Journal of Coastal Research	14	4	1255–1264	Royal Palm Beach, Florida	Fall 1998

Long-Term Beach Profile Variations Along the South Shore of Rhode Island, U.S.A.

Elizabeth M. Lacey and John A. Peck

Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882, U.S.A.

ABSTRACT

LACEY, E.M. and PECK, J.A., 1988. Long-Term Beach Profile Variations Along the South Shore of Rhode Island, U.S.A. *Journal of Coastal Research,* 14(4), 1255–1264. Royal Palm Beach (Florida), ISSN 0749-0208.

The south shore of Rhode Island consists of eight microtidal, wave-dominated, sandy barriers separated by headlands of glacial till and outwash. Beach profiling was performed approximately bi-weekly in the fall, winter and spring and monthly during the summer at four barrier beach stations since 1962 and at an additional four stations since the mid-1970s. The profile data yield cross-sectional profiles and volumetric time-series plots which document the morphological and volumetric changes that occurred at these beaches. Time-series analysis of the profile-volume data reveals that an annual period is present and in-phase at all the profile stations. The annual cycle of high profile volume in the summer and low volume in the winter reflects onshore-offshore sediment transport and is related to the seasonal change in intensity and frequency of storms. Periods between 1.5 and 5 years in the profile-volume data from four stations are out-of-phase likely due to longshore transport of sediment. Long-period cycles (>9 years) are observed at the majority of the profile stations and may represent responses to variations in longshore sediment transport, sea level and climate.

ADDITIONAL INDEX WORDS: *Barrier beach, annual beach cycle, beach profiles, beach volume, New England.*

INTRODUCTION

A clearer understanding of many beach processes requires long-term good-quality data bases. In general, analysis of long-term (decadal) beach dynamics has relied on maps and charts or vertical aerial photographs (SMITH and ZARILLO, 1990), because beach profiling has generally covered only a short time period, usually less than a decade (*e.g.,* SONU and VAN BEEK, 1971; AUBREY, 1979; CLARKE and ELIOT, 1988; ELIOT and CLARKE, 1989; LARSON and KRAUS, 1994). On occasion, when long-term beach profiling has occurred, the data were collected at wide sampling intervals such as quarterly/annually (*e.g.,* MORTON *et al.,* 1994). ELIOT and CLARKE (1989) indicate that approximately 10 years of monthly observations are required to minimize the effects of seasonal and other short-term changes. We present data from the world's longest continuous record (33 years), to our knowledge, of beach profiling at a sandy, microtidal, wave-dominated barrier environment. The Rhode Island beach profile project was initiated and supervised for 31 years by Dr. Robert McMaster (deceased), at the University of Rhode Island. Since its inception, data have been obtained by graduate students with research assistantships and annual reports have been generated. In addition, several theses (*e.g.,* GRAVES, 1990) have used this beach profile database.

Since 1962, beach profile surveys have been performed at four barrier beach stations along the south shore of Rhode Island. In the mid-1970s, surveying began at four additional stations. The surveys have been conducted to monitor morphological variations of the beaches through time. In this paper, we present the long-term volume time-series data for each profile station. Spectral analysis of the volume time-series reveals several significant cycles within the data. A one year cycle, related to annual changes in the intensity and frequency of storms, is present at all beach stations. Longer time periods of approximately 1.5 to 5 years may be related to longshore sediment transport, and periods of > 9 years may be related to longer-term changes in climate (as represented by variations in wind strength) and sea level.

Regional Setting

Rhode Island's south shore is bounded to the north by Rhode Island, to the east by lower Narragansett Bay, to the south by Block Island Sound, and to the west by Long Island Sound (Figure 1). The RI south shore consists of headlands of glacial sediment with sandy barriers lying between the headlands. Sediment was supplied mainly by the reworking of the Pleistocene till and glaciofluvial sand and gravel during the Holocene transgression. Based on aerial photographs from 1939–1985, BOOTHROYD *et al.* (1988) determined that barriers usually retreat at a faster rate (generally exceeding 0.3 m/y) than headlands erode. The RI south shore has an approximate east-west shoreline orientation (Figure 1). The barrier spits are from 1 to 5 km long and 0.2 to 0.3 km wide and front lagoons (referred to locally as coastal salt ponds). The larger lagoons have inlets (referred to locally as breachways) stabilized by jetties that were constructed in the 1950's and 60's (BOOTHROYD *et al.,* 1985).

Physical factors including winds, waves, storms, tides and

96153 received 2 November 1996; accepted in revision 20 March 1997.

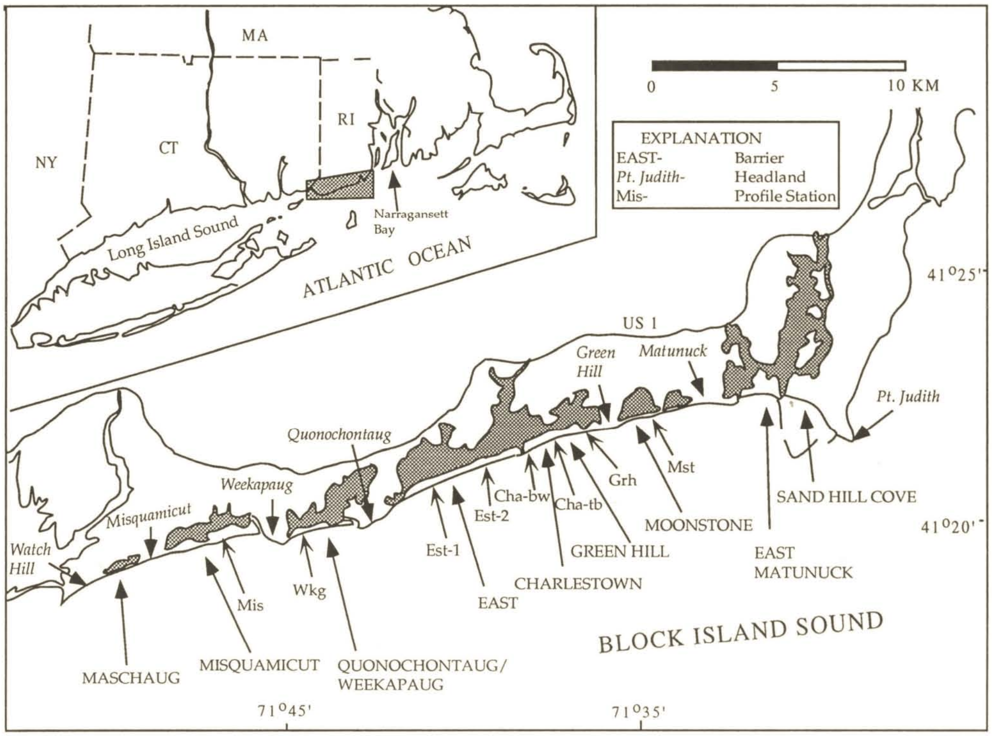

Figure 1. Location map of the barrier beaches along the south shore of Rhode Island showing physiographic units and profile station locations. Inset shows the location of the south shore of Rhode Island. (Modified from BOOTHROYD *et al.,* 1986.)

sea level influence beach morphology. Winds are responsible for generating both fair weather and storm waves in Block Island Sound. Fair weather waves (less than one meter) dominate during the late spring and summer (GRAVES, 1990). Storms producing larger waves generally occur along the Atlantic coast in the winter and early spring (DOLAN and DAVIS, 1992). Along the RI south shore, winds from the south and east may build up large waves due to the great fetch in those directions.

Waves from coastal storms cause the most dramatic short-term changes in beaches and barriers (DOLAN *et al.,* 1988; MCMASTER, 1961–1996). Most of the storms that affect the Atlantic Coast are extratropical storms or "northeasters" which are associated with cyclonic (low pressure) disturbances and originate in the mid-latitude westerly wind belt (DOLAN *et al.,* 1988). Tropical cyclones including hurricanes and less intense tropical storms are cyclonic disturbances that develop in warm tropical waters (DOLAN *et al.,* 1988) and essentially follow the Gulf Stream (INMAN and DOLAN, 1989). Hurricanes (in particular the hurricanes on September 21, 1938, Hurricane Carol on August 31, 1954, and Hurricane Belle on August 10, 1976) have caused significant change to the Rhode Island shore (MCMASTER and FRIEDRICH, 1986; BOOTHROYD *et al.,* 1986). The 1938 hurricane, with winds over 190 km/hr, made landfall at the time of spring high tide with a 4 m storm surge. The resulting shoreline change included headland erosion (up to 9 meters), landward retreat of the berm (up to 12 m), retreat (up to 15 m) or complete removal of the foredune, formation of numerous temporary inlets, and deposition of extensive washover fans and surge platforms (NICHOLS and MARSTON, 1939).

The RI south shore is a microtidal (mean open ocean tidal range of 0.8 to 1.2 m) wave-dominated coast (BOOTHROYD *et al.,* 1986). The tides are semidiurnal with two nearly equal highs and lows each day. Although tides may be important for the seaward transport of wave-suspended sediment, tidal currents alone are not sufficient for the transport of sand-sized sediment in the nearshore due to their low velocity (GRAVES, 1990).

Sea-level rise may have a long-term effect on barrier morphology by allowing storm waves access to increasingly higher elevations (GRAVES, 1990). The average rate of sea-level rise in this region is 2.37 mm/yr based on yearly averaged sea-level data from 1930 to 1996 at the Newport, RI tide gauge (NOAA, 1996).

METHODOLOGY

Eight barrier beach stations were surveyed on the Rhode Island south shore. The stations, from west to east, are located at Misquamicut Beach (Mis), Weekapaug Beach (Wkg), two sites on East Beach (Est-1, Est-2), Charlestown Breachway Beach (Cha-bw), Charlestown Town Beach (Cha-tb), Green Hill Beach (Grh) and Moonstone Beach (Mst) (Figure 1, Table 1).

The beach profile is obtained by a two-person team using

Table 1. *Beginning date, ending date and total number of beach profile surveys.*

Profile Station (a)	Date of First Survey	Date of Last Survey (b)	Number of Surveys
Mis	7/26/77	2/29/96	346
Wkg	12/19/62	2/29/96	617
Est-1	12/19/62	2/29/96	620
Est-2	8/20/76	2/29/96	329
Cha-bw	11/19/76	2/29/96	348
Cha-tb	11/20/75	2/29/96	377
Grh	12/19/62	2/29/96	617
Mst	12/19/62	2/29/96	605

(a)Refer to Figure 1 for station locations
(b)Last survey date used for this article, profiling is continuing

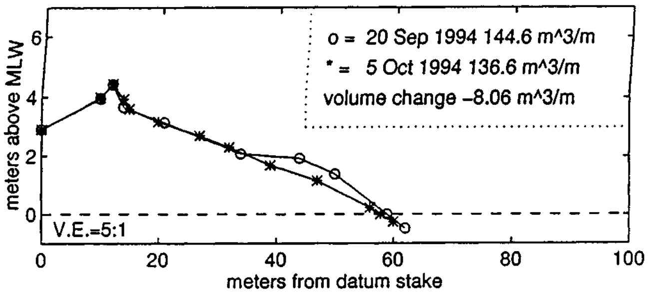

Figure 2. Representative beach profile. Two consecutive profiles from station Wkg (Weekapaug Beach) are overlain to show profile changes that occurred between September 20, 1994 and October 5, 1994.

a transit and stadia-rod. All elevation profiling is referenced to a datum stake, ρ, which is at a known elevation above mean low water (MLW) and located landward of the foredune crest. The transit is first set up at the instrument stake location, on the foredune crest. The surveyor then performs a backsight to the reference stake. Next the height of the instrument is determined, and then the transit is rotated 180 degrees. A transect perpendicular to the shore is made by selecting foresight stations which represent inflection points and textural changes seaward of the foredune crest (Figure 2). The beaches are generally surveyed on a bi-weekly basis during the fall, winter and spring and monthly during the summer. Whenever possible, the survey is conducted near the time of low tide to take advantage of maximum beach exposure.

Although this database represents, to our knowledge, the world's longest continuous beach profiling record, there are several limitations to the profiling method. (1) The datum stakes are located at varying distances landward of the dune crests at the respective beaches. Therefore, the absolute profile volumes should not be compared between profile sites. However, relative volume changes between the beaches may be compared. (2) Due to transgression during the last 33 years, the location of the reference stake at several of the beaches has been moved landward. The resulting additional volume has been calculated and added to the previous survey volumes. This addition affects the absolute number of the earlier survey volumes but, again, not the relative volume changes in the time-series. (3) Although transit data have been collected by numerous different graduate students, consistency has been maintained by having the same person (Mr. James Allen) selecting the stadia-rod locations throughout most of the survey history. (4) Measurements collected during inclement weather (especially wind and fog) were likely to be less accurate than measurements made during fair weather due to difficulty in reading the stadia rod. (5) On occasion, beaches could not be surveyed at the above-specified time interval due to limited funding and/or access difficulties. The longest unsurveyed interval was between 7/8/91 and 12/4/91 at the Cha-bw profile station. (6) The individual survey profiles usually represent the integrated results of wave and water conditions since the previous survey, and, depending on the survey date, may not show the significant post storm erosion and recovery which occurs within a few hours (LARSON and KRAUS, 1994).

Using programs written in MATLAB (© MATHWORKS INC., 1992), the transit data were plotted as elevation profiles (Figure 2) and profile volumes were determined. The profile volume equals the cross-sectional area [bounded by the datum stake (ρ) and the intersection of the profile with mean low water (MLW)] times one meter width. If an elevation station is measured below MLW then a point is interpolated at MLW. If the last station does not reach MLW then the last two points from the profile are used to extrapolate the slope from the last point to MLW.

Spectral analysis of time-series data can be used to identify recurrent periods within the record. The time-series data were Fourier-transformed using the Blackman-Tukey method with the program AnalySeries (PAILLARD *et al.*, 1996). The results were plotted as a power spectrum where the abscissa represents both frequency (cycles/year) and period (years). Period is the inverse of frequency. The ordinate represents power which is the square of the amplitude of all the cosine components that comprise the record. Spectral analysis was performed on the volume time-series data, the monthly mean wind data from Warwick RI, and the monthly mean sea-level data from Newport RI. Warwick and Newport are located approximately 50 km to the north-northeast and 25 km to the east-northeast, respectively. Prior to spectral analysis, the volume data were interpolated to a twenty day interval. Twenty days is the average time between surveys as calculated by the total time each of the stations has been surveyed divided by the number of surveys at each station (Table 1). The monthly mean meteorological and sea-level data were assigned as having a 30 day interval. Peaks in the power spectra rising appreciably above the level of sampling errors were visually determined to be significant.

RESULTS

Long-term volume changes from the time surveying began through February 1996 are presented for each of the beaches (Figures 3A-H). The volume represents the total profile volume which includes the foredune and the berm. However, most of the high-frequency variability in the volume time-series results from changes confined to the berm. Large, rapid decreases in profile volume (*e.g.,* October 1988) reflect the erosion of both berm and foredune during major storm events. Some of the low-frequency volume changes are due in large part to changes in the more stable foredune portion of the profile. For example, the general increase in profile volume during the 1980s at Est-1 is due to accretion and vegetation of the dune ramp.

The two profiles on East Beach, Est-1 and Est-2, are 2 km apart on the same barrier spit (Figure 1) but display opposite long-term volume trends. In the early 1980s, Est-1 displayed a low-profile volume whereas Est-2 was at its maximum profile volume. Since about 1985, Est-1 shows an overall increase in profile volume whereas Est-2 displays little net change (Figures 3C and 3D). The profiles Cha-bw and Cha-tb are located one and a half km apart on the Charlestown Barrier (Figure 1). These two profiles display similar long-term trends in profile volume with lower volumes in the early 1980s and 1990s (Figures 3E and 3F). The reduction in profile volume in the early 1990s was larger at Cha-bw than at Cha-tb. During the first 13 years of surveying, Wkg and Mst remained relatively stable. Since 1976, the Wkg and Mst profile stations display major fluctuations in volume (Figures 3B and 3H). The Grh profile shows a steady decline in volume (with intermittent short-term periods of increasing volume) since surveying began at this station in 1962 (Figure 3G). The average retreat rate between 1939–1985 in this segment of the Green Hill Barrier was 0.78 m/yr based on a review of aerial photographs (BOOTHROYD *et al.,* 1988). The steady decline at the Grh station is atypical compared to the other stations (Figures 3A-3H).

Spectral analysis using AnalySeries (PAILLARD *et al.,* 1996) of the volume time-series data showed power at periods of less than one year at four of the profile stations (Mis, Wkg, Est-2, Mst) (Figure 4, Table 2). The volume time-series clearly show the annual variability at all the beaches with low-profile volume in the winter and high-profile volume in the summer (Figures 3A-H). Both Mis and Wkg exhibit low-annual profile volume variability of about 10 m³. An annual change of 10 m³ is approximately 50 percent of the berm volume at Mis but only 20 percent of the berm volume at Wkg (GRAVES, 1990). Cha-tb, Grh and Mst exhibit an intermediate-annual profile volume variability of about 20 m³. This represents approximately 55 percent of the Cha-tb berm volume, 65 percent of the Grh berm volume and 50 percent of the Mst berm volume (GRAVES, 1990). Est-1, Est-2 and Cha-bw exhibit the highest-annual variability of about 25, 25 and 40 m³ respectively. This represents approximately 40 percent of the berm volume at Est-1, 25 percent of the berm volume at Est-2 and 55 percent of the berm volume at Cha-bw (GRAVES, 1990). Spectral analysis of the volume time-series reveals the significance of one year periodicity at all the beaches (Figures 4A-H, Table 2). Est-1 has a very

→

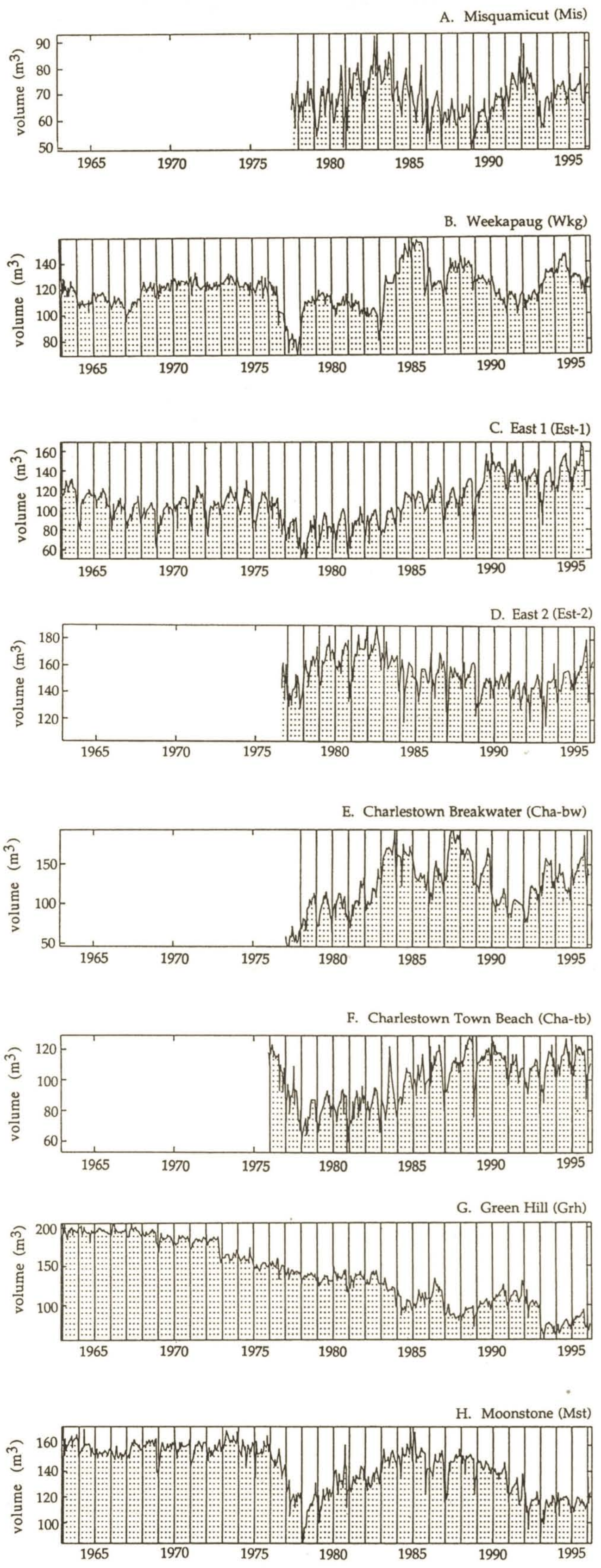

Figure 3. Long-term beach profile volume records for the eight beach profile stations shown in Figure 1. Solid vertical lines represent yearly divisions, dotted vertical lines represent seasonal boundaries.

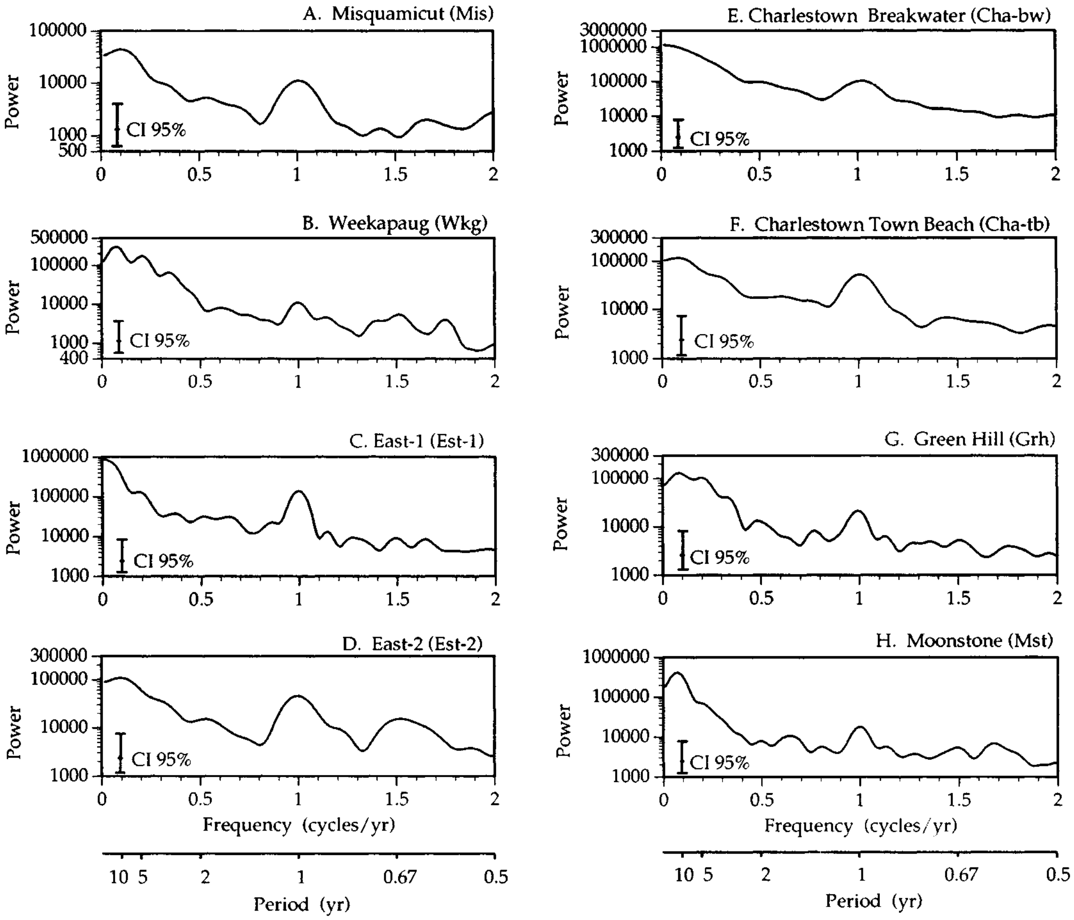

Figure 4. Spectra of the profile volume records. The abscissa is labeled both as frequency (cycles/yr) and period (yr). Period is the inverse of frequency. The ordinant is power on a logarithmic scale. The error bar represents the 95% confidence interval (CI).

strong seasonal signal, whereas the annual variability at Wkg is less pronounced.

In addition to the annual cycle, there are longer-period changes in the profile-volume time-series. Several of the profile stations (Wkg, Est-1, Grh, and Mst) display periods between approximately 1.5 and 5 years (Figures 4A-H, Table 2). With the exception of Cha-bw, all the beach profile stations display periods greater than 9 years (Table 2). However, it should be noted that these long-period changes are beyond the limit of resolution of the spectral analysis technique. The limit of resolution is one quarter of the temporal length of the data set. Based on the length of time that surveying has been performed, the resolvable limit is approximately 5 years for Mis, Est-2, Cha-bw and Cha-tb and approximately 8.3 years for Wkg, Est-1, Grh and Mst.

Table 2. *Peaks in volume time series spectra (years).*

Station (a)								
Mis	9.2*					1.0		0.6
Wkg	14.5*	4.8	3.0			1.0	0.66	0.57
Est-1	14.5*	5.4				1.0		
Est-2	9.8*					1.0	0.67	
Cha-bw						1.0		
Cha-tb	11.5*					1.0		
Grh	11.9*	5.0	3.1	2.1	1.3	1.0		
Mst	14.5*				1.5	1.0	0.67	

Based on results of spectral analysis. See Figures 4A–H
(a)Refer to Figure 1 for profile locations
*Indicates exceeds the limit of resolution of the spectral analysis technique; see text for explanation

DISCUSSION

In this section we discuss the changes in the beach profile-volume time-series beginning with the short-period changes. Profile-volume changes with periods less than 1 year have been identified at four of the beach stations (Table 2). Short-term berm volume changes have been documented in response to individual storm events (LARSON and KRAUS, 1994) and tidal cycles (FOX and DAVIS, 1976). The origin of the sub-year periods in the profile volume may be related to seasonal

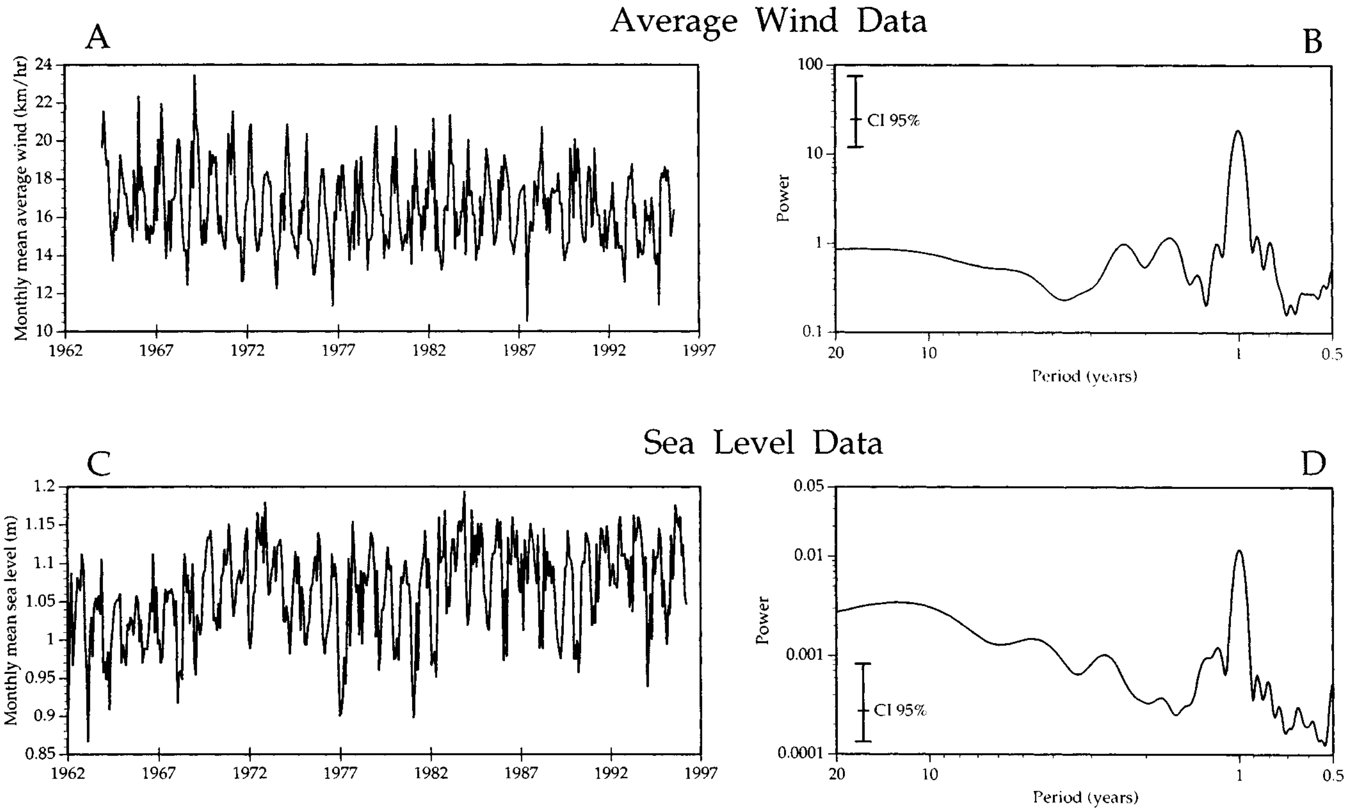

Figure 5. (A) Monthly mean average wind speed is the mean of daily average wind speed data for each month. The daily average winds speed is based on 21 or more observations at hourly intervals at T.F. Green Airport in Warwick, RI (Pilson, 1991; NOAA, 1988–1995). The data have been converted from mph to km/hr. (B) Spectrum of monthly mean average wind data shown in Figure 5A. (C) Monthly mean sea-level data from Station No. 8452660 in Newport, RI (NOAA, 1996). (D) Spectrum of sea-level data shown in Figure 5C.

climatic variations. This inferred seasonal climatic variation may also be reflected in the high-frequency variation superimposed on the annual variation in wind and sea-level data for Rhode Island (Figure 5). Because the average time between surveys is 20 days, we will limit our discussion of the sub-year periods.

A one year period was found in the spectral analysis of the profile-volume data at all eight beach stations (Figures 4A-H, Table 2). The volume time-series data, sea-level data, and wind data were band-pass filtered using the program CORPAC (Martinson *et al.*, 1982) between 0.96 and 1.15 years to remove contributions in the volume record with periods greater than and less than one year. The annual variation of high-profile volume during the summer/fall and low-profile volume during the winter/spring is in-phase at all eight profile stations (Figure 6) due to the dominance of onshore/offshore sediment transport. An annual cycle, corresponding to seasonal changes in the frequency and intensity of storms, is frequently identified in time-series of beach change (Aubrey, 1979, Torry Pines Beach, California; Clarke and Eliot, 1988, Warilla Beach, New South Wales; Dolan *et al.*, 1988, mid-Atlantic coast; Larson and Kraus, 1994, Duck, North Carolina).

Spectral analysis of the average-wind data from Warwick, RI showed significant power at a one year period (Figure 5B). The average wind velocity and beach profile-volume data, band-pass filtered at 1 year, clearly show the inverse relationship between wind strength and profile volume (Figure 6). We use the monthly mean average-wind velocity as a proxy for storm activity. We infer that increased storm activity during the winter/spring results in an increase in storm wave conditions and significant wave heights which, in turn, produce a reduction in profile volume. Dolan and Davis (1992) indicate that monthly extratropical storm frequencies have a clear maximum between December and April and a minimum between June and August for the U.S. east coast. During the winter/spring in RI, there are higher average-wind velocities, approximately 19 km/hr (Wright and Sullivan, 1982), whereas in the summer/fall there are lower average wind-velocities, approximately 16 km/hr (Wright and Sullivan, 1982) (Figure 5A). The annual variation in storminess is related to the seasonal migration of the polar front, the feature associated with mid-latitude cyclone formation and tracking. These storms are accompanied by high winds that often produce large, erosive waves. In studying wind and wave data from the Coast

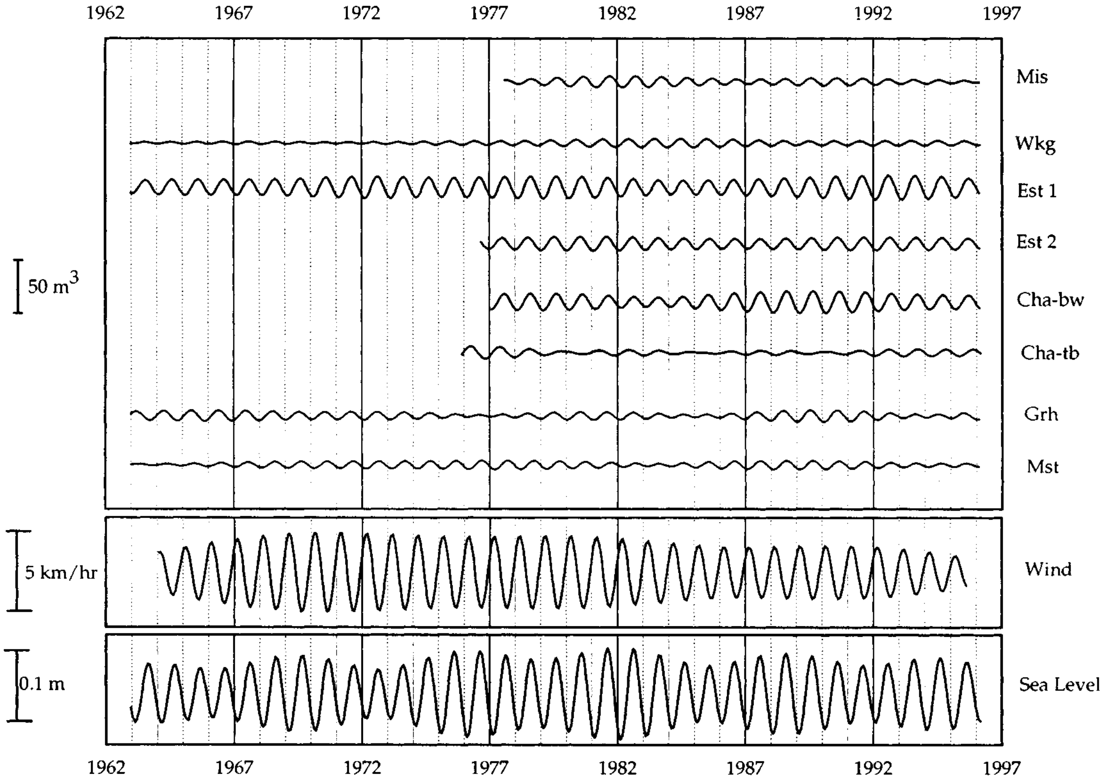

Figure 6. Beach-profile volume data, monthly average wind data from Warwick, RI (PILSON, 1991; NOAA, 1988–1995), and monthly mean sea level data from Newport, RI (NOAA, 1996) band-pass filtered between 0.96 and 1.15 years. Note the strong inverse relationships between wind velocity/profile volume and wind velocity/sea level.

Guard station at Point Judith, RI, (Figure 1) MCCARTHY (1973) found a good correlation between wind speed and wave height. The beaches along the south shore of Rhode Island are depositional under light wind conditions, independent of direction (MCCARTHY, 1973).

There is an inverse correlation between the one year cycle in sea level and wind strength (Figure 6). The annual variation in sea level is largely a function of the prevailing wind and not the wave activity. In the winter (December through March) the prevailing wind direction is from the northwest (*e.g.*, from the northwest 37% of the time for January). In the summer (June through September), the prevailing wind direction is from the southwest (*e.g.*, from the southwest 37% of the time for July) (WRIGHT and SULLIVAN, 1982). The high frequency of the strong northwesterly winds blowing offshore produces a setdown in the winter/spring resulting in lower sea level. During the summer/fall, the weaker onshore winds from the southwest produce a setup and result in higher sea level. It is important to note that the inverse relationship between wind strength and sea level applies to the annual cycle in the data (Figure 6). Depending on the track of individual winter/spring storms (storms that produce erosive storm wave conditions), onshore winds may produce a setup and elevate sea level for a short period of time.

Wkg, Est-1, Grh, and Mst have peaks in the power spectra at periods between 1.5 and 5 years (Figures 4B, C, G and H, Table 2). The Wkg, Grh and Mst profile-volume data were band-pass filtered to isolate the contribution of 1.5 to 3 year periods, and the profile-volume data from Wkg, Est-1 and Grh were band-pass filtered to extract the 4.0 to 6.6 year component. The filtered data displayed phase shifts between the stations that may be attributed to longshore sediment transport. In the 4.0 to 6.6 year band-pass filtered data, the Wkg time-series peaks and troughs lead the Est-1 peaks and troughs by 0.65 years on average (Figure 7). This is possibly due to longshore sediment transport fluctuations (to the east) between the two stations that are located approximately 5.5 km apart (Figure 1). The sea-level data filtered over a similar interval (4–6 years) did not show a relationship to beach volume change. CLARKE and ELIOT (1988) found periodicities of 2.0, 1.7 and 1.0 years in the amplitude spectra of the time-series describing sediment movement along and across Warilla Beach (New South Wales). The 1.7 year cycle was associated with longshore sediment transport and the biennial and annual cycles with onshore-offshore sediment exchange. Proposed driving mechanisms included storm surge, sea level variation, nearshore water circulation, change in beach saturation associated with groundwater recharge, coastal rainfall, wave-regime variations, and rip-

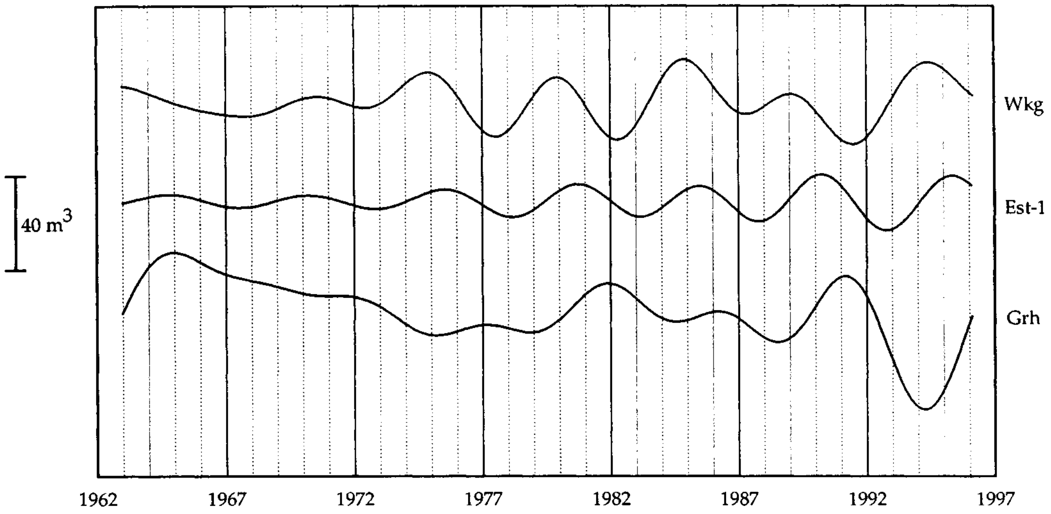

Figure 7. Beach-profile volume data for Wkg, Est-1 and Grh band-pass filtered between 4 and 6.6 years.

current activity (CLARKE and ELIOT, 1988). A combination of these processes may also be affecting the RI south shore beaches.

Long-period peaks in the profile-volume spectra occur between 9.2 and 14.5 years at all the beaches with the exception of Cha-bw (Table 2). However, interpretation of these long-period components is tentative due to the length of the time-series (Table 1). Discussion of the long-period peaks will be limited to the profiles (Wkg, Est-1, Grh and Mst) with the longest time-series (33 years). To determine relative trends, the data for Wkg, Est-1, Grh and Mst and sea level were low-pass filtered retaining variation greater than 8.6 years (Figure 8). The trend in the filtered Grh profile data is a function of the steady decline in profile volume at the Grh station which is atypical of the other stations. The profile volume for Wkg, Est-1, Mst and sea-level data display roughly similar trends from 1963 to 1986. However, between 1986 and 1996, Est-1 has a peak in volume while Wkg, Mst and sea level have troughs. An earlier investigation of the same Rhode Island south shore beach profile data (BOOTHROYD *et al.*, 1986) found strong 10 year and secondary 5 year cycles of erosion and deposition at Wkg, Est-1, Grh and Mst. The 10 year cycle at Wkg, Est-1 and Mst-1 were described as being in-phase under a qualitative inspection and Grh was slightly out of phase (BOOTHROYD *et al.,* 1986). They attributed these cycles to longshore sediment supply fluctuations and wave climate cycles. The current study includes 10 additional years of data since the investigation by BOOTHROYD *et al.* (1986) and also shows that Grh is out-of-phase with the other three beaches until approximately 1986. However, since 1986, Wkg, Grh and Mst appear to be roughly in-phase (Figure 8) and Est-1 is out-of-phase with the other stations due to foredune accretion as a result of vegetation of the dune ramp at Est-1.

CONCLUSIONS

Beach profiling of the south shore of Rhode Island (up to 33 years) record morphological and volumetric changes on a variety of time scales. Annual variations in profile volume were observed at all beach stations and are between 20 percent (Wkg) and 65 percent (Grh) of the berm volume. Spectral analysis of the volume time-series data indicates that the annual variability is in-phase at all the profile stations. The annual variability is attributed to onshore-offshore sediment transport associated with seasonal variations in storm frequency and intensity. On the annual scale, prevailing wind direction influences the regional sea level with lower sea level during the winter when there are predominantly offshore winds creating a setdown. The volume time-series data from four stations have 1.5 to 5 year cycles that are out of phase due to longshore sediment transport. Longer-period cycles (>9 years) in sea level and three profile stations are similar and may be attributed to variations in longshore sediment transport, sea level, wind and wave climate.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the late Dr. Robert McMaster for initiation and supervision of the RI south shore beach profiling project for over thirty years, Mr. James Allen for his helpful field assistance for over thirty years, and Dr. Jon Boothroyd for information regarding Rhode Island coastal sedimentary processes. Many graduate students were instrumental in the data collection and processing including Jim Gibeaut, Scott Graves, Russ Keltz, and Jules Hummon. Dr. Joseph Kelley and an anonymous reviewer provided helpful reviews. Partial funding for the graduate student beach profiling assistantship has been provided by the Coastal Resources Management Council, the Coastal Resources Center, and the State of Rhode Island.

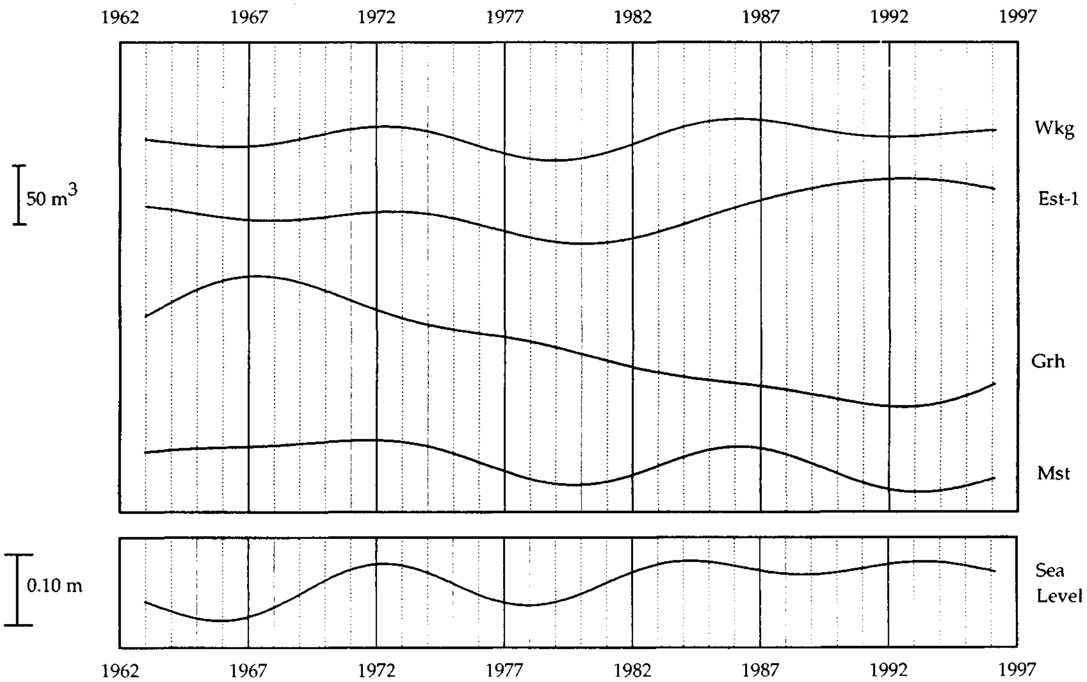

Figure 8. Beach-profile volume data for Wkg, Est-1, Grh, Mst and sea-level data from Newport, RI (NOAA, 1996) low-pass filtered at 8.6 years.

LITERATURE CITED

AUBREY, D.G., 1979. Seasonal patterns of onshore/offshore sediment movement. *Journal of Geophysical Research,* 84(C10), 6347–6354.

BOOTHROYD, J.C.; DACEY, M.F.; GIBEAUT, J.C., and ROSENBERG, J.J., 1986. Geological Aspects of Shoreline Management: a Summary for Southern Rhode Island, University of Rhode Island, Kingston, Rhode Island, *Unpublished Technical Report No. 6-SRG,* 104p.

BOOTHROYD, J.C.; FRIEDRICH, N.E., and MCGINN, S.R., 1985. Geology of microtidal coastal lagoons: Rhode Island. *Marine Geology,* 63, 35–76.

BOOTHROYD, J.C.; GALAGAN, C.W., and GRAVES, S.M., 1988. Advance and Retreat of the Southern Rhode Island Shoreline, 1939–1985; Including 1985 Berm Volume. University of Rhode Island, Kingston, Rhode Island, *Unpublished Technical Report No. 7-SRG,* 82p.

CLARKE, D.J. and ELIOT, I.G., 1988. Low-frequency changes of sediment volume on the beachface at Warilla Beach, New South Wales 1975-1985. *Marine Geology,* 79, 189–211.

DOLAN, R. and DAVIS, R.E., 1992. An intensity scale for Atlantic coast northeast storms. *Journal of Coastal Research,* 8(4), 840–853.

DOLAN, R.; LINS, H., and HAYDEN, B., 1988. Mid-Atlantic coastal storms. *Journal of Coastal Research,* 4(3), 417–433.

ELIOT, I. and CLARKE, D., 1989. Temporal and spatial bias in the estimation of shoreline rate-of-change statistics from beach survey information. *Coastal Management,* 17, 129–156.

FOX, W.T. and DAVIS, R. A. Jr., 1976. Weather patterns and coastal processes. *In*: R.A. Davis, Jr. and R.L. Ethington, (ed.), *Beach and Nearshore Sedimentation.* Society of Economic Paleontologists and Mineralogists Special Publication No. 24, pp. 1–23.

GRAVES, S.M., 1990. Morphotomology of Rhode Island Barrier Shores: A Method of Distinguishing Beach from Dune/Barrier Component Histories Within a 29 Year Record of the Shore Zone Profile Data, with Special Reference to the Role of the Beach as a Buffer and Modulator of Erosional Coastline Retreat. University of Rhode Island, Narragansett, Rhode Island, Unpublished thesis, 382p.

INMAN, D.L. and DOLAN, R., 1989. The Outer Banks of North Carolina: Budget of sediment and inlet dynamics along a migrating barrier system. *Journal of Coastal Research,* 5(2), 193–237.

LARSON, M. and KRAUS, N.C., 1994. Temporal and spatial scales of beach profile change, Duck, North Carolina. *Marine Geology,* 117, 75–94.

MARTINSON, D.G.; MENKE, W., and STOFFA, P., 1982. An inverse approach to signal correlation. *Journal of Geophysical Research,* 87, 4807–4818.

MATHWORKS INC., 1992. MATLAB Reference Guide, 24 Prime Park Way, Natick, MA 01760.

MCCARTHY, J.F., Jr., 1973. Beach profile changes along the southern coast of Rhode Island. *In*: R.L. McMaster, (compiler), *Transit Surveying of Selected Block Island Sound Beaches in Washington County, Rhode Island 1961–1972.* Volume III.

MCMASTER, R.L., (compiler) *et al.,* 1961-present. *Transit Surveying of Selected Block Island Sound Beaches in Washington County Rhode Island.* University of Rhode Island, Narragansett, R.I., Unpublished technical reports.

MCMASTER, R.L. and FRIEDRICH, N.E., 1986. *Southwestern Rhode Island Beaches and Shoreline Processes 1938–1984.* University of Rhode Island Coastal Resources Center. Narragansett, R.I., Unpublished technical report, 60p.

MORTON, R.A.; PAINE, J.G., and GIBEAUT, J.C., 1994. Stages and durations of post-storm beach recovery, southeastern Texas coast, U.S.A. *Journal of Coastal Research,* 10(4), 884–908.

NICHOLS, R.L. and MARSTON, A.F., 1939. Shoreline changes in Rhode Island produced by hurricane of September 21, 1938. *Geological Society of America Bulletin,* 50, 1357–1370.

NOAA, 1988–1995. *Local Climatological Data Monthly Summary, Providence Rhode Island, T.F. Green Airport,* Department of Commerce, Washington, D.C.

NOAA, 1996. *Sea Level Variations for Station 8452660.* Department of Commerce, Washington, D.C.

Paillard, D.; Labeyrie, L., and Yiou, P. 1996. Macintosh program performs time-series analysis. *Eos Transactions, AGU,* 77, 379.

Pilson, M.E.Q., 1991. Aspects of Climate around Narragansett Bay. University of Rhode Island. Narragansett, Rhode Island, Narragansett Bay Project, *Unpublished Technical Report Number NBP-91-64.*

Smith, G.L. and Zarillo, G.A., 1990. Calculating long-term shoreline recession rates using aerial photographic and beach profiling techniques. *Journal of Coastal Research,* 6(1), 111–120.

Sonu, C.J. and van Beek, J.L., 1971. Systematic beach changes on the outer banks, North Carolina. *Journal of Geology,* 79, 416–425.

Wright, M.I. and Sullivan, R.J., 1982. *The Rhode Island Atlas.* Rhode Island Publications Society, Providence, Rhode Island, 240p.