ABSTRACT

FACTORS THAT INFLUENCE CHANGES IN TEMPORAL AND SPATIAL ACCUMULATION OF DEBRIS ON AN ESTUARINE SHORELINE, CLIFFWOOD BEACH, NEW JERSEY, USA

by
Laura Pace

A field investigation was conducted on an estuarine shoreline in Raritan Bay, New Jersey to identify the temporal and spatial distribution changes in accumulation of marine debris, and the factors that influence these changes. Methodology consists of 12-monthly collections of debris and profile data, and collection of local climatological and tide data. Debris was classified by type, length, weight, fragmentation, and probable function and weathering noted for each collected item. Wind roses were constructed to determine dominant wind speed and direction and wind characteristics for time intervals between field sampling.

Plastics are the primary component of debris; glass and styrofoam are common. Debris was small, light, and fragmented, and 74.2% of plastics were consumer-related. Beach usage appears to be the main source of debris but winds may transport wrack debris < 5.0 g beyond wrack lines. A cross-shore pattern of spatial distribution of debris exists due to movement by wrack lines and high onshore wind speeds and wind direction. Debris type, sub-environments,

beach elevation and debris weight influence cross-shore movement. Larger quantities found in the western portion of the beach compartment may be due to beach use, longshore transport of debris or both.

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by
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FACTORS THAT INFLUENCE CHANGES IN TEMPORAL AND SPATIAL ACCUMULATION OF DEBRIS ON AN ESTUARINE SHORELINE, CLIFFWOOD BEACH, NEW JERSEY, USA

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This thesis is dedicated to Greg and my family.

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INTRODUCTION

1.1 Statement of Objectives

The accumulation of marine debris along shorelines is a recurrent problem that endangers marine life, reduces aesthetic amenities, and creates a financial burden for communities. Marine debris is human-generated, persistent, solid debris originating from land-based and ocean-based sources. Debris accumulation endangers marine wildlife through entanglement or ingestion. Small plastic pieces and fragments can be easily ingested (Conant 1984), and marine wildlife become entangled in a variety of debris items (e.g., polypropylene cord and rope, fishnet, latex balloons and ribbons) (Lucas 1992). Entanglement of birds occurs (frequently in monofilament fishing line and six-pack rings) in every Atlantic seaboard state (Center for Environmental Education 1987), potentially inducing a change in behavior patterns that reduce the ability for wildlife to survive (Laist 1987; Pruter 1987; Lucas 1992).

Debris accumulation contributes to aesthetic degradation of coastal environments (Center for Environmental Education 1987; Heneman 1988; Ofiara and Brown 1989; Ryan 1990). The aesthetic value of a beach is important to beach users (Dixon and Dixon 1981; Center for Marine Conservation 1987). Beach aesthetics reduced by debris are frequented less by people, potentially affecting the economic viability of communities and industries dependent on beach-related activities. Major washups of debris along New Jersey and New York shorelines in 1987 and 1988 highlight the correlation between debris accumulation and beach use, travel and tourism, and recreational fishing in these states (Ofiara and Brown 1989; Swanson and Zimmer 1990). The 1987 and 1988 washups resulted in declines in beach use, recreational fishing, and use of charter and party boats. Travel and tourism related to these activities experienced revenue losses (R.L. Associates and U.S. Travel Data Center 1988; Thomas Conoscenti and Associates, 1988; Ofiara and Brown 1989).

Debris along shorelines also creates a financial burden for communities responsible for removing debris from beaches due to repeated beach cleanups and surveillance costs (Dixon and Dixon 1981; Center for Environmental Education, 1987; Wagner 1990).

Policies based on source reduction of debris entering the marine environment have limited results as considerable amounts of solid wastes wash ashore annually. Federal laws (e.g. Clean Water Act; Marine Protection, Research and Sanctuaries Act; Marine Plastic Pollution Research and Control Act, MARPOL Annex; V; Fishery Conservation and Management Act) (O'Hara et al. 1994) regulate specific sources of marine debris. The Clean Water Act has been successful in reducing some floatable debris from domestic and municipal sewage operations and industrial processes. The MARPOL Protocol of the International Convention for the Prevention of Pollution from ships is an international agreement on marine pollution from ocean-bound vessels. Annex V of the Protocol deals with the disposal of plastics and garbage from ships. As of January 1994, 65 countries have agreed to abide by its international requirements (Johnson 1994; O'Hara et al. 1994).

Litter abatement through public education can reduce input of debris from sources such as storm drains, recreational boating and beach use. Heightening public awareness about floatable solid pollution originating from many various, unrelated sources and its connection to debris stranded along shorelines can eventually curb marine debris (Clean Ocean Action 1993).

Remedial responses yield immediate results by manually removing debris from portions of the shoreline. This short-term approach is necessary to maintain local economies dependent on beach-related activities. In a time of fiscal cutbacks at every governmental level, limited resources for beach cleanup operations can be used more efficiently by focusing on areas that initially trap and accumulate debris. Removing debris from these areas first reduces the amount of materials transported to other locations, in turn reducing further cleanup efforts. An approach that identifies these areas with the greatest litter accumulation may make beach cleanups more efficient.

The purpose of this study is to identify the temporal and spatial distribution changes in accumulation of debris on an estuarine shoreline segment and the factors that influence these changes.

CHAPTER 2

LITERATURE SURVEY

2.1 Background

Floatable marine debris (Science Applications International Corporation 1987) is widespread in the marine environment (Laist 1987). Heyerdahl (1971) was the first to report the presence of floating solid wastes and tar in the ocean (Golik and Gernter 1992). Since then, research on floatable marine debris has classified types of debris, identified potential sources, correlated prevalent types of floatable debris to consumer (e.g. packaging materials) and commercial use (e.g trawl netting) and documented environmental and economic impacts.

Previous studies focus on the hazardous effects of floatable debris found offshore to marine wildlife (Bourne W. R. P. 1977; Perkins and Beamish 1979; DeGange and Newby 1980; Conant 1984; Cawthorn 1985; Day et al. 1985; Fowler 1987; Carr 1987; Sadove and Morreale 1990; Beck and Barros 1991; Fowler et al.1992) and on the distribution and abundance of floating debris in the open ocean (Colton et al. 1974; Carpenter 1978; Morris 1980; Dixon and Dixon 1983; Wilbur 1987; Day and Shaw 1987; McCoy 1988; Day et al. 1990; Gregory 1990; Heneman 1990; Lecke-Mitchell and Mullin 1992).

Debris stranded along shorelines includes floatable debris from offshore and land-based activities. Previous investigations examine accumulation, distribution, and type of debris stranded along shorelines, and identify potential sources (Willoughby 1986; Science Applications International Corporation 1987; Caulton and Mocogni 1987; Heneman 1988; O'Hara 1990; Slip and Burton 1990; Gabrielides et al. 1991; Shiber and Barrales-Rienda 1991; Gilligan et al. 1992; Garrity and Levings 1993; Corbin and Singh 1993).

Plastic wastes comprise the largest portion of debris by quantity (Center for Environmental Education 1987; O'Hara 1990; Ryan 1990; Gilligan et al. 1992). Plastic wastes generally consist of fishing gear (e.g. fishing line, rope), styrofoam, utensils, straws, bags, lids, containers, cups, six-pack connector rings, tampon applicators, condoms, and sheet plastic (Swanson et al. 1978; Science Applications International Corporation 1987; Heneman 1988; Swanson and Zimmer 1990; O'Hara 1990; Cutter et al. 1991; Lucas 1992; Garrity and Levings 1993). Composition and quantity of debris collected during beach cleanups in New Jersey (e.g. Clean Ocean Action 1992 and 1993 cleanups; Center for Marine Conservation 1988 and 1992 National Beach Cleanups) is similar to debris characteristics found on shorelines of the U.S. and other countries (Science Applications International Corporation 1987; O'Hara 1990; Ryan 1990; Gilligan et al. 1992; Corbin and Singh 1993).

Sources of debris that can eventually strand on shorelines consist of sewage operations, solid waste disposal practices, littering by the public (land-based activities), commercial shipping, recreational boating (ocean-based activities) (Heneman 1990; O'Hara et al. 1994) and possible illegal dumping (Science Applications International Corporation 1987).

Debris sources in New Jersey consist of land-based and ocean-based activities. Sewage operations comprise sewage treatment plants and combined sewer systems. When heavy rainfall overloads a sewage treatment plant, part of the incoming wastewater containing floatable litter will bypass the treatment system and discharge untreated into marine areas (Science Applications International Corporation 1987). A combined sewer is a collection system that carries both domestic and industrial wastewater and street runoff to sewage treatment plants. When excess rainfall exceeds the sewers' capacity to carry water, the combined wastewater and rainwater is diverted to overflow points along rivers and coastal waters and discharged untreated. The purpose of overflow points is to remove surface water from the sewer, however some debris is small enough to pass through grids and become floatable debris (Science Applications International Corporation 1987; O'Hara et al. 1994).

Solid waste disposal consisting of marine refuse transfer facilities in the City of New York transfer collected garbage onto barges at marine transfer stations located primarily on the Hudson and East Rivers and Lower Bay of New York. Barges cross the Upper Bay of New York and Kill van Kull to Arthur Kill or the Lower Bay to Arthur Kill en route to Fresh Kills landfill on Staten Island. Lightweight litter such as paper and plastic often blow into waters during garbage transfer, barge transport, and unloading of garbage at the landfill (Science Applications International Corporation 1987; O'Hara et al. 1994).

Non-point source pollution originates from various, unrelated sources such as beach use and littering along streets. Litter left by beach users remains on the beach or is carried offshore by wind and currents, adding to debris in the ocean (O'Hara et al. 1994). Litter quantities depend on the seasonal level of beach use. Records of coastal communities show that litter left on beaches corresponds directly to the number of beach users (Science Applications International Corporation 1987). Rains wash street litter (e.g., plastic wrappers) down storm drains which empty into waterways (O'Hara et al. 1994).

Commercial ships and recreational boats may add to debris stranding on beaches. Commercial ships generate a year-round source of marine debris and recreational boating generates a seasonal source, discarding more debris during the boating season that extends from June to September.

Identifying the source of marine debris is difficult because individual items may originate from various sources. For example, boating or beach use are sources of plastic packaging materials. Physical weathering (discoloration, cracking, fragmentation) decreases the probability of verifying sources. The extent of weathering does not necessarily relate to the distance from the source, as changing local current patterns and wind patterns can avert debris from being stranded shortly after release (Science Applications International Corporation 1987).

2.2 Factors Influencing Debris Accumulation

Previous studies identify the importance of prevailing winds and surface currents in 1) influencing debris accumulation and distribution onshore (Podosky 1989; Gregory 1990; Gabrielides et al. 1991; Golik and Gernter 1992; Corbin and Singh 1993); 2) transporting debris onshore (Dixon and Dixon 1981; Golik and Gernter 1992; Garrity and Levings 1993); and 3) transporting floating debris in surface water layers (Dixon and Dixon 1981; Ryan 1987). Larger accumulations of debris are found on windward shores facing the direction of prevailing winds and currents (Ryan 1987; Slip and Burton 1990; Corbin and Singh 1993). Ryan (1987) found debris was most abundant on west-facing beaches in the Tristan da Cunha Island group, Gough Island, and Prince Edward Island group in the Southern Ocean due to exposure to prevailing westerly winds. Podosky (1989) found the western half of Cross Island in the Gulf of Maine had twice the accumulation of plastic debris than the eastern half that he attributed to the prevailing southwesterly-northwesterly wind direction.

Slip and Burton (1990) attributed the high incidence of strandings on the west coast of Macquarie Island and the low incidence on the east coast to the influence of the West Wind Drift Current of the Southern Ocean combined with prevailing westerly winds. Corbin and Singh (1993) found a greater volume of debris on the windward east coast of St. Lucia than on the sheltered west coast.

Proximity to potential sources of debris is related to the location of debris accumulation. Golik and Gernter (1992) found that proximity to possible debris sources was a significant factor in explaining the spatial variability in accumulation of debris along the Israeli coastline, and Garrity and Levings (1993) found that distance from sources to be the most important factor in linking spatial variability to debris accumulation along the coast of Panama.

Short-term meteorological controls (wind direction, wind speed) determine the transport pathway and incidence of debris strandings. Prevailing winds (dominant direction of daily winds, e.g., southerly winds) (Swanson et al. 1978; Swanson and Zimmer 1990; Nordstrom 1992) over several hours or two to three-day time periods generate short-term wind driven surface currents which influence debris movement in surface water layers. Swanson et al. (1978) and Swanson and Zimmer (1990) showed that persistent southerly winds generated surface currents that drove floatables onto Long Island beaches.

In the Hudson-Raritan Estuary, marine debris is transported by tidal currents but debris is also affected by wind-driven transport (Science Applications International Corporation 1987; Swanson and Zimmer 1990). Wind driven currents can alter the strength and direction of dominant tidal and freshwater currents thus modifying the pathway of debris transport. The variability in strength and direction of wind driven currents is influenced by wind speed, and how long winds have blown from a similar direction (Science Applications International Corporation 1988).

Oey et al. (1985) indicated that the strength and direction of wind driven currents in Raritan Bay reverse direction when wind direction reverses (Science Applications International Corporation 1987). For example, on 16 August 1980, an eastward flowing surface current changed to a southward flowing direction when winds became south-southeastward and fairly strong (Oey et al. 1985).

Winds determine if debris strandings occur in significant amounts. Onshore winds increase the likelihood of strandings by increasing the importance of wind-driven currents that carry debris toward the shoreline and by increasing wave action. (Science Applications International Corporation 1988). The wind record can indicate a pattern between the direction of prevailing winds and the direction of debris transport and stranding. Southerly to southwesterly winds during the summer will transport marine debris to the north and east in the New York Bight and strand debris on both New Jersey and Long Island ocean beaches (Swanson and Zimmer 1990). In the Hudson-Raritan Estuary, northwesterly to northeasterly winds will force floating debris onto Raritan Bay and Sandy Hook beaches (Science Applications International Corporation 1987). An east to northeast wind will move debris toward Union and Cliffwood (located west of Union Beach) beaches and a west to northwest wind will move debris toward Leonardo Beach in Raritan Bay (Figure 1).

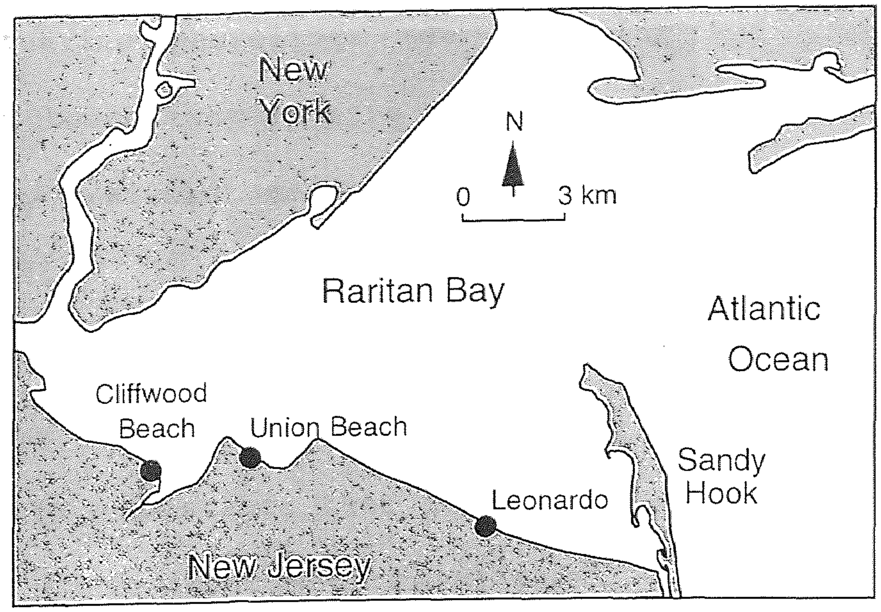

Figure 1 Locations of debris transport and stranding in Raritan Bay due to prevailing winds. Modified from Jackson and Nordstrom 1994.

2.3 Debris Stranding on Estuarine Shorelines

Results from analyses of debris strandings on ocean shorelines are not applicable to estuarine shorelines. Greater quantities of debris tend to accumulate and be stranded in shorter intervals of time after release into waterways on estuarine beaches than beaches fronting oceans (Science Applications International Corporation 1987, 1988). Estuarine shoreline segments can become sinks for litter accumulation due to differences in shoreline orientation relative to the direction of the wind.

Estuarine shorelines are irregular and composed of isolated beach compartments defined by headlands or coves formed by resistant rock, marsh, or human structures (e.g. groin, jetty) (Nordstrom 1992). These isolated compartments have different orientations and high variability in morphology over short distances due to local differences in fetch length (distance that winds blow over the water) and exposure to dominant and prevailing winds. The irregular orientation common to estuarine shorelines isolates beach compartments, permitting little or no exchange of materials between them and forms isolated longshore drift cells (movement of materials in horizontal circular cells). Thus limited longshore transport (movement parallel to the shoreline) of debris occurs. On low-energy beaches (e.g. Cliffwood Beach), features as small as peat outcrops create small drift cells that trap debris moved alongshore (Nordstrom 1992).

The transport of debris by winds, waves, and currents is influenced by abundant vegetative growth found on estuarine beaches and the reduced ability of low-energy waves to move vegetation. Vegetation can be viewed as a process in that it reduces wave energy and related debris movement (Nordstrom 1992). Vegetation extending bayward of the dune crest traps debris moved by winds. Vegetative growth on the beach and vegetation litter in the wrack line obstruct waves, currents, and swash up-rush, preventing movement of debris materials under or behind the wrack line. The wrack line consists primarily of sea grass and marsh grass and indicates the limit of wave reworking and the boundary of wave-induced transport and wind-induced transport of debris. High wave-energy and raised water levels related to storms remove the wrack or displace it higher on the beach above the limit of wave reworking. During non-storm conditions, thick wrack deposits form barriers to both cross-shore (movement from the water line to the dune crest) and longshore transport of debris and have effects similar to small groins (Nordstrom 1992). Beach morphology is affected by vegetation (dune grass) on the backbeach. Vegetation enhances dune building processes by trapping sand transported by aeolian processes and storm waves. Debris entrained by winds and storm waves are stranded in vegetated areas.

The beach slope also influences the movement of debris.

The weight of debris (e.g. glass, metal) can prevent transport by winds, waves, and currents across steep slopes (e.g., foreshore; above vegetation line) and restrict extended cross-shore movement. Major slope changes are more likely to occur under high wave-energy conditions associated with winter storms than under low wave-energy conditions during summer (Nordstrom 1992).

2.4 Hypothesis and Procedure

A field investigation was conducted on Cliffwood Beach, located in Raritan Bay, New Jersey to identify changes in temporal accumulation and distribution of debris on the estuarine shoreline. Based on shoreline orientation relative to prevailing winds and currents I hypothesize that:

* Greater accumulation of debris will be found at the northwest end of the beach compartment due to waves and longshore currents.

* Lightweight debris will accumulate landward of the location of wave action due to winds from the northwest.

The methodology consists of monthly collections of debris and profile data during low tide, at three sites that extend from the dune crest to the break in slope, and collection of existing local climatological (wind speed, direction) and tide data.

CHAPTER 3

METHODOLOGY

3.1 Study Site

The Hudson-Raritan Estuary is the greatest general source of floating debris to New Jersey's coastal areas because most of the individual sources of debris are located around the margin of the estuary (Swanson and Zimmer 1990). Raritan Bay is a funnel-shaped estuary located on the north end of New Jersey's ocean shoreline. The tides are semi-diurnal with a mean range of 1.5 m and a spring range of 1.8 m (NOAA 1994)

Cliffwood Beach is located on the southwest side of Raritan Bay (Figure 1). The shoreline reach is 2.3 km long and is bounded by Matawan Creek to the southeast and by Whale Creek to the northwest. Winds from the west are dominant but northwesterly winds and northeasterly storm winds with higher wind speeds are common. The beach is exposed to ocean sea and swell that enters the bay to the north of Sandy Hook but locally generated wind-waves are dominant. The difference in shoreline orientation on either side of Matawan Point causes northeasterly waves to generate currents to the south-southeast in the southern portion of the Cliffwood Beach shoreline and currents to the west in the western portion of the shoreline. Local net drift occurs to the west along the shoreline where the study area is located.

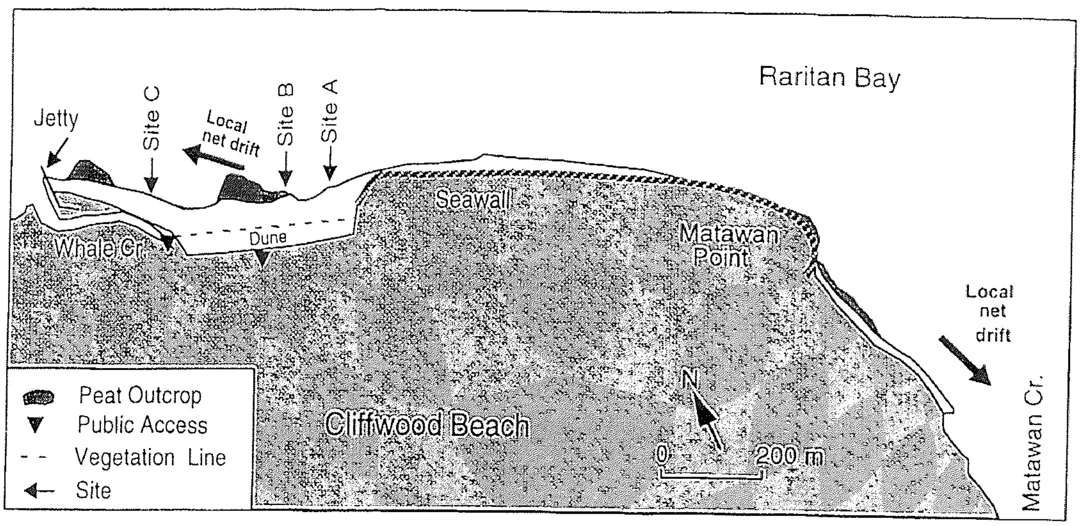

Figure 2 Description of the study area on Cliffwood Beach. Modified from Jackson and Nordstrom 1994.

The study area is a sand beach within the shoreline reach, 680 m in length, and is bounded on the southeast by a seawall and on the northwest by Whale Creek. A dune ridge extends the length of the study area (Figure 2). The beach profile (Figure 3) consists of a vegetated dune landward of an unvegetated backbeach. The backbeach extends bayward to a steep foreshore that is subject to wave action over the tidal cycle. The break in slope separates the foreshore and a gently sloping low-tide terrace.

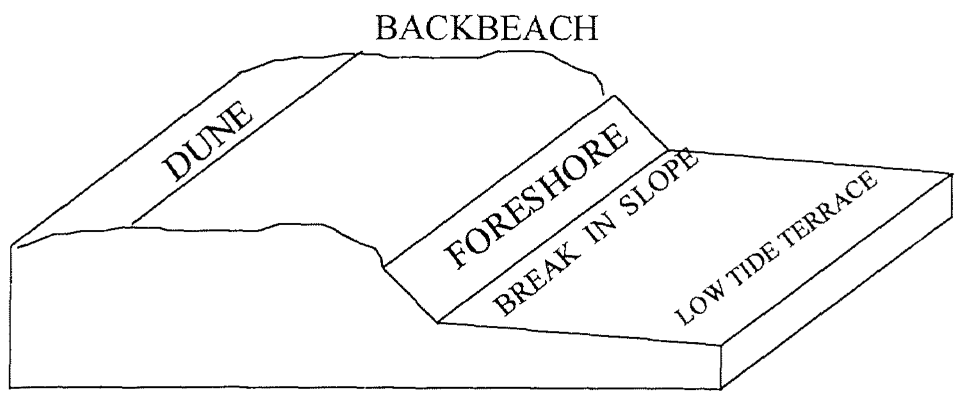

Figure 3 Beach Profile.

Peat outcrops are visible on the low-tide terrace near the break in slope (Jackson and Nordstrom 1994). The dunes, backbeach, foreshore, low-tide terrace, and peat outcrops are sub-environments that tend to trap certain types of debris. For example, small drift cells in peat outcrops often trap fragmented pieces of glass because the weight of the glass restricts further cross-shore transport. Lightweight debris (e.g. styrofoam, paper) transported to the backbeach is trapped by vegetation growing on the dunes during onshore winds. Cliffwood Beach was selected for the study because the seawall and Whale Creek compartmentalize the shoreline, and provide excellent conditions to monitor the movement of debris. In addition, beach cleanup operations by New Jersey Department of Environmental Protection cleared the beach of debris in the third week of August 1994, providing a clean study area to begin unbiased sampling of debris.

3.2 Field Design

The 12-month field study was conducted from September 1994 to August 1995. Three sites were selected to gather debris that represent the center portion and both ends of the beach compartment (Figure 2). Site A is located at the south east end of the beach compartment and minimum beach use occurs in this section. Site B is near the midpoint of the beach compartment and adjacent to a public access point. Medium beach use occurs due to the beach entrance. Site C is located at the northwest end of the beach. There is heavy beach use due to an adjacent parking lot and public access point.

Belt transects at each site were established by two shore-perpendicular lines spaced 10 m apart. These lines extended from the dune crest to the break in slope (Figure 4) (Gabrielides et al. 1991; Golik and Gertner 1992). The cross-shore lengths of the belt transects ranged from 35 to 85 m. Sampling areas were established by shore parallel lines at 5 m intervals along the two shore-perpendicular lines (Caulton and Mocogni 1987). Each sampling area was 5 m in the cross-shore direction and 10m in the longshore direction. Temporary datums located on the crest of the b ndune were used to establish the sampling areas each month using measuring tapes and stakes (Figure 4) (Dixon and Dixon 1981).

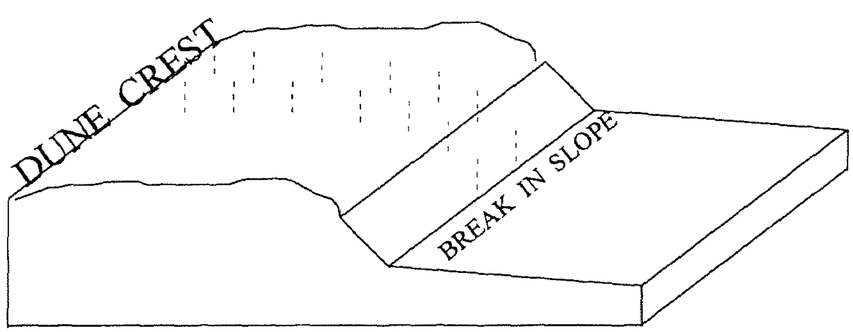

Figure 4 Belt transect with sampling areas.

Surface debris exposed 2/3's or more was collected mid-monthly at low tide (Gabrielides et al. 1991; Golik and Gertner 1992; Corbin and Singh 1993), bagged and labeled according to site, sampling area, and date. Debris located within recent and old wrack lines was bagged separately and identified.

Location of the bayward limit of vegetation and wrack lines at each site were measured monthly from the dune crest with a measuring tape. Beach elevation measurements were recorded at 5 m intervals along the two shore-perpendicular lines of each belt transect using a stadia rod and transit (Jackson and Nordstrom 1994). Beach orientation was measured with a compass in the field (Jackson and Nordstrom 1992).

3.3 Research Variables

The characteristics of debris collected and controls affecting the probability and spatial variability of debris accumulation are identified by variables and defined in Table 1.

Table 1 Research Variables

Variable	Definition
Debris Characteristics:	
Type	Anthropogenic debris classified as plastic, styrofoam, glass, metal, paper, rubber, wood and cloth (Gilligan et al 1992)
Length	Dimension of longest axis for each debris item (mm)
Weight	Weight of each debris item (g)(Gilligan et al. 1992)
Fragmentation	Classification of the degree of fragmentation of debris items (%)
Weathering	Debris classified according to state of decay (Slip and Burton 1990)
Probable Function	Debris identified according to function (Garrity and Levings 1993)
Wind and Tide Conditions:	
Wind Speed	Mean 3-hr speed (ms-1) (NOAA Local Climatological Data)
Wind Direction	Mean 3-hr direction (resultant) (deg) (NOAA Local Climatological Data)
Mean High Tide	Mean monthly high tide level (m) (NOAA National Ocean Service)
Beach Characteristics:	
Beach Elevation	Elevation of beach at 5 m intervals from dune crest to break in slope (m)
Vegetation Line	Location of bayward limit of vegetation growth from dunecrest (m)
Wrack Line	Location of organic debris brought up by wave action from dune crest (m)

Debris was classified by type (e.g. plastic, glass, metal), measured along the longest axis to the nearest millimeter (mm), and weighed to the nearest hundredth of a gram (g). Styrofoam and other polystyrene plastic items (referred to as styrofoam) were classified separately from other plastics due to their unique buoyancy and related floating and stranding characteristics (Garrity and Levings 1993). Subjective estimates of fragmentation were made for each collected item. Four measures of fragmentation ranked items intact at 100%, >75%, 51-75%, 26-50%, and ≤ 25%. The extent of weathering (e.g., discoloration, cracks, tears) was noted for debris items and each item was classified by probable function (e.g. household, industrial, fishing) and (Marine Pollution Bulletin 1992).

Mean wind speed and wind direction, and tide characteristics were computed from local climatological and tide data for the field study period. Wind data was obtained from Newark International Airport, Newark, New Jersey, from the National Weather Service Office, National Oceanic and Atmospheric Administration (NOAA). Wind roses were constructed from 3-hr wind speeds from Newark Airport for the time interval between field sampling. Wind roses of wind speed and frequency were constructed from daily average wind speed and direction for the entire study period.

Tide data was obtained from the National Ocean Service, Office of Ocean and Lake Levels, NOAA. Tidal information was not available for Cliffwood Beach for September 1994-August 1995. Keyport, located south of the field site was the closest location for which tidal conditions could be computed (NOAA 1994, 1995). Inferred tides for Keyport were computed by recording the "highest" high tide between each debris sampling period, and plotted to estimate the monthly mean high tide for Cliffwood Beach.

Monthly profiles were produced from the beach elevation data and surface slopes calculated. Location of vegetation line and the location and width of wrack environments were measured monthly at each site.

3.4 Data Analysis

Debris was counted and classified by type, weight, maximum length, fragmentation, weathering, and probable function.

Characteristics of debris (type, length, weight, and fragmentation) collected in the wrack was compared to non-wrack debris to determine similarities and differences, and identify types of debris that was trapped or transported cross-shore by wrack lines.

Longshore location of debris was examined to identify similarities and differences of debris densities through time. Density computations were done with and without debris quantities from the wrack lines to see if wrack debris affects the density of debris. A comparison of monthly piece counts in sampling areas and wracks can determine how much debris is transported by wrack lines, and if a temporal distribution exists.

The cross-shore location of debris was examined for temporal distribution patterns during user months and non-user months and separation of debris relative to wracks and vegetation. Debris type by cross-shore location was examined to identify the trapping capabilities of sub-environments. For example, does styrofoam accumulate in wrack lines and/or above the vegetation line? Sub-environments below the foreshore (e.g., peat outcrops), and above the vegetation line (e.g., vegetated dunes) were examined to see if certain types of debris accumulate there. The results for each site were compared to determine if a general pattern of cross-shore distribution exists on Cliffwood Beach.

Slope values of beach elevation were compared to the weight of debris and debris movement in sampling areas to see if an increase in beach elevation and weight of debris influenced debris movement.

Monthly wind roses were constructed to determine the dominant wind direction and highest wind velocities between monthly field sampling. The monthly modal wind direction was compared to monthly debris densities to see if wind direction determines the location of debris accumulation throughout the study period. Monthly wind roses were compared to the accumulation of debris < 5.0 g landward of the vegetation line to identify if wind speeds play a role in transporting light debris above the vegetation line.

CHAPTER 4

RESULTS

4.1 Characteristics of Debris

4.1.1 General Characteristics

A total of 5795 pieces of debris were collected during the study period. Figure 5 presents a classification by type for all debris gathered during the study period. The largest percentage of debris was plastic (42.5%), followed by glass (29.7%), styrofoam (17.8%), paper (8.0%), and metal (2.0%).

The majority of debris collected was small and lightweight (Figures 6 and 7). Fifty-two percent of the debris was 4 mm or less in length and 83% weighed 5 g or less. The small size was due to fragmentation. Sixty-two percent of all debris was up to 25% intact compared with 22% that was 100% intact (Figure 8). An analysis of probable function combined sampling areas and wrack debris data. Three-quarters (74.2%) of the debris was consumer or household related items. Twenty-one percent of the items could not be identified and were labeled unknown. Less than

5% was related to manufacturing, fishing and boating activities, or medical use (manufacturing 4.6%, commercial fishing/boating 0.4%, medical 0.1%) (Figure 9). Two-thirds (65.5%) of the debris collected had no indication of weathering and the remaining 34.4% indicated various signs of weathering. Almost half (45.6%) of the weathered debris had discolored surfaces, 19% of the items had tears or holes, 14.2% had scratched surfaces and 9.5% had cracked surfaces. One percent of metal contained rust, and 4.7% of glass had a dull, worn surfaces, indicating extended exposure to elements of weathering before stranding.

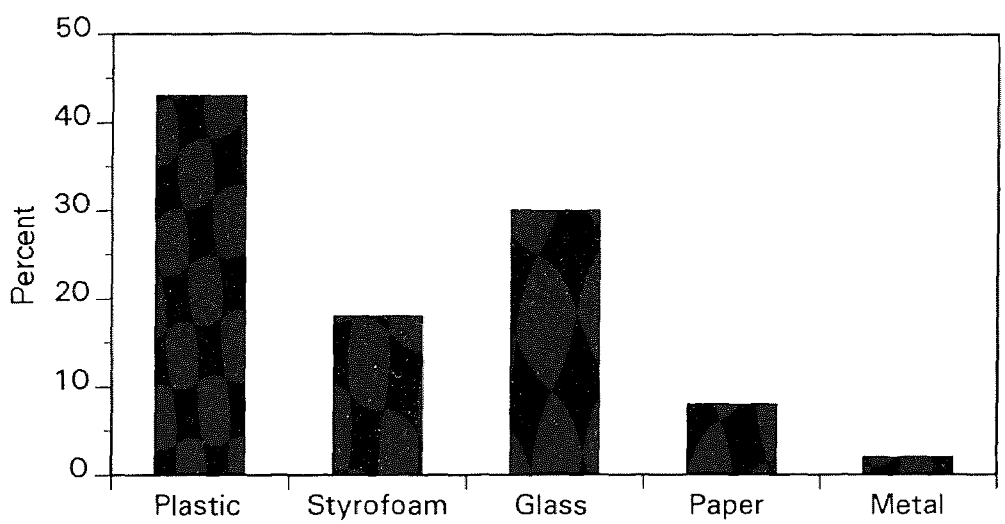

Figure 5 Percent of debris by type.

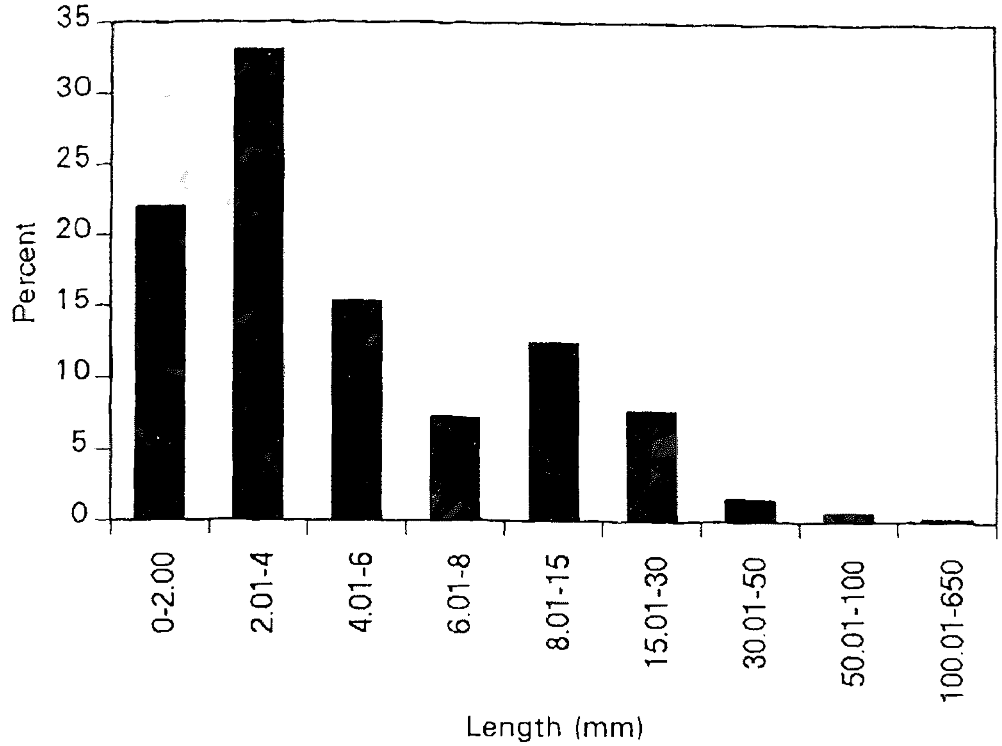

Figure 6 Percent of debris by length.

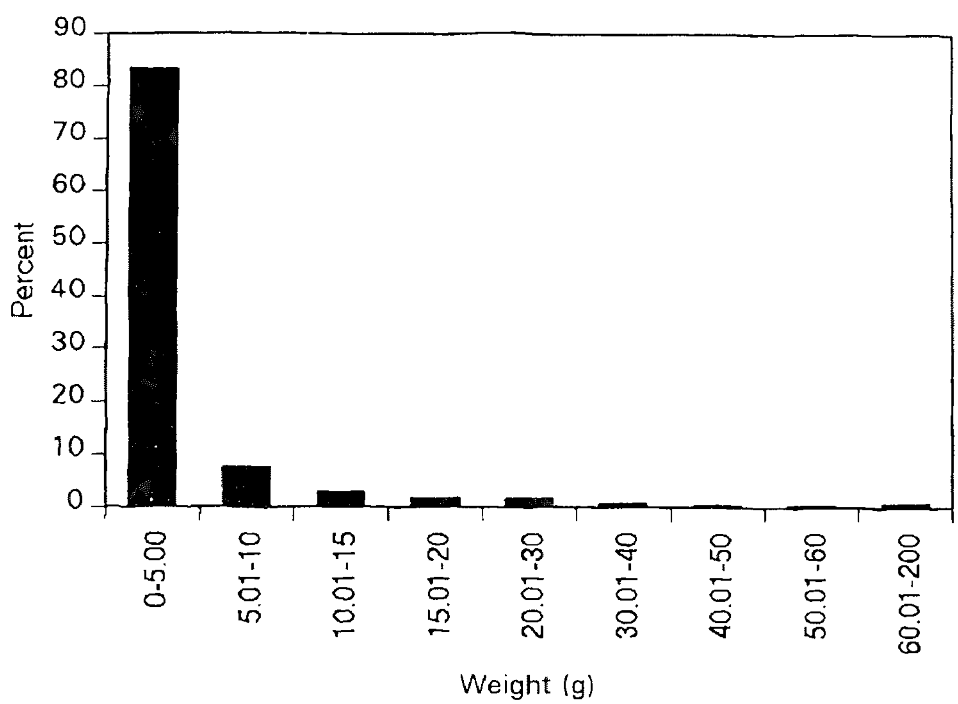

Figure 7 Percent of debris by weight.

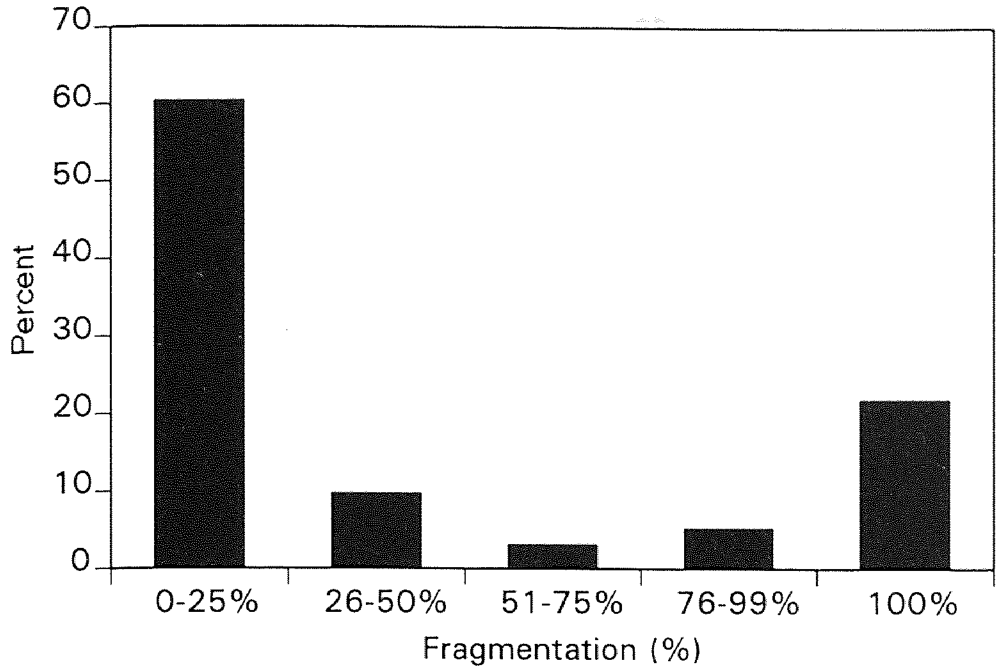

Figure 8 Percent of fragmentation.

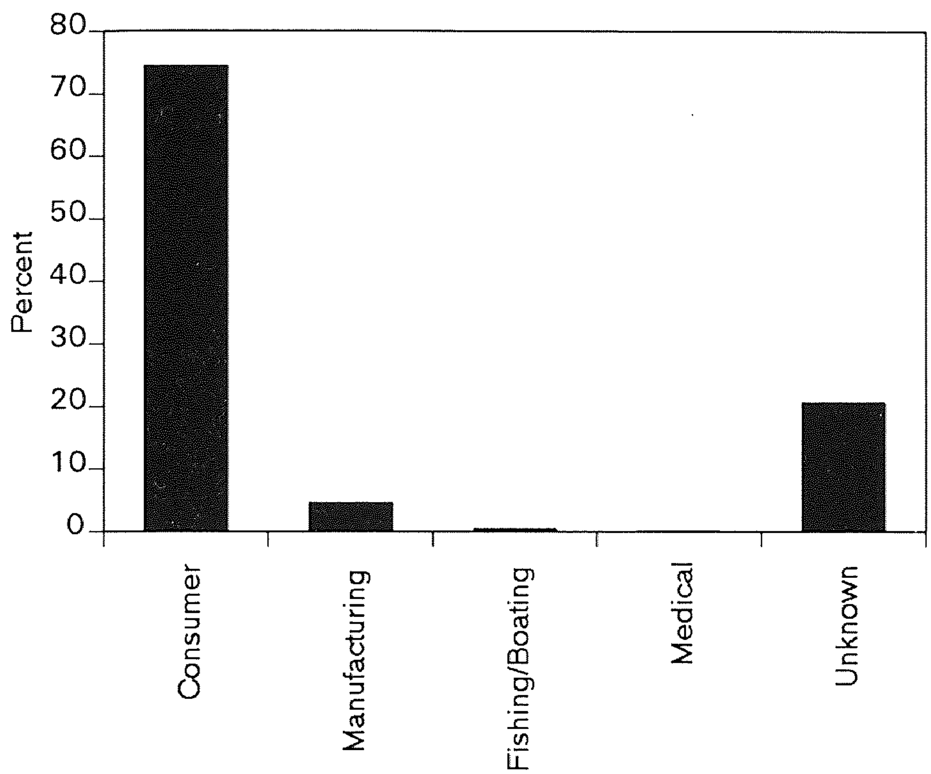

Figure 9 Percent of probable function.

4.1.2 Characteristics of Wrack Debris

Wracks indicate the limit of wave reworking and the landward boundary of wave-induced transport of debris. The location of the wrack will change due to changes in high water and surge associated with storm activity. More than one wrack may exist at a time because high wave-energies and raised water levels during to storms deposit additional wrack lines on the beach. Wracks, notably thick deposits of vegetative litter, influence cross-shore transport by trapping anthropogenic debris that is suspended in the swash uprush (Pethick 1984). The size of the wrack will increase with increasing wave energy. The minimum and maximum locations of the wrack on the beach profile for each site were identified during the study period and presented in Table 2.

Results of the tide data show that the "highest" high tides during the study period were fairly consistent in height. The minimum was 2.6 m and the maximum was 3.2 m, indicating that major storms did not indicate occur during the study period. Consequently wrack lines were not displaced higher on the beach profile above the limit of wave reworking.

Table 2. Minimum and maximum cross-shore location of wrack lines from the dune crest during the study period.

Location	Minimum (m)	Maximum (m)
Site A	13.0	38.0
Site B	32.5	60.5
Site C	3.0	35.0

Comparison of percentages of debris type for wrack and sampling areas without wrack data (Table 3) reveals that the characteristics of wrack debris are similar to debris in with the exception of glass. Wracks contained 21.6% more plastic and 29% less glass than sampling areas. Differences are small for styrofoam (8.3%) and paper (.55%), and non-existent for metal (0%). This indicates that wracks provide cross-shore transport for plastic, styrofoam, and paper but are not primary transporters of glass debris.

Table 3. Debris type for wracks and sampling areas for all sites.

Type	Wrack	Sampling Area	Difference
Plastic	58.2	36.6	21.6
Styrofoam	23.9	15.6	8.3
Glass	8.3	37.3	-29.0
Paper	7.6	8.15	-.55
Metal	2.0	2.0	0.0

A comparison of the weight of debris shows that 82.1% of debris in sampling areas weighs 0-5.0 g, 8.6% weighs 5.01-10.0 g. and the mean weight is 4.6 g. Wrack debris has similar results; 85.4% weighs 0-5.0 g, 5.0% weighs 5.01-10.0 g, and the mean weight is 4.2 g. Both data sets show that 6.4% of the debris weighs 10.01-30.0 g. This indicates that 97.1% of debris in sampling areas and 98.6% of wrack debris is extremely lightweight.

A comparison of maximum length shows that 56.7% of debris in sampling areas and 50.4% of wrack debris is 0-4.0 mm in length. Almost 23% of debris in sampling areas and

22% of wrack debris is 4.01 to 8.0 millimeters in length. This indicates that the majority of debris is small.

An estimate of the degree of fragmentation for individual items resulted in almost two-thirds (65.1%) of debris in sampling areas intact up to 25% and 13.9% of debris is 26-50% intact. Combined, 79% of the debris is intact up to 50%. The percentages for wrack debris is 47.3% and 8.% respectively and the combined total is 55.3%. Fragmentation estimates support the small measurements for length.

Piece counts of debris in sampling areas, wrack lines and the total amount for each sampling period are presented Table 4. The quantity of debris in wracks per month represents < 40% (minimum of 3%, maximum of 39%) of the total piece count per month with the exception of December 1994 (50%). Twenty-seven percent of the annual quantity of debris collected was located in the wrack. Greater quantities occur during months of beach use (September 1994, April-August 1995) and lower quantities occur during non-user months (October 1994-March 1995).

Table 4. Piece counts: sampling areas, wrack lines, and total quantity for each sampling period.

Date	Sampling Area: piece counts of debris	Wrack line: piece counts of debris	Debris Total: piece counts of debris
9-21-94	396	12	408
10-27-94	171	83	254
11-16-94	267	22	289
12-16-94	275	277	552
1-18-95	155	68	223
2-17-95	255	116	371
3-17-95	252	107	359
4-14-95	479	90	569
5-16-95	460	116	576
6-19-95	447	188	635
7-22-95	474	306	780
8-15-95	592	186	778

4.2 Location of Debris

4.2.1 Longshore Location of Debris

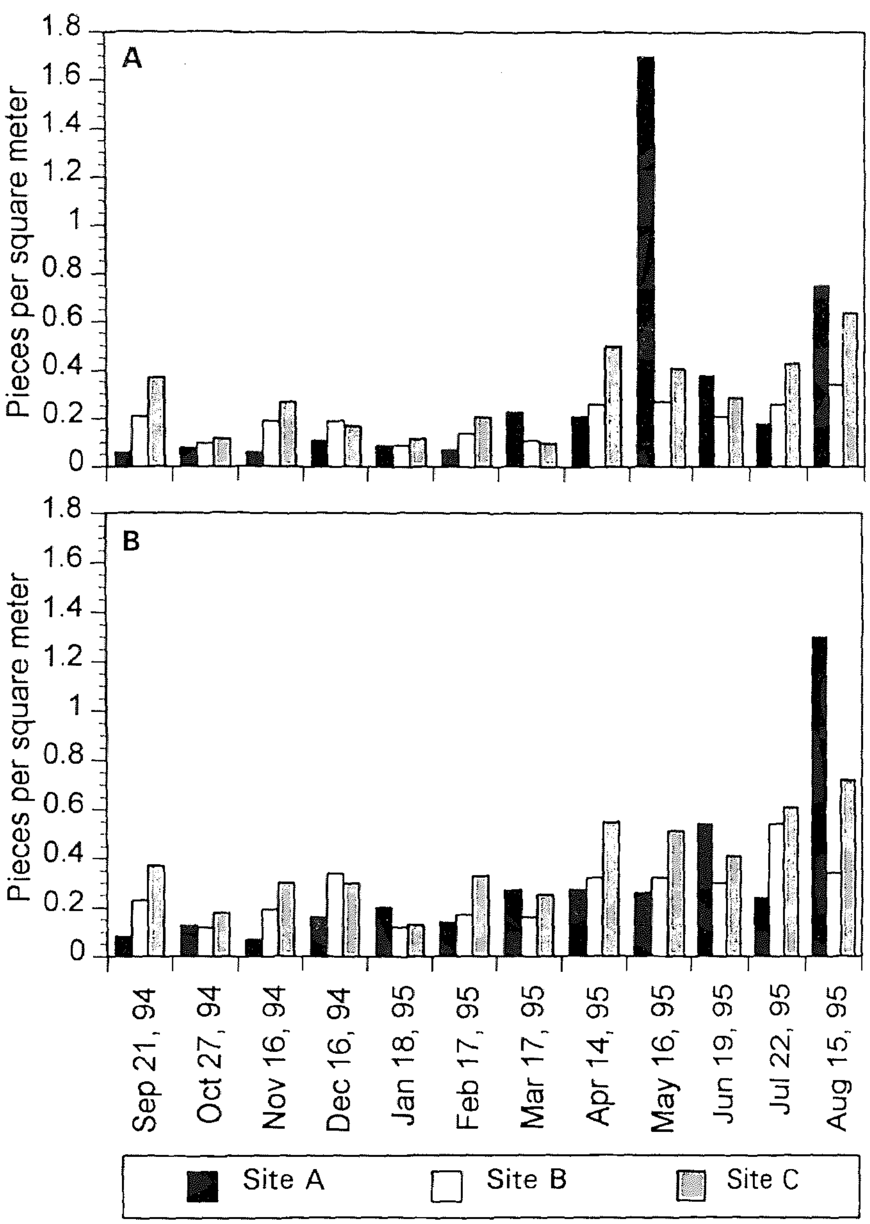

Figure 10 Debris densities with wrack debris (A) and without wrack debris (B) for sampling periods.

Results for debris density per square meter (with and without the quantities from wrack lines) (Figure 10) show the highest density of debris in Site C and the lowest in Site B. Maximum debris density occurred during the months of September 1994, and the time period from April to August 1995. The lowest density occurred during the time period from October 1994 to March 1995. September is a potential user month as summer ends and April is a month when fishermen use the beach.

4.2.2 Cross-shore Location of Debris

From September 1994 to August 1995, the majority of plastic, styrofoam, paper, and metal for all sites tend to be located above or between wrack lines and extend to the backbeach and dune area. It appears that movement is related to the location of wrack lines on the beach profile and vegetation that traps airborne debris, particularly styrofoam. Over 90% of styrofoam is within the vegetation line and reaches into the dune area. The remainder is found between the wrack line and the vegetation line or between wrack lines. Metal tends to be within 10 m of wrack lines. A lesser amount of metal is between the wrack and vegetation line.

Small amounts of metal found in the dune area may be attributed to people. Glass is the most prevalent type of debris found below wrack lines. Glass is also found above wracks or between multiple wrack lines. Smaller amounts are found in the dunes and may be attributed to beach use or bulldozing the dune area after storms.

Sub-environments exposed during low tide that are near or at the shoreline trap glass. Significant quantities of glass were collected past the peat outcrop at site B (21 pieces) and on the outcrop (17 pieces) in June and July 1995 during beach-user months and the boating season. Eight pieces were collected past the break in slope at site A in October 1994 after the boating and beach season. The prevalence of glass found at the shoreline indicates that glass is the most common type of debris found below wrack lines. The bulk of glass weighed over 5 gm. At site B, 81% of glass weighed from 5.01-40 g past the peat outcrop, and 88% weighed from 5.01-20 g on the outcrop. At site A, 75% of glass weighed from 5.01-20 g.

4.3 Controls on Location of Debris

4.3.1 Wind Speed and Direction

The dominant wind direction is from the northwest and the highest wind speeds are from the northwest and northeast (Figure 11). The monthly mean wind speed ranged from a low of 3 ms^{-1} to a high of 5 ms^{-1} and the maximum 3-hr wind speed ranged from 7 to 14 ms^{-1} during the study period.

Monthly wind roses present wind characteristics between sampling periods (Figure 12).

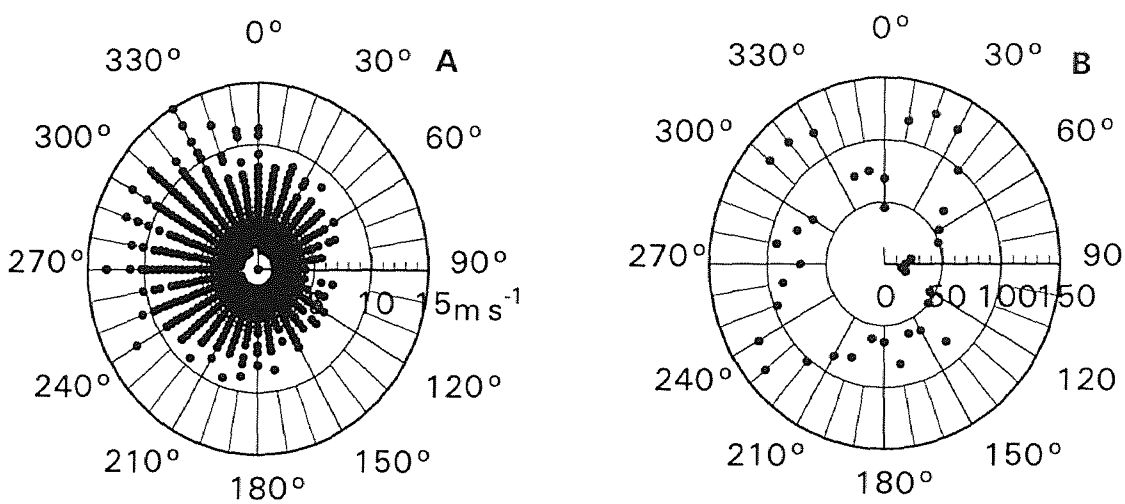

Figure 11 Average wind speeds (A) and frequency of wind direction (B) during the study period (ms^{-1}).

An analysis of monthly wind roses and location of light debris (< 5.0 g) shows that a large percentage of debris collected above the vegetation line for each sampling period was < 5.0 g (Table 5) with the exception of August 1995 due to missing data of bayward limit of vegetation growth. Eight of eleven sampling periods in Site A and ten of eleven sampling periods in Site B had percentages greater than 50% for light debris. Results are presented in Table 5.

Table 5. Percentage of debris < 5.0 g above the vegetation line for each site during sampling periods.

Sampling Period.	SITE A	SITE B	SITE C
9-21-94	47.0	67.0	53.0
10-27-94	83.0	92.0	no vegetation line
11-16-94	28.0	83.0	60.0
12-16-94	79.0	48.0	no vegetation line
1-18-95	95.0	97.0	no vegetation line
2-17-95	100.0	54.0	no vegetation line
3-17-95	100.0	72.0	no vegetation line
4-14-95	96.0	93.0	no vegetation line
5-16-95	94.0	95.0	no vegetation line
6-19-95	46.0	77.0	79.0
7-22-95	66.0	90.0	54.0

These results correspond to high onshore wind speeds that occurred prior to the same sampling period (Figure 12). For example, high wind speeds from the northwest and northeast prior to the 10-27-94 sampling period (Figure 12, wind rose dated 9-22-94 to 10-26-94) correspond to 95% of the debris in Site A and 97% of the debris in Site B weighing < 5.0 g above the vegetation line for sampling period0 10-27-94.

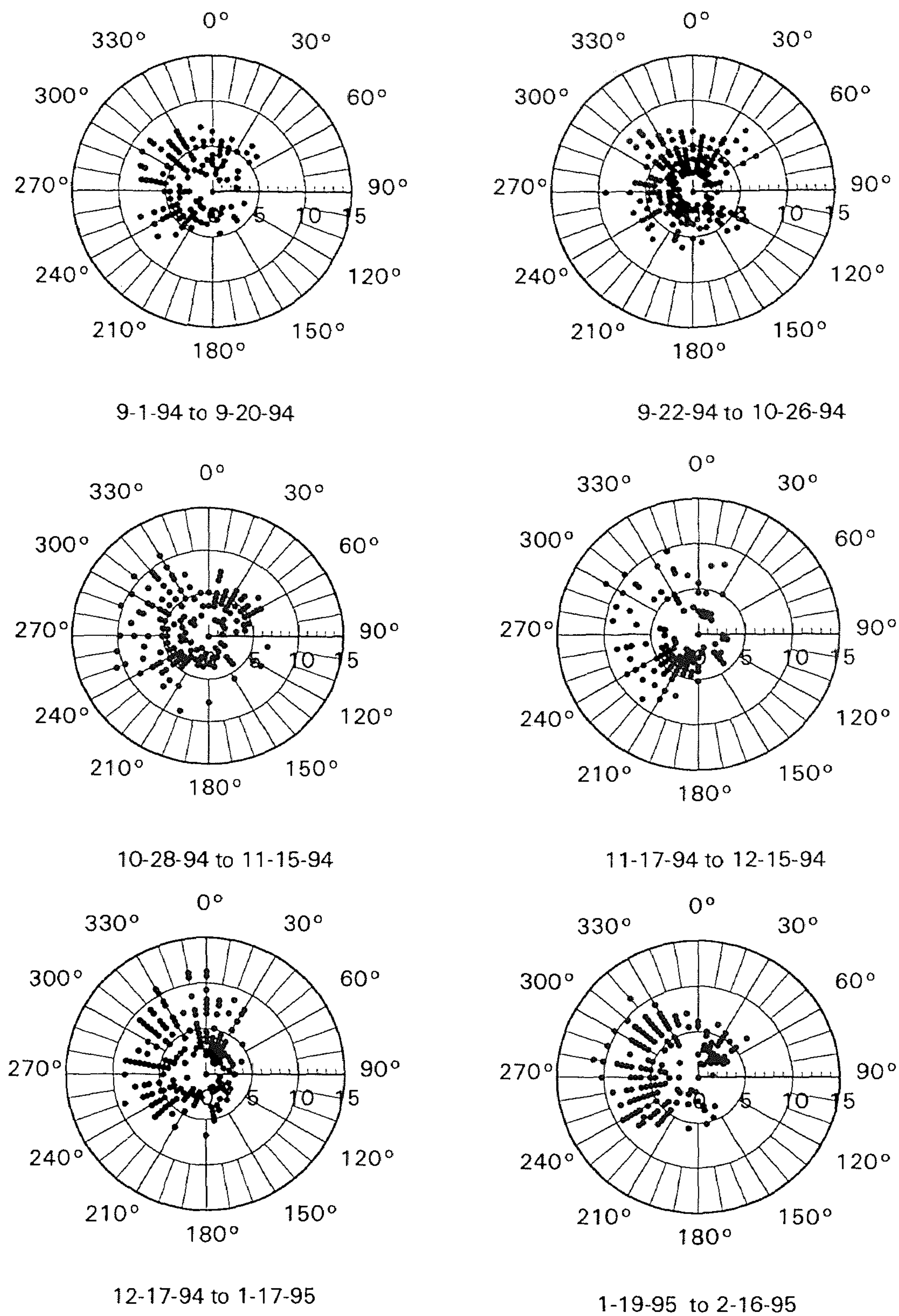

Figure 12 Wind roses for time intervals between debris sampling periods (ms^{-1}).

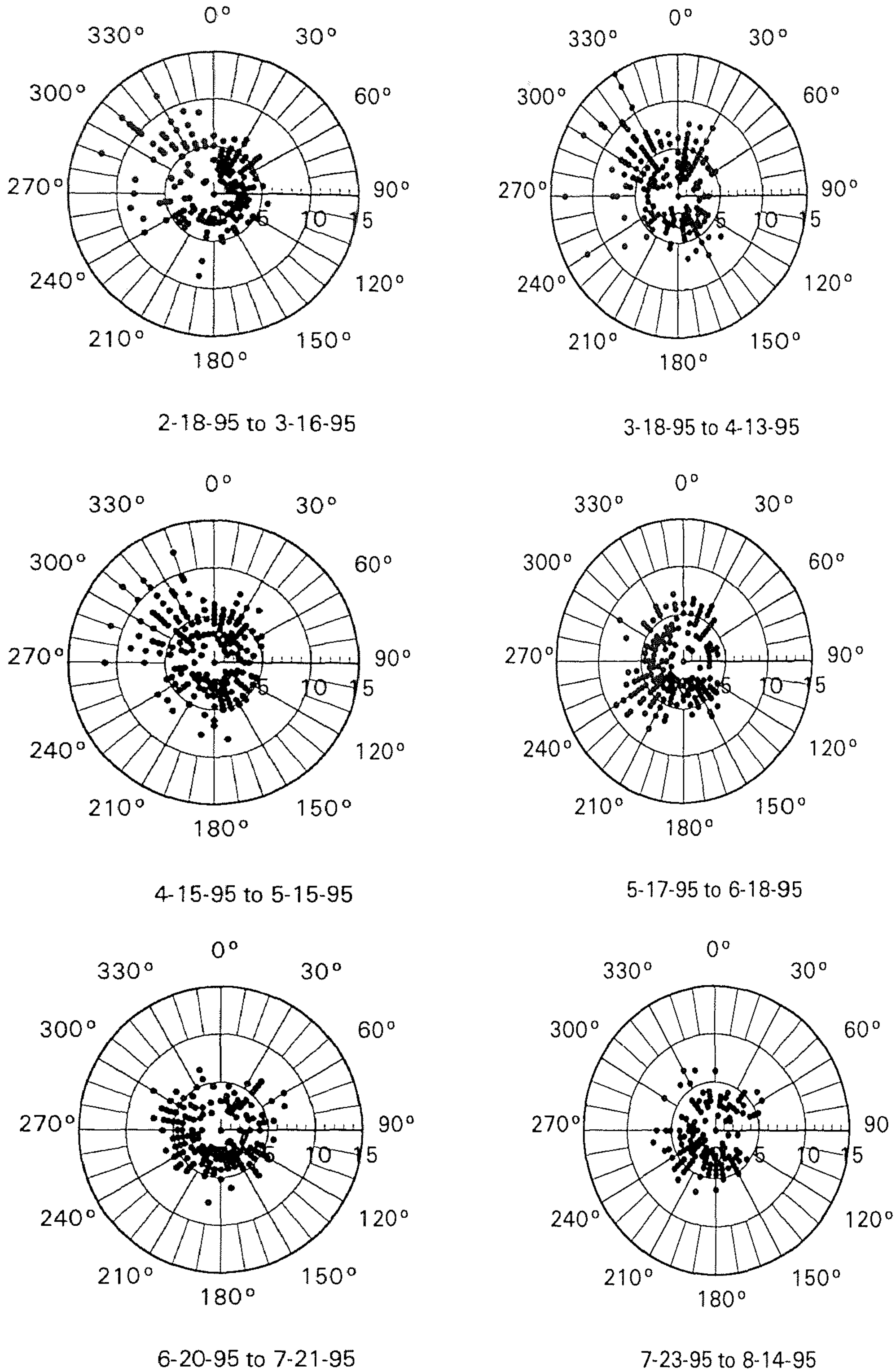

Figure 12 (continued) Wind roses for time intervals between debris sampling periods (ms^{-1}).
Shoreline orientation at Sites A and B is 128° and 308° and 148° and 326° at Site C.

4.3.2 Beach Characteristics

Beach environments on the profile can serve as sinks for debris accumulation. Several outcrops of marsh peat at Site B extend from the foreshore to the low tide terrace. The dune crest has sparse to dense coverage of dune grass at Site A and Site B, and sparse to no coverage at Site C. A dune ridge extends the length of the study area. Maximum dune heights occur in the mid-beach section near Site B by the access point. Shifts occur in the bayward limit of the vegetation line at all sites through time. The minimum and maximum bayward limit of vegetative growth from the dune crest and the monthly mean range of movement of the vegetation line toward or away from the dunecrest for each site is presented in Table 6.

Table 6. Minimum and maximum limit of vegetative growth and monthly mean range of vegetative movement (m).

Location	Minimum limit	Maximum limit	Monthly mean range of vegetative movement
Site A	10.0	19.0	2.1
Site B	20.0	27.5	3.3
Site C	5.0	7.5	2.2

Major amounts of plastic and styrofoam were collected within the minimum and maximum limit of the vegetation line and in the vegetated dunes, indicating that vegetated dunes serve as sinks for plastic and styrofoam. Small amounts of glass and metal were also found. Exceptions occurred in Site B and C. The 5m sampling area from the dunecrest in Site B had an annual quantity of 77 glass pieces, which may be attributed to people. Consistent distribution of glass from the dunecrest to the foreshore in Site C may be related to bulldozing this portion of the beach throughout the year.

Slope values for sub-environments in Sites A, B, and C at the beginning (10-27-94) and the end of the study period (7-22-95) are presented in Table 7.

Table 7. Slope values (deg) for sub-environments measured on 10-27-94 and 7-22-95.

	Site A		Site B		Site C	
	10-27	7-22	10-27	7-22	10-27	7-22
Dune	9.03	9.01	12.31	11.44	10.03	9.62
Vegetation Zone	3.63	4.34	3.39	3.08	0.00	9.62
Backbeach	2.63	2.42	1.53	1.20	2.08	1.92
Foreshore	3.00	2.90	2.25	4.00	3.67	5.56

The dunes have the highest slope values and the lowest slope values are on the backbeach. The vegetation zone and foreshore sub-environments have similar slope values that are greater than the backbeach values. This indicates that the majority of debris will be on the backbeach, debris weighing >5.0 gm will be found on the foreshore, and light debris will be in vegetated areas. The monthly profiles for Sites A, B, and C (Figure 13) shows little change in beach elevation during the study period.

CHAPTER 5

DISCUSSION

Debris composition on Cliffwood Beach is consistent with recent studies that identify plastics as the primary component of marine debris, and styrofoam, glass, and metal as common (Gilligan et al. 1992, Corbin and Singh 1993, Garrity and Levings 1993). In this study the percentage of plastic items is increased to 60.3% if styrofoam is included.

Garrity and Levings (1993) classified plastic and styrofoam debris by probable function. A comparison of probable function for plastic and styrofoam from this study revealed similar results. In both studies the majority of plastic debris was consumer-related items, fishing or boating-related debris represented 3% of plastic debris, and medical-related debris was the smallest category (1%).

Styrofoam identified as consumer-related had similar percentages, items related to boating and fishing activities was the smallest category for styrofoam in both studies and manufacturing-related debris differed for identifiable styrofoam.

The probable function of plastics can be inferred from Corbin and Singh (1993). They found the main component of plastic samples were plastic bags and cups, suggesting that the majority of plastic debris is consumer-related.

Debris collected in wrack lines and sampling areas had similar characteristics for type, weight, length, fragmentation, and probable function. The majority of debris was small, light, and fragmented. Two-thirds (65.5%) of the debris samples had no visible signs of weathering, which suggests the majority of debris was deposited recently in the beach environment.

The presence of predominantly small, light, fragmented debris items on the beach profile and in wracks can be hazardous, through ingestion, to seabirds (e.g., gulls) foraging the upper foreshores and wrack lines for food (Nordstrom 1992).

Wrack lines contained 27% of the debris collected, implying that marine debris transported by wind driven currents and tidal currents from sources surrounding the Hudson-Raritan Estuary are minor contributors of debris on

Cliffwood Beach. However winds may move light debris out of the wrack lines and into sampling areas. Results from Garrity and Levings (1993) also note that debris moves out of wrack lines.

Beach usage appears to be the primary source of debris due to greater quantities present in sampling areas and higher densities of debris/square meter found during user months than non-user months. The large proportion of unweathered debris correlates to recent beach users leaving refuse behind.

A cross-shore pattern of spatial distribution of debris exists at Site A and Site B but heavy beach use and bulldozing obscure the distribution pattern at Site C. Wrack lines relocated higher on the beach profile over tidal cycles and high wave-energies transport debris cross-shore. Major components of the wrack line are plastic and styrofoam; glass, metal, and paper are found in smaller amounts. Glass and metal generally fall out below the wrack line or are found 5-10 m above the wrack on the backbeach and above the vegetation line as the result of beach use. Glass and metal pieces weighing < 5.0 g can be carried by uprush and deposited within the limit of the wrack line.

Lighter debris (plastic, styrofoam, paper) is carried by the wrack to the limit of wave reworking and then into vegetated areas by winds. Results from Garrity and Levings (1993) substantiate the type of debris found in wracks and cross-shore movement of debris. The shorelines in this study and in Garrity and Levings (1993) are bounded by natural barriers, thus reducing longshore movement of debris. They noted a lack of evidence of longshore movement and plastic and styrofoam were main components of the wrack line. Debris items were found above the wrack line, then transported cross-shore past the highest wrack line and into upland vegetated areas. Other studies have observed plastic items in wrack lines and cross-shore movement of debris by wracks (Ryan 1987; Wilbur 1987). Ryan (1987) located plastics within 20 m of recent wrack line and Wilbur (1987) found high concentrations of plastic near the highest wrack lines.

Sub-environments restrict cross-shore movement of debris by trapping litter and becoming sinks for debris. Weight is an important factor in determining the type of debris trapped in sub-environments. The low-tide terrace at Site A and peat outcrops on the low-tide terrace or within

5.0 m bayward of the peat outcrops at Site B are sinks for glass weighing over 5.0 g. Vegetated dunes are a sink for airborne debris (styrofoam, plastic, paper) weighing < 5.0 g. Most styrofoam, light plastic, and paper are trapped within the limit of the shifting vegetation line throughout the study area.

Beach elevation influences debris movement by wrack lines and in sub-environments. Glass > 5.0 g is deposited on the low-tide terrace and peat outcrops where lower slope values occur because low wave energies typical of estuarine shorelines may not carry items > 5.0 g beyond the steep upper foreshore. Airborne debris can be carried above the vegetation line where higher slope values occur.

Onshore winds generate wind-driven waves. Wind-driven waves are responsible for longshore currents which carry debris along a shoreline in a particular direction. The difference in shoreline orientation on either side of Matawan Point causes northeasterly waves to generate longshore currents to the west in the western portion of the shoreline and there is local net drift to the west (Jackson and Nordstrom 1994). Larger amounts of debris were found in Site C in the western portion of the beach compartment but it can not be determined if debris accumulation is a result of heavy beach use or longshore transport or both. Most debris studies on shorelines identify wind-driven surface currents in the basin to explain the longshore location of debris (Swanson et al. 1978; Ryan 1987; Podosky 1989; Slip and Burton 1990; Swanson and Zimmer 1990; Cobin and Singh 1993 The importance of prevailing wind direction in longshore transport of marine litter and cross-shore movement of debris by wrack lines has been recognized, but the significance of high onshore wind velocities and direction to cross-shore movement of litter has been overlooked.

This study examined the effect of onshore winds on debris located on the beach profile. Monthly wind roses show the aeolian contribution to cross-shore movement of debris. Mean wind speeds (3.814-5.723 ms-1) were not strong enough to move debris weighing > 5.0 g landward of wrack lines during the study period. However maximum wind velocities (7.20-14.91 ms-1) that occurred between sampling periods were strong enough to carry light debris (0-5.0 g) above the vegetation line and into the dunes. The high percentages of light debris recorded above the vegetation line consistently correspond to high wind velocities that occurred during the time interval between field sampling.

High onshore wind speeds increase wave action which result in larger wrack lines that carry greater quantities of debris onto the beach. Because mean wind speeds were low (< 6 ms-1), wrack lines were generally smaller in width and transported smaller debris quantities onshore. The small percentage (27%) of debris found in wrack lines corresponds to low wind speeds and small wrack lines observed during the study period.

Beach usage controls temporal changes in the accumulation of debris on Cliffwood Beach. Beach use varies on estuarine beaches; other beaches with little or no recreational use may exhibit different controls in the temporal changes of debris accumulation.

Increased beach usage during spring and summer months and an insufficient number of trash cans are the most important factors controlling the level of debris on Cliffwood Beach. Beach debris can be reduced at the local level on Cliffwood Beach through public education and the presence of trash bins in convenient locations to encourage the proper disposal of litter.

Wind speed and direction, debris characteristics (type, weight), beach morphology (sub-environments, beach elevation) and wrack lines determine the spatial distribution of debris in the cross-shore direction on Cliffwood Beach. Results from this study can not fully determine if existing meteorological data can be used to determine the likelihood of debris accumulation along estuarine shorelines. However the importance of high onshore wind speeds and direction should be noted in influencing the spatial distribution of light debris cross-shore.

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