile is much more variable than the summer profile.

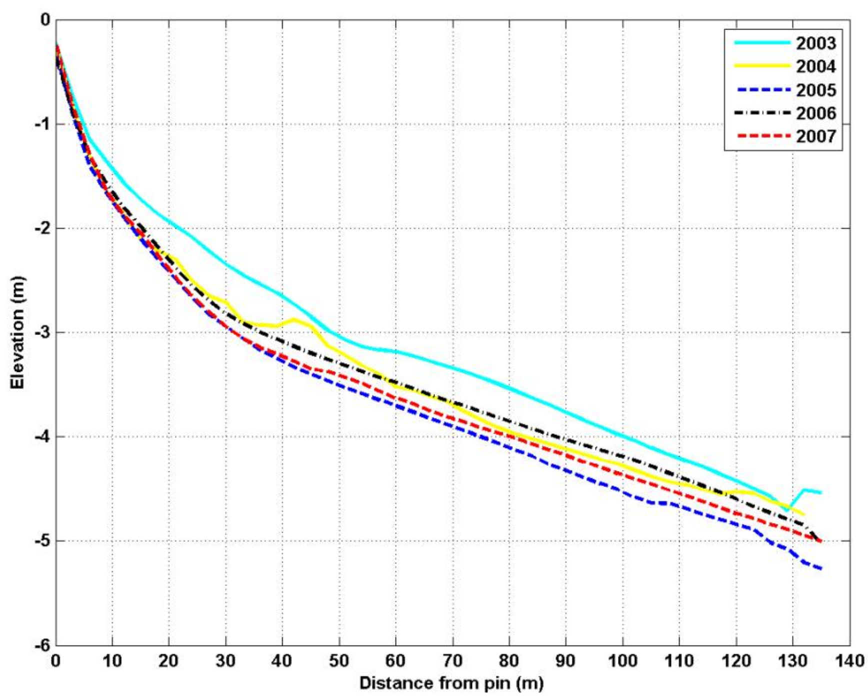

Figure 137. Mean annual profiles from WE2 show that the beach underwent erosion from 2003-2005, then recovery in 2006, and additional erosion in 2007.

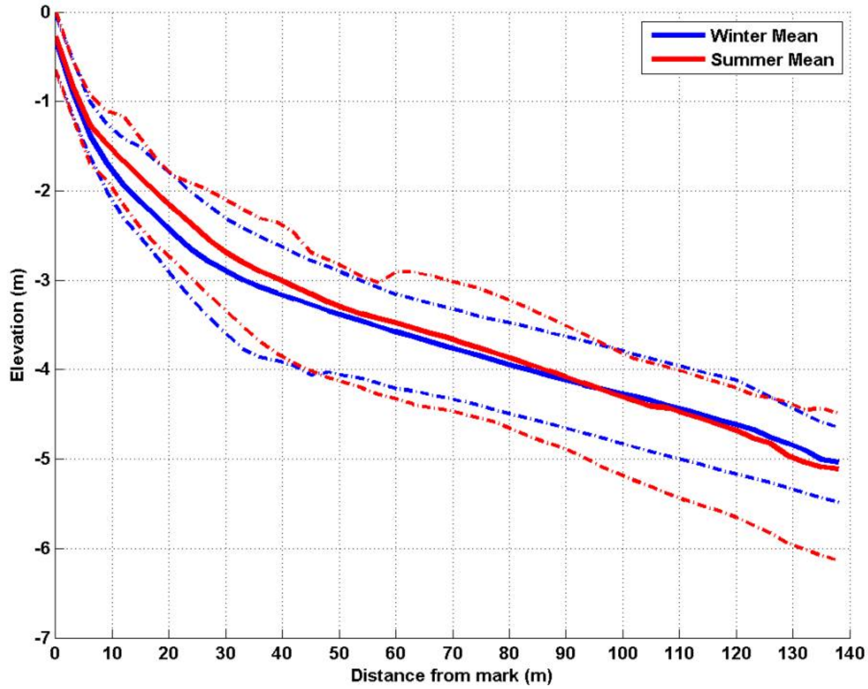

Figure 138. Mean seasonal profiles at WE2 exhibit typical summer vs. winter shapes, with more sediment in the berm area during the summer.

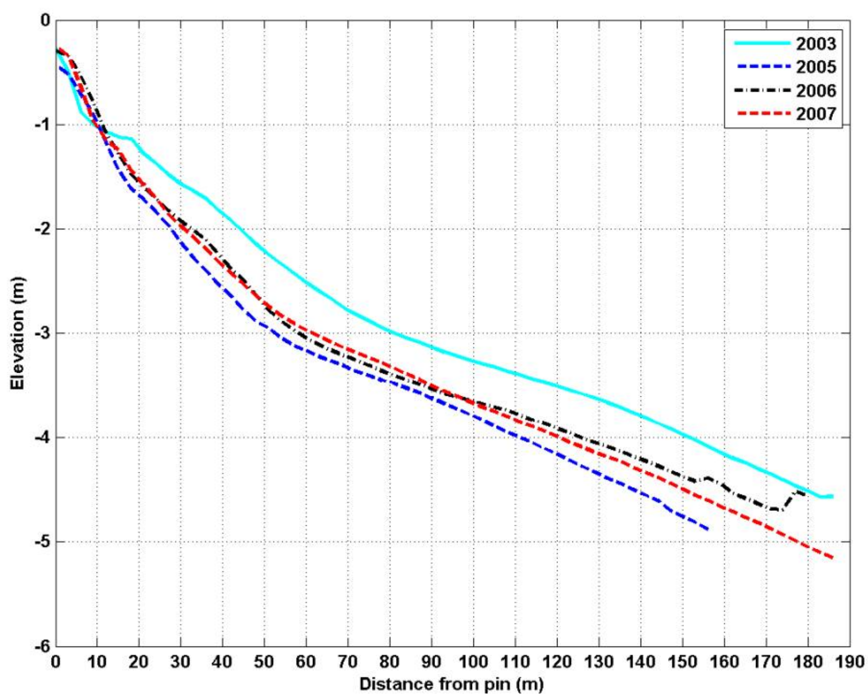

Figure 139. Mean annual profiles for WE3 show that the beach eroded from 2003-2005, and began recovery in 2006-2007.

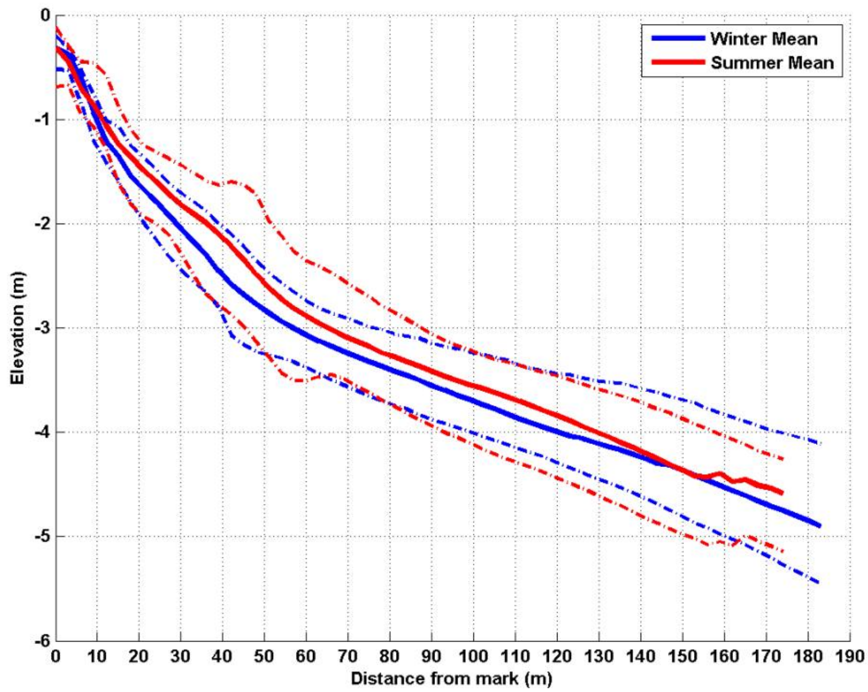

Figure 140. Mean seasonal profiles at WE3 exhibit a typical summer profile shape, with a better developed berm, while the winter profile is flatter.

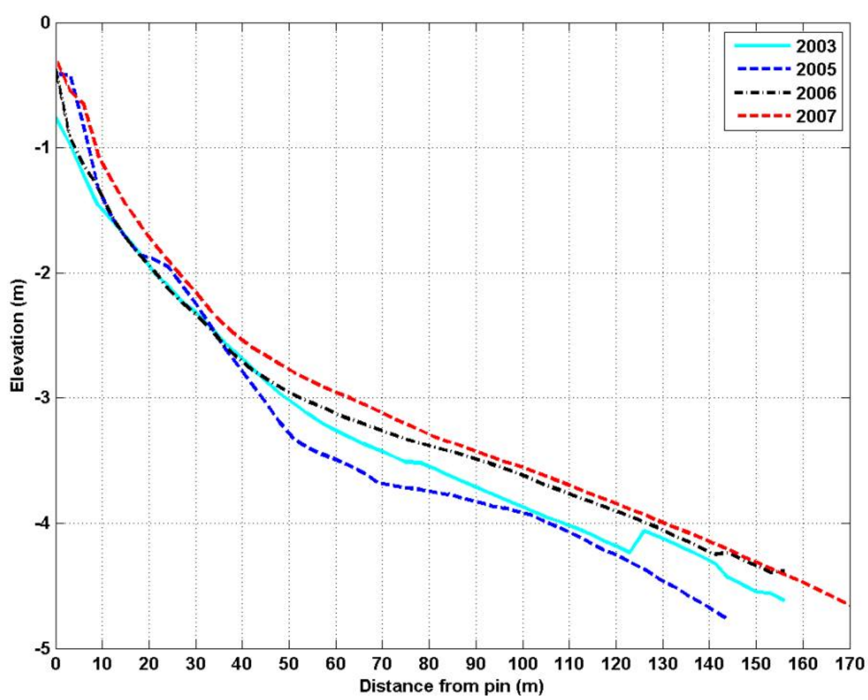

Figure 141. Mean annual profiles for WE4 show erosion from 2003-2005, then accretion in 2006 and 2007.

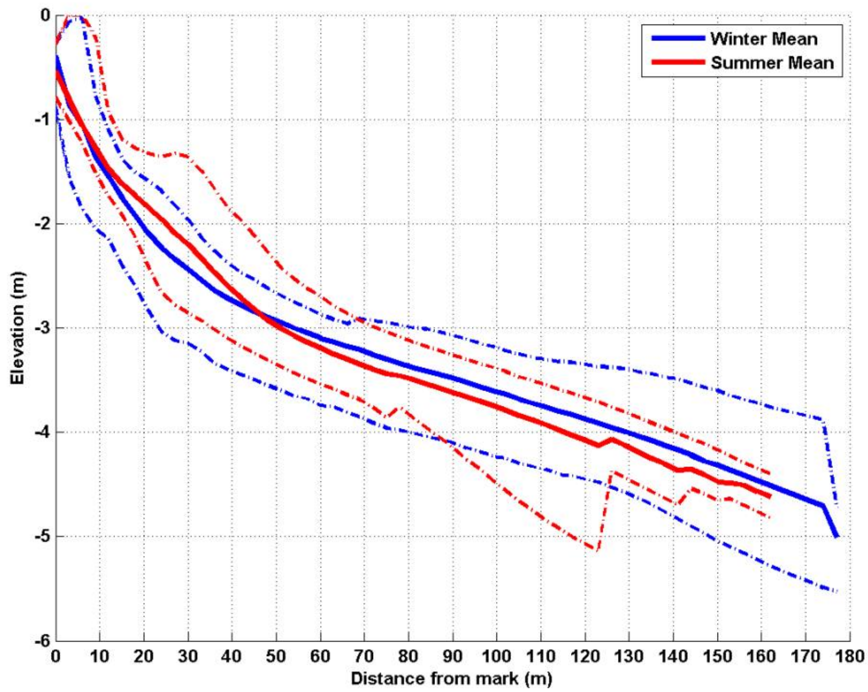

Figure 142. Mean seasonal data at WE4 show a typical summer vs. winter beach shape.

Ogunquit Beach, Ogunquit

Background geology and characteristics

Ogunquit Beach, located just south and contiguous with Moody Beach, extends southwards from the boundary with Moody Beach for approximately 2.2 km and terminates at the Ogunquit River as a barrier spit that abuts a bedrock headland. The Ogunquit spit most likely formed with transgression of the sea over a low-lying coastal plain of glacial outwash (Heinze, 2001). The spit is prograding into the inlet as a result of a net southerly longshore transport of sand. Once sand reaches the inlet, it circulates in a counterclockwise gyre, and is deposited both in the ebb and flood-tidal deltas.

Dunes along this beach are primarily artificial and were built in 1974 and 1975 by the Department of Agriculture's Soil Conservation Service (Dickson, 2005). The dunes are cored with gravel and sand imported from an upland source. The top elevation of the dune exceeds the floodplain height and the seaward slope of the dunes is unnaturally steep. Behind the dunes is an extensive back barrier salt marsh system. Erosion has removed part of the frontal dune in the last decade, although there are periods of dune accretion as a result of a relatively successful dune management plan by the Town of Ogunquit. Nelson (1979) found no significant erosional or accretional trend, although the data are strongly influenced by the dike construction in the 1970s. More recent analysis by MGS shows that the dune is relatively stable though the seaward edge may recede rapidly 3 to 6 meters (10 to 20 feet) in response to large storm events (such as the series of northeasters the week of Memorial Day 2005 or the Patriots' Day Storm in 2007). All of Ogunquit Beach is part of the Coastal Barrier Resources System (Dickson, 2006a).

Ogunquit Beach has 4 measured beach profiles, OG1-OG4. The overall beach is shown in **Figure 143**. The starting marks have not yet been surveyed by MGS.

Annual and seasonal beach profile changes

The beach profiles along Ogunquit Beach all start within or behind the frontal dune crest. Data at OG1 were available between 2001 and 2006. From 2001-2002, the profile underwent accretion, especially from the berm seaward (**Figure 144**). Erosion occurred in 2003, removing sediment from the upper portion of the profile, while areas of the profile below about -4 m below the pin (at the 120 m mark) accreted. 2004 data indicate that the profile continued to erode along its entire length, most notably in the offshore area where storage occurred in 2003. Profile lowering and erosion continued in 2005 and 2006, with 2005 being the most erosive. Between 2001 and 2006, the profile lost up to 0.5 m of sediment vertically along its length. Seasonal data at OG1 (**Figure 145**) show that the beach profile undergoes typical seasonal changes, with accretion in the berm and upper portions of the profile (out to 130 m from the mark) during the summer, and erosion and offshore sediment storage in the winter. The maximum envelope for the summer profile reaches a much higher elevation than the winter one. Standard deviation data (**Figure 146a**) show large summer berm variation, between 40 and 60 cm, over a large portion of the profile (out to 130 m). The variable berm crest appears to be located at about 40-50 m from the mark. Winter variability appears to be 30 cm or less.

Data at OG2 were available for 2001-2007. The beach at OG2 underwent similar changes as OG1, with substantial accretion between 2001-2002, recession in 2003 (back to near 2001 conditions, **Figure 147**). The 2004 mean profile shows little change from 2003, with some accretion in the offshore portion of the profile. Slight erosion along the profile occurred in 2005, with fairly dramatic erosion into 2006. 2007 saw slight berm growth and recovery, but loss of sand in the offshore. Seasonal data (**Figure 148**) indicate little difference between the summer and winter profile shapes, with a slightly better developed berm during the summer. The standard deviation data (**Figure 146b**) show that the berm and beach for both summer and winter are quite variable, with winter changes on the order of up to 60 cm vertically, and 40-50 cm vertically during the summer.

Similar to OG1 and OG2, the profile at OG3 underwent accretion from 2001-2002, followed by erosion to near 2001 conditions in 2003 (**Figure 149**). Additional erosion occurred in 2004, with substantial berm loss in 2005 and 2006. 2007 saw slight berm recovery, though the dune appears to have been eroded and the profile lowered in the offshore. Seasonal data show typical winter vs. summer profile shapes (**Figure 150**), with an inflection point at 110 m offshore. The calculated standard deviation data show summer berm variability up to about 40 cm, concentrated at about the 60 m mark (**Figure 146c**). Winter data show variability of 30 cm or less.

Unlike the others, OG4 demonstrated very similar profiles between 2001-2002, with only slight accretion at the berm at the 40 m mark in 2002 (**Figure 151**). No data were available from 2003. In 2004, the profile eroded at the berm and upper portions, but stayed the same farther offshore. 2005 saw additional berm lowering and the entire profile's elevation lowered. The dune and berm continued to recede in 2006. In 2007, the dune lowered

Figure 143. Ogunquit Beach has 4 measured beach profiles, OG1-OG4. The starting marks for the profiles have not been surveyed by MGS as of April 2007. The 4 profiles have been approximately located on the figure.

further, though a small berm developed at about 20 m from the pin. Erosion continued farther offshore on the profile. Seasonal data (**Figure 152**) show a slightly more prominent summer berm, with more sediment offshore in the winter. The highest variability was in the berm, which fluctuated during the summer up to 60 cm, at about the 40-50 m mark. Winter variability was about 20 cm along the entire profile (**Figure 146d**).

The beach profiles at Ogunquit indicate that the beach is undergoing erosion during the time period that data were collected. Significant erosion seems to accompany larger storm events, like the May 2005 northeasters and the Patriots' Day Storm of 2007. Profiles also appear to undergo expected seasonal changes with summer berm development (albeit highly variable), and winter offshore sediment storage.

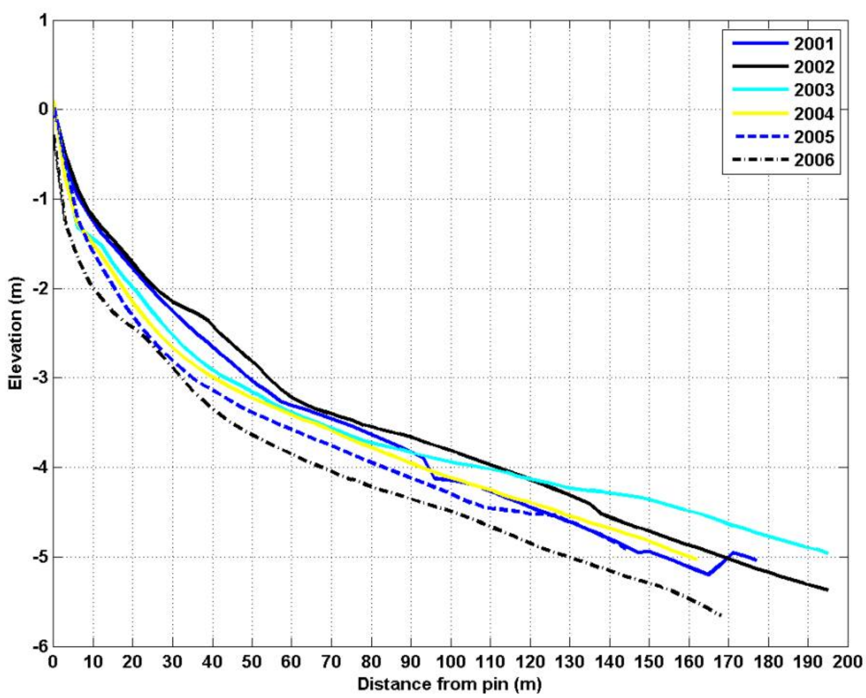

Figure 144. Mean annual profiles at OG1, aside from some accretion in 2001-2002, showed a consistent erosive trend through 2006.

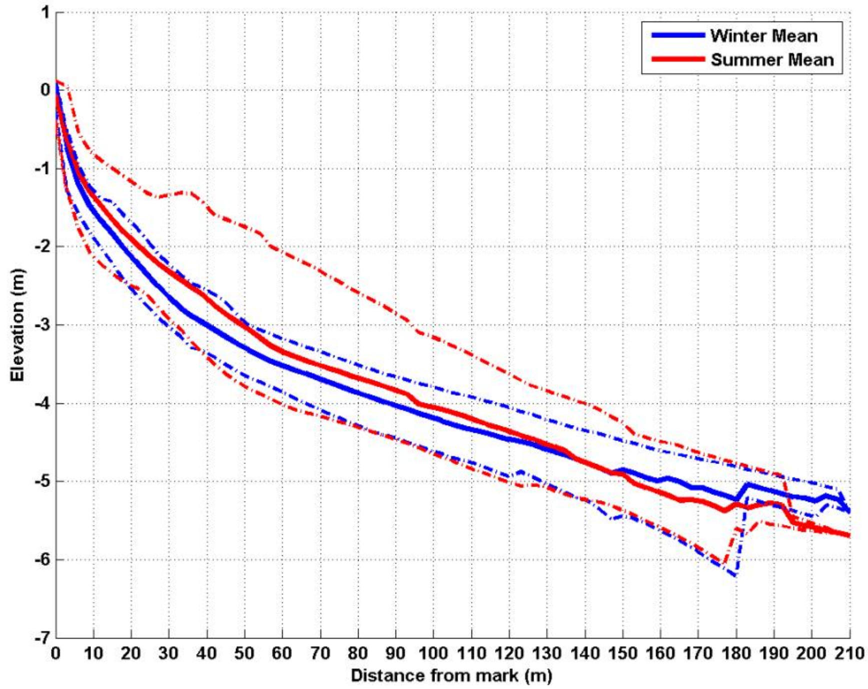

Figure 145. Seasonal profile data at OG1 exhibit a typical summer vs. winter beach profile shape.

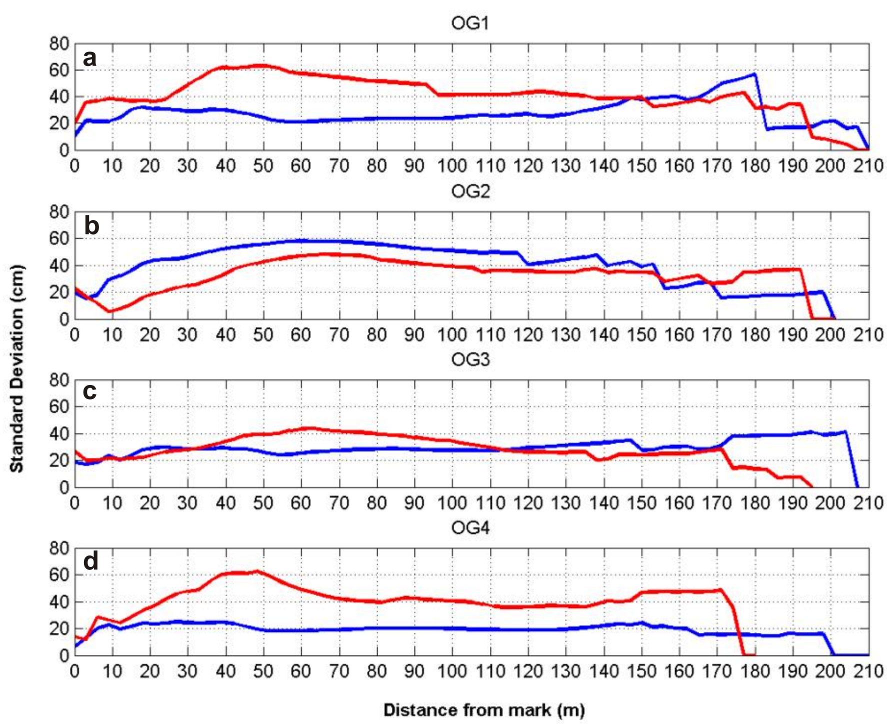

Figure 146. (a) Standard deviation data for OG1 show that summer berm variability is great, while the winter profiles do not fluctuate as much. (b) Data at OG2 indicate that both summer and winter profiles have a large amount of variability, especially in the berm area. (c) Data indicate that the beach at OG3 undergoes larger fluctuations during the summer (in the berm area) than the winter. (d) At OG4, standard deviation data show that the summer profile shape is highly variable, while the winter shape is much more stable and consistent.

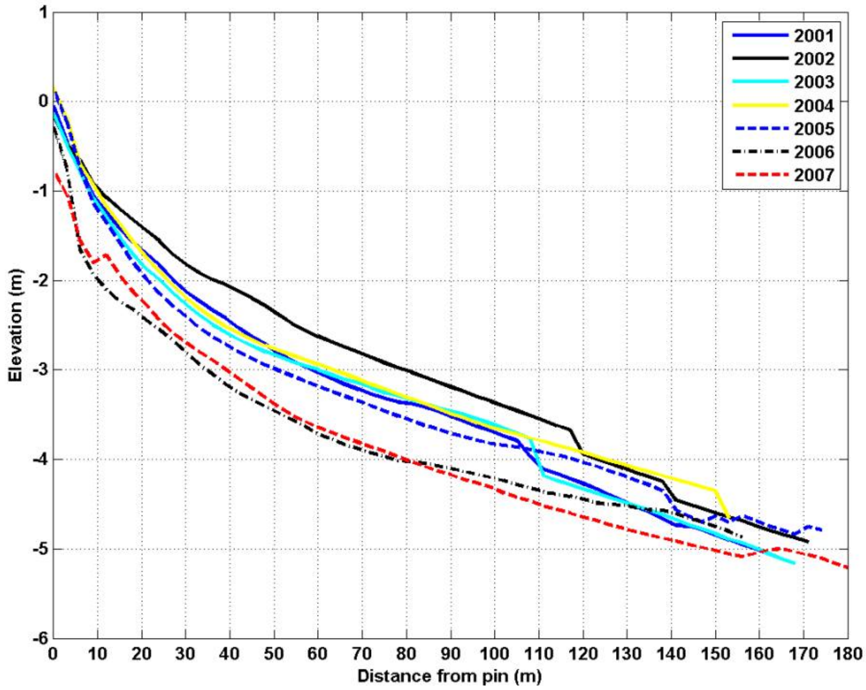

Figure 147. Mean annual profiles at OG2 show that the profile was at its most accretive shape in 2002, and generally, has been erosive through 2006, with slight accretion in 2007.

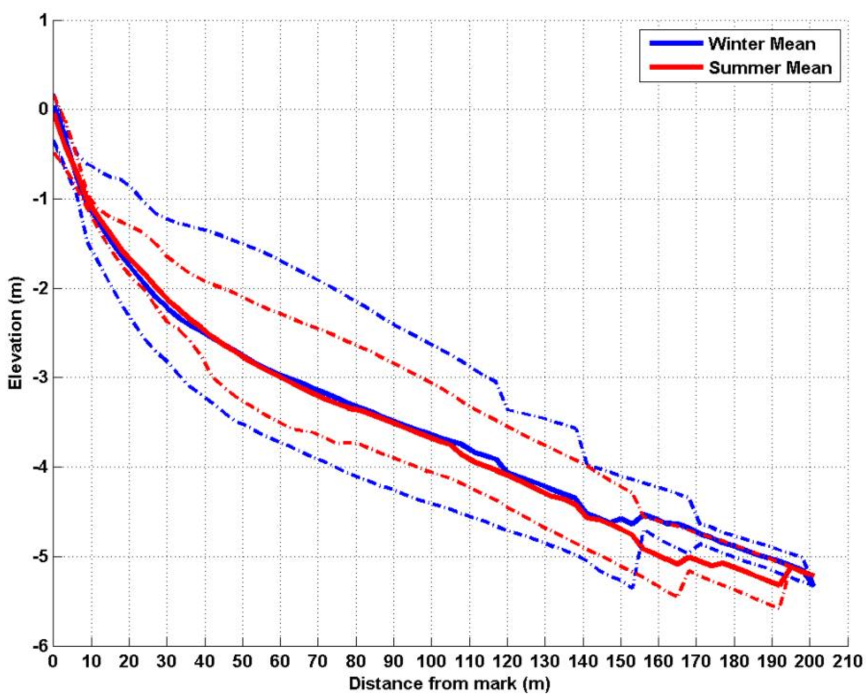

Figure 148. Seasonal mean data show that OG2 does not undergo marked changes between the summer and winter.

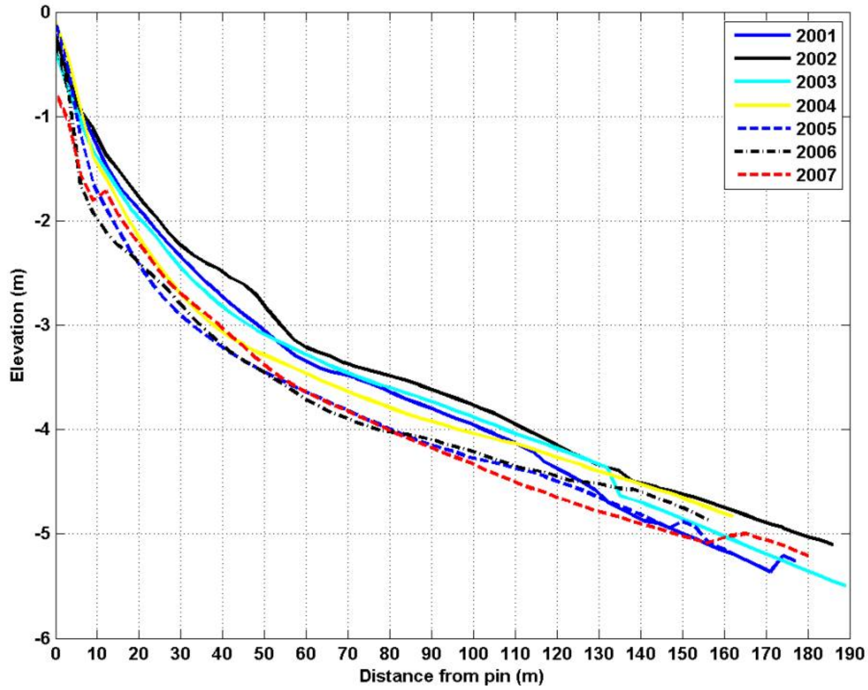

Figure 149. Similar to OG2, the mean annual data at OG3 exhibit the most seaward profile in 2002, with consistent erosion through 2006, and some accretion in 2007.

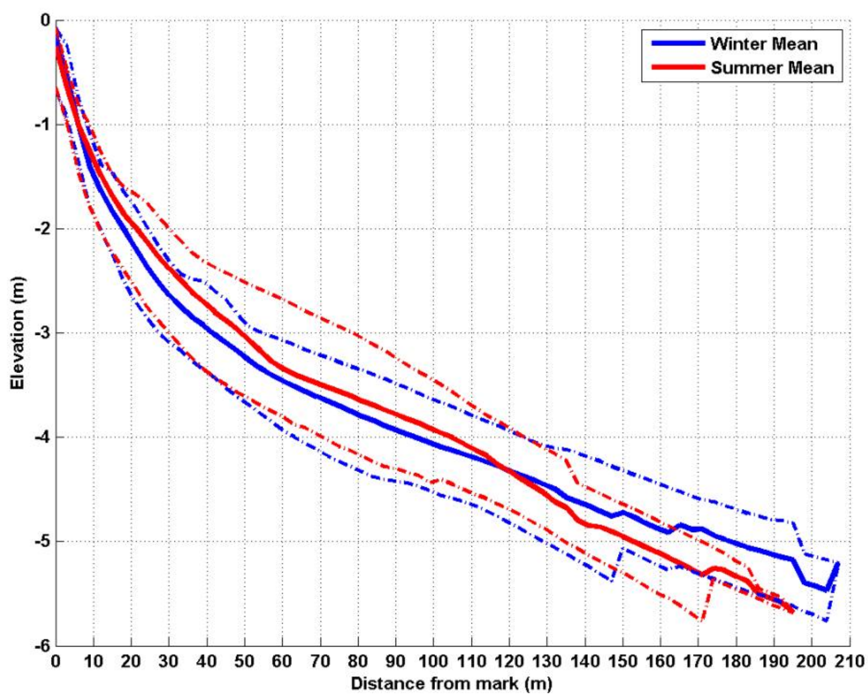

Figure 150. Seasonal profile data at OG3 show a typical winter vs. summer profile difference.

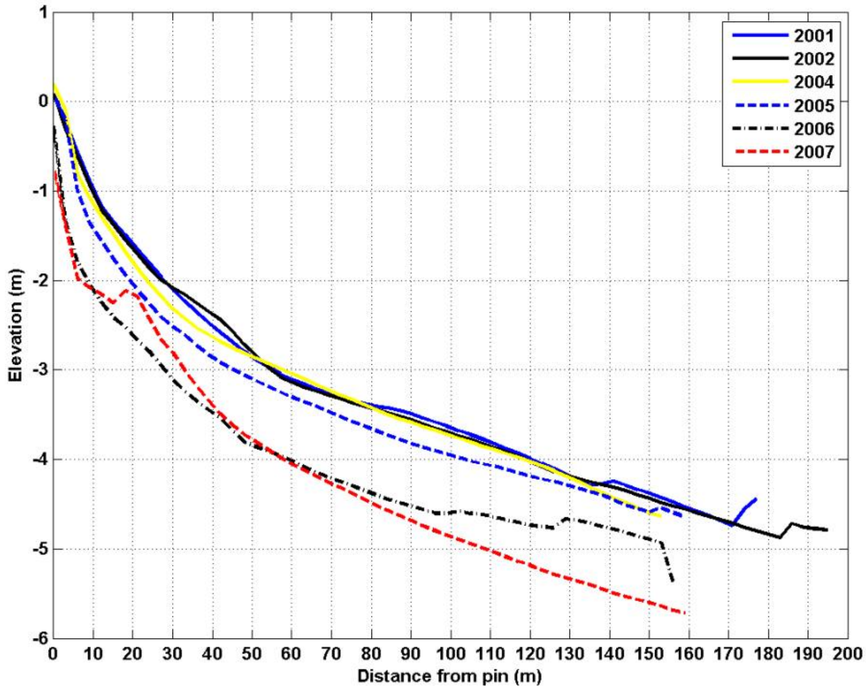

Figure 151. Mean annual data for OG4 show continued erosion through 2006, with slight accretion in 2007 at the upper portion of the profile.

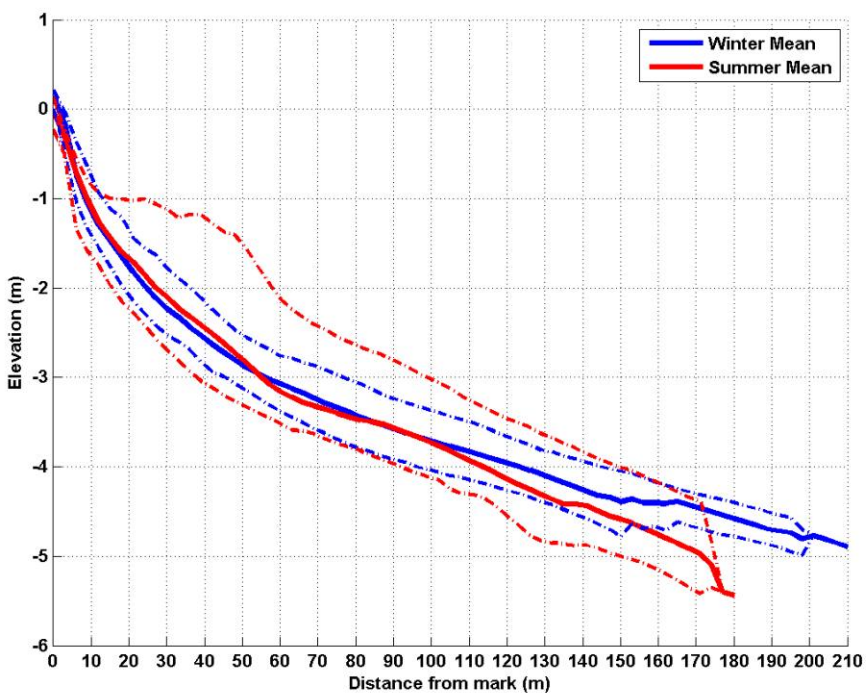

Figure 152. Seasonal mean profile data for OG4 demonstrate traditional winter vs. summer profile shapes.

Long Sands Beach, York

Background geology and characteristics

Long Sands Beach in York is an approximately 2.2 km long stretch of fringing beach generally oriented southwest-northeast. It is bounded by bedrock of Cape Neddick to the north, and Cow Beach Point to the south. Long Sands Beach is heavily armored with a seawall along its entire stretch. There are little to no natural sand dunes along the beach. Horizontal shoreline change along the beach is difficult to detect due to the presence of seawalls.

Long Sands Beach has 4 measured beach profiles, LS1-LS4, all located on parking signs built into the seawall. LS1 is located east of Oceanside Avenue, while LS2 is located midway between Juniper Road and Beacon Street. LS3 is located along Long Beach Avenue just south of Mitchell Road, and LS4 is located along Long Beach between Tralee and Dingle Roads (**Figure 153**). All starting points were surveyed by MGS in 2005.

Annual and seasonal beach profile changes

At Long Sands Beach, all profiles start from a seawall. The data available at LS1 were from 2001-2002, and 2005-2007. It appears that a different starting point was used at LS1 for 2001-2002 data collection, and data from 2003-2004 were not entered into the online database (**Figure 154**). From 2001-2002, LS1 experienced slight lowering adjacent to the seawall, but berm growth at about the 30 m mark. From 2005-2006, the upper portion of the profile (from about 70 m from the mark landward, or about an elevation of 0.6 m NAVD) underwent slight recession and scarping adjacent to the wall. During the same time, seaward of the 70 m mark, the beach accreted. In 2007, the upper portion of the profile, from about 100 m from the mark landward, accreted back to a 2005 position, while seaward of 100 m, some erosion occurred. Seasonal data (**Figure 155**) show that the winter profile had much more sediment than the summer profile; this may be due to skewing of data since two different starting benchmarks were used (i.e., 2001-2002, and 2005-2007). The standard deviation data (**Figure 156a**) show that both summer and winter profiles undergo about the same amount of variation, on the order of 20-30 cm, along the entire length of the profile.

At LS2, data were only available from 2005-2007. During this period, the profile appears to have undergone consistent accretion along its entire length (**Figure 157**). Seasonal data show little prominent summer berm development (**Figure 158**), though there appears to be a slightly larger volume of sediment on the upper portion of the profile (within 20 m of the mark) during the summer. Standard deviation data (**Figure 156b**) indicate similar variability (20-30 cm) between summer and winter (slightly higher in summer) along the entire profile.

LS3 demonstrates a marked break in slope for all profiles at the 40 m from the pin mark, at an elevation around 1 m NAVD (**Figure 159**). This may mark the base of the seawall or an underlying substrate that is difficult to erode, or for sediment that is trying to migrate onshore to move past. From 2005-2006, slight accretion occurred at the top of the profile, while seaward of the 40 m mark, the beach deepened about 30 cm until the 90 m mark, where the 2006 and 2005 profiles became quite similar again. In 2007, accretion occurred, with the beach seaward of the 40 m mark gaining approximately 50 cm in elevation between 2006-2007. Seasonally, LS3 exhibits a more varied summer profile in terms of topography along the upper portion of the profile, and a greater volume of sediment starting at the 40 m mark (**Figure 160**). The standard deviation data (**Figure 156c**) indicate that the profile undergoes more variability during the winter, especially between the 40-95 m area, ranging from about 40-50 cm vertically. The summer profile varies only by about 20 cm until offshore (at 90 m), where variability approaches that of the winter profile. This seasonable difference is likely due to different incoming wave directions and the interannual variability in sand bar locations.

At LS4, data were available from 2002, and 2004-2007. Like LS3, the upper portions of the profile are quite similar until a marked inflection point at around the 20 m mark (elevation between 0 and 1 m NAVD); again, this may mark a hard bottom, base of seawall, or some less erodable underlying surface (**Figure 161**). From 2002-2004, the entire profile gained elevation, with the most notable changes seaward of the 20 m mark. Little change occurred from 2004-2005, and apparently the profile eroded slightly between 2005-2006. In 2007, accretion added sediment to the profile seaward of the 20 m mark. The summer mean profile exhibits a greater concentration of sand along the profile from about the 20 m mark seaward (**Figure 162**). There is more variability in the winter profile at around the 10 m mark (about 30 cm vertically), though the standard deviations of the summer and winter profiles stay similar seaward of this, with around 20 cm of vertical variability (**Figure 156d**).

The beaches at Long Sands Beach generally appear to be stable to accretional. The profiles are generally flat, with little prominent berm features. This may be caused by the large seawall that fronts the entire beach which precludes landward migration of the beach and dune system. Since many high tides reach the seawall (it is a regularly active structure reflecting waves back seaward across the profile) a solid four-season berm does not have the chance to develop along this type of beach. The limited amount of sediment within this beach system means that seasonal variation summer beach and winter bar formation is imperative for the beach to maintain itself. If significant sediment is lost offshore, the lowered profile may not fully recover.

Figure 153. Long Sands Beach has 4 measured beach profiles, LS1-LS4, all located on parking signs built into the seawall. LS1 is located east of Oceanside Avenue, while LS2 is located midway between Juniper Road and Beacon Street. LS3 is located along Long Beach Avenue just south of Mitchell Road, and LS4 is located along Long Beach between Tralee and Dingle Roads.

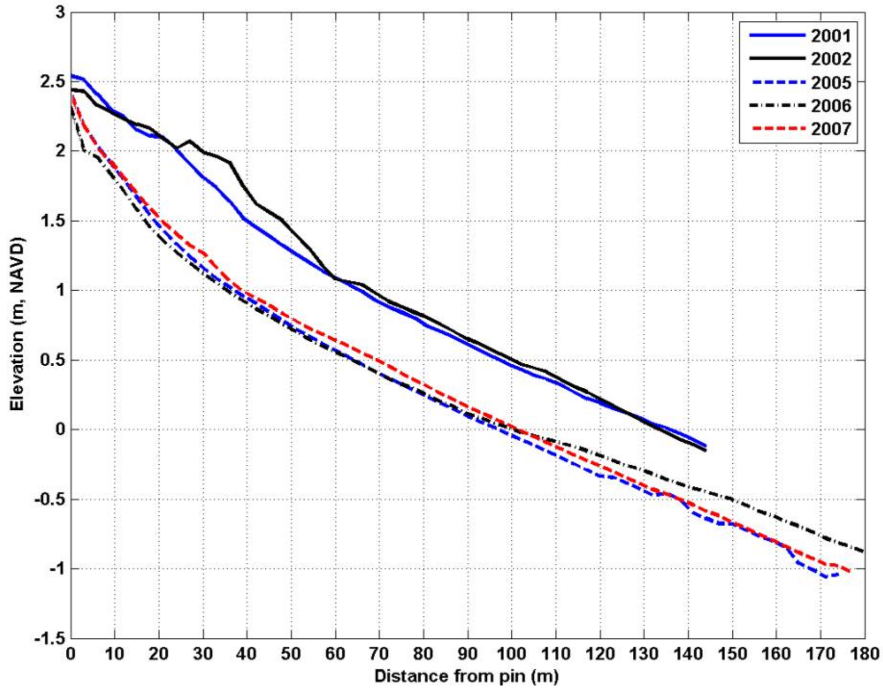

Figure 154. Annual mean profiles at LS1 appear to have been collected from 2 different starting points. From 2001 to 2002 LS1 lost some sand near the seawall, but there was also significant berm growth. Slight erosion near the seawall took place from 2005 to 2006. From 2006 to 2007 the profile near the seawall gained sand at the expense of the lower profile.

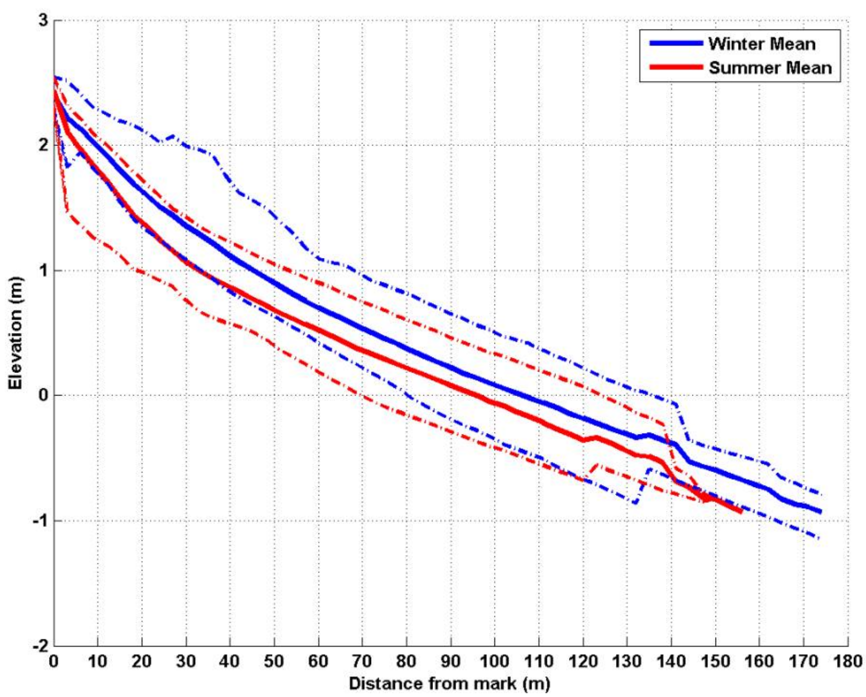

Figure 155. Seasonal profile means at LS1 show more sand on the winter profile than the summer, even near the seawall, but this may be an artifact of two profile starting points. The envelope of profile variation is about a meter in both winter and summer.

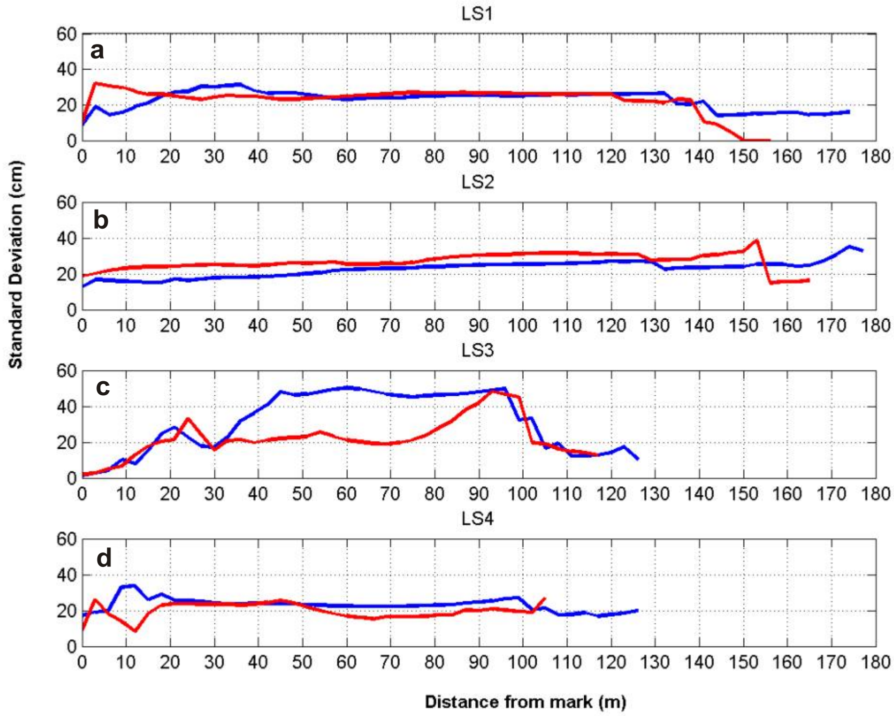

Figure 156. At LS1 (a) standard deviation data show more summer variability in sand elevation against the seawall than in the winter. Most of the profile has 0.2 to 0.3 m of variation in both summer and winter. At LS2 (b) standard deviations are similar in summer and winter with slightly higher variability in summer. At LS3 (c) winter variability is significantly higher than in summer. At LS4 (d) the upper profile has more variability near shore while the rest of the profile is similar between the seasons.

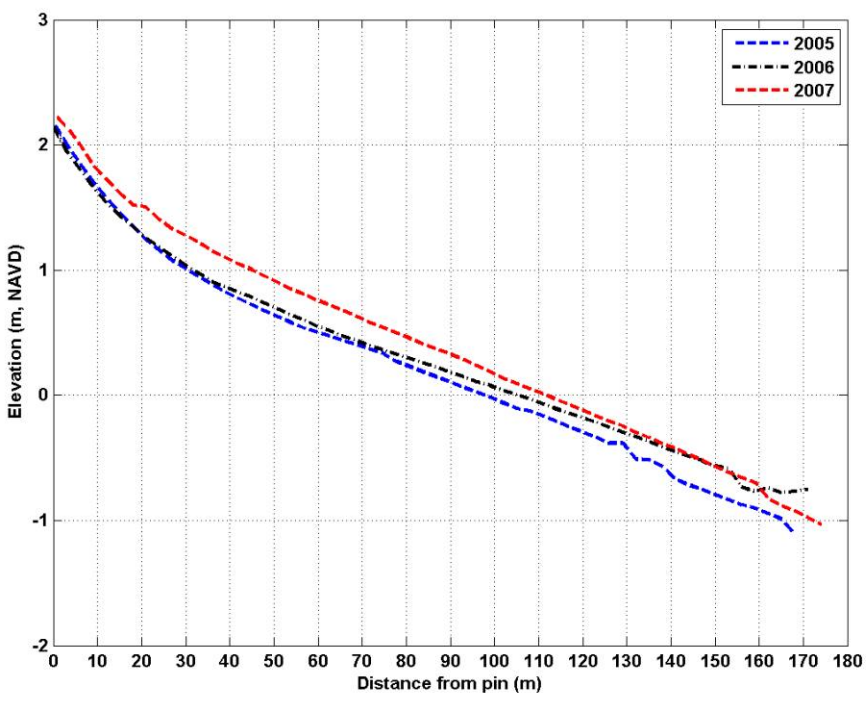

Figure 157. Annual mean profiles at LS2 show accretion from 2005 to 2007. From 2005 to 2006 the largest gain was on the lower profile, but by 2007 the upper profile showed a gain of about 0.2 m.

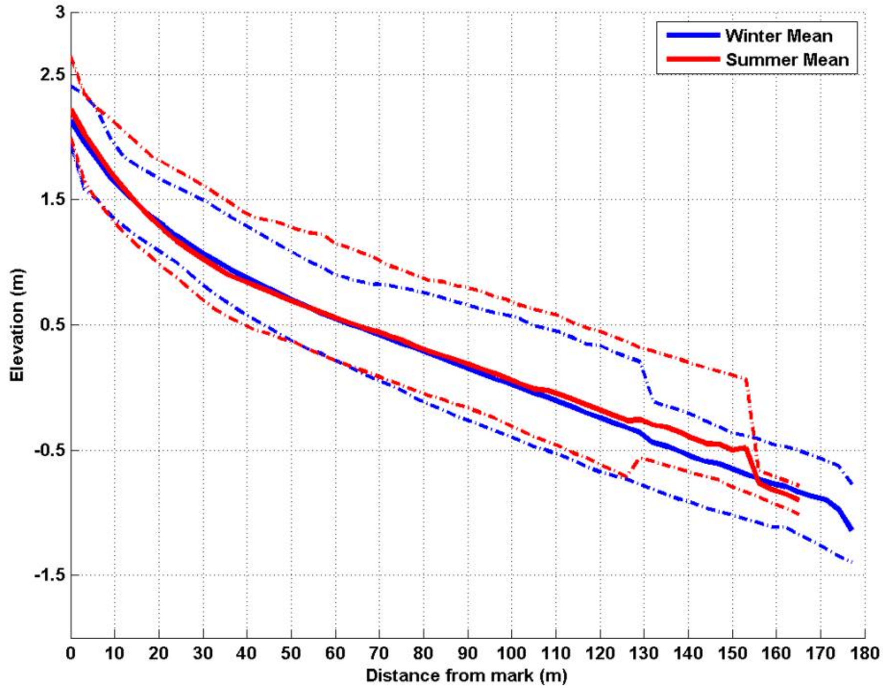

Figure 158. Seasonal data at LS2 show winter and summer profile positions are very similar. The envelope of profile elevations shows a greater range in summer than in winter. There is little indication of summer berm formation.

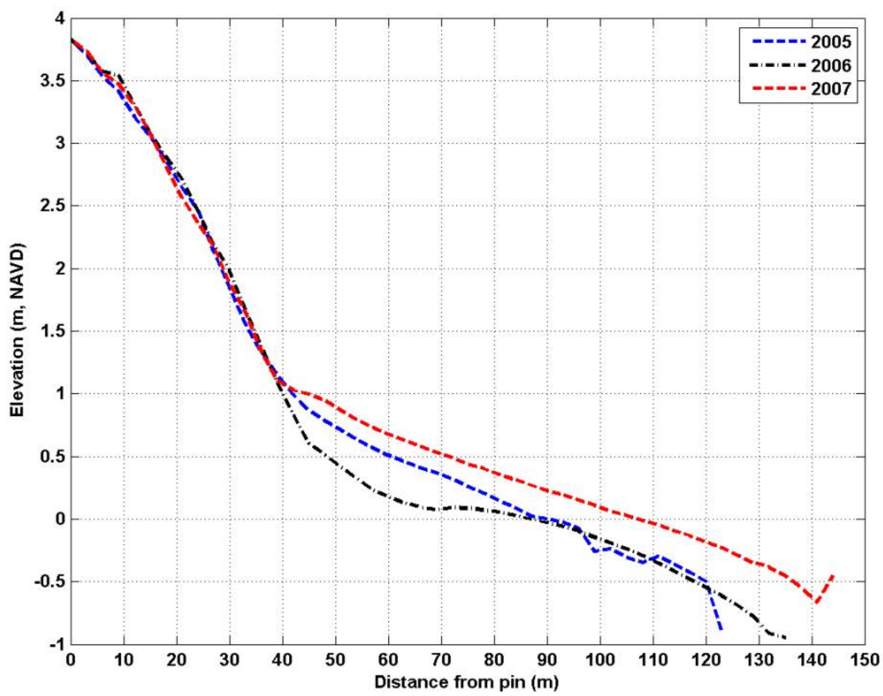

Figure 159. Annual mean profiles at LS3 show variability only on the lower profile. Sand was lost from 2005 to 2006 on the lower profile, but it vertically gained 0.5 to 1 m of sand in 2007.

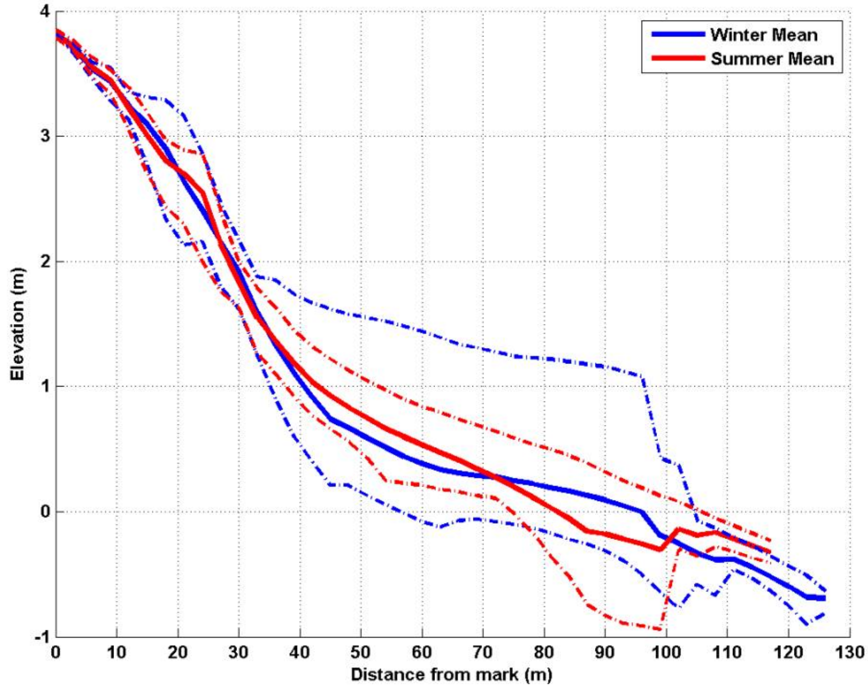

Figure 160. Seasonal profile means at LS3 are not as similar as they are at LS2. Closer to the base of slope, the summer mean is higher than offshore where the winter mean is higher. This crossover between seasons is expected as sand shifts offshore in the winter months. The winter envelope is considerably larger than the summer envelope and suggests sand bars on the lower profile may be at different locations over several winters.

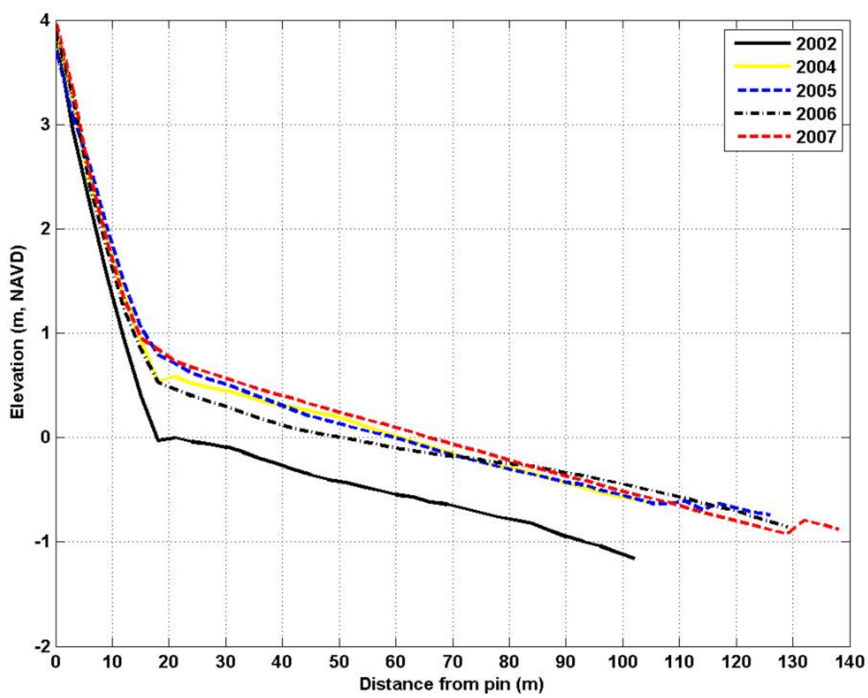

Figure 161. Annual mean profiles at LS4 show the lower profile building up over a period of 5 years. This rise in the beach elevation occurred mostly between 2002 and 2004 and less change has taken place in recent years.

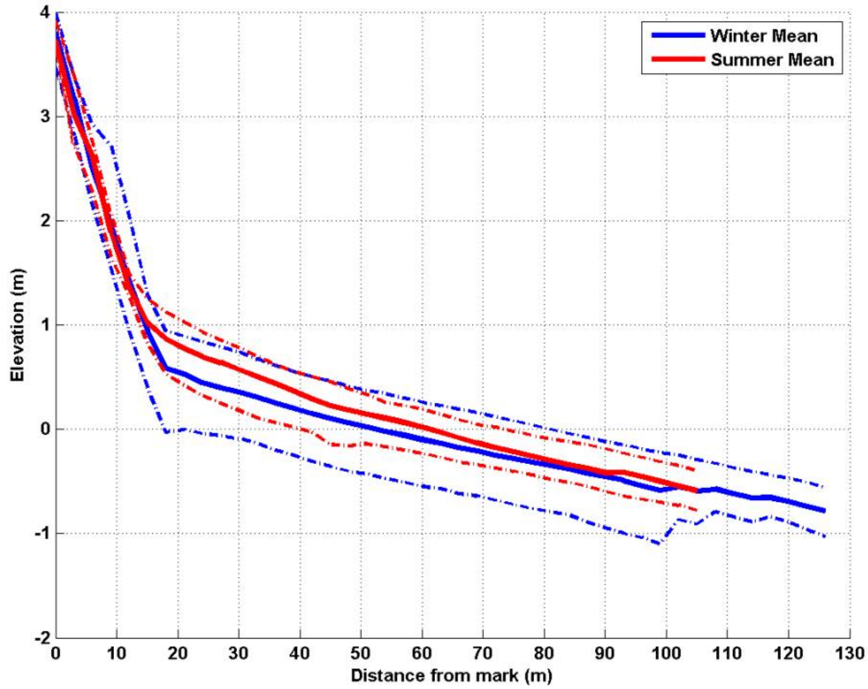

Figure 162. Seasonal profile means at LS4 show typical onshore movement of summer sand near the base of the steep slope. Variability in the envelope of winter profiles is greater than in summer and probably due to the higher waves in winter.

Discussion of Data Limitations and Recommendations

This first edition of the State of Maine's Beaches report is meant to provide a general qualitative description of the changes observed at each profile location for beaches involved in the SMBPP monitoring program. The data collected by volunteers enable the formation of a contiguous temporal dataset that is vital to tracking longer-term changes along Maine beaches.

The Emery Method is considered to be a fast, relatively accurate, simple method for collecting topographic data. The primary advantage of the method is that it can be used to compare changes in a particular location over time through repeated surveys. Its limitations include vertical and horizontal inaccuracies from the simple equipment, variable sharpness of the horizon, and human error in positioning the equipment or even in recording values. Vertically, the method is an approximation of true slopes because the horizon is used as a level even though there is curvature to the Earth's surface. This latter error is not especially important for reproducing survey lines for comparison over time. Some of these errors are apparent in the datasets. For example, many profiles saw a substantial increase in the standard deviation values as one proceeds farther from the starting point. This is not likely from more natural variability in the offshore, but likely is due to profiling error; that is, as a profiling team moves farther from a starting point, it is much more difficult to stay on the exact same line of the previous month's profile. This increases the error associated with the Emery method of profiling as one surveys farther seaward.

We recommend that a substantial effort be placed upon updating the online database with missing beach profile data, since some beaches (Willard Beach for example) was missing considerable amounts of data, even though data have been collected through 2007, which precluded analysis.

We also recommend that **all profiles** begin at a back stake, located farther in the back dune, behind the frontal dune crest, or behind a seawall (not on the wall) whenever possible. Profile locations that had multiple starting points were very difficult to work with in terms of determining which starting point was used, if it was a new front stake or back stake, etc.

We recommend that all starting locations be accurately surveyed with the MGS RTK-GPS so that exact location (with accurate x, y, z earth coordinates) can be determined. This should be completed in summer 2007. New back stake locations may be set during this field effort.

Future of the program and future reports

The Maine Geological Survey will be complementing the SMBPP data with alongshore surveys of the seaward edge of dune vegetation. We will also be adding nearshore surveys that extend profile lines into the offshore in order to create a contiguous beach profile that extends well into the surf zone.

Future reports will be issued in conjunction with the Maine Beaches Conference, and will include analysis of changes observed since the last report.

We would like to thank all of the volunteers that make this program possible; without your interest and dedication, this data collection effort would be impossible and much less would be known about the behavior and trends on Maine's most popular recreational beaches.

Please check the Maine Geological Survey website for additional electronic copies or newer editions of this report.

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Appendix A: Generalized Wave Conditions by Season

This Appendix provides a short summary of the hydrodynamic conditions that were present during the winter, summer, and fall months of each year that beach profiles were collected (from 1999-2007). Here, summer months are defined as May through August, fall months are September to December, and winter months are defined as January through April.

Data were available from the National Data Buoy Center (NDBC) Station 44007, which is situated 12 NM southeast of Portland, ME. Where gaps in data existed, the Gulf of Maine Ocean Observing System (GoMOOS) Buoy C02 (Casco Bay) was used. The data provided was the mean significant wave height, which is the average of the highest 1/3 of waves recorded over a certain time period (1 hour).

Figure A1 shows averaged mean significant wave height data for the time period of 1999-2007. Typical wave heights in the Gulf of Maine follow a seasonal trend; the highest waves are generally recorded during the winter months, associated with more prevalent and powerful northeast storms, which create larger, erosive waves. Summer months are typically calm, with dominant southwest winds, and wave heights are generally around 0.7 m. In the fall, mean wave heights increase to around 1 m, mostly due to the influence from waves generated by tropical cyclones and early season northeast storms.

For each year that has complete yearly data (1999-2006), a figure is provided showing overall significant wave height data over the course of the entire year (Figures A2-A9). In these figures, thick black lines divide the yearly data into 3 seasons - winter, summer, and fall. Note that a yearly figure was not produced for 2007, since data were only analyzed through the winter of 2007. For each individual year, additional figures are provided that show significant wave height data for the winter, summer, and fall months (Figures A10-A34). Data are discussed in terms of seasonality for each year.

Winter, 1999

The mean wave height for winter 1999 was 1.14 m, with a maximum of 5.58 m being recorded during a storm in the third week of March. January included many events where waves exceeded 2 m, with 2 storm events exceeding 4 m. 58% of waves were equal to or greater than 1 m in January, with over 17% exceeding 2 m. February was characterized by 2 large events, one in the first week that exceeded 4 m, and a second at the end of the month that exceeded 5 m. The rest of the month was relatively quiet. March had a very active first several weeks with 4 back-to-back storms exceeding 3 m, with 2 of these reaching over 4 m (and one reaching 5 m). The largest waves of winter were recorded in the 3rd week of March, with wave heights reaching over 5.5 m. Waves dropped to generally below the 1-1.5 m mark in April, as only 8.5% of recorded waves exceeded 1 m (Figure A10).

Summer, 1999

Mean wave height for summer was 0.68 m, with a maximum wave height of 2.45 m, reached in the last week of May. May was characterized by 2 events that exceeded 1.5 m, and only 20% of waves exceeded 1 m. June was relatively quiet, with no waves recorded over 2 m, though one event approached 2 m at the end of the month. July had waves less than 1.5 m through its entirety, with only 6.3% of waves exceeding 1 m. August had a string of smaller events with waves less than 1.5 m, though one event at the end of the month exceeded 1.5 m and approached 2 m, though none exceeded 2 m (Figure A11).

Fall, 1999

The mean wave height for fall was 1 m, with a maximum of 3.87 m reached in early November. September included a calm start, but had 3 events in the second half of the month that exceeded 2.5 m. October was active, with numerous smaller events in the 1-2 m range, and 2 events exceeding 2.5 m. November was more active, with about 46% of waves being larger than or equal to 1 m. The largest event of fall occurred in early November, with waves exceeding 3.5 m. Towards the end of the month, a series of storms reached near 3.5 m and continued into December. December included 4 events that exceeded 2.5 m, with 2 of these exceeding 3 m (Figure A12).

Winter, 2000

The mean wave height for winter was 1.13 m, with a maximum wave height of 4.97 m achieved in January. January was characterized by 4 events that exceeded 2 m, three of these exceeded 3 m, and 2 exceeded 4 m, including the maximum wave height which was recorded on January 11. February was generally calmer in terms of maximum wave heights, but 46% of recorded waves were greater than or equal to 1 m. 3 events exceeded 2.5 m, with a maximum of 2.75 m recorded on February 20. The first half of March was generally calm, with wave heights below 1.5 m; however, wave activity increased in the second half of the month, with numerous events at or above 2 m,

though only one event exceeded 3 m (3.78) towards the end of the month. April was very active, with 50% of waves exceeding 1 m. The largest event (reaching 4 m) occurred on April 10, while a longer duration event, with waves greater than 2 m, occurred from April 19-April 23 (Figure A13).

Summer, 2000

The mean wave height for summer was 0.76 m, with a maximum of 2.92 from early June. May marked a much lower overall wave climate than April, with only 22% of waves being greater than 1 m. Three events exceeded 2 m, including the maximum wave height of 2.38 m on 5/19. June was characterized by typical summer conditions, with the majority of waves less than 1 m, aside from a large, near 3 m event that occurred around 6/8. July was similar to June, with only 1 event exceeding 2 m on 7/16. August was a relatively calm month, with only 15% of waves exceeding 1 m. The largest event occurred on 8/24, with waves reaching 2 m, though a longer duration event (only reaching 1.5 m) occurred 8/13-8/17 (Figure A14).

Fall, 2000

The fall of 2000 had a mean wave height of 0.83 m, with a maximum recorded wave height of 4.47 m in December. September was a calm month, with only near 19% of waves reaching or exceeding 1 m in height. The largest waves, near 2 m, were recorded towards the end of the month. October had the highest waves at the start of the month, with 4 events reaching or exceeding 2 m by 10/7. The latter portions of the month were generally calm. November was characterized by 2 larger events occurring at the beginning and end of the month. The first event had waves near 2.5 m, while the second, larger event, occurred from 11/26-11/29, with peak waves of 3.66 m recorded on 11/28. December 2000 was relatively calm at the start of the month, with 4 events occurring from the middle of the month to the end that exceeded 2 m. The 2 largest events occurred at the middle of the month (reaching over 4 m), while at the end of the month, waves reached near 5 m (Figure A15).

Winter, 2001

Mean wave height was 0.98 m, with a maximum of 6.69 m reached in March. January was relatively calm. Though over 23% of waves exceeded 1 m, only 0.1% exceeded 2 m. February was characterized by a large event, with waves exceeding 4.5 m, in the first week of the month (2/6), and 5 events had waves greater than 2 m, with 2 events having waves greater than 3 m. March was very active, with over 18% of waves recorded exceeding 2 m, and 12% exceeding 3 m. Some of the largest waves of the year were recorded in the beginning of the month during a long duration (waves greater than 2 m from 3/6-3/9) event, with waves reaching near 6 m. The end of the month had the largest waves, with waves exceeding 6 m on 3/23, and a second event reaching 5 m on 3/31 and into April. April was calmer, with the largest event continuing from the end of March storm, with waves in the 5 m range. Only 1 additional event exceeded 2 m near 4/13, while remainder averaged below 1.5 m (Figure A16).

Summer, 2001

Mean wave height was 0.69 m, with a maximum of 2.39 m occurring in May. May only had 1 event exceeding 2 m near 5/18, with about 80% of waves recorded being below 1 m in height. June was very calm, with only 7% of waves recorded exceeding 1 m in height. The largest event occurred early in the month, with waves exceeding 2 m on 6/3. July was also very calm, with less than 5% of waves only exceeding 1 m. All events were below 1.5 m in height. August was a bit more active, with an event at the beginning of the month that exceeded 2 m, and a smaller event exceeding 1.5 m towards the end of the month (Figure A17).

Fall, 2001

Mean wave height was 0.92 m, with a maximum of 2.63 m recorded in October. September marked the start of active hurricane swell, with almost 32% of waves exceeding the 1 m mark. Waves reached 2.5 m on 1 occasion, near 9/20. October was a very active month, with 40% of waves reaching or exceeding 1 m. The largest event was at the beginning of the month, with waves exceeding 2.5 m, while a second, longer duration event (10/13-10/16) exceeded 1 m for its duration, and reached near 2.5 m on 10/15. A number of smaller events neared 2 m during the second half of the month. November was characterized by smaller events reaching between 1.5-2 m in the first half of the month, and a longer duration event 11/25-11/30 (waves between 1.5-2.5 m, with a peak near 11/28). December began with the ending of a storm left over from November, with waves touching near 2 m. The largest event occurred near Christmas, with waves reaching near 2.25 m, and staying generally at or greater than 1 m through 12/31 (Figure A18).

Winter, 2002

The mean wave height was 1.06 m, with a maximum of 3.95 m reached in March. January had 2 events that exceeded 2 m in height, and about 1/3 of waves recorded exceeded 1 m in height. The larger events were near 1/7 and on 1/24. February was much more active than January, with over 53% of waves recorded exceeding the 1m mark. The first part of the month was generally calm, with waves < 1.5 m. The largest event occurred from 2/11-2/14, with waves exceeding 3 m. 6 events exceeded 2 m, mostly in the second half of the month. March was another active month, with 51% of waves exceeding 1 m, and 10% exceeding 2 m. The 2 largest of these occurred at the beginning (3/4, maximum over 3.5 m), and at the end of the month (3/27, approaching 4 m in height), with 5 total events exceeding the 2 m

mark. April was a bit calmer, with larger events exceeding the 2 m mark. 44% of waves were above the 1 m mark. The largest event occurred at the end of the month, with waves exceeding 2.5 m near 4/29-4/30 (Figure A19).

Summer, 2002

The mean wave height was 0.77 m, with a maximum of 4.87 m in May. May was generally dominated by smaller, 1-1.5 m, events, with about 28% of waves exceeding 1 m in height. The largest event occurred between 5/14-5/16 (above 1m), with peak waves near 4.9 m on 5/14. June was relatively active, with 32% of waves greater than 1 m in height. 5 events exceeded 1.5 m, with 2 events reaching or exceeding 2 m. The largest occurred on 6/16-6/17, with waves reaching about 4.5 m. July was more typical of summer conditions, with around 9% of waves only exceeding 1 m in height. The largest event occurred between 7/22-7/23, with waves reaching 1.5 m. August was a very calm month, with more than 95% of waves recorded being less than 1 m in height, and no waves exceeding 2 m (Figure A20).

Fall, 2002

The mean wave height was 1.05 m, with a peak of 5.87 m reached in November. September was relatively calm, with only 22% of waves exceeding 1m in height. 4 events reached or exceeded 1.5 m, but none exceeded 2 m. October was much more active, with over 41% of waves exceeding 1m, and 17% exceeding 2 m. The longest duration event occurred from 10/12-10/20, with several wave events exceeding 1 m the entire time, and reaching a peak of 5.7 m on 10/17 (3 separate events reached 3 m or more). Another event occurred later in the month, around 10/27, that reached 3 m as well. November was another active month, defined by 2 very large storm events, both of which occurred in the first half of the month. The first, which peaked at over 5 m, occurred between 11/7-11/10 (all greater than 1 m), and the second between 11/16-11/19, with a peak on 11/18 near 6 m, which was the largest event of the year. December continued the active fall/early winter pattern, with 48% of waves recorded over 1 m, and over 10% greater than 2 m. 6 events exceeded 2 meters, with the largest towards the end of the month, with waves reaching over 4 m near 12/26. The longest duration event with waves greater than 1 m occurred between 12/11-12/16, with waves reaching between 3 and 3.5 m (Figure A21).

Winter, 2003

The mean wave height was 1.11 m, with a maximum of 6.15 m in January. Aside from this large event, with waves greater than 2 m from 1/4-1/5 and peaking at over 6 m on 1/5, the month was generally calm, with wave heights generally at or less than 1.5 m. The first half of February was calm, though 1 event tops 2 m. The remainder of the month includes 2 additional events that exceed 2 m, with the largest reaching 4 m and being of longer duration (2/18-2/21 above 2 m). March had a higher percentage (46%) of waves over 1 m, with many events between 2-3 m, especially in the beginning of the month. The latter half of the month included 2 events that reached 2 m, and several smaller 1-2 m events. April had a very high percentage of waves that exceeded 1 m (68%), but very few large wave events. Many of the events had lower waves (1-2 m) of longer duration. 2 longer duration events where waves were greater than 1.5 m were from 4/9-4/14, and 4/20-4/24 (with a peak at 2.5 m). A third, shorter duration event reached over 2.5 m on 4/28 (Figure A22).

Summer, 2003

The mean wave height was 0.74 m, with a maximum of 2.56 m. May marked a distinct transition from the winter months, with only 26% of waves exceeding 1 m, and only 1.5% exceeding 2 m. It was comprised of 3 smaller events between 1-1.5 m for the first half of the month, lower waves for the second half, except for a larger event that reached 2.5 m on 5/25 during a 5/24-5/27 event. June was even calmer, with only 11 % of waves exceeding 1 m, and none exceeding 2 m. July was relatively calm as well, with only 4 events exceeding 1 m, and none of these exceeding 2 m. August was just as calm, with relatively the same amount of wave activity, except only 9% of waves exceeding the 1 m mark (Figure A23).

Fall, 2003

The mean wave height was 1.05 m, with a maximum of 7.09 m recorded in December. About 43% of waves in September were above 1 m. It exhibited several lower wave height (1-2 m)-longer duration swells in the beginning of the month. The second half of the month was punctuated by 3 higher wave height events, with the largest being on 9/29-9/31, peaking at around 3.5 m. October was more active than September, with 50% of waves above 1 m, and around 9% of these above 2 m. 3 events (10/1, 10/5, and 10/15) exceeded 3 m, with 1 event reaching over 4 m on 10/15-10/16. November was slightly less active, with the majority of waves in the first half of the month less than 1.5 m. The second half was characterized by 3 events, the second of which was a long duration event (11/20-11/25) with wave heights greater than 1.5 m and peaking at near 3 m. The third event on 11/30 had the largest waves, with a peak near 3.5 m. December was very active in terms of larger waves, with almost 14% of waves exceeding 2 m, and 5% exceeding 3 m. The largest waves of the year were recorded in December. The largest event occurred 12/6-12/7, with waves peaking at over 7 m before the NDBC buoy went off-line between 12/7-12/16. Another event occurred on 12/18-12/19, with waves reaching upwards of 5 m. the rest of the month was much calmer, with an additional event reaching near 2.25 m between 12/25-12/27 (Figure A24).

Winter, 2004

The mean wave height was 0.91 m, with a maximum of 3.81 m. January was characterized by unusually low waves, with only 10% exceeding 1m, and no waves exceeding 2 m in height. February was more typical of winter months, with several events exceeding 2 m, with the largest being on 2/4 (over 3 m) and 2/22 (near 2.6 m). March continued a period of winter wave activity, with nearly 54% of waves greater than 1 m, and 10% greater than 2 m. Several long duration events over 1 m occurred during March (between 3/9-3/13, peak on 3/12 of 3.8 m), and 3/18-3/22 (peak near 2.5 m), and the rest of the month consistently greater than 1 m. April was also quite consistent, with a large event at the beginning of the month, peaking with waves near 4 m on 4/2-4/3. The remainder of the month generally exhibited lower overall waves on the order of 1-2 m, with several events reaching the 2-2.5 m mark on 4/15 (Figure A25).

Summer, 2004

The mean wave height was 0.73 m, with a maximum of 2.11 m. The summer months were relatively calm, with May being the most active in terms of waves consistently over 1 m (26%). The majority of the activity in May was in the second half of the month, with several smaller events between 1-1.5 m. June was slightly more active in terms of distinct events that exceeded 1 m, with four events, though none reached 2 m in size. Waves above 2 m were only recorded in July, accounting only for 0.1% of that month's totals. This event, which occurred on 7/15, was a longer duration event that lasted from 7/15-7/18 with waves above 1 m. August was a relatively calm month, with an active beginning and middle, with the rest of the month quiet. Only 13% of waves were above 1 m in August, and none were above 2 m (Figure A26).

Fall, 2004

Mean was 1.10 m, with a maximum of 5.06 m, largest of the year. September was generally calm, with about 84% of waves less than 1 m. The largest event, 9/9-9/11, just exceeded 2 m, while a second event at the end of the month reached 1.5 m. October was much more active, with 55% of waves exceeding 1 m, and almost 12 % reaching or exceeding 2 m. It is characterized by 2 small and 1 major events, with the large, long duration event lasting from 10/21-10/30 (greater than 1 m, with 10/24-10/26 greater than 2 m and a peak of 4.3 m on 10/25). November was less active on the whole, but reached a larger peak wave height. The first half had numerous 1-2 m events, with the largest of the month, peaking near 5 m, occurring on 11/29. December was an extremely active month, with 60% of waves exceeding 1 m, and 15% exceeding 2 m. Seven events over 2 m were recorded, with 5 of these exceeding 3 m, and 3 exceeding 4 m. The five largest events occurred on 12/2 (4.3 m), 12/8 (4.8 m), 12/11 (3.5 m), 12/24 (4 m), and the largest on 12/27-12/28, reaching 4.8 m (Figure A27).

Note for 2005

Much of the wave data from the NDBC 44007 buoy were missing due to a buoy malfunction from 1/28-5/17. In order to fill the data, MGS used available data from the GoMOOS Casco Bay buoy (CO2) and Western Maine Shelf buoy (B02) to fill the data gaps. BO2 data were used from 1/28-2/15, while CO2 data were used from 2/15-5/17 due to an additional gap in the CO2 data.

Winter, 2005

The mean wave height was 1.22 m, with a peak of 4.79 m. January was a very active month, with 9 events having waves over 2 m, and 3 of these events with waves above 3 m. Generally, the largest events were in the second half of the month: 1/15, 1/17-1/18, and the largest on 1/24-1/25, reaching 3.4 m. A longer duration, lower wave height (1.5-2m) event occurred from 1/27-1/29. Almost 57% of the waves during February were greater than 1m, with about 21% greater than 2 m, making for a very active winter month. The beginning of the month saw a long duration event from 2/3-2/9, with waves peaking over 3 m on 2/4-2/5. Four additional events recorded waves greater than 3 m, including a short event on 2/11, 2/15, which reached maximum wave height of 4.5 m, 2/19 (4 m), and 3.3 m on 2/22. March continued the active winter, with 5 events exceeding 2 m, 2 of these exceeding 3 m in height. The largest event reached over 4.5 m around 3/13, with a smaller event around 3.5 m on 3/1. Two smaller events occurred at the end of the month, with wave heights reaching 2.5 and 3 m respectively. April was also very active, with almost 52% of recorded waves exceeding 1 m and almost 17% exceeding 2 m. April was dominated by 3 large events, the largest at the beginning of the month, peaking at 4.5 m on 4/4. Two additional events occurred, to 2.5 m on 4/25, and to 3.5 m on 4/28 (Figure A28).

Summer, 2005

The mean wave height was 0.83 m, with a maximum of 5.95 m, the largest of the year. May was an abnormally active month, characterized by two very large events. The first took place between 5/7-5/12, with a peak of near 4 m on 5/8, and waves consistently greater than 2 m between 5/7-5/9. The second "event" occurred as part of a series of northeast storms struck the coast during the week of 5/25, with wave heights approaching 6 m on 5/25, and staying above 3 m for 5/24-5/26. June was much less active, more typical of "summer" months. Only 16% of recorded waves were at or above the 1 m mark. The largest event occurred during 6/14-6/17 (waves greater than

1 m), with a peak of 2.27 m on 6/16. July was also quite calm, with less than 10% of waves above 1 m, with no events above 2 m. August continued the summer calm, with even less percentage of waves above 1 m. The largest event reached 1.7 m on 8/22 (Figure A29).

Fall, 2005

The mean wave height was 1.03 m and the maximum was 5.05 m. September began with a large event reaching 2.5 m, then remained relatively calm (<1.5 m) until the end of the month, when a storm created wave heights up to 2.85 m on 9/30. October started relatively calm, with only a short-term event reaching 3 m on 10/9. However, 21% of waves in October were greater than 2 m in height. A long duration event occurred from 10/13-10/16 with wave heights greater than 2 m and a peak of 3.5 m. This was followed by 2 larger, shorter events, with waves reaching 3.8 m on 10/24, and up to 4.8 m on 10/26. November was also quite active, with 4 events reaching or exceeding 2 m. The largest event occurred on 11/10, reaching 3.71 m. Two additional events occurred after this, exceeding 2 m on 11/17-11/18, and a longer duration event from 11/23-11/25 that exceeded 3 m. December included only 3 events that exceeded 2 m, with the largest event occurring 12/16-12/17 and reaching over 5 m in height (Figure A30).

Winter, 2006

The mean wave height was 0.99 m and the maximum was 5.39 m, occurring in January. January was quite active in terms of the percentage of waves that were at or greater than 1 m, with over 46%. However, only 3 events exceeded 2 m. These occurred on 1/5 with waves reaching 3 m, 1/15 with waves near 2.4 m, and the largest event on 1/19 with waves surpassing 5 m. The remainder of the month was generally at or below 1.5 m. February had several large events occur at the beginning of the month, with waves exceeding 3 m on 2/1, and again doing so on 2/4. The next larger event occurred on 2/13, and 2/18, which both reached about 2.8 m. The rest of the month was at or below 1.5 m. March was quite inactive for a winter month, with only 20% of waves exceeding 1 m, and only 4.5% exceeding 2 m. It is marked by 2 large events, the first with a peak on 3/11 with waves at 2.1 m, followed by calm until the strongest storm of the month occurred between 3/26-3/29, with waves peaking over 3 m on 3/27. April's largest event, reaching 3.7 m, occurred at the beginning of the month on 4/5-4/6. This is the only event that easily surpassed the 2 m mark. Two additional events on 4/25 and 4/27 reach the 2 m mark. The remainder of the month is generally calm (Figure A31).

Summer, 2006

The mean wave height for summer was 0.85 m, and the largest event occurred in mid-May, with 3 events exceeding 3 m in May. About 44% of waves were below 1 m in May, with 42% between 1 and 2 m; of the remaining 14%, only about 1% was greater than 3 m. June had an active start to the month, with an event reaching almost 3 m around June 10. The remainder of June, July, and August were relatively quiet, with a mean value of 0.70 m. About 85% of the waves recorded during this time were less than or equal to 1 m in height (Figure A32).

Fall, 2006

The mean wave height for fall was 1.01 m, with the largest waves recorded around October 30-31, 2006, reaching over 6 m in height. In September, 63% of the recorded waves were below 1 m in height, with 35% between 1-2 m and only 2% exceeding 2 m in height. In October, 65% of recorded waves were less than 1 m in height, with 25% being between 1-2 m, and about 10% over the 2 m mark. November was characterized by more wave activity, with only 46% of recorded waves being less than 1 m in height (35% between 1-2 m, and 19% greater than 2 m in height). December was generally calmer, with recorded waves not exceeding 3 m (Figure A33).

Note for 2007

Data were downloaded the Gulf of Maine Ocean Observing System's Buoy C02 (Casco Bay) for January 2007 to April 2007. The NDBC Station 44007 was damaged during the winter of 2007.

Winter, 2007

The winter of 2007 had a mean wave height of 1.19 m. About 49% of waves recorded were less than or equal to 1 m in height, with 36% between 1-2 m. Of the remaining 15%, about 4% of waves were greater than 3 m. The month of January had a mean value just over 1 m, with 49% less than 1 m and 44% between 1-2 m. 2 events exceeded 3 m in height. February saw a relatively powerful, but short, storm that caused wave heights to reach 6 m on 2/15. 56% of waves were below 1 m, and 38% between 1-2 m. March began with large waves, in excess of 6 m from 3/2-3/4. A second storm hit between 3/17-3/18, with waves between 4-5 m. The month of April was dominated by the "Patriots' Day" storm, which battered many areas of the Maine coastline with large waves. During this storm, wave heights reached over 8 m around 4/17, and were above the 3 m mark from 4/16-4/19. The latter part of the month was generally calm (Figure A34).

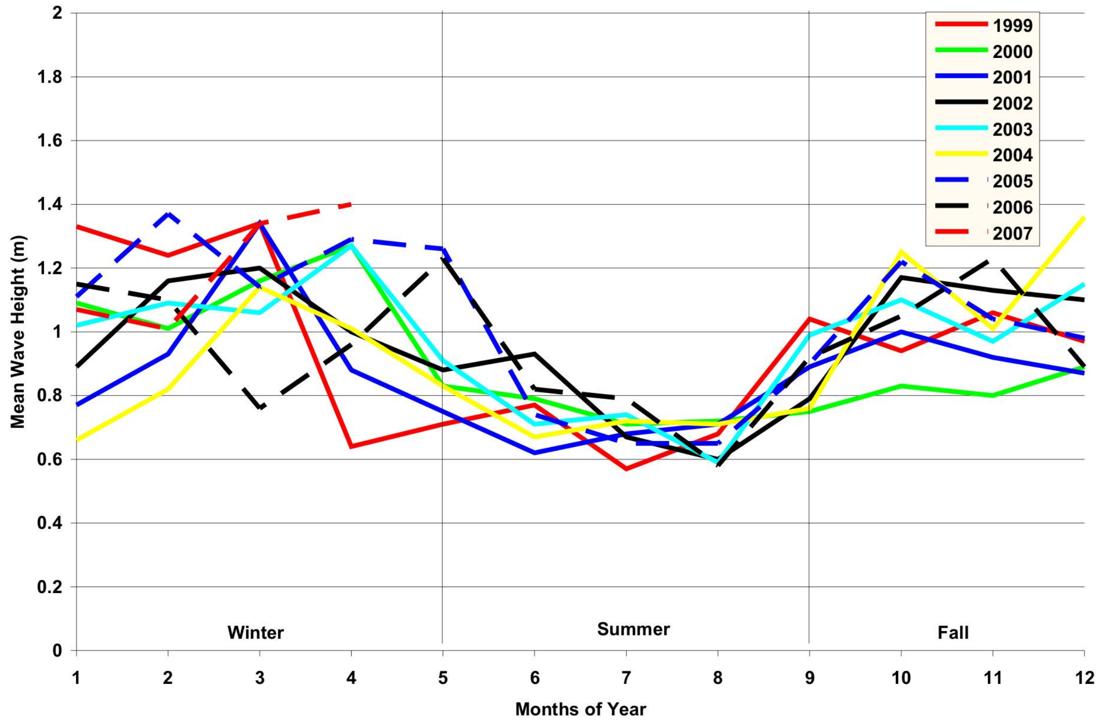

Figure A1. Mean significant wave height data calculated for the time period of 1999-2007 for each month of the year. During winter months, wave heights average around 1.1 m, while during the summer, this drops to near 0.75 m. In the fall, waves average around 1 m.

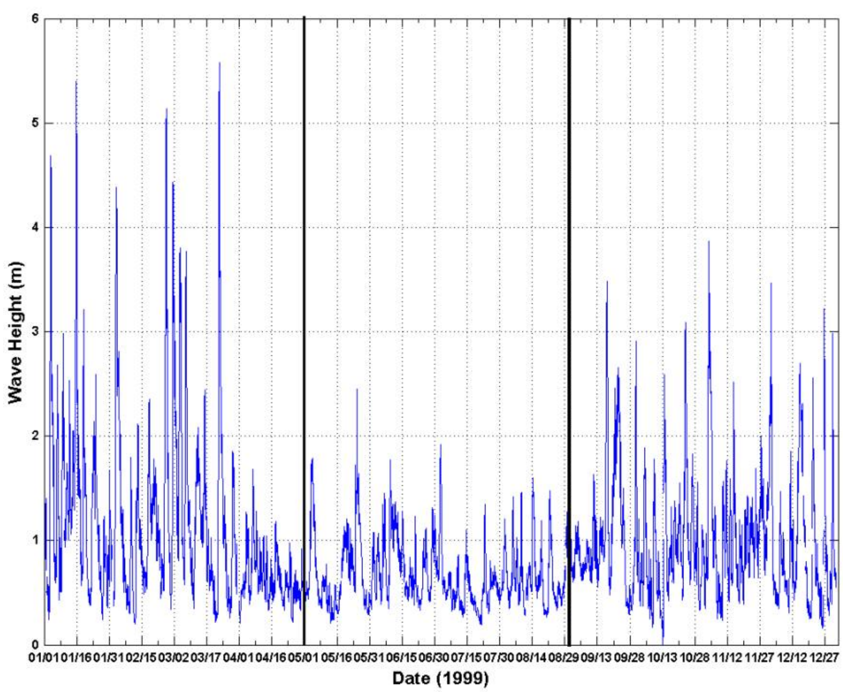

Figure A2. Significant wave height data for 1999 recorded at NDBC Station 44007. Note the increased frequency of larger events and higher wave heights that occurred in the winter as opposed to the fall and summer.

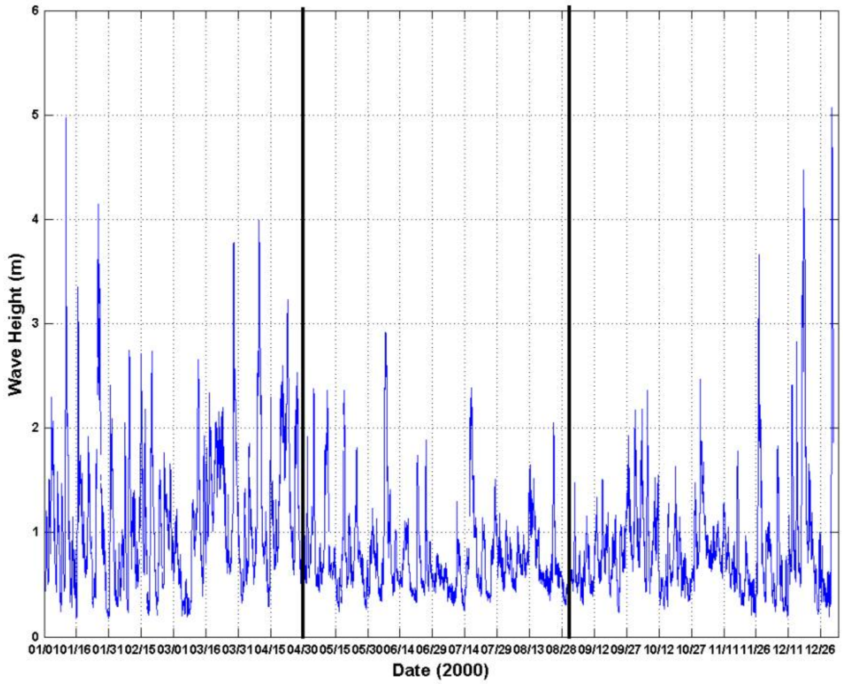

Figure A3. Significant wave height data for 2000 recorded at NDBC Station 44007. There were several large events in both the winter and the fall, while the summer was markedly calmer.

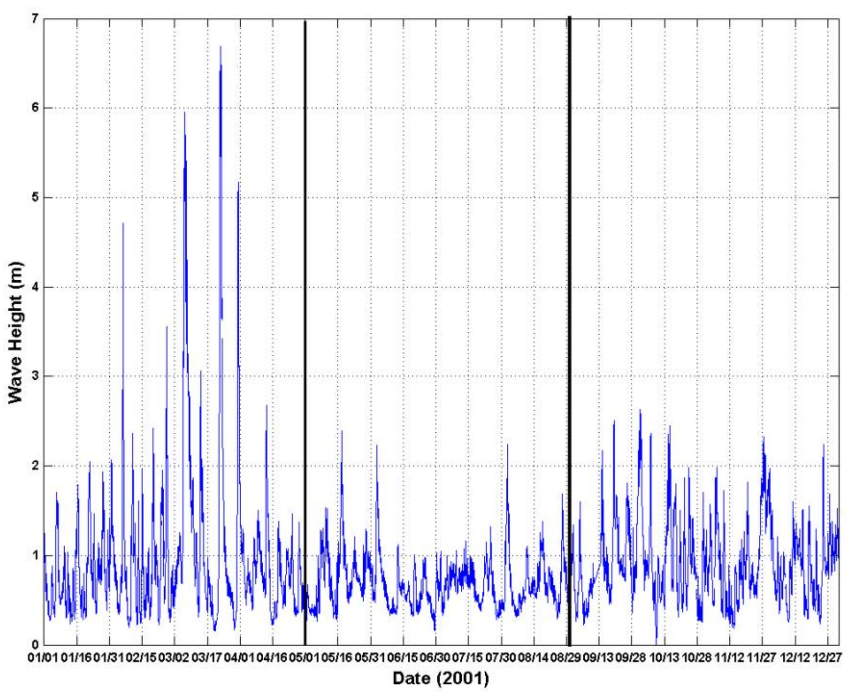

Figure A4. Significant wave height data for 2001 recorded at NDBC Station 44007. Larger wave events were concentrated in the winter, with a generally calm summer and fall.

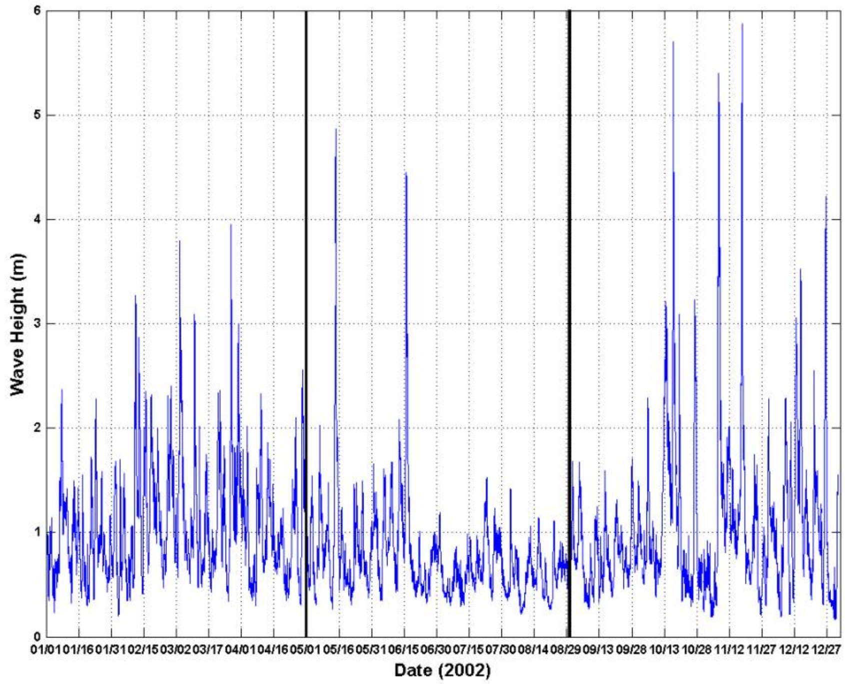

Figure A5. Significant wave height data for 2002 recorded at NDBC Station 44007. Unlike the other years, the largest events were concentrated in the fall and early summer.

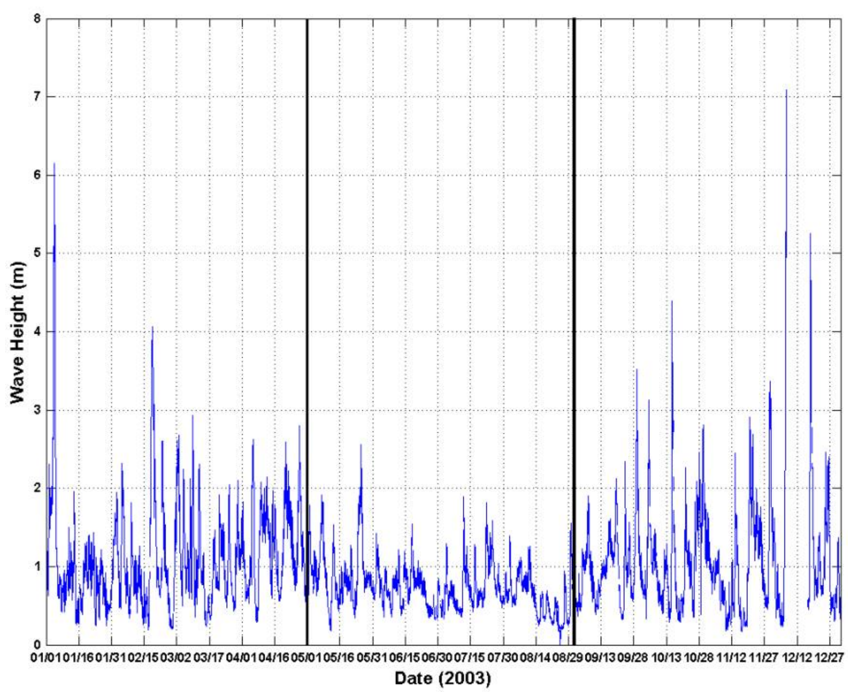

Figure A6. Significant wave height data for 2003 recorded at NDBC Station 44007. The largest events were concentrated in the early winter and late fall, with a very calm summer.

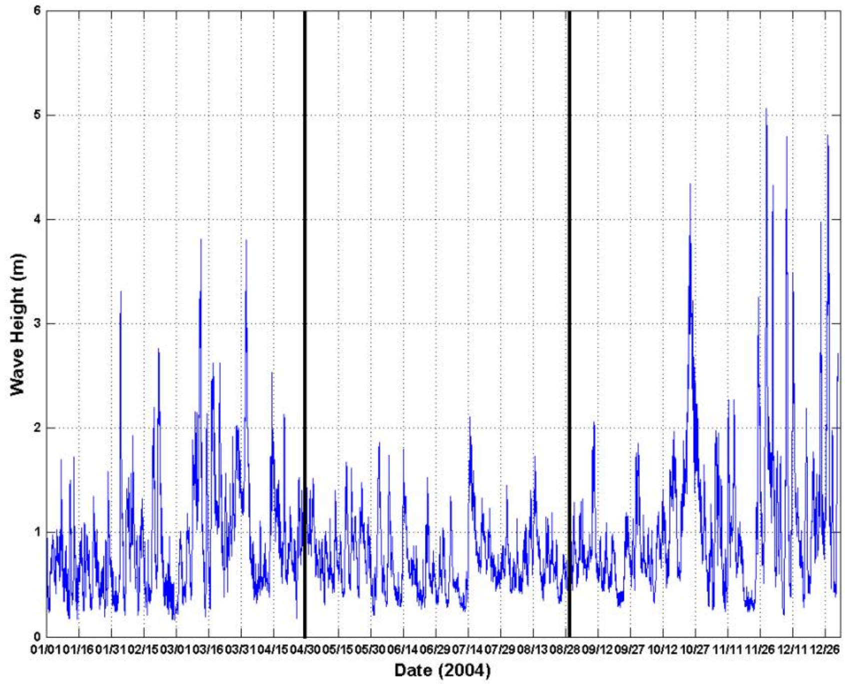

Figure A7. Significant wave height data for 2004 recorded at NDBC Station 44007. The largest wave events were concentrated in the fall and mid-winter, while summer was generally calm.

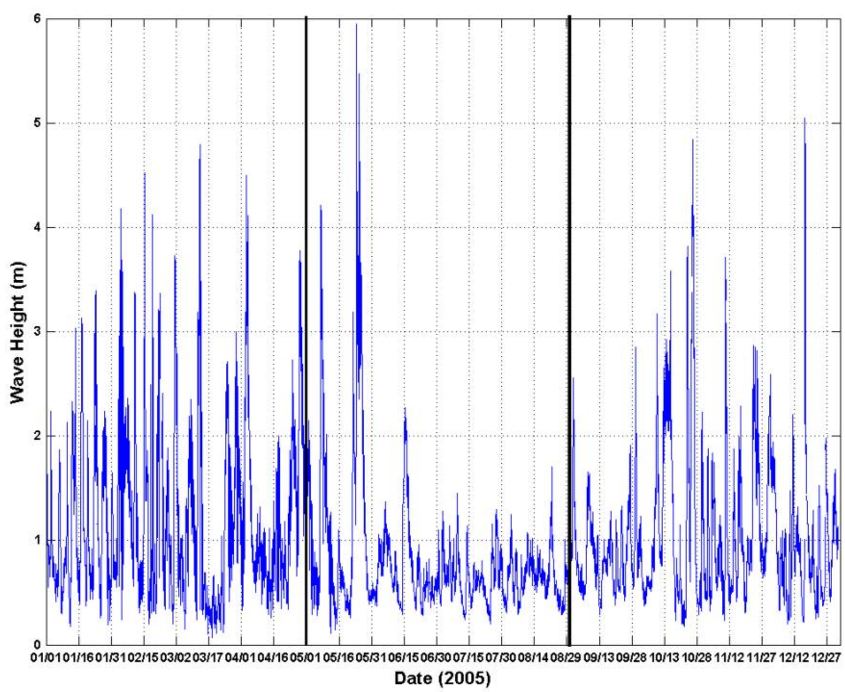

Figure A8. Significant wave height data for 2005 recorded at NDBC Station 44007 and GoMOOS Buoy C02 (Casco Bay). 2005 was a very active storm year, with numerous large events in the winter and fall, and a significant event in the early summer (which recorded the largest wave heights of the year).

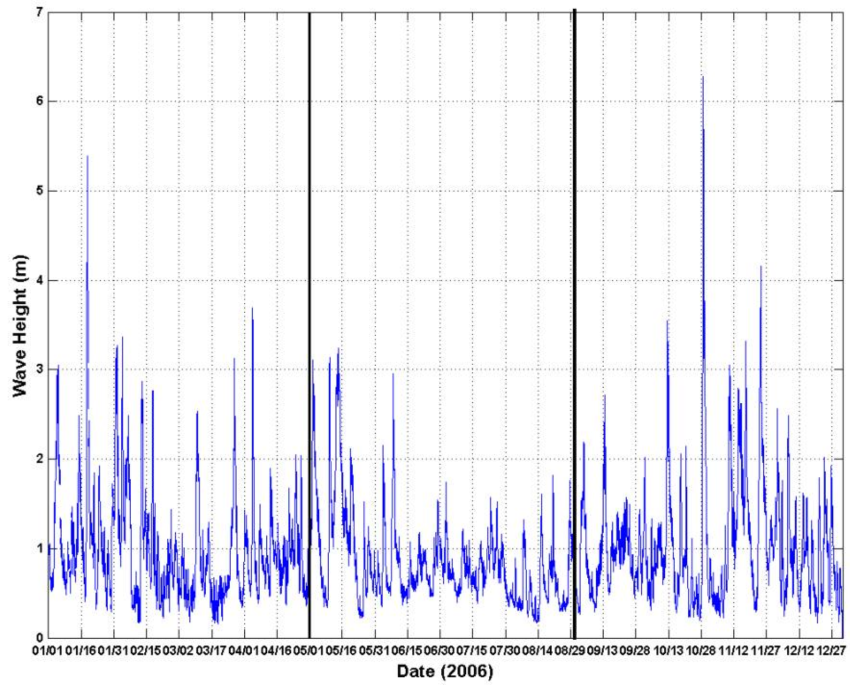

Figure A9. Significant wave height data for 2006 recorded at NDBC Station 44007. The largest wave events occurred in early winter and mid-fall, with a slightly active early summer.

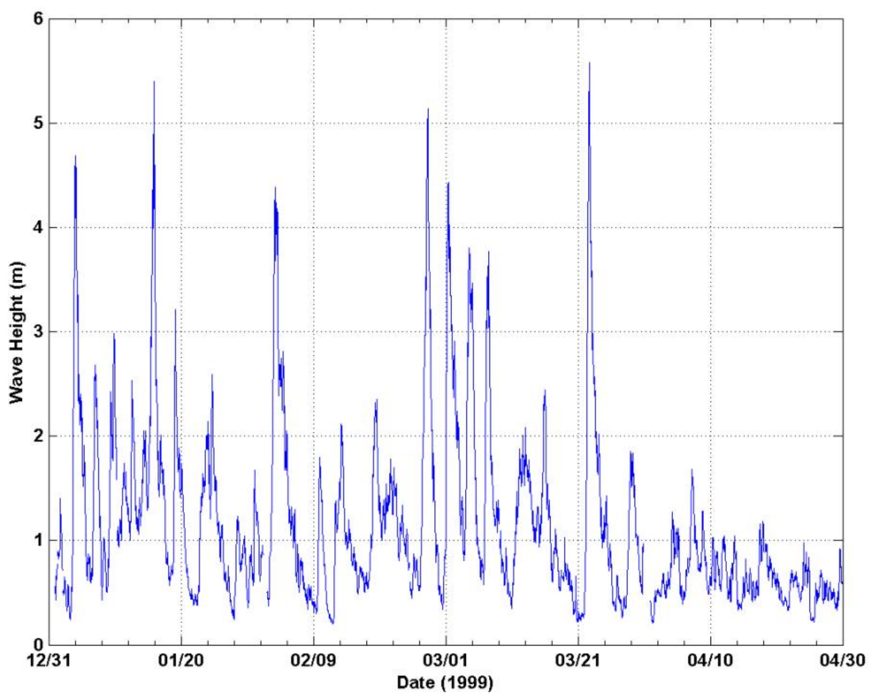

Figure A10. Significant wave height data for the winter of 1999. There were six events where wave heights exceeded the 4 m mark.

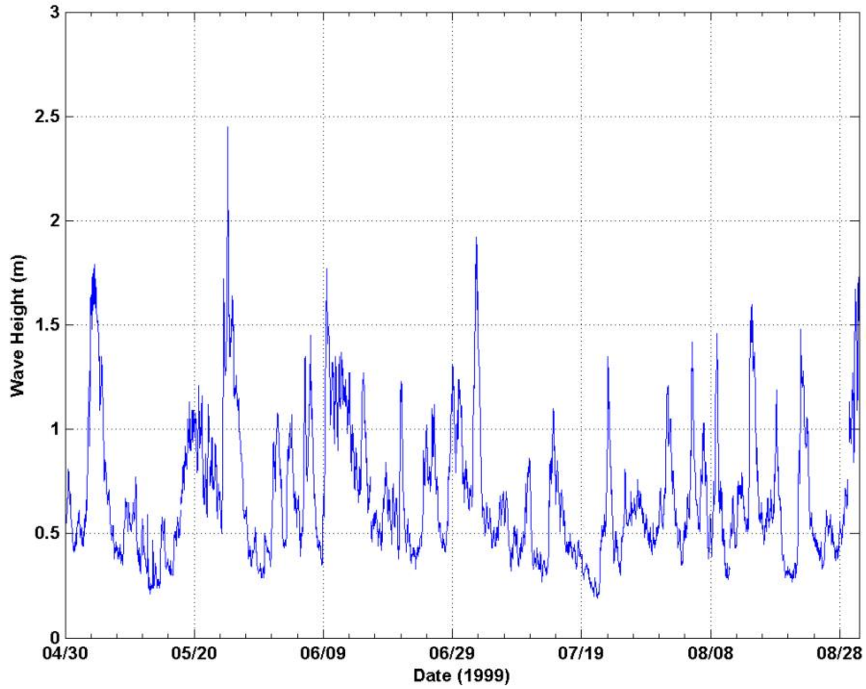

Figure A11. Significant wave height data for the summer of 1999. Wave heights were generally less than 1 m, with only one event exceeding the 2 m mark.

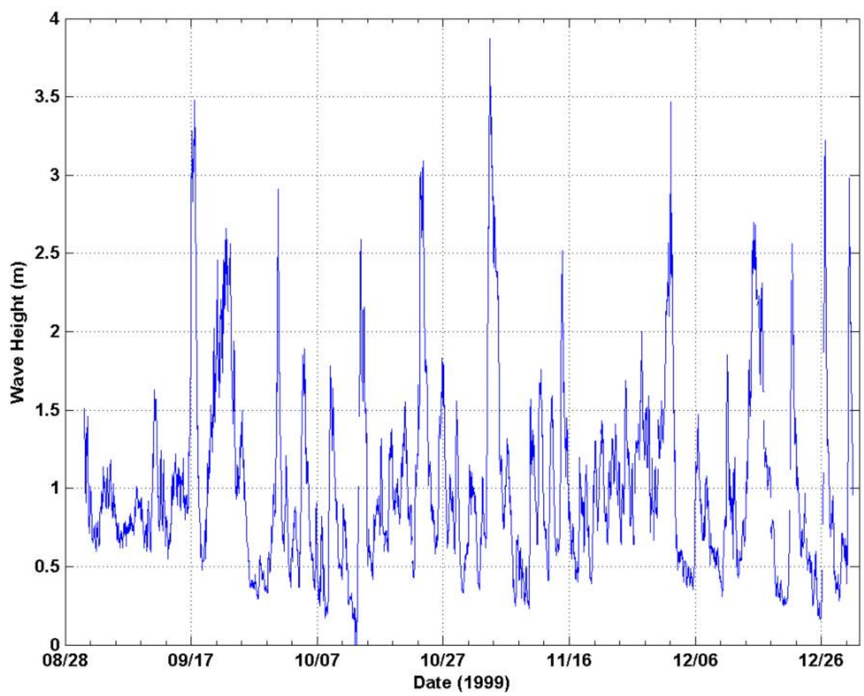

Figure A12. Significant wave height data for the fall of 1999. Five events had wave heights that exceeded the 3 m mark.

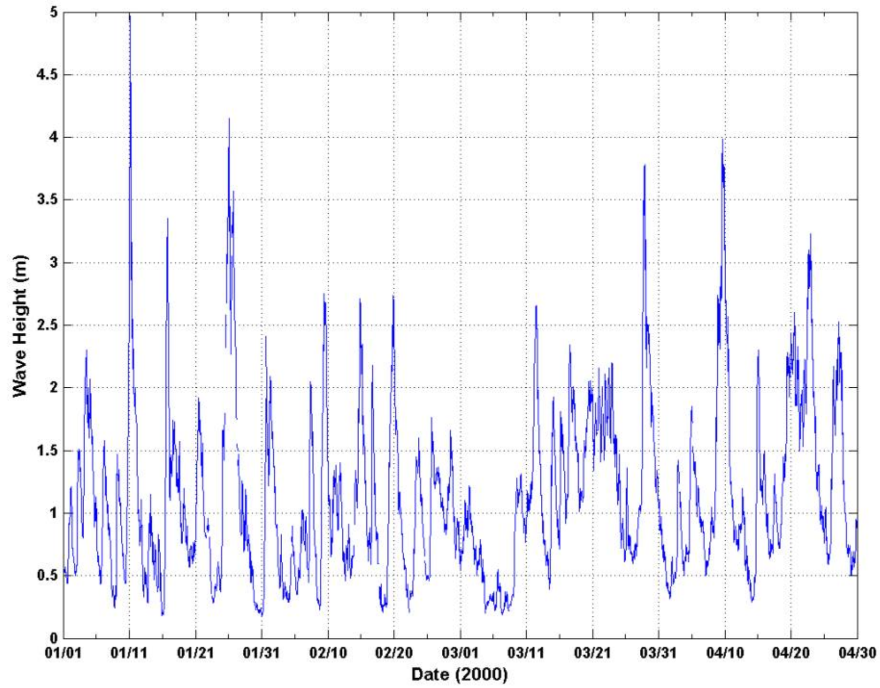

Figure A13. Significant wave height data for the winter of 2000. Three events had wave heights that met or exceeded the 4 m mark.

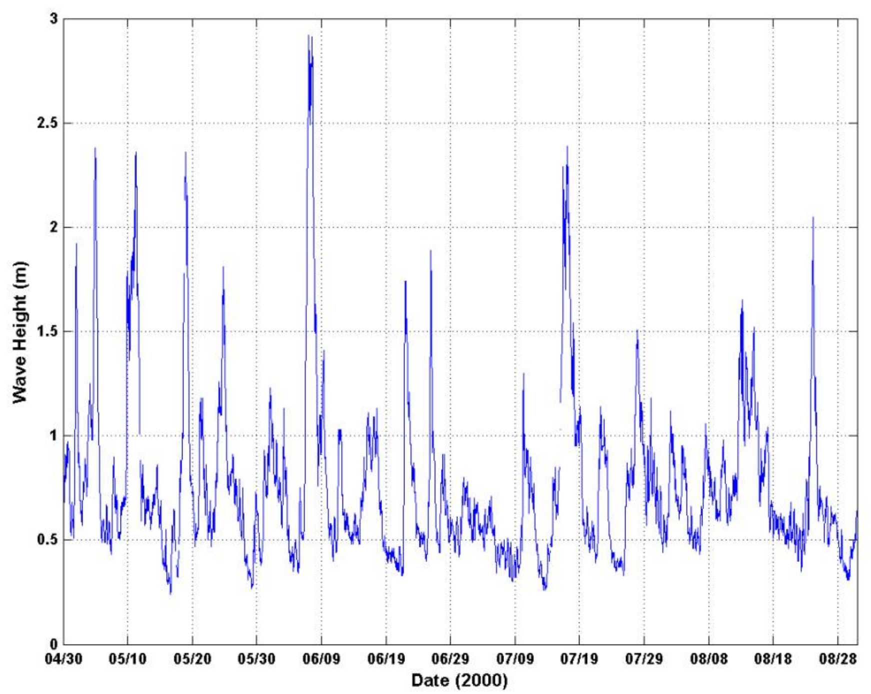

Figure A14. Significant wave height data for the summer of 2000. Typical with other summers, wave heights were generally less than 1 m, though several events exceeded the 2 m mark.

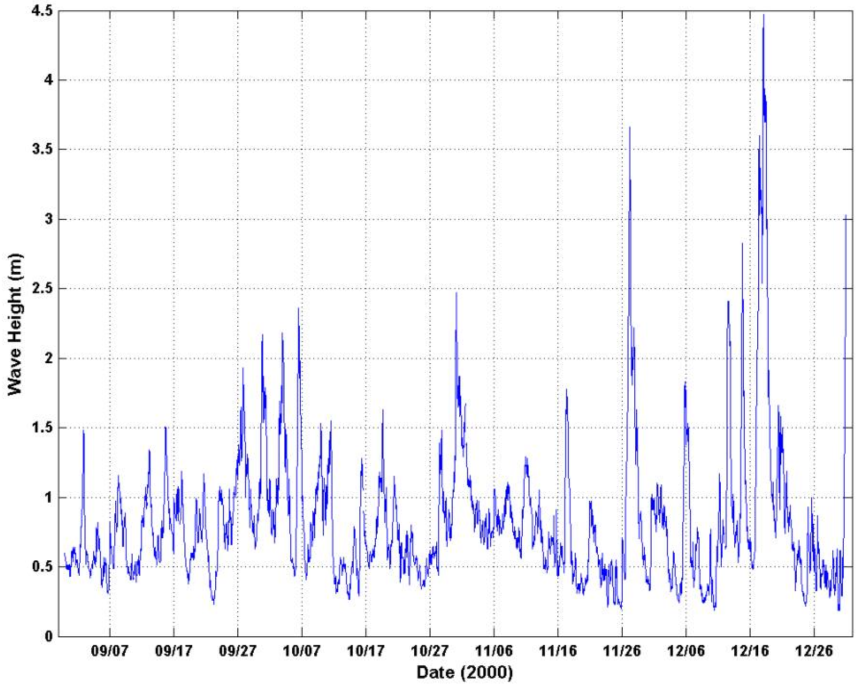

Figure A15. Significant wave height data for the fall of 2000. Late fall had several events that exceeded the 3 m mark.

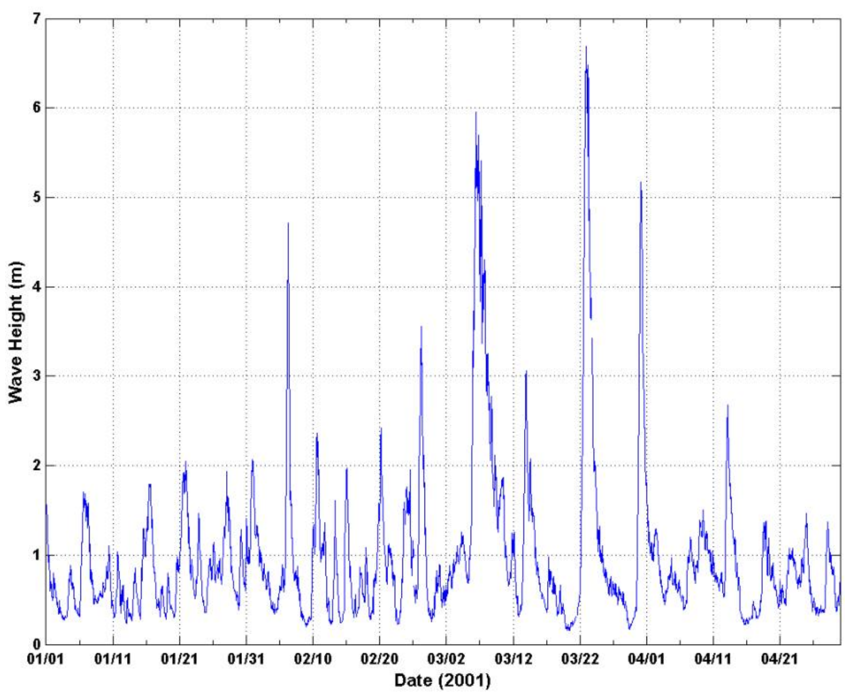

Figure A16. Significant wave height data for the winter of 2001. Wave heights were generally less than 2 m, and several events in February, March, and April exceeded the 4 m mark.

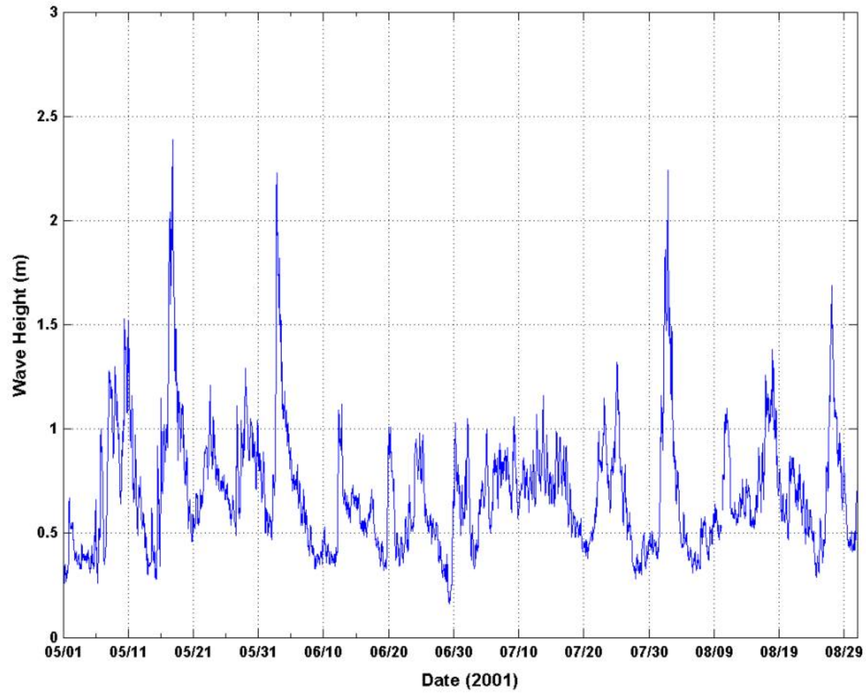

Figure A17. Significant wave height data for the summer of 2001. Three events (in May, June, and July) exceeded wave heights of 2 m.

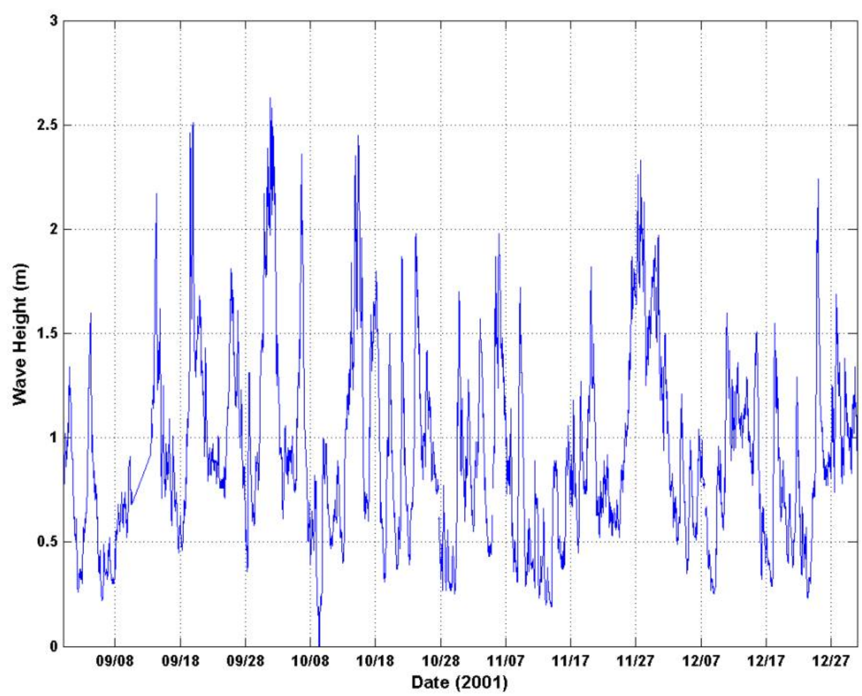

Figure A18. Significant wave height data for the fall of 2001. The mean value was near 0.92 m, and most events had waves that were below 2.5 m in height.

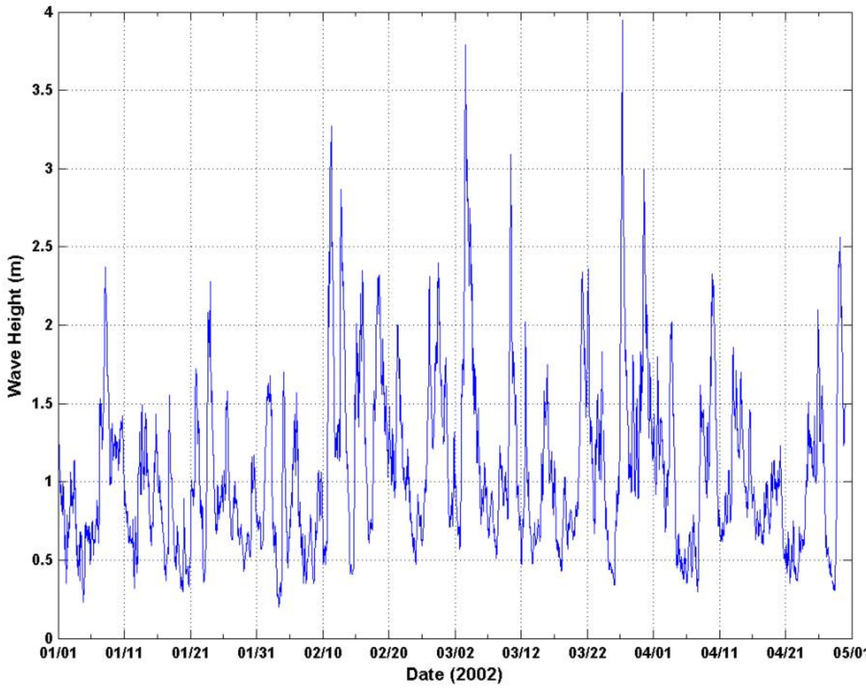

Figure A19. Significant wave height data for the winter of 2002. Four events exceeded the 3 m mark, but overall wave heights were above 1 m for over 50% of the time. The largest events occurred in February, March, and April.

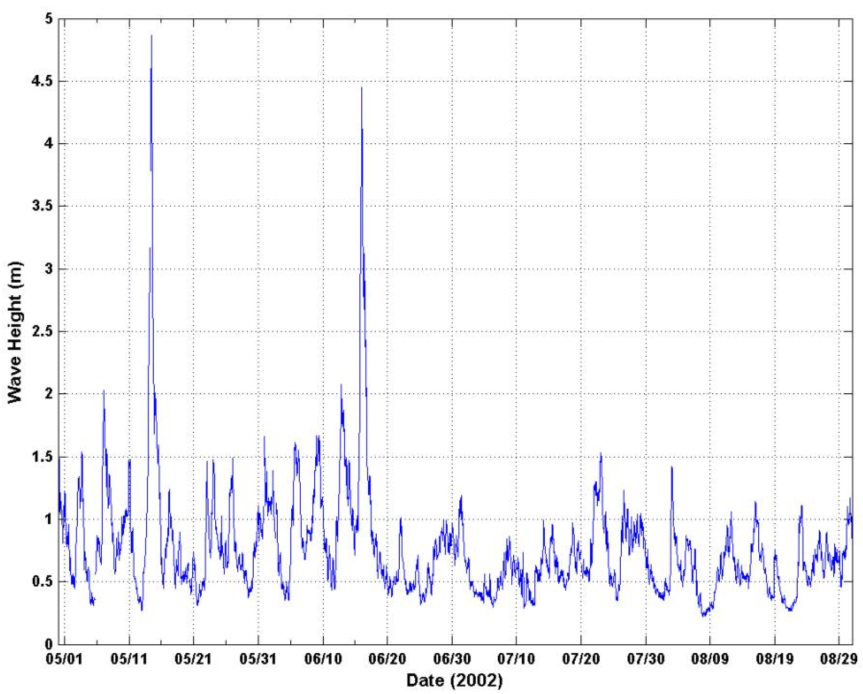

Figure A20. Significant wave height data for the summer of 2002. Unseasonable large events, in excess of 4 m, occurred in May and June, with the remainder of the summer being relatively calm.

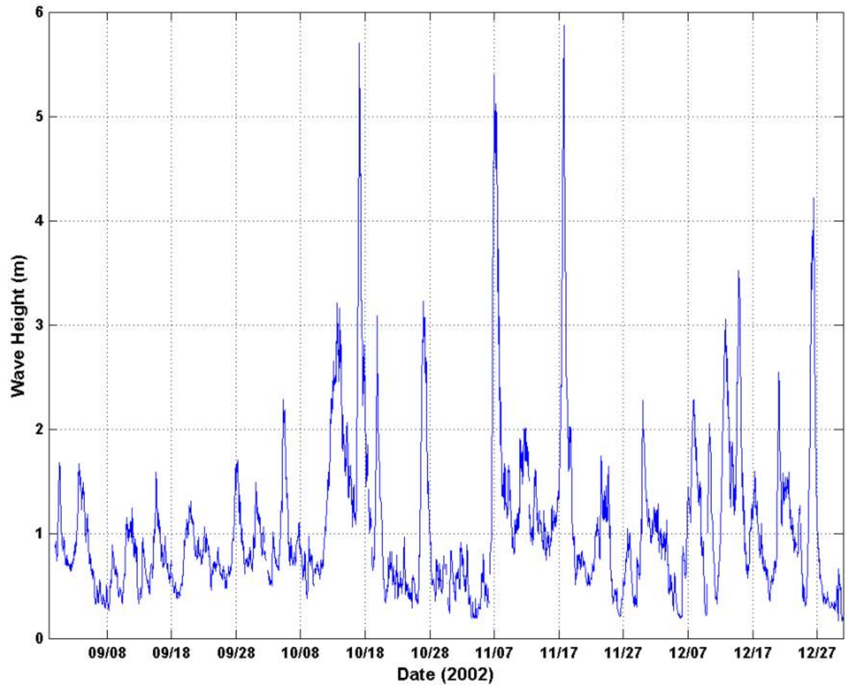

Figure A21. Significant wave height data for the fall of 2002. 2002 had a very active fall; there were several large events that exceeded 5 m (in October and November) that also exceeded the winter 2002 storm events.

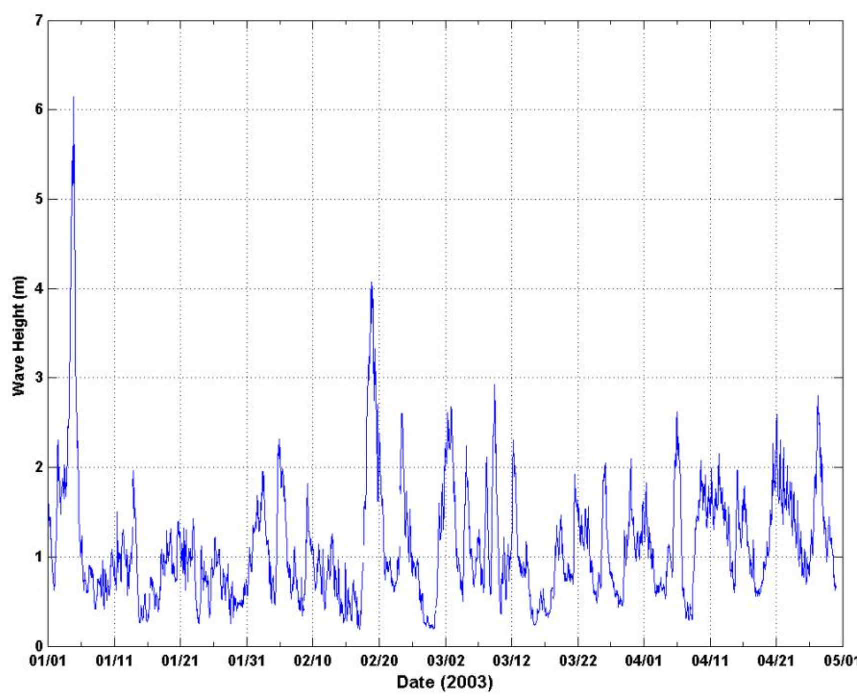

Figure A22. Significant wave height data for the winter of 2003. The winter had a large event, with wave heights exceeding 6 m, in January. Other than another event that approached 4 m in February, the winter was otherwise void of large wave events.

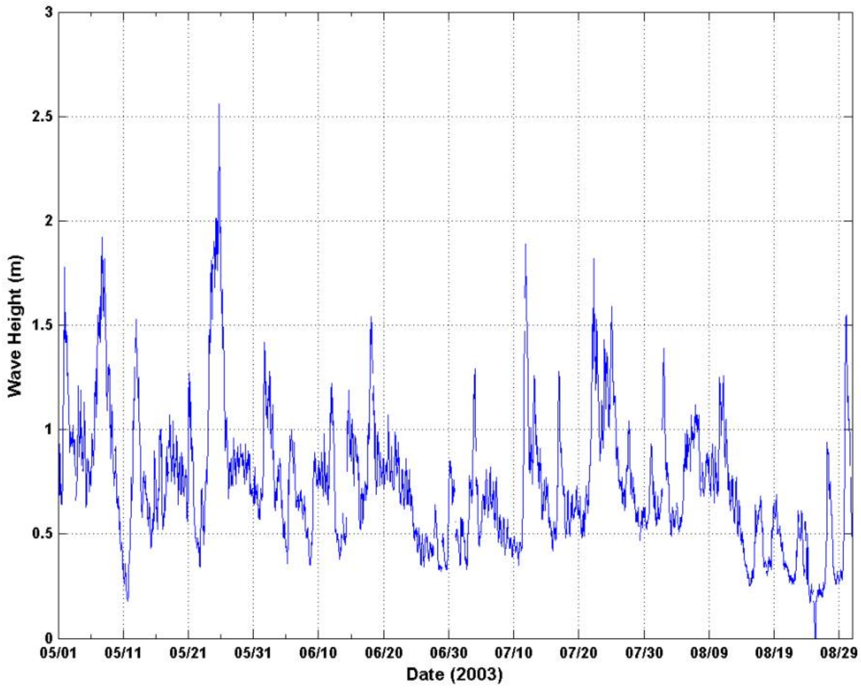

Figure A23. Significant wave height data for the summer of 2003. Only a single event in May exceeded the 2 m wave height mark.

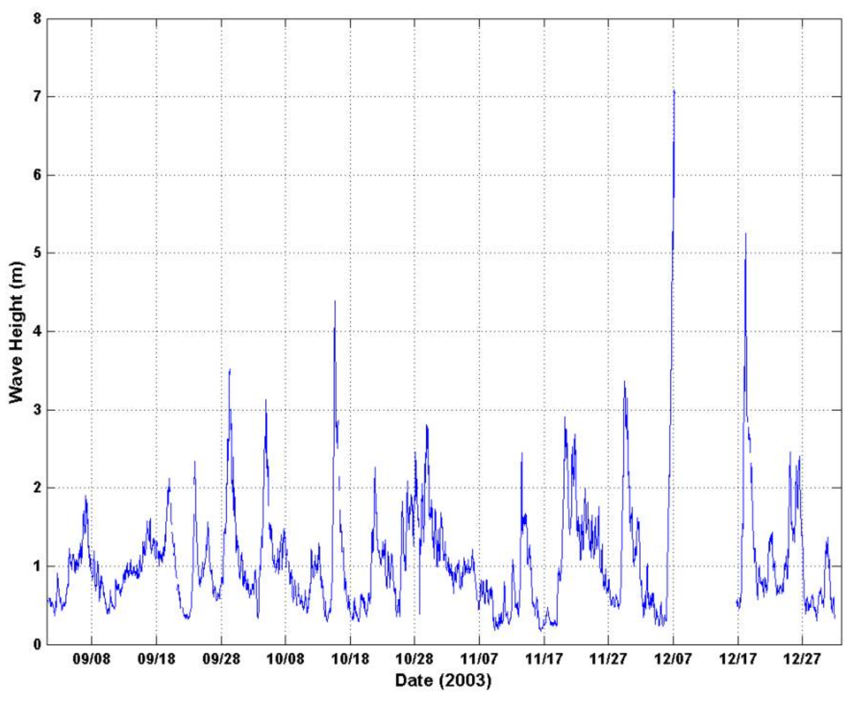

Figure A24. Significant wave height data for the fall of 2003. The fall was characterized by six events exceeding the 3 m mark, with the largest in December exceeding the 7 m mark.

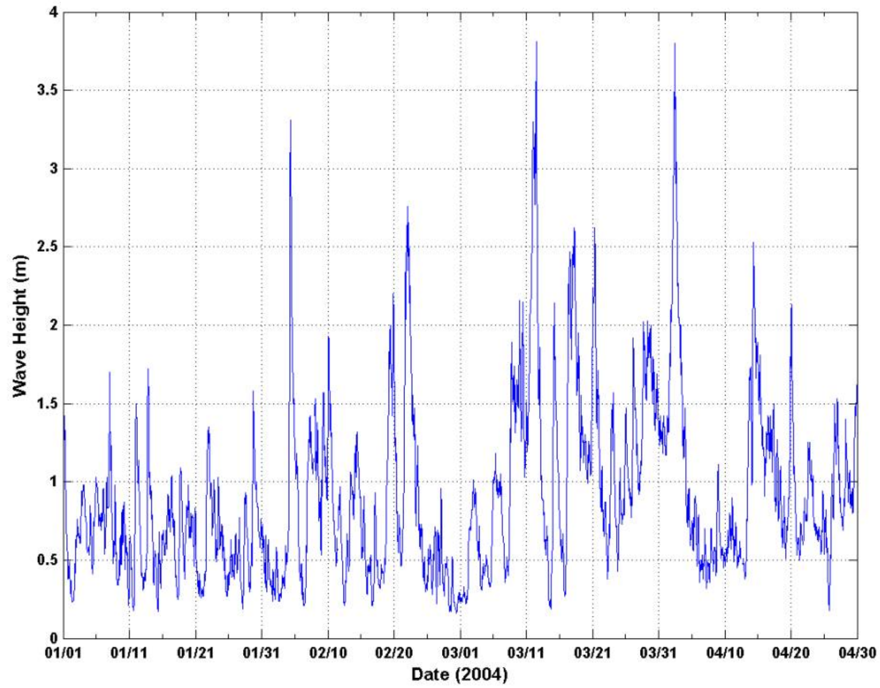

Figure A25. Significant wave height data for the winter of 2004. January was relatively calm, with larger events that exceeded 3 m occurring in February, March, and April.

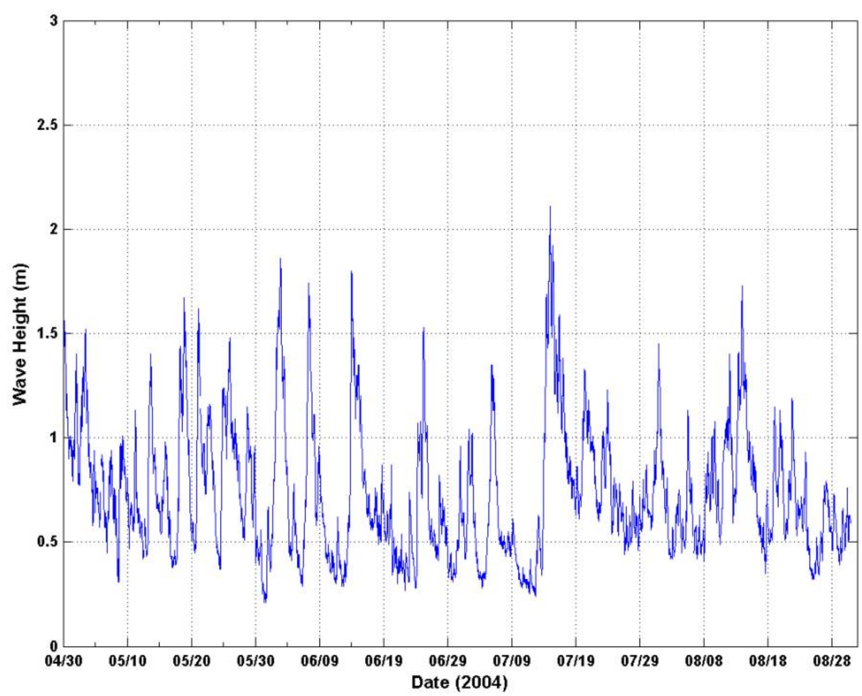

Figure A26. Significant wave height data for the summer of 2004. The summer months were relatively calm, with the largest event occurring in July.

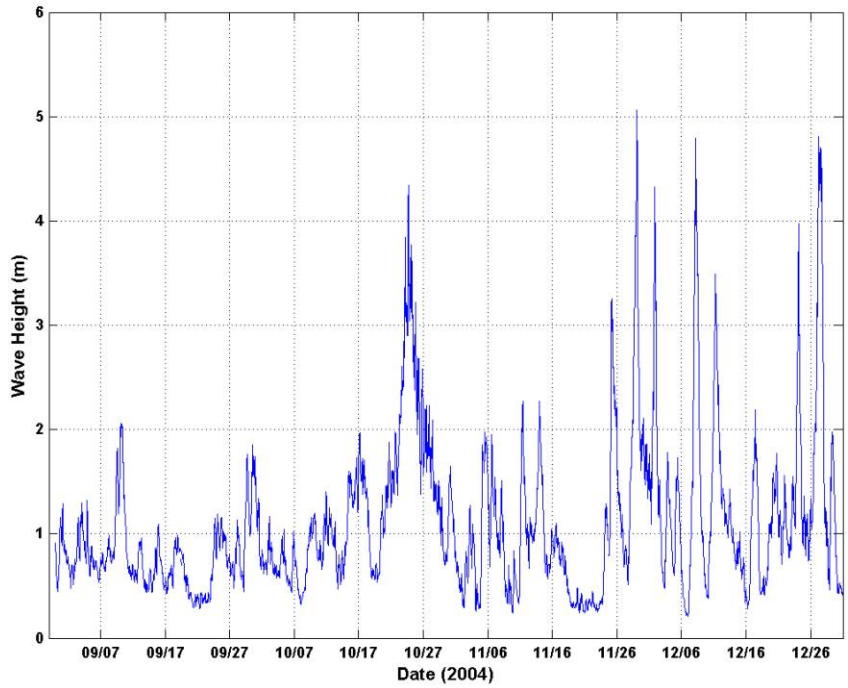

Figure A27. Significant wave height data for the fall of 2004. The beginning part of fall - through mid October, was relatively calm. A large event occurred in late October, and several large wave events that exceeded 4 m were recorded in December.

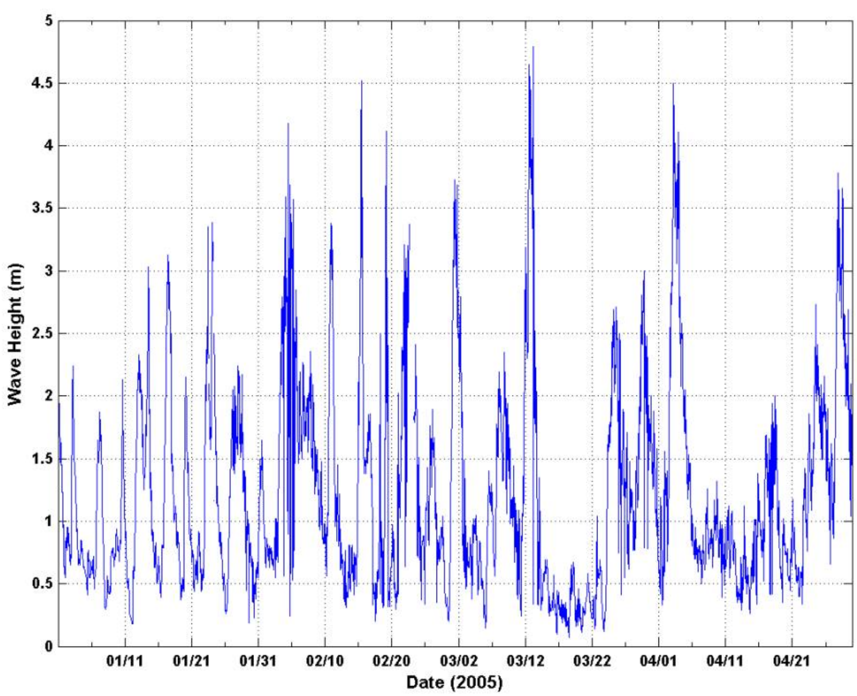

Figure A28. Significant wave height data for the winter of 2005. Winter 2005 was very active, with numerous storm events producing waves that exceeded the 3 m mark, the largest of which occurred in February, March, and April.

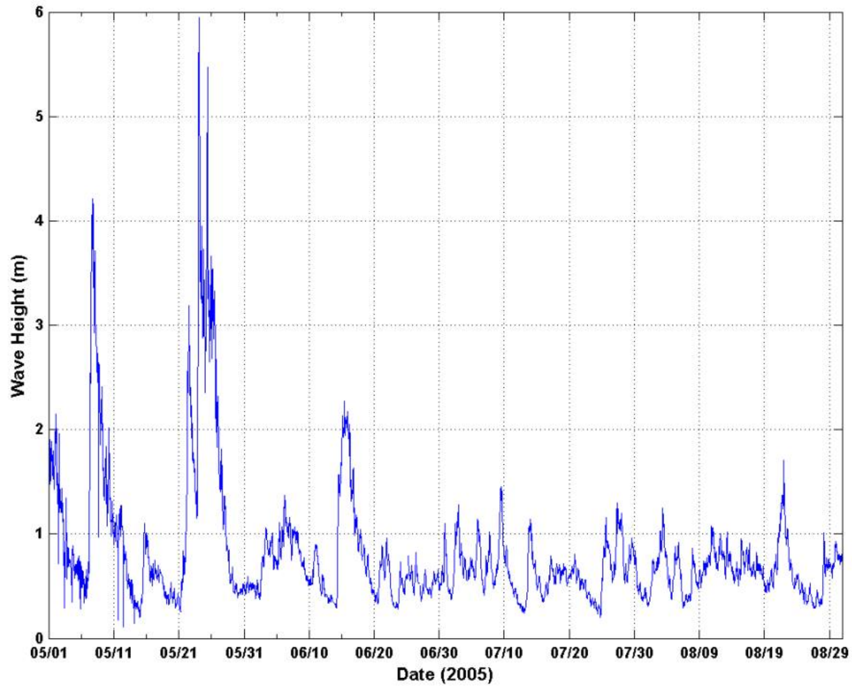

Figure A29. Significant wave height data for the summer of 2005. Similar to the summer of 2002, two very large unseasonable events produced waves that exceeded the 4 m mark in May. The second event was the result of a series of northeast storms that battered the coastline for a period of a week. The remainder of the summer was generally calm.

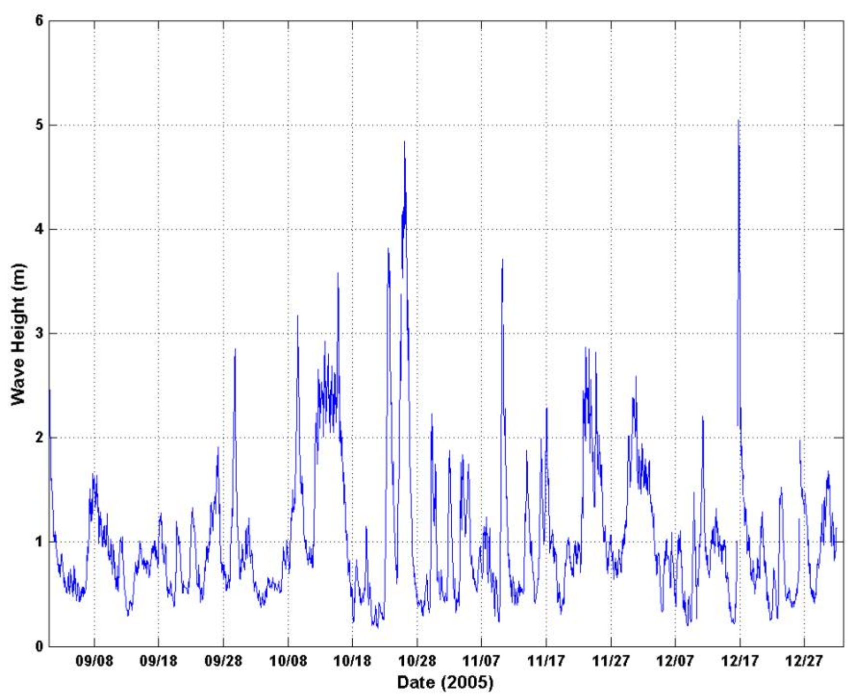

Figure A30. Significant wave height data for the fall of 2005. An active October saw three events produce waves over 3 m, while additional events in November and December occurred.

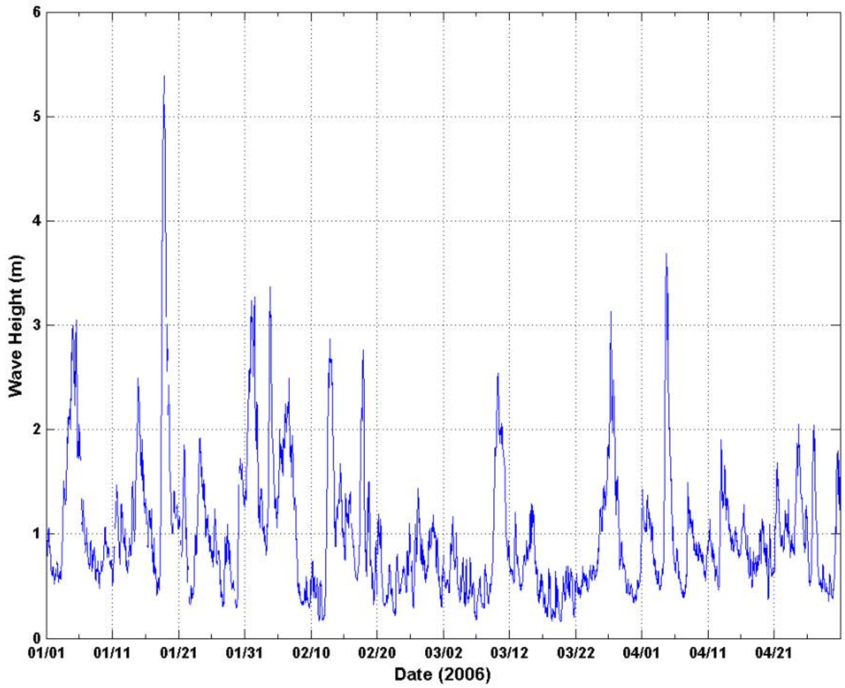

Figure A31. Significant wave height data for the winter of 2006. The largest event occurred in January, exceeding 5 m. Four additional events exceeded the 3 m mark, in February and April.

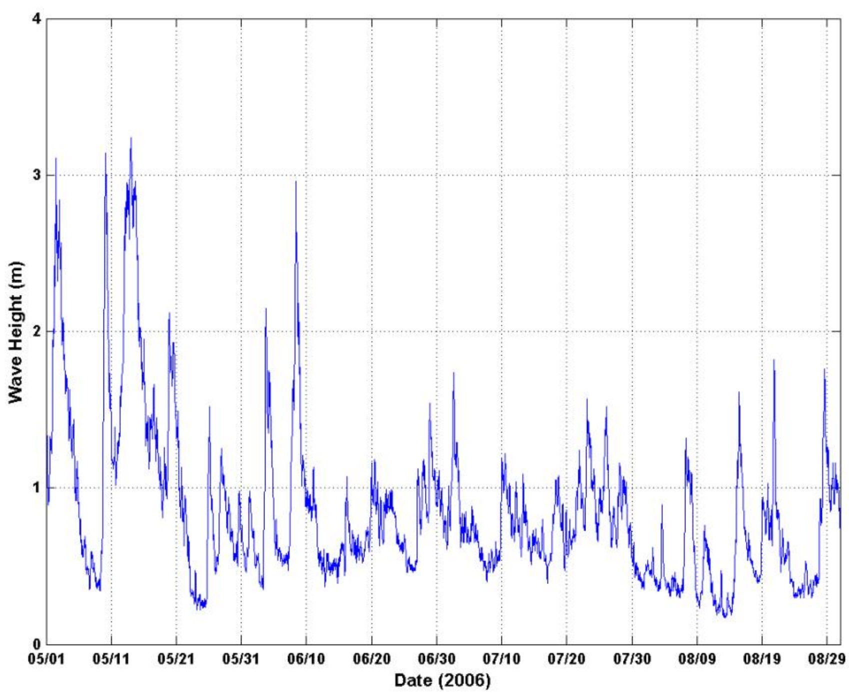

Figure A32. Significant wave height data for the summer of 2006. May was active in the summer, with several events producing waves in excess of 3 m. Aside from an event in early June, the remainder of the summer was calm.

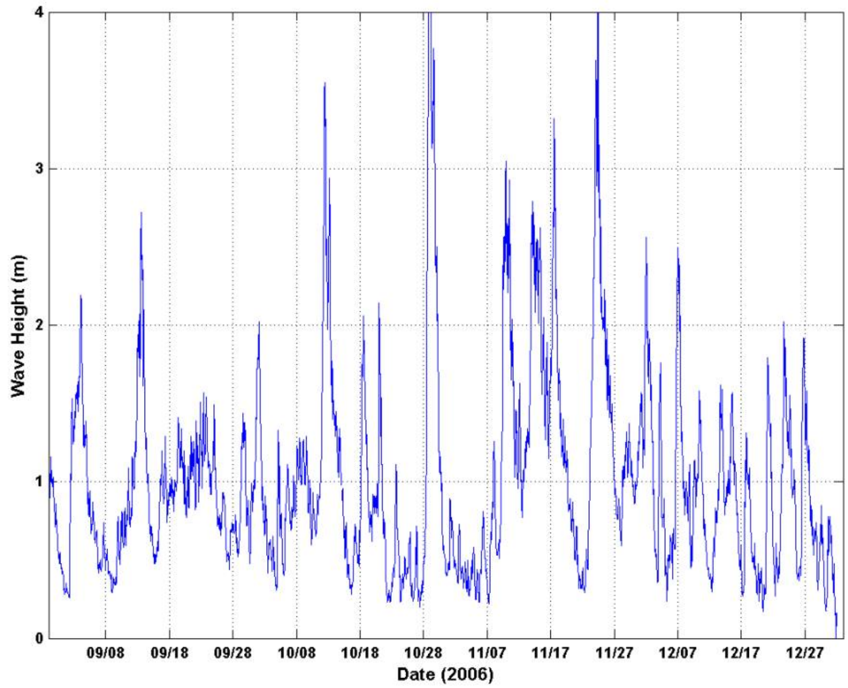

Figure A33. Significant wave height data for the fall of 2006. The fall was active, with five events in October and November that exceeded the 3 m mark, two of these producing waves that reached 4 m.

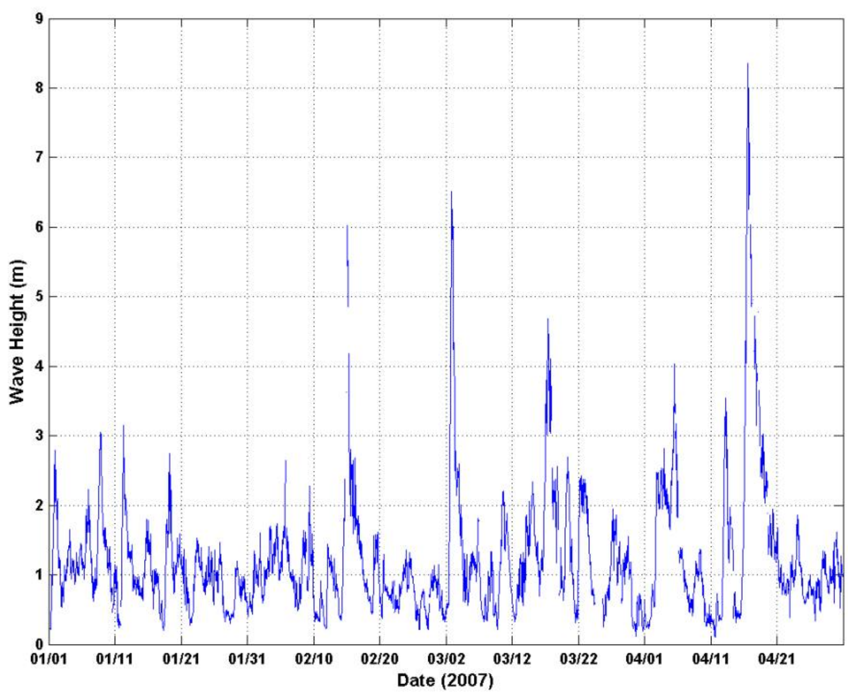

Figure A34. Significant wave height data for the winter of 2007. The winter of 2007 was characterized by a relatively calm January and early February. A short event produced waves reaching 6 m in mid-February. March had a large event that produced waves that exceeded 6 m, and one that exceeded 4 m. April saw the Patriots' Day storm, which produced wave heights that exceeded 8 m.