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A LONGITUDINAL STUDY OF ENTOMBED BEACH LITTER AT SAN SALVADOR ISLAND, THE BAHAMAS

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ABSTRACT

Student groups from Youngstown State University have engaged in the excavation and analysis of entombed beach debris at selected sites along the eastern beaches of San Salvador Island, The Bahamas since March 2007. Additional studies were conducted in January 2008, March 2008, and December 2008. Surveys of surface beach debris accumulations on San Salvador's beaches conducted from 1996 to 1999 indicated that materials that wash up on the east side beaches of San Salvador are not of local origin (Shaklee, R.V., and W.R. Buckler, 2000). Our current research consisted of excavations conducted along transects on different areas of East Beach. The sites were selected for their varying wind and wave conditions. A total of seven transects were excavated over the two year period of our study. Pits were excavated at ten meter intervals away from the waterline and into the coastal dunes. Excavations were performed in one meter by one meter squares. Sands and foreign materials were excavated in ten centimeter layers to determine variations in debris accumulation and concentration at specific depths. Sifting of excavated material was done using 2 centimeter by 2 centimeter screening devices.

INTRODUCTION

The negative impacts of ocean borne pollutants on marine environments are well documented. Studies of the impact of ocean borne debris can be classified into four broad categories: beach litter surveys, sea floor studies, studies of floating debris, and studies of entombed beach debris.

Beach litter surveys dominate the literature on investigations of ocean borne pollution. Prior to 1986, beach litter surveys were conducted at sporadic intervals. They lacked consistency in terms of survey design. Results could not be replicated nor compared from one locale to another. That situation changed when the Center for Marine Conservation (later renamed the Ocean Conservancy) initiated the concept of coordinated annual coastal clean-ups with the systematic cataloging and analysis of collected debris (O'Hara, 1987). The 1986 effort served as a forerunner to a continuing series of annual events that take place on beaches around the world. These studies have focused on evaluating surface accumulations of debris on beaches from around the world. Beaches have been studied in areas of intensive popular use. Examples of such studies include the Caribbean (Garrity and Levings, 1993), the Mediterranean (Golik and Gertner, 1992), South Africa (Ryan and Moloney, 1990), and Hawaii (Dameron, Parke, Albins, and Brainard, 2007). Beaches in remote locales such as Northern Australia (Whiting, 1998), Antarctica (Coney, Barnes, and Morton, 2002), Java (Willoughby, 1986), and Indonesia (Uneputty and Evans, 1997) have also been scrutinized.

Other areas dealing with ocean pollution have received far less attention. Costs play a major factor in limiting the number and scope of some sampling operations. Sea floor studies have been an area of increasing focus since 1993 when off-shore debris was identified as a new problem (Williams, Simmons, and Fricker, 1993). Examples of later investigations include studies of European coastlines (Galgani et al, 2000), coastlines in the eastern Mediterranean (Galil, Golik, and Turkay, 1995), and coastal areas of Curacao (Nagelkerken, Wiltjer, Debrot, and Pors, 2001).

The evaluation of the amount and distribution of floating debris in world oceans has been one of the most difficult areas of investigation. A limited number of studies have been conducted, examples of which include studies of the Mediterranean (Aliani, Griffa, and Molcard, 2003), the Gulf of Mexico (Lecke-Mitchell and Mullen, 1997), and areas of the southeast Pacific (Thiel, Hinojosa, Vasquez, and Macaya, 2003).

Another area of limited focus is the potential long-term impact of beach debris as it becomes entombed within the sands of the beach. While the beach debris studies associated with beach clean-ups are important, they are sporadic in nature and fail to take into account the long-term impact ocean debris has on local beaches during interim periods between clean-up events. The numbers of studies conducted on entombed beach debris have been limited in both scope and locale. Examples include the evaluation of beaches in Japan (Kusui and Noda, 2003) and the evaluation of entombed material on a cobble beach in Wales (Williams and Todor, 2001).

Sources Of Beachfront Pollution

Much of the beach litter collected and evaluated by the annual Ocean Conservancy clean-ups is attributed directly to beach users. Remnants of the filter tips of cigarettes have consistently been one of the most commonly collected items in Ocean Conservancy surveys. Madzena and Lasiak (1997) confirm that debris deposited on beaches adjacent to major metropolitan areas can be traced to rivers that facilitate the downstream movement of materials and their deposition into nearshore waters. The materials are then deposited onto the beach surface by the action of incoming tides and longshore currents. The third source of ocean borne debris is traced to ocean-going vessels that dump refuse directly into the ocean environment.

The following report details geographic variations in beach debris accumulation on three beach segments located along the eastern coastline of San Salvador Island, an isolated island situated on the eastern edge of the Bahamas Archipelago. The objectives of this study were:

- To evaluate the type and amount of beach debris that accumulates on San Salvador's beaches
- To determine the source of beach debris accumulating on the beaches of San Salvador Island
- To evaluate geographic variations in beach debris accumulation on beaches with differing environmental conditions

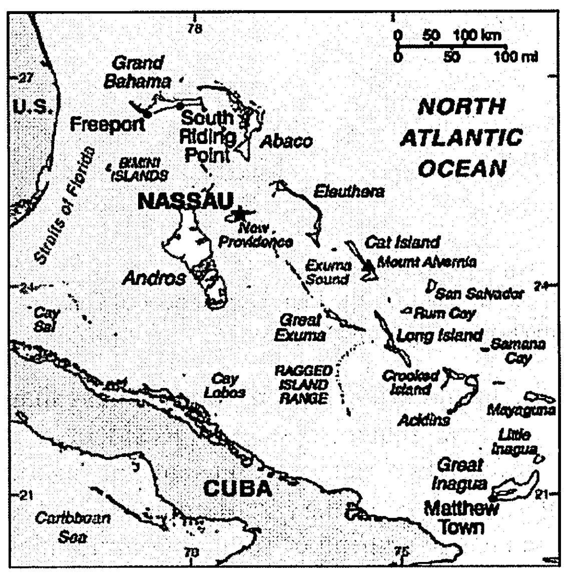

Figure 1: The Bahamas Archipelago
Source: U.S. Central Intelligence Agency, 2008, The World Factbook – Bahamas, **https://www.cia.gov/cia/ publications/ factbook/print/bf/html.**

STUDY AREA

San Salvador Island is situated along the eastern flank of the Bahamas Archipelago (Figure 1) where it is subjected to primarily easterly winds and water currents. The island (Figure 2) measures 16.2 km (10 miles) in length and 11.4 km (7 miles) in width producing an overall surface area of 155 km^2 (60 square miles). Hypersaline lakes cover half of the island's surface area.

The shoreline consists of an alternating series of rocky headlands and calcareous sand beaches co-mingled with transitional areas of mixed sand and limestone beaches.

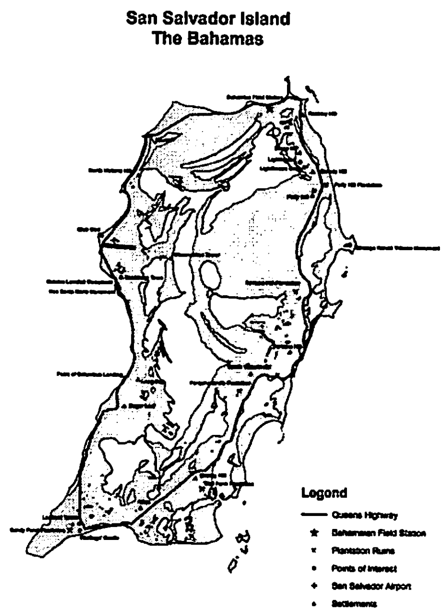

Figure 2: San Salvador Island
Map produced by Thomas Buckler, Department of Geography, Youngstown State University.

The island's population numbers less than one thousand permanent residents. Residents are concentrated in two general areas of the island represented by five primary settlements. United Estates consists of a string of smaller communities located in the northeastern quadrant of the island in an inland locale. The other four settlements are located along the island's leeward west coast, two of which, Victoria Hill and Cockburn Town, have a waterfront orientation. The remaining two settlements, Long Bay and Sugarloaf, lie in inland locales.

Island residents, by and large, are not recreational water users. Recreational water use is limited to three facilities: the Club Med Columbus Isle Resort; the Riding Rock Inn, a recreational scuba diving resort; and the Bahamian Field Station, a university teaching and research facility. A limited number of vacation resort homes have been developed on the island, a number that has been increasing in recent years. Except for boat activity associated with scuba diving operations at Club Med and the Riding Rock Inn, San Salvador lacks commercial and/or recreational boating activities that might contribute appreciably to the debris load in coastal waters or on the beaches. The island has no permanent or intermittent streams thereby eliminating the potential for inland wastes being flushed into the marine environment. The island is surrounded by a fringing barrier reef system that serves as yet another barrier to inbound ocean-borne debris.

San Salvador Island provides a unique opportunity to examine the impact of floating debris from far-flung sources on the open ocean.

- San Salvador's isolated locale insures that the bulk of the material washed up on its shores is derived from foreign sources
- The island lies on the western edge of the North Equatorial Current, consequently there are no immediate, up-current sources of buoyant debris
- San Salvador residents are not recreational water users
- Previous studies (Alter, Shaklee and Buckler, 1999) indicate beach litter accumulation on the island's eastern beaches is generated exclusively by external sources

East Beach Site Characteristics

As indicated in the study by Shaklee and Buckler (2000), East Beach is an ideal locale for studying the long-term impacts of floating material in world oceans.

- East beach is a high energy wind and wave environment with zones of surface sand accretion and prograding sand dunes
- Material accumulating on the beach surface is not of local origin
- Wave direction along East Beach is perpendicular to the shoreline
- Conditions generally promote a moderate southerly wave refraction along the beach face

- Over a twenty-four hour observation period buoyant materials cast into the water moved less than two meters south of their initial point of entry (Baltic, 2008)

METHODOLOGY

Our methodology was modeled after successful surface beach surveys conducted elsewhere in the world (Ohara and Younger, 1990; Rees and Pond, 1995) that categorized beach debris into specific classes of anthropogenic waste. The surface collection methodology employed in coastal cleanup studies was combined with traditional archaeological excavation techniques to identify potential layers of debris that could be associated with specific tidal events.

POLLY HILL BEACH ACCESS ROAD
MARCH 2007 EXCAVATION

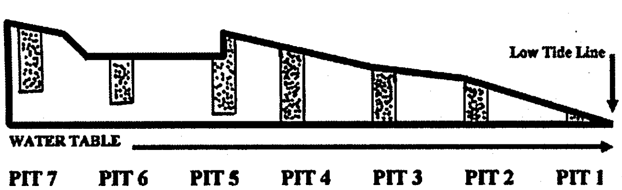

Figure 3. Profile of the series of excavations of entombed beach debris conducted at East Beach, San Salvador Island, The Bahamas (illustration is not to scale).

Initial excavations were conducted at ten meter intervals along a transect that began at the low tide line and extended to the fringe of secondary dunes lining the beach (Figure 3).[1] Pits were excavated as one meter by one meter squares in layers of ten centimeters. Where possible, excavations extended to a depth at or near the water table. The depths of individual pits varied according to elevation and distance from the low tide line (range from 0.1 meters to 1.75 meters in depth).

[1] Initially, all transects started at the low tide line and extended up the beach face into the vegetated zone bordering the beach. In later sampling, excavations within the swash zone were suspended when it became clear that entombed debris was not accumulating in area of wave activity.

Sand was sifted to extract buried debris within the excavated material. Sifting devices were improvised using flotsam gathered from the beach surface and consisted of beverage crates with two centimeter by two centimeter openings in the base of the crates. The coarser screening mechanisms facilitated the shifting of wet sand. Unfortunately, the use of coarse screening devices precluded the consistent collection of smaller shards of plastic materials which constitute the bulk of the beach debris.

Transect selection was dictated by the use of a standard measure (100 meters) from the beach access point. This process brought a random element to selecting the site of the transects and helped insure that site selection was not influenced by a visual reconnaissance of the shoreline which might promote the selection of a sample site based on the amount of accumulated surface debris at specific locales.

RESULTS

The results derived from our excavations of transects along the eastern beaches of San Salvador varied significantly from one set of environmental circumstances to another. Our original study site, excavated in March 2007, was located 100 meters north of the beach access road at Polly Hill. A companion transect was sampled 100 meters south of the Polly Hill beach access road in March 2008. A second pair of transects were sampled in March 2008 in the vicinity of the Holiday Tract settlement north and south of a promontory formed by a fossil reef and known locally as the 'Thumb.' A third pair of transects were sampled in a northern portion of the beach in an area accessed by a beach access road at Dixon Hill. The final transect was at the point where the beach intersects the cliff line at the northernmost point of Hanna Bay.

Polly Hill Transects

The transects sampled at the Polly Hill beach access road were located one hundred meters north and south of the beach access point. The northern site was sampled in March 2007. The southern site was sampled in March 2008.[2] The northern site was the most unique of all seven sites sampled in this research. At some point prior to our sampling of the site, a storm tide had breeched the line of vegetation protecting the bordering primary dunes. Tidal action scoured out a depression behind the primary dune, creating a sink where flotsam and debris could accumulate. The materials were stranded as the storm tide receded and were subsequently entombed by wind-blown sand (Figure 4).

Figure 4. The excavation located on the lee side of the primary dune at the Polly Hill northern transect.

The first three excavations all lay within the swash zone, a total distance of 20 meters from the low tide line. An insignificant amount of debris was collected at the surface (4 pieces) and no entombed materials were found within this zone.

The fourth excavation lay on the seaward edge of the primary dune at a distance of 30 meters from the low tide line. A large quantity of material was inventoried from the surface and from the top 20 centimeters of the excavation. Another significant concentration of debris was uncovered at a depth of 80-90 centimeters indicating the probability of a separate storm tide event. The amount of material recovered from below the 90 centimeter level was insignificant.

The excavation, initiated 40 meters from the low tide line, was at the base of a sea grape (Figure 4). The site was on the land side of the primary dune and bisected the forward edge of the depression created by tidal breech. Large quantities of debris were found at the surface and within the top 30 centimeters of the excavation. The exposed root system of the sea grape was responsible for the entrapment of significant amounts of debris. As the storm tide receded massive quantities of material were stranded at the surface. These two elements help explain the amount and nature of the debris recovered at this site.

The excavation located 50 meters above the low tide line exhibited two distinct layers of debris, one at a depth of 90-100 centimeters and the second at a depth of 120-150 centimeters. The differences between the depths of the two layers clearly indicated a scenario where debris was deposited during two separate storm events.

The final excavation at the north Polly Hill site was 60 meters from the low tide line. It was partially embedded in the ledge created by the scour action of the storm tide. A sea grape also covered this site and major debris concentrations were collected from the root system at the base of the bush. A second layer of deposition was uncovered at a depth of 80-90 centimeters.

The southern transect at Polly Hill produced very different results. It was laid out in an area where the beach narrows and the distance between the low tide line and the bordering vegetation is minimal. At the time of our survey the high tide was undercutting the vegetation bordering the beach. Consequently, at this site we were limited to a single excavation at the edge of the vegetation line atop the bordering primary dune.

[2] In the opinion of the authors any differences between the samples collected at the two Polly Hill locations were a function of local environmental conditions rather than a function of the time differential between the collection events.

Significant amounts of debris were recovered from the top 40 centimeters. Only trace amounts of debris were recovered from the area below 40 centimeters.

Holiday Tract Transects

The Holiday Tract transects were chosen specifically to evaluate the impact a promontory would have on interrupting the flow of debris down the face of the beach and its impact on the entombment of debris within the beach environment. The area lies in a location that is equidistant between the southern boundary of Storr's Lake and the northern boundary of the Pigeaon Creek Estuary. The beachfront is interrupted by a promontory, nicknamed the 'Thumb,' formed by a dune ridge underlain by a fossil coral reef. The promontory blocks the southerly migration of debris down the face of the beach, as evidenced by the massive amount of beach debris on the north side of the Thumb (Figure 5). We presumed the area north of the Thumb would show evidence of large quantities of entombed debris while the area south of the Thumb would be relatively free of entombed debris due to the blocking effects of the promontory.

Figure 5. Debris accumulation at the base of the Thumb.

The results differed substantially from our initial hypothesis. The transect located 100 meters north of the Thumb yielded moderate quantities of debris at the surface and within the top 20 centimeters of the excavation. Below the 20 centimeter level, there was an absence of entombed material in the excavated area.

The transect 100 meters south of the Thumb produced a much different profile. There were consistent concentrations of debris at all levels of the excavations. A zone of debris concentration at a depth of 30-70 centimeters was identified in the excavation 10 meters from the low tide line. The excavation conducted 20 meters from the low tide line yielded a zone of debris at a depth of 50-90 centimeters. The relative location of the debris fields within the beach profile leads us to believe the debris was deposited during the same storm event.

The absence of entombed debris in the excavations of the northern transect presents an interesting question, particularly given the massive quantities of material that collects at the surface in the area. One potential explanation is that the wave turbulence created by storm tides is magnified by the placement of the Thumb along the beachfront. The turbulence, in turn, creates a periodic scouring of the sands of the beach adjacent to the Thumb and the removal of entombed material.

Dixon Hill Transects

The third pair of transects were sampled in the vicinity of the beach access road that adjoins the Dixon Hill Cemetery. One transect was located 100 meters north of the beach access point and the second transect was located 100 meters south of the beach access point. The northern transect consisted of four excavations, the deepest of which was 130 centimeters. Surface debris was collected at the excavation 20 meters from the low tide line. Significant quantities of debris were collected to a depth of 70 centimeters in the pit that was excavated 40 meters from the low tide line.

The transect 100 meters south of the beach access point exhibited significant amounts of debris at all levels within the excavations. The beach in this corner of the island follows a slight northwestern slant, reversing the southerly longshore current experienced along other beach segments on the eastern coastline. The beach also narrows as it extends to the north, creating a smaller zone of sand accretion.

North Hanna Bay Transect

The Hanna Bay transect was located at the northern terminus of East Beach where it intersects the cliff line that forms the northeast corner of the island. Sampling was performed in December 2008. The number of sample pits was limited because the beach surface constricted as it approached the rocky headland. The first of the three excavations started at the low tide line. A second excavation was taken at 10 meters from the low tide line. The third excavation was at the base of the cliff that intersected the beach. The depth of the second excavation was 60 centimeters. All significant debris was collected at the surface or within the top 20 centimeters of the sand. It is expected that the sand in this locale is periodically scoured away by storm tides and wave turbulence.

Collected Materials

The types of materials collected and inventoried during the excavation of entombed debris were comparable to materials collected during the San Salvador surface debris studies (Shaklee and Buckler, 2000). One major difference lay with the percentage of plastics in the entombed debris study (Table 1). Plastics dominated the number of materials collected in both studies but the percentage of plastics in the entombed debris study was appreciably smaller. Three factors are considered as possible explanations for that discrepancy. One consideration is that tar balls were not counted in the 1996-1999 surface debris study. Tar represented a significant percentage of the materials inventoried in the entombed debris study which would impact the statistical distribution of the types of materials. A second consideration is the coarse character of the screens used in the entombed debris study. It is likely that smaller plastic shards were not collected by the two centimeter by two centimeter screens. A third consideration lies with the trend towards shards and pieces of materials recorded in the entombed debris study compared to the greater tendency to collect identifiable whole units in the surface collection study. We feel this trend may be a reflection of changing technologies towards more degradable plastic products in the intervening decade between the two studies.

In the entombed material study, shards of plastic (> 0.5 cm) dominated the inventoried material. Identifiable plastic pieces tended to be container handles, necks, and bases that are constructed of thicker plastic due to the need for greater support. Other plastic fragments included rope fragments. Glass bottles, light bulbs, and metal containers tended to be collected in an intact state and were identifiable as containers with specific functions.

TABLE 1
COLLECTED MATERIALS
(Number of pieces)

	Entombed Materials 2007-2008	Surface Collections 1996-1999[3]
Plastics	61%	74%
Glass	13%	12%
Tar	13%	Not Recorded
Foamed Plastic	10%	6%
Rubber	1%	5%
Wood	1%	2%
Metal	1%	1%

CONCLUSIONS

The entombed beach debris research described herein indicates that there are distinct ebbs and flows in the deposition and accumulation of anthropogenic wastes in beachfront environments.

- Our excavations within the swash zone (between the high tide and low tide

[3] Shaklee, Ronald V. and William R. Buckler, 2000. A Longitudinal Study of Surface Beach Litter Accumulation on San Salvador, Island, The Bahamas: 1996-1999. Unpublished Manuscript, Youngstown State University, Youngstown, OH, 15 pp.

boundaries) produced no debris buried within the sand of the beach
- We presume beach debris is deposited and then re-floated with successive incoming and receding tides and migrates down the face of the beach until it is either returned to the open ocean, sinks to the ocean floor, or is stranded above the high tide line by wind or wave action

Our excavations in locations above the high tide line and within the vegetative zone of bordering coastal dunes produced buried debris at all levels within the excavation.

- We presume that beach debris becomes incorporated into the sand load of the beach when it becomes deposited above the normal high tide line by seasonal high tides, higher energy storm tides, or when lighter materials are pushed above the high tide line by wind action
- Coastal vegetation, particularly deep-rooted woody shrubs, plays an important role as a debris trap, especially in instances where high waves breech the primary dune and carry materials into the swale behind the primary dune
- Materials lying on the beach surface above the high tide line eventually become entombed by windblown sand
- Storm events with higher energy wind and wave action produce distinct episodes of debris accumulation within the swale beyond the primary dunes and these events are identified as distinct layers of materials within the sand load of the beach
- Storm events may also be responsible for scouring out previously deposited materials as the face of the beach is reduced through wind and wave action

FINAL OBSERVATIONS

From a purely observational standpoint, we feel the amount of debris collecting on the surface of San Salvador's eastern shoreline has diminished over time. We intend to replicate the 1996-1999 study to determine if there has been a quantifiable change in beach debris over the intervening decade.

We have also noticed a seeming decline in the concentration of tar on the beachfront of East Beach since our initial visits to the island in the 1980s. We are unable to offer quantifiable confirmation of a decline in tar as a beachfront pollutant, but our students seem to have far fewer incidents of tar on their shoes and clothing than was the case in an earlier era. Perhaps global efforts directed towards containing pollution from offshore drilling platforms and the restrictions placed on ships that prevent them from purging their bilges and fuel bunkers in the open ocean is having an effect on this particularly noxious form of beachfront pollution.

While performing the collection of surface debris, we noted that a high percentage of small, lightweight, plastic shards became entwined in layers of seaweed that collected at the high tide line. In some of our excavations, these organic layers were still visible and were associated with layers of anthropogenic material. We suspect that some of our debris layers may have been associated with organic debris but that this material decomposed over time, leaving the anthropogenic materials in an isolated layer.

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