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The Anguilla Beach Monitoring Program Report 1992-2014: Temporal analysis of twenty two years of monitoring data

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ABSTRACT

Monitoring of beach profiles has been conducted by the Department of Fisheries and Marine Resources since 1992 and expanded over the years to now include sixty two study sites spread across nineteen beaches, fifteen on mainland Anguilla and four on its offshore cays. This report details the results from sixteen of these beaches that were studied prior to 2012, before the number of monitoring sites was expanded to its present compliment. Across these beaches, between 1992 and 2014, a total cumulative loss of 332 m in overall beach width has been documented which, when taking into account the number of profile sites per beach, in any given location there has been a mean width loss of 7.1 m. When adjusting based on the number of years each location has been reliably monitored, this in turn equates to a mean beach width loss of 0.7 m/yr^{-1}. Of the mainland beaches studied, Sile Bay suffered the greatest overall loss per monitoring location with a mean decrease of 20.9 m (1.9 m/yr^{-1}), followed by Meads Bay with 16.6 m (0.9 m/yr^{-1}), Shoal Bay East with 12.4 m (0.8 m/yr^{-1}), and Shoal Bay West with 12.3 m (0.7 m/yr^{-1}). Of the offshore cays Sandy Island had the greatest loss in beach width per monitoring location with a mean decrease of 12.6 m (0.8 m/yr^{-1}). In total 81% of the beaches suffered from erosional losses, or 79% of all monitoring locations. Reasons behind these losses appear varied and complex, and often due to a lack of recovery following hurricane events or strong ground swell seasons. For the most part this lack of recovery seems to occur where either sand mining for aggregate has removed dune systems or coastal developments (and probable dune removal to facilitate the development) have taken place essentially directly on the beach. Erosion at some sites took place without these influences however (for example Shoal Bay East), with the cause thought to be due to a degrading reef system. Some sites displaying erosion may in part be due shifting sands rather that solely sand loss (for example Sandy Island, Prickly Pear East). Of the two accreting mainland beaches Sandy Hill Bay was highest with a mean overall change per profile location of 1.5 m, followed by Maundays Bay with 1.3 m over the study period. The increases at Maundays Bay are due to a number of beach nourishment programs carried out there following major hurricane events. This study highlights the need for responsible coastal development and implementation of mandatory setbacks, tight regulations relating to coastal sand mining, and the increased protection of important defensive coral reef areas. The study also points to the need for detailed investigations prior to coastal engineering interventions, for while the beach nourishment at Maundays Bay has been successful to date, other interventions at the east end of Barnes Bay have not yet shown any positive impacts. If Anguilla is to preserve its beaches that are a crucial driving force behind its tourist dependent economy then the importance of this cannot be understated.

Introduction

With the introduction of anthropogenic interests, beach systems become of high significance as an important resource of high financial significance. In Anguilla this became the case in the early 1980's with the small beginnings of a now nationally important tourist industry. The economic potential of vast stretches of white sandy beaches was realized, and over the following decade development continued. By the early 1990's it was noticed, mainly due to beach front developments acting as points of visual reference, that erosion was occurring at certain important locations, especially during major hurricane events. It was noticed that these changes seemed especially severe on the developed beaches or in areas where sand had been removed for the construction industry. It was at this point that the Department of Fisheries and Marine Resources (DFMR), despite not having jurisdiction over the beach areas, decided to set up a monitoring program, with the assistance of development partners – UNESCO and the University of Puerto Rico Sea Grant College Program, to study these changes. Initially the Department of Physical Planning were also involved with this work, but their involvement had ceased by the mid 1990's.

In 1992 the first set of points were established, following the addition of more in 1994 to cover a greater number of beaches and also include the closer offshore cays. In 1996, and following Hurricane Luis in 1995, more profile locations were added to an important tourist beach reporting concerns with regards to erosion. Again in 1999 two further points were added to Upper Shoal Bay East where, despite attempts to stabilize the sand dunes using pallet fencing, erosion was occurring at what were then unprecedented levels. No further sites were added until 2008, when despite logistical challenges caused by distance from mainland, two further offshore cays were added to the program. Selected new sites were added gradually during the following few years until 2012, when the program halted due to the possibility of it being taken over by another agency. In 2013 it was decided that DFMR would continue to lead this important work, and again some new sites were added to address new areas of concern. To date there are 62 active profile sites located on nineteen of the beaches around the island and its offshore cays.

Since the program's beginning no official reports have been produced, although data collected have been used indirectly when needed and some of the findings have been incorporated into published regional analyses (Cambers 2003; UNESCO 2003; Cambers 2009; Cambers & Roberts-Hodge 2015). Without an official written analysis however it is not possible to formally reference changes or provide evidence to back up recommendations made on proposed coastal developments. This current report sets out to change this situation and provides a detailed record of all the profile locations studied past and present, together with a detailed analysis of beach width changes at those sites with a reliable record established prior to 2012, and using those data collected between 1992 and 2014. It is hoped that this report will prove an important resource for Anguilla when making future decisions on coastal developments and help preserve and use wisely the crucial coastal resources for generations to come.

Methodology

The Anguilla Department of Fisheries and Marine Resources (DFMR), beach monitoring program started in 1992. The program now monitors 19 beaches, 15 on land and 4 on the offshore cays, with a combined total of 62 on-going profile locations (see figure 1). Three profile locations have been cancelled since the program started due to topographical changes, thus in total 65 sites are referenced within this report.

Monitoring is, as far as possible, undertaken quarterly by three or four persons, using basic yet standard equipment: Abney level, two red and white aluminum poles measuring 2.2m, a metric measuring tape, camera, and beach monitoring data collections forms. At each monitored site there is a reference point, signified by a particular landmark. These reference points are usually areas that are safely secured on the beach, whether on vegetation marked with a brightly colored flagging tape or paint spray and at certain locations the foundation of buildings. All reference point coordinates are stored in a hand held GPS.

Monitoring begins by measuring the present height of the reference point above the sand level. This measurement is extremely important as it provides a comparative start point – point A on the data sheet - from which previous rounds of monitoring can be compared. A ranging pole is placed at point A and moving away from the reference point in a known direction, a second ranging pole is placed at the next noticeable change in incline. This becomes point B. The distance between point A and point B (AB on figure 2) is measured, and the incline recorded using the ranging poles and Abney level. This process is continued (to point C, D, E etc.) until the offshore step is reached – this is the sharp drop-off that is usually present just beyond the swash zone. In cases where this step is not present, measurements are usually taken until the surveyor reaches knee deep water. This methodology produces beach profile segments which can be plotted on a graph (using the Beach Profile Analysis software, version 3.2, 2001) to illustrate the beach width and cross-sectional area, the changes over time in which provide erosion and/or deposition rates for each study site.

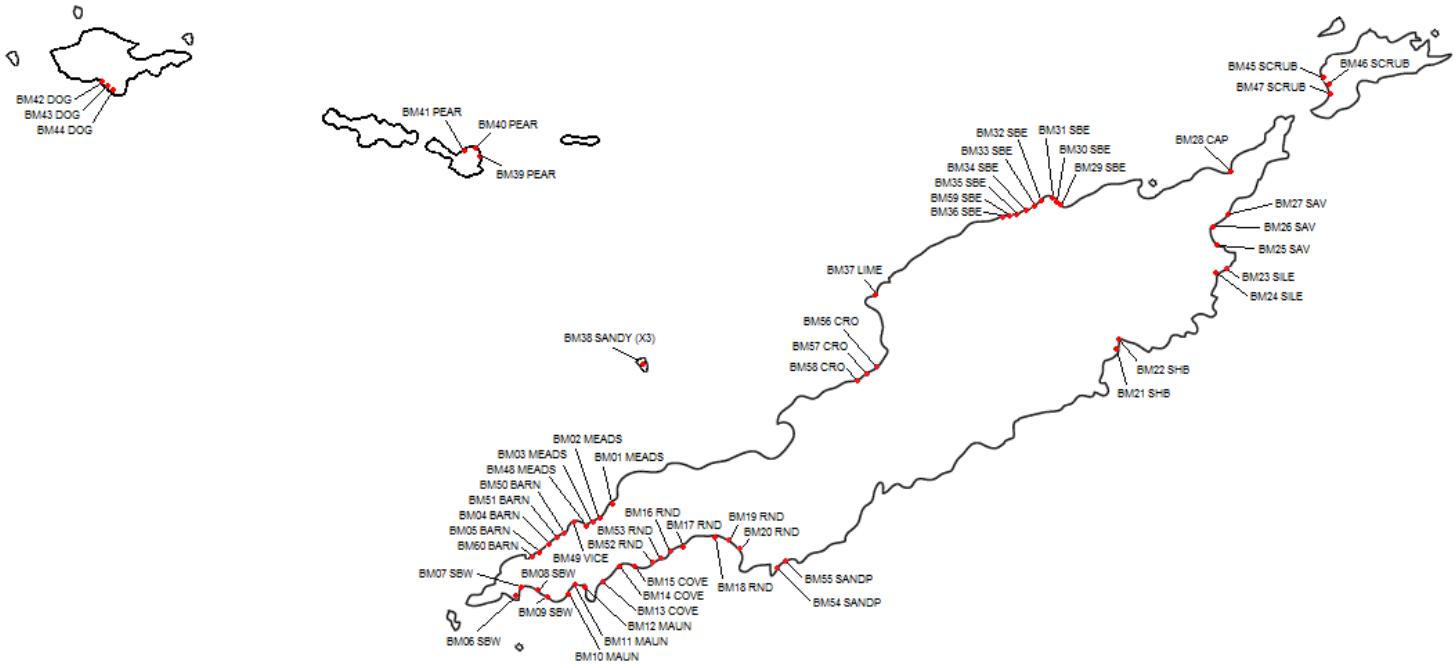

Figure 1: Map of all profile sites monitored as of 2015, with reference names indicating beach on which point is located. *Note*: Originally reference numbers began at Meads Bay, and moved anti-clockwise around the island numerically. In 2013 however, it was decided to begin adding new sites so these numbers do not follow that pattern. To date there are 60 ongoing reference points, but as the one at Sandy Island is used as a central marker for three measurements, a total of sixty two profiles are currently monitored.

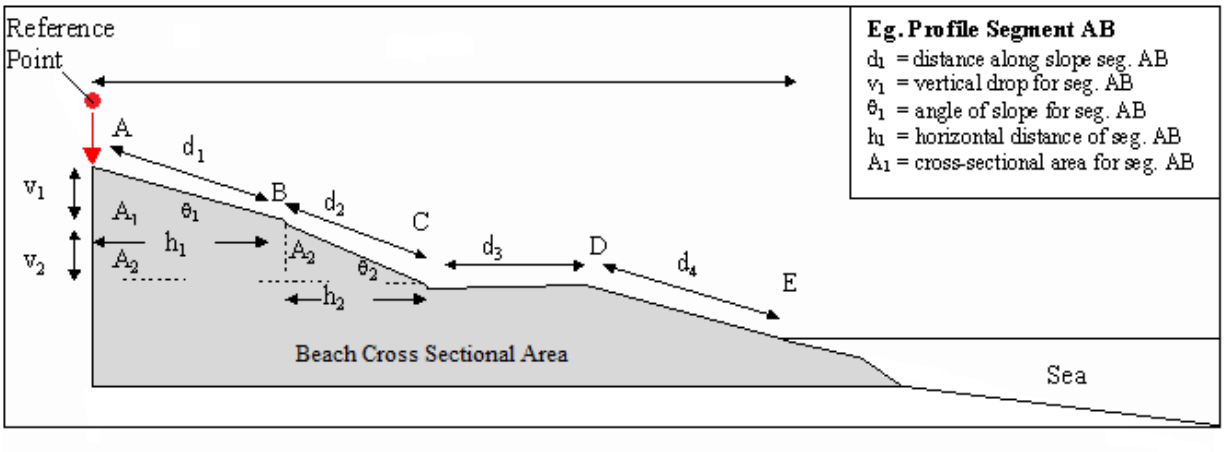

Figure 2: Schematic of beach profiling methodology (taken from Daniel, 2001)

Note on changes to reference points: Each profile site has a reference (or starting) point. As depicted in figure 2 this reference point is above the average beach sand height and marked by red paint on a tree trunk or other permanent structure such as a fence or building. The permanency of this structure is critical to provide a fixed reference over subsequent years, irrelevant of how sand and other beach material changes. Unfortunately however, hurricanes and other storm events can cause the loss of this reference point and so a new point would have to be established. As this monitoring work started before the advent of easily accessible GPS handheld units, high levels of accuracy when replacing reference points was not possible. Today, GPS coordinates have helped rectify this to a certain extent (height of reference point is not possible to accurately measure with current available equipment), but before that, if a reference point was lost, this accuracy could not be guaranteed. This means, when analyzing the data, historical reference point changes have to be highlighted by dividing the data into subsets. Comparisons between these subsets are more limited than if the reference point had remained unchanged. For example, overall erosion and deposition rates inferences can still be made by working out rates for each subset and then combining means, but an overall beach material loss analysis across years where a change in reference point has occurred is not possible.

Beach Descriptions

Below are descriptions of the 19 beaches with details on all current profile monitoring locations as illustrated previously in Figure 1, with reference to discontinued profile monitoring locations (at Barnes Bay and Cove Bay), coastal development and vegetation present. Supporting photographs can be found in Appendix I, with Appendix II providing full profile details, including reference numbers, co-ordinates and profile measuring instructions.

MAINLAND BEACHES

1. *Meads Bay*

One of Anguilla's largest beaches, Meads Bay is popular with tourists and has a number of large developments on or bordering it, often up to the vegetation line. The sand is generally deep and can form steep slopes into the ocean which are created by the often large swells present. Notable sand movement occurs in the area, but it appears in equilibrium as it is usually re-deposited, sometimes only days later. The remaining vegetation largely consists of sea grapes, palm trees, grasses and low lying shrubs. Three profile locations (BM01-03) were started in 1992, with a further added early 2013 (BM48) close to the newly completed Viceroy development.

2. *Viceroy Beach*
   A small cove-like beach nestled in the sea rocks almost mid-way into the large coastal development of Viceroy (now renamed Four Seasons). Historically this beach comes and goes, and at times loses all of its sand. Due to difficult rocky access along the coast and newly constructed breakwaters, this is among Anguilla's more secluded beaches, less than 100 m wide and often almost completely covered by swash. A concrete wall lies at the back of the beach, and the surrounding rocks are covered with hanging vines and other flora. Due to the large resort development and breakwater structures DFMR decided to include this beach in its monitoring program, and in early 2013 the monitoring site BM49 was established here.

3. *Barnes Bay*
   This beach was one of the most notoriously eroded in Anguilla during Hurricane Luis in 1995 and Hurricane Lenny in 1999 (Plate 1), especially along its eastern end. Extensive bedrock was exposed and the coastline retreated inland. Much of the material lost on the western end has now returned, although the eastern stretch can still be problematic. The central and western ends of Barnes Bay were originally where beachfront development was concentrated (small villas and a restaurant), and the original locations of two early monitoring sites started in 1994. Reference point losses led to one of these points being discontinued, leaving only BM04. In 2011 a new point was added (BM05).The relatively recently completed Viceroy development down the eastern end has been artificially nourishing the beach via an offshore dredger (in 2015) with large boulders in the form of small offshore breakwaters in an attempt to retain the new sand (Plate 2). For this reason two subsequent monitoring sites (BM50-51) were established in this area early in 2013.

4. *Shoal Bay West*
   The most westerly tourist orientated beach, Shoal Bay West is secluded in nature, mainly due to its well-disguised public access points. It is home to two large developments, both of which are constructed directly on the low sand terrace behind the beach. The beach often appears relatively deserted. Even without analyzing data, the erosion that occurs at this beach is widely known, and at different times has resulted in the entire loss of the beach (Plates 3 & 4). Although not formally recorded, photographic evidence suggest some limited beach nourishment has taken place here in January 2000 following Hurricane Lenny (Plate 5). Four monitoring sites (BM07-09) were established here in the early 1992.

5. *Maundays Bay*
   This beach is well-manicured and the location of one of the original large tourist developments on Anguilla, Cap Juluca. Over the thirty or more years this development has been present (again utilizing the land right up to the vegetation line and seaward) hurricanes have caused significant erosion (Plate 6). The damage usually warranted the beach sand to be redistributed, with diggers, and with dredgers pumping the sand from the bay back on the beach (Plate 7). As an interesting note, much of the sand used to build the resort was sourced from the sand dunes that once existed at Sile Bay. The waters in this bay are usually calmer than anywhere else around the island, and so background erosion rates are considered to be minimal. Remaining beach vegetation consists of palm trees and sea grapes. Three profile locations (BM10-12) were established here in 1996, with no subsequent additions.

6. *Cove Bay*
   Despite its location in the heart of Anguilla's tourist development area, this beach is still relatively undeveloped with the associated wild and natural feel. One restaurant and a fishing jetty exist here, with its semi exposed nature leading to conditions that make it ideal for water sports. However the beach does experience medium to large swells at times and notable sand movement. During storms particularly bad conditions can exist here, which is likely the reason for the large dunes that are still present towards its western end. All this provides stark contrast to neighboring Maundays Bay that has a very sheltered nature. The vegetation line is marked with sea grape trees and dune vegetation (grasses, small shrubs etc.). Four monitoring sites were originally established here in 1992, although two were discontinued in 1998 and 1999 due to overall topographical changes, leaving BM14 & BM15. In 2011 a new site (BM13) was added down the far western end of the bay.

7. *Rendezvous Bay*

The largest sandy beach arc on Anguilla, Rendezvous Bay is the quintessential Caribbean beach destination. In Anguillian terms the beach front is heavily developed with large resorts and smaller villas and restaurants, although in reality it still has some significant undeveloped stretches. This beach is home to what is set to be the largest development on Anguilla, Cuisinart Resort and Spa that has recently purchased the golf course and associated villa development, and has almost finished construction of a tertiary multi-story hotel, said to become the tallest building on the island. Much of this development has been constructed set back from the vegetation line, although the dunes were lowered in preparation for the original development in the 1990s and some vegetation has been removed to create better sunbathing areas for tourists. This most recently happened in front of the new golf course hotel[1], where small dunes and associated flora were 'cleaned' to achieve the desired look. Some beach nourishment has taken place here in 2014, and developers put gabion baskets in place to help protect the beach and aid in the accretion of sand, providing a bigger nicer beach for its guest. In 2008 after Hurricane Omar devastated the island sand was taken from the bay and placed on the beach. Originally three monitoring sites (BM17-19) were established in 1994, with two subsequent additions (BM16 & BM20) in 2011. Due to the aforementioned changes in the Merrywing area two further sites (BM52 & BM53) were added mid-2013.

8. *Sandy Point Bay*

Located bordering the village of Blowing Point (and Blowing Point beach), Sandy Point Bay forms a small beach which curves westward out to a sandy point. It is the only beach in Anguilla with such an extended point. Development in the area, aside from the Blowing Point ferry terminal, includes a restaurant, hotel and some private villas. In 2008 work began on a dolphinarium in the bay (Plate 8). Due to its location near Sandy Point and potential impacts of the structure on sand movement, two monitoring sites were added (BM54-55) in mid-2013.

9. *Sandy Hill Bay*

This pretty arc of beach is located on the eastern side of the island in the small village of Sandy Hill (also known as Sea Feathers Bay). The beach itself is relatively sheltered by a fringing reef, although its aspect means it can still be badly affected by ground swells; which occasionally remove a great amount of sand leaving bare rock shore areas. The removal of Sargassum from along this beach (manually and by heavy equipment) over recent years has also contributed to potential sand loss. A small number of fishing boats are moored in the bay and it is a popular beach with local residents. The vegetation line is dotted with sea grapes and other relatively low lying vegetation. Two profile locations (BM21-22) were established here in 1992.

10. *Sile Bay*

Located on the eastern end of the south side of the island, Sile Bay is exposed, and although protected by offshore reefs, rough seas usually prevail for most of the year. Today the beach lacks the swathes of great white sand dunes that historically reportedly existed here, as sand mining of the beach and dune system here in the 1980's has removed the majority of it (Plate 9). Some of the material was reportedly used for constructing the Cap Juluca development at Maundays Bay. In an attempt to retain the material remaining a short retaining wall was built (Plate 10), although without the dunes to replenish and balance erosional processes this did not succeed and only a limited amount of sand remains. The bay is used by two local fishermen, with a vessel mooring a short distance away from the shore line. There is currently no development in the area so it still has a very wild and natural feel. The vegetation line is marked with a few sea grape trees, but is mostly low lying shrubs with interspersed patches of grass. Two monitoring sites (BM23-24) were established here in 1992, but their usefulness is currently in question due to the lack of a beach.

[1] This is actually Merrywing Bay rather than Rendezvous Bay, but as both are essentially connected, with only a short stretch of rocks separating the two, both are considered the same beach for the purpose of this report

11. *Savannah Bay*

With only a small wooden restaurant on the Junks Hole side of the Bay, the long arcing beach has a very wild and natural feel. Like neighboring Sile Bay, rough seas persist here most of the year, although reefs a short distance from shore provide some protection from incoming swells. This is the most easterly of the south coast mainland monitoring locations on the island's south coast, and the vicinity is a popular spot for the restricted[2] practice of sand mining. The exposed nature of this area means it is popular with water-sports enthusiasts, and shore based fishing activities often take place here. Hurricane damage over the years has caused degradation to the surrounding reefs[3], leaving stretches of broken up dead coral under the water's surface. The far right hand corner of the bay is sometimes a haven for sea turtles, and the vegetation line consists of thick sea grape trees and scrubby plant life. Despite the sand mining some dunes still exist, mostly because the current practice is to take sand from inland behind the dunes, and not yet from directly on the beach. However, if the removal of material continues as it does presently it is possible Savannah Bay may one day suffer the consequences illustrated at Sile Bay. Three profile sites (BM25-26) were established here in 1994.

12. *Captains Bay*

A rough dirt track provides access to Captains Bay, making it one of the most remote beaches on Anguilla, and the most easterly of the north coast mainland monitoring locations. It is a relatively small bay with a fairly wide yet steep sand profile created by the often large swells that crash onto the beach. Despite this, and notable sand movement (Plate 11), beach erosional/depositional processes appear to the observer to be in equilibrium. Despite the poor access beach goers still visit the beautiful location, and a luxury villa is located on the nearby low cliff that can also be accessed via helicopter. The vegetation line is predominantly sea grape trees and grasses. One monitoring site (BM28) was established here in 1992.

13. *Shoal Bay East*

Anguilla's most famous beach, Shoal Bay East is a long and beautiful stretch of perfect white sand, with an elbow like sand feature dividing its upper and lower ends known as a cuspate foreland. It has been named the world's best beach not just by its Caribbean visitors but also by many top tourist magazines. Probably the busiest tourist spot on the island, this beach is flanked by numerous hotel/resort developments and busy restaurants. Snorkeling is popular here due to the offshore reefs that in places are still in relatively good condition. Over recent years the upper end of Shoal Bay has undergone a period of really heavy erosion and lost huge amounts of sea grapes and palm trees (Plates 12-15). It is thought that erosion here has been of concern since before this monitoring program began and likely was influential in initiating it. Dune enhancement measures were attempted here in the mid-1990's using pallet fences (Plate 16) but were unsuccessful and soon destroyed, although looking back, erosion was minor compared to the situation today. Six monitoring sites (BM31-36) were established here in 1992, with the addition of two subsequent locations (BM29 & BM30) in 1999. In 2015 a further site (BM59) was included in the vicinity of the newly developed Zemi Beach Hotel.

14. *Limestone Bay*

The second smallest beach that forms part of the beach monitoring program, Limestone Bay is located a short distance east of Flat Cap Point with some relatively new villa developments on its western edge and the Limestone Bay Café which has been closed for a number of years. It has clear pristine waters much of the time, although heavy wave action is common, making it rougher than most other beaches on Anguilla's north coast. This leads to notable profile changes, although on average the beach is quite narrow and relatively steep. The vegetation line is mainly sea grape with scattered older large trees. One site (BM37) was established in 1994.

[2] Sand mining is prohibited in terms of the beaches protected under the Beach Protection Act, but when the activity takes place behind the vegetation line this protection is lost.

[3] As with much of the south coast, the reefs here are comprised mainly of dead *Acropora palmata* skeletal remains, having reportedly not recovered from white band disease in the 1970's and 1980's (Bythell & Buchan, 1996). More details can be found in Wynne (2016).

15. *Crocus Bay*

Located in the western central part of the island, Crocus Bay is located in one of the most picturesque parts of mainland Anguilla. Above it, Crocus Hill is the highest point on the island at 65 m/213 ft, and provides some stunning views. The beach itself is relatively level in nature, although high levels of erosion and deposition have occurred here in the past. One such event occurred here at the end of March 2008 when huge quantities of stones were exposed after being uncovered from under the beach sand. Controversially a local entrepreneur removed much of this material and sold it as aggregate to the construction industry (Plate 17). Crocus Bay is a fair size beach and is popular with both tourists and locals, especially since the establishment of Da'Vida Restaurant and Beach Bar that began construction in 2008. The vegetation line is fringed with Tamarind, palm trees and other trees/shrubs, and the bay is also a small scale fishing port, with a number of vessels moored in the area. The recent addition of a private jetty has now opened the beach up to charter vessels and tourist yachts. Monitoring here began in 2014 after the jetty proposal was submitted to the Government of Anguilla, and record of its impact on sand movement deemed necessary. With that three profile locations (BM56-58) were added.

OFSHORE CAY BEACHES

16. *Sandy Island*

The smallest of Anguilla's offshore cays (not including islets and emergent rocks) is, as its name suggests, is made up of sand that has been deposited on the emergent part of Dowling Shoal. It is roughly triangular in shape, but can vary somewhat depending on sand movements. The cay is crown land but leased to Sandy Island Restaurant developers, who operate a small wooden restaurant on the island. Established vegetation grows in the center of the cay, which consists mainly of palm trees and sea grapes, although storm events often cause significant damage. This site was established in 1994 with a central marker (BM38) from which three profiles radiate.

17. *Prickly Pear Cays*

Comprises of two privately owned medium sized offshore cays, with a number of small rocky outcrops and an associated reef system. Prickly Pear West is undeveloped with only one small beach that is not monitored as part of this program. Prickly Pear East has a long pristine beach with two restaurants at its western end and a vegetation line dominated by fairly low lying sea grapes, grasses and other shrubs. Both cays are classified as Important Bird Areas by Birdlife International. Three profile locations (BM39-41) were established in 1994.

18. *Dog Island*

The most distant of the offshore cays monitored and second in size only to Scrub Island, Dog Island is privately owned and uninhabited other than a population of feral goats and thousands of sea birds. A successful rat eradication project was conducted here and it is considered an Important Bird Area by Birdlife International. The main beach, known as Great Bay, is an impressive stretch of sand on the southern side of the cay. Notable sand movements happen here due to large swells, sometimes eroding almost vertical sand cliffs into the beach over 2 m high (Plate 18). This process however appears in equilibrium. The vegetation line consists mainly of densely packed sea grape trees. One site (BM42) was established here in 2008, with two others added in 2010 (BM44) and 2011 (BM43). Logistical issues mean that it is not always possible to conduct work there quarterly.

19. *Scrub Island*

Off the eastern tip of Anguilla, Scrub Island is the largest of the offshore cays. It is a privately owned and uninhabited, with the remnants of an unfinished development and landing strip. Scrub Bay, on the western side of the cay, is the main beach and is a long stretch of sand with a vegetation line consisting of sea grape trees and other shrubs. Three profile sites (BM45-47) were established here in 2008, although logistical issues mean that it is not always possible to conduct work there quarterly.

Results

Results presented below are for monitoring locations that have temporal spans long enough to provide meaningful results. This means that those points added after 2012 (BM48-60) are not included, and will thus be included in future reports only. Similarly, data is not presented where a reference point was lost repeatedly over a short period of time. However, providing there is a good time span of data, results are included that were obtained from reference points discontinued before the profile reference numbers were established, for example the two at Cove Bay cancelled in 1998 and 1999. In total this yields 47 profile locations across 16 beaches. Dog Island and Scrub Island have been included in the analysis (unless otherwise stated) as despite not necessarily having the temporal span required, this is due to problems accessing the islands rather than their inclusion in the program after 2012. Site BM25 has also been included even though the data only covers a three year period as monitoring did happen there during previous years but it was excluded from the analysis due to datasheet queries.

General Trends

Across the 47 profiles suitable for analysis (16 beaches), a cumulative total loss in beach width of 332 m has been recorded, which equates to a mean loss of 7.1 m per profile location (Table 1). Figure 3 presents mean annual rates of change for each profile location, while figure 4 presents mainland mean annual beach width changes. When taking into account the number of years these data represent this equates to a mean annual loss of 0.66 m/yr^{-1} per profile location. When combining profiles from the same beach together (Table 2) 13 of the 16 beaches suffered an overall loss of beach material (81%), with a mean loss of 6.5 m per beach or 0.62 m/yr^{-1}.

Highs and Lows

From the previous tables and figures various highs and lows are documented in terms of overall loss in beach width and annual rates of change. Care should be taken when drawing conclusions from combined results as consideration of the number of profiles per beach, number of years surveyed and overall erosion trends is needed. These results exclude cancelled profile locations and those at Dog Island and Scrub Island due to limited number of years surveyed.

The beaches that have suffered from the most severe losses in beach width over the study period (Table 2) are Sile Bay with 20.9 m mean loss per profile (-1.87 m/yr-1); Meads Bay with 16.6 m mean loss per profile (-0.94 m/yr-1); Sandy Island with 12.6 m mean loss per profile (-0.80 m/yr-1); Shoal Bay East with 12.4 m mean loss per profile (-0.80 m/yr-1); and Shoal Bay West with 12.3 m mean loss per profile (-0.66 m/yr-1).

The profile location with the highest mean rate of change (Table 1) was “Sile Bay East’ (BM23) with a loss of 3.11 m/yr-1. Following this, ‘Mason Fence’ (BM31) was next with a mean annual loss of 2.65 m/yr-1over the eighteen years of available data. With rates of loss all above 1 m/yr-1 were Shoal Bay East ‘South of Gwens’ (BM29) and ‘Gwens Reggae Bar North’ (BM30); ‘Sandy Island North’ (BM38); ‘Meads Bay West’ (BM03);‘Savannah Bay Junks Hole’ (BM27); ‘Cove Bay East’ (cancelled in late 1990’s so no reference); and finally ‘Savannah Bay South’ (BM25).

The only beaches that have benefited from overall accretion during the study period are Sandy Hill Bay with a mean gain of 1.5 m per profile and Maundays Bay (Cap Jaluca profiles) with a mean gain of 1.3 m per profile. In total, only ten of the profile sites (21%) were documented to have a mean gain in beach width over the study period. Of these, that with the greatest mean annual rate of increase was ‘Cap Juluca East’ (BM12) at 0.42 m/yr-1; followed by ‘Cove Bay West’ (BM14) at 0.40 m/yr-1; ‘Rendezvous Bay East’ (BM19) at 0.37 m/yr-1; ‘Sandy Hill Bay South’ at 0.36 m/yr-1; and ‘Prickly Pear South’ (BM39) at 0.32 m/yr-1.

Beach Case Studies

The following case studies are presented using profile graphs from selected monitoring locations from nine beaches (Figures 5-17). These serve to illustrate examples of erosion regimes from around the island along with brief discussions on potential influencing factors[4]. These will be discussed in more detail in the following section.

Meads Bay

Over the study period of 21 years, Meads Bay, one of the most important tourist beaches on Anguilla, has suffered an average beach width loss of 16 m per profile location (0.94 m/yr^{-1}), the second most severe of all beaches monitored. Figure 5 presents mean annual data for one of the three monitoring locations on this beach. The graph clearly shows the loss of beach width following Hurricane Luis in 1995 and subsequent accretion until Hurricane Lenny in 1999 that also caused the loss of the original reference point. After re-establishing the reference point erosion continued until 2002, after which beach material began to be re-deposited back. In 2006 erosion continued again through Hurricane Omar in 2008 an on into 2014. This example illustrates the natural ability for this beach to rejuvenate itself following hurricane damage, at least to some extent, recognizing that recovery has yet to take place following the last event, almost a decade ago.

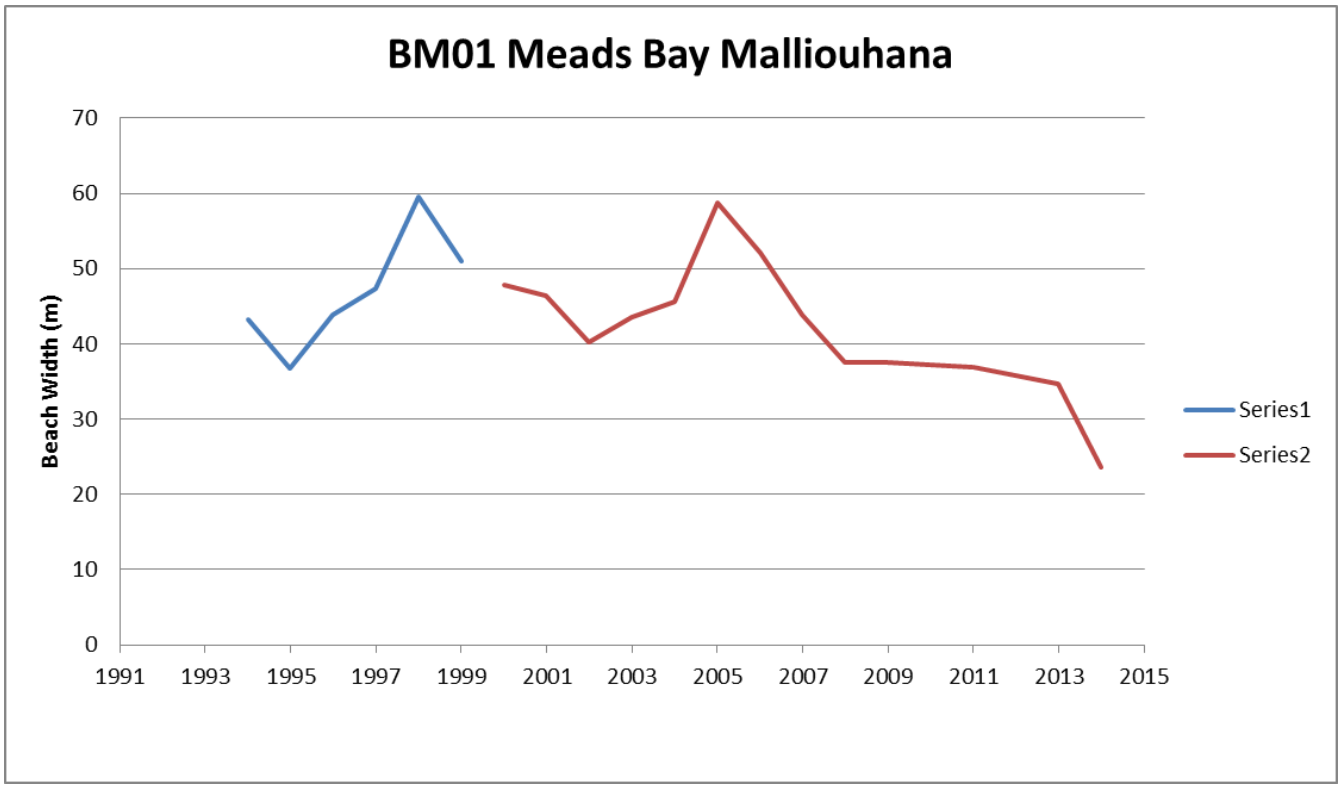

Figure 5: Mean annual beach width for the monitoring location at the eastern end Meads Bay. Data has been split to identify where a change in reference point happened following Hurricane Lenny

[4] A full set of raw profile graphs can be obtained as a supplementary document by contacting fishersmr@gov.ai

Shoal Bay West

The beach at Shoal Bay West is among those in Anguilla that is relatively well known for erosional processes over recent decades. This local knowledge is backed up by the graphs presented in Figures 6 & 7 which illustrate a gradual loss of beach material. Similar trends are present along all four profile locations. Although hurricanes have caused considerable damage here (Plates 3-5) their effect is somewhat camouflaged by the background erosional regime present, with Hurricane Omar in 2008 appearing to have very little influence. With this being said, Figure 7 does however show periods of increased losses following Hurricane Luis in 1995, Hurricane Lenny in 1999 and Hurricane Earl in 2010.

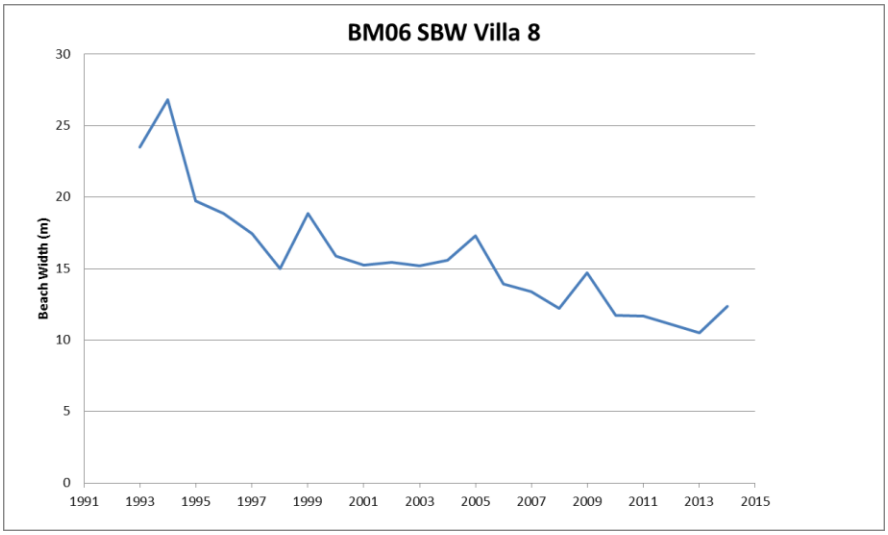

Figure 6: Mean annual beach width for the western end of Shoal Bay West

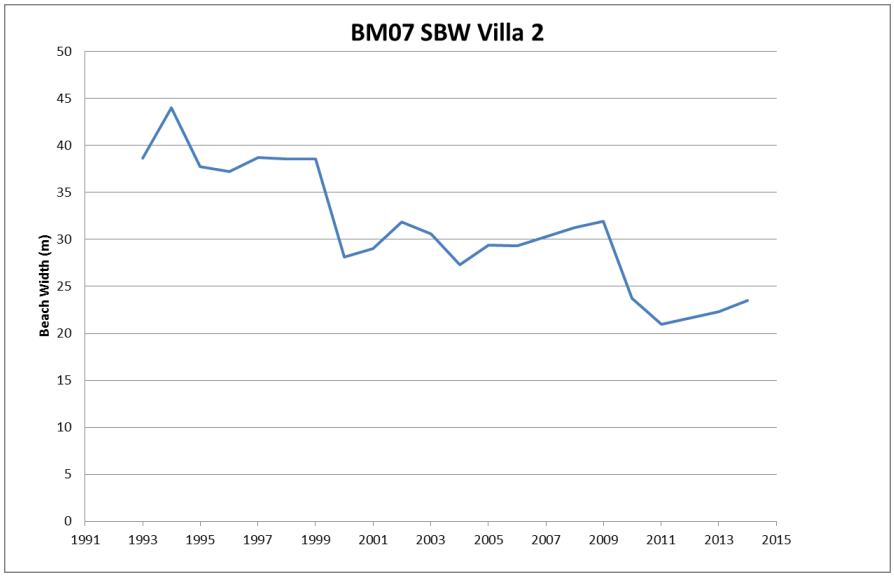

Figure 7: Mean annual beach width for the mid-western end of Shoal Bay West

Maundays Bay

This beach has undergone significant beach nourishment programs by the management of Cap Juluca Hotel, following damage by hurricanes (Plate 7). This is illustrated in Figure 8, which also depict the difference in regime that occurs on the western end of the beach compared with that on the eastern end. Reports and photographic evidence shows significant damage here following Hurricane Luis in 1995, although beach monitoring did not start here until after this event. In the western end, erosion continued after this storm, which led to the first beach nourishment. Sand was dredged from offshore and put along the shore line, combined with rebuilding and replanting the dune slope to increase the hotels aesthetic appearance. Between November 1995 and February 1996 a total of 40,000 cubic yards of sand were dredged from the bay and placed on the beach (Cambers, pers. comm.). In 1998 Hurricane Georges submerged the whole beach and a further 30,000 cubic yards of sand were dredged from the bay and placed on shore. This material was again lost when Hurricane Lenny hit in 1999, causing massive erosion leading to the undermining of the villa developments and many of their villa stair cases left as 'islands' unconnected to the buildings (Plate 6). Further beach nourishment, the construction of a major vertical sea wall in front of the villas, and replanting of vegetation restored the area by September 2000, and led to a period of relative stability until Hurricane Omar in 2008. Once again beach nourishment, this time via sand from Barbuda as well as offshore dredging, replenished the beach until Hurricane Earl in 2010 removed it again. Although these events can also be seen in the eastern profile, changes there were less severe and stability more prevalent. The evidence over the past 20 years indicates that although the beach can be restored via costly beach nourishment measures and a level of stability achieved, this is only a temporary solution until the next hurricane arrives.

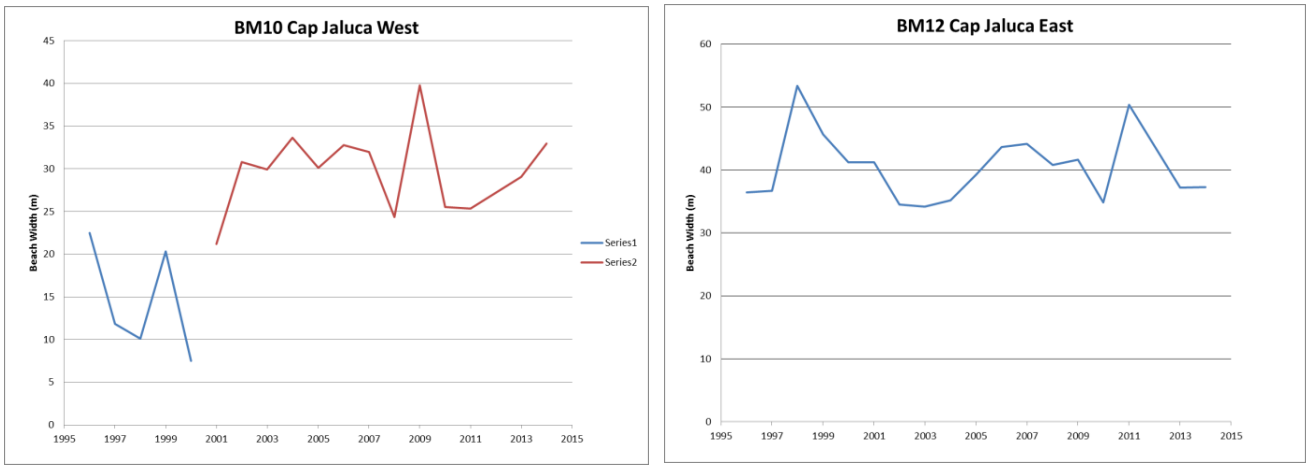

Figure 8: Mean annual beach width for the western end of Maundays Bay (BM10) and the eastern end of Maundays Bay (BM12). Over the illustrated period, despite beach nourishment, the western end has lost a total of 3.2 m in beach width (-0.2 m/yr^{-1})whereas the eastern end has gained 0.9 m (0.05 m/yr^{-1}). This, combined with the third profile location gives an overall mean beach width increase of 1.3 m, or an accretion rate of 0.27 m/yr^{-1}.

Sile Bay

On the south eastern coast of Anguilla, the loss of Sile Bay beach is the best illustration provided by this study as to the adverse effects of sand mining and the removal of dune systems. Back in the 1980's there were reportedly large sand dunes present here that were removed as aggregate for the construction industry. The subsequent beach loss that was observed is probably a contributing factor for the beginning of the beach profiling program in Anguilla, and the reason for a small retaining wall that was built in the area (Plates 9 & 10). This wall however, designed to retain the small amount of sand remaining behind and 'catch' any sand washed up over it, appeared to have the opposite effect as now no sand remains behind it. This all took place before monitoring began, and a profile location set up to include the retaining wall, as well as one a short distance along the coast. The profile at the retaining wall showed a few minimal fluctuations, likely due to inherent variations in measuring coastal features, but the one further along the beach clearly illustrates a long-term degradation (Figure 9). It shows how the removal of material from one area can affect that in other close by areas over subsequent years, a process that is due to the lack of beach material storage provided by a neighboring dune system. Without the dunes providing this back up the natural balance is lost when storm or other erosional events occur. Although not part of the beach monitoring program, as mentioned earlier a similar situation is still currently occurring at Windward Point Bay, where the removal of larger quantities of beach material from the back of the bay has resulted in a significant loss of beach width over the years.

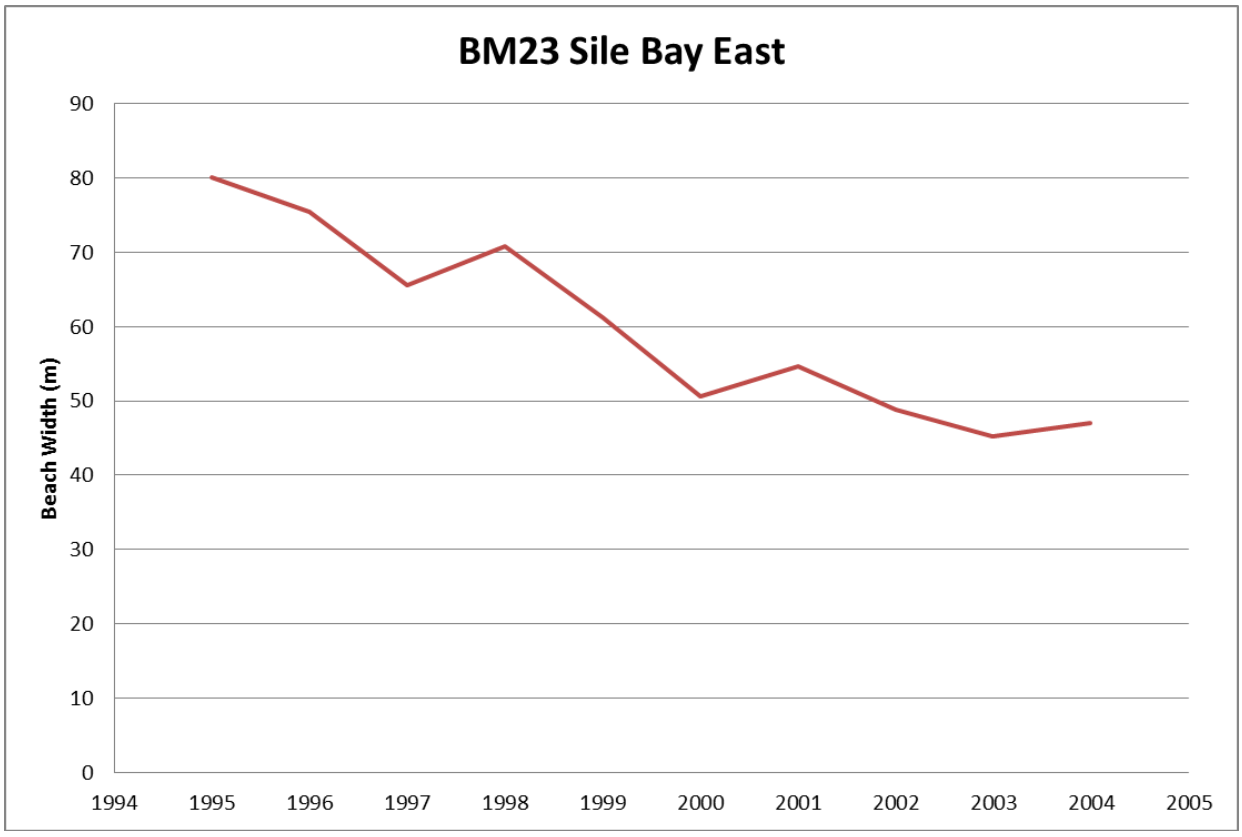

Figure 9: Mean annual beach width for the eastern end of Sile Bay. This profile location exhibits the second greatest overall loss of any within this study, undergoing a beach width reduction of 33 m during the nine year period illustrated.

Captains Bay

The monitoring site at Captains Bay was originally set up in 1992 as a control site due to the lack of coastal development behind it (some development on the low rocky cliff, but nothing that would affect sand movements). The changes in beach profile noted here appear highly seasonal and also change from year to year as if pulses of sand arrive on the beach periodically that are later washed back out into the bay, sometimes exposing underlying rocks (Plate 11). There are often very large swells and seasonally powerful ground seas that would be responsible for this. Over the 18-year study period a 2 m loss in beach width (-0.11 m/yr^{-1}) has been recorded (Table 2), although a change in reference point following Hurricane Luis in 1995 means data are most comparable between 1996 and 2013, with Figure 10 illustrating a loss of 6.4 m during this time. Surprisingly, despite being renowned for powerful seas, Captains Bay seems less affected by hurricanes than one might expect, although Hurricane Omar (2008) and Hurricane Earl (2010) had a noticeable effect, as they did elsewhere in Anguilla (Figure 4). Indeed, these two storm events are clearly visible in the profile data, and appear to be the main events responsible for the overall loss in beach width during this period.

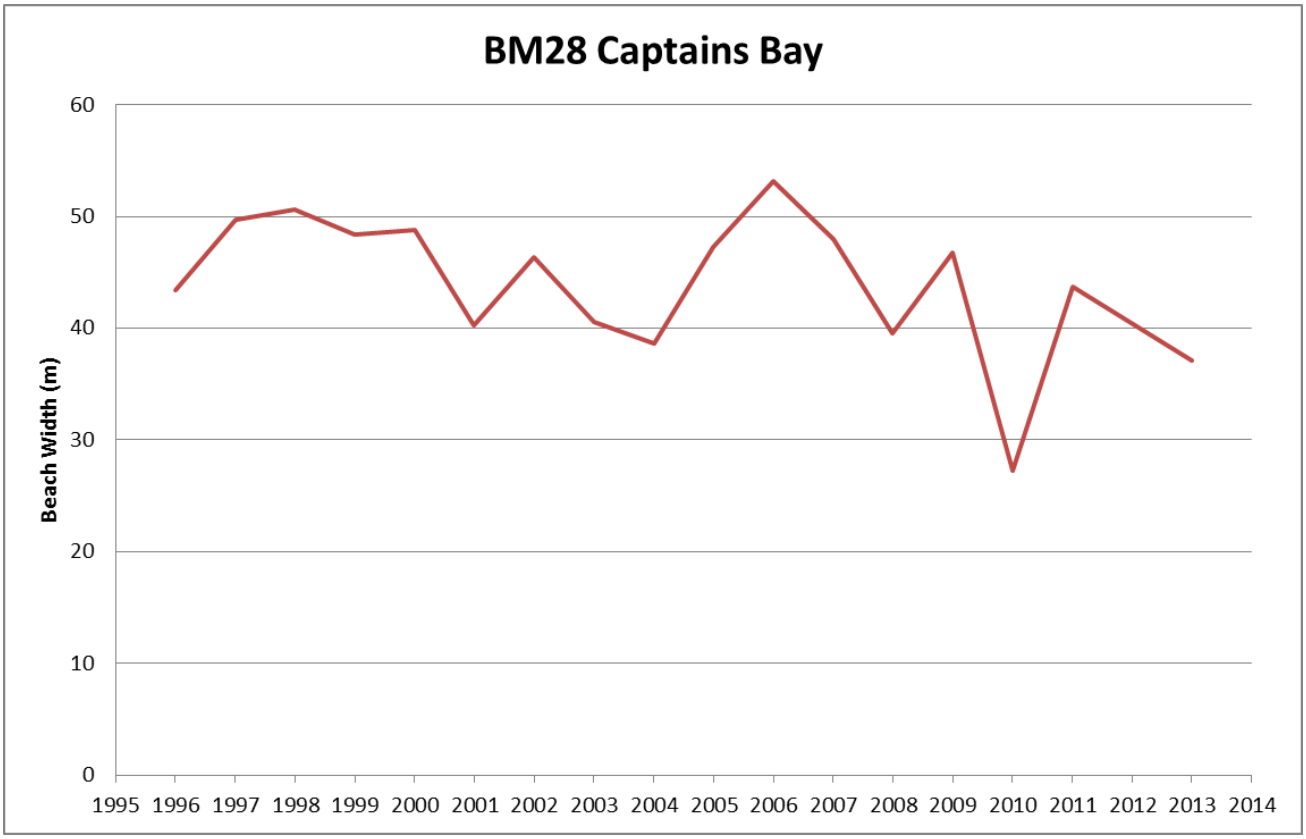

Figure 10: Mean annual beach width for Captains Bay between 1996 and 2013 with the effect of Hurricane Omar in 2008 and Hurricane Earl in 2010. Other erosion events do not appear related to hurricanes and are likely due to inter-annual seasonal ground sea variations.

Shoal Bay East

One of Anguilla's longest beaches, Shoal Bay East is where greatest erosional concern has been focused over recent years (Plates 12-16). When this monitoring program started here in 1992 the beach regime appear stable and the area was known for its expansive and white sandy beaches. In the late 1990's two extra points were established towards the end of 'Upper' Shoal Bay East, presumably due to concerns over erosion there. Indeed, right from the beginning these two sites exhibited erosion, with sporadic accretion from time to time (Figure 11). Then, following Hurricane Omar in 2008 this erosion increased and ultimately ended up with the loss of this entire end of the beach. Gwens Reggae Bar, a locally owned restaurant that operated in the area, and built set back from the beach, had to be relocated to Lower Shoal Bay East in 2014.

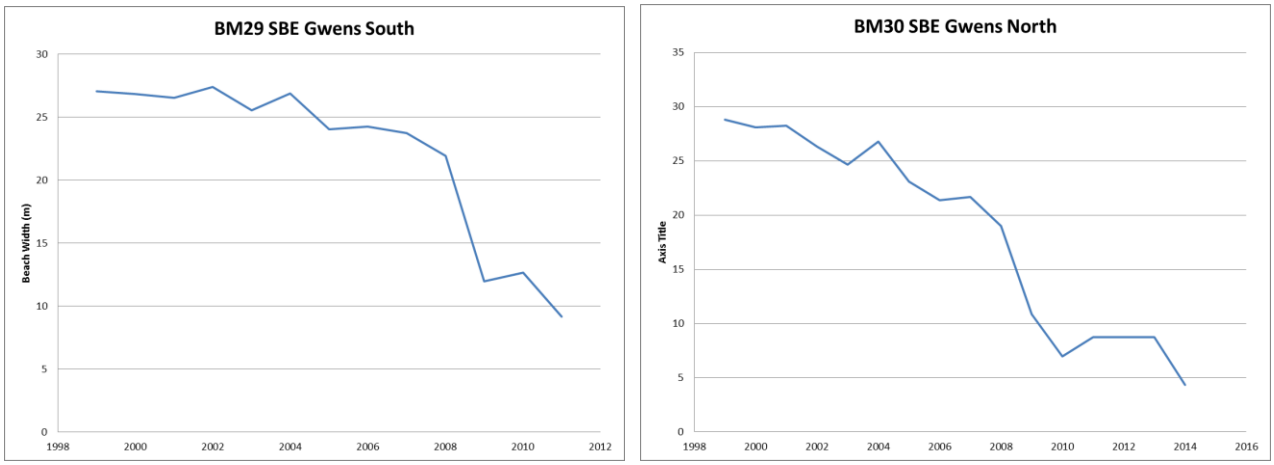

Figure 11: Mean annual beach width for the two easternmost Upper Shoal Bay East profile points between 1999 and 2011/2014 respectively. During these periods BM29 lost a total of 17.9 m in beach width (-1.49 m/yr^{-1}) and BM30 lost a total of 24.5 m in beach width (-1.75 m/yr^{-1}).

Similar patterns were being seen at other locations moving westwards along the Bay. The profile location known as 'Masons Fence' (BM31), also situated in Upper Shoal Bay East began losing material at around the same time, although again punctuated with periods of accretion (Figure 12). Once again this erosion increased noticeably around 2008. Here individual profiles (not illustrated) show the dune slope as a vertical cliff that is being steadily cut back. Past Shoal Point on the eastern end of Lower Shoal Bay East erosion initially remained more gradual until Hurricane Omar in 2008 again began a period of increased erosion at the profile location known as 'Lakes Fence' (BM32). To date, erosion has not moved noticeably beyond this end of the beach with profile points further to the western end of the beach still accreting overall or at least remaining relatively stable (Figure 13). However, this story of change is not yet over, and the sea continues to encroach inland in the eastern areas. This is especially concerning as, at the time of writing, a small salt pond within Shoal Point might soon breach, and if this occurs it may exponentially increase erosion in the area. Furthermore, although not included here as a figure, the profile immediately west of 'Lakes Fence' known as 'Elodius' (BM33) has also begun to exhibit an overall loss since 2001, again with a noticeable event in 2008 following Hurricane Omar, and as of 2014 had retreated by a total of 5 m.

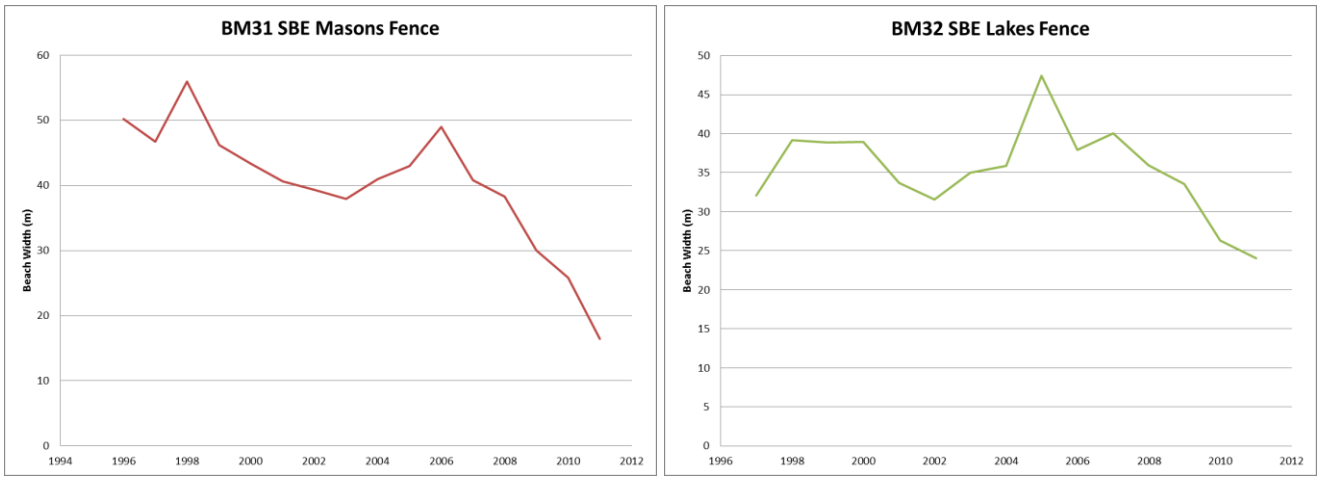

Figure 12: mean annual beach width for the two profile locations immediately westward of those depicted in the previous figure 11. The profile location at Masons Fence has exhibited the greatest total loss during the study period of 47.6 m (although the graph above only illustrates 33.8 m of this). The delay in erosional onset beyond Shoal Point is illustrated by BM32 where relative stability is apparent until Hurricane Omar in 2008.

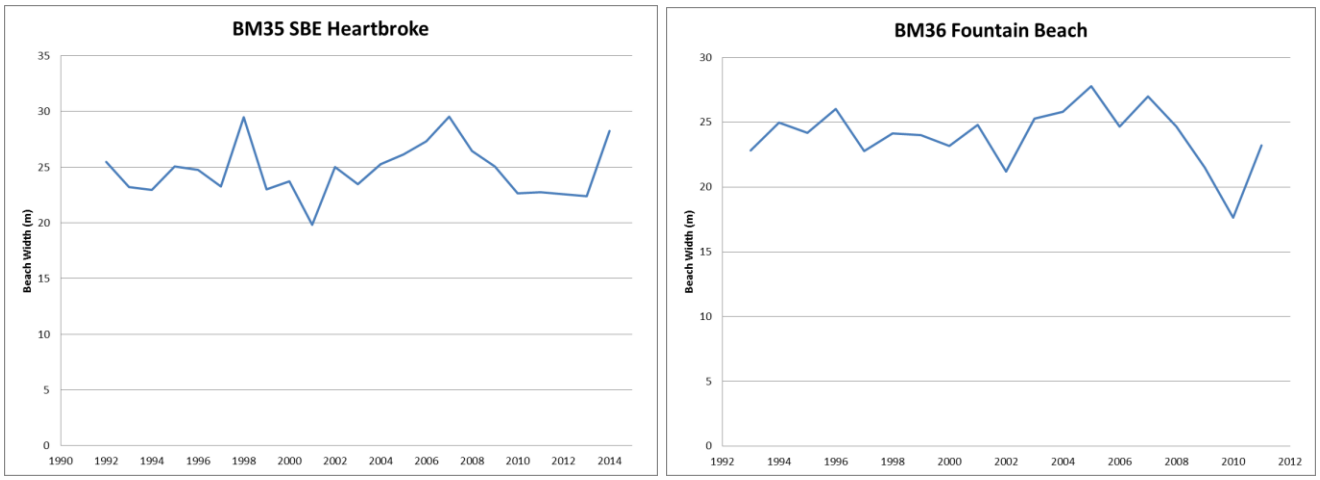

Figure 13: Mean annual beach width for the two profile locations at the western end of Lower Shoal Bay East illustrating the more stable erosional regimes still in effect there. Noticeable loss of material did take place during Hurricane Omar and Hurricane Earl, but the beaches seem to be recovering back to previous levels.

Limestone Bay

In a similar way to Captains Bay described earlier, the beach at Limestone Bay exhibits more seasonal changes not always linked to major hurricanes. Beach material can also change seasonally, with sand at certain times of year and stones at others. Having said this, there has been a gradual decline in beach width that appears punctuated by two of the major hurricane events: Lenny in 1999 and Omar in 2008 (Figure 14). A lack of recovery since these events appear to be what is behind this overall 9.3 m loss of beach width over the 18 year study period here.

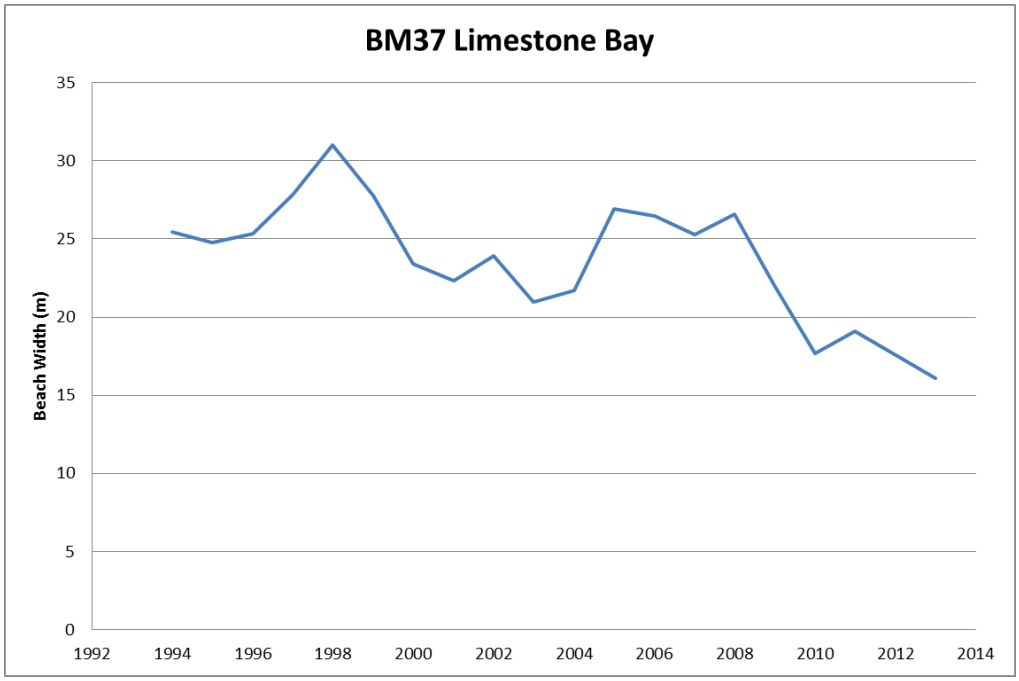

Figure 14: Mean annual beach width for the monitoring location at Limestone Bay between 1994 and 2013 illustrating an overall loss in beach width of 9.3 m.

Sandy Island

The low lying nature of Sandy Island means it is often inundated during hurricane events. In 1995 for example, during the second year of monitoring, Hurricane Luis reportedly submerged the cay and the beach disappeared. The beach quickly returned once the storm subsided, the wooden restaurant was rebuilt and vegetation replanted/regrew. Since then, the erosional regime has been quite mixed across the small cay, with the northern profile relatively stable up to 2008 whereas the eastern one has been through a period of decline (Figure 15), and the western one quite unpredictable (not illustrated). As with many locations around Anguilla, Hurricane Omar in 2008 seems to mark a turning point however with the northern profile's stability changing to a sudden decline and the eastern decline punctuated with sudden accretion. Such a change suggests the island is currently shifting in a southeasterly direction, although future monitoring will be needed to confirm whether there is an overall loss in beach sand or whether the island is indeed moving its position. Such conclusions will be of critical importance for the understanding of the cay and its future, as the current mean overall loss in beach width per profile location is 12.4 m, quite significant for an island of such a small size.

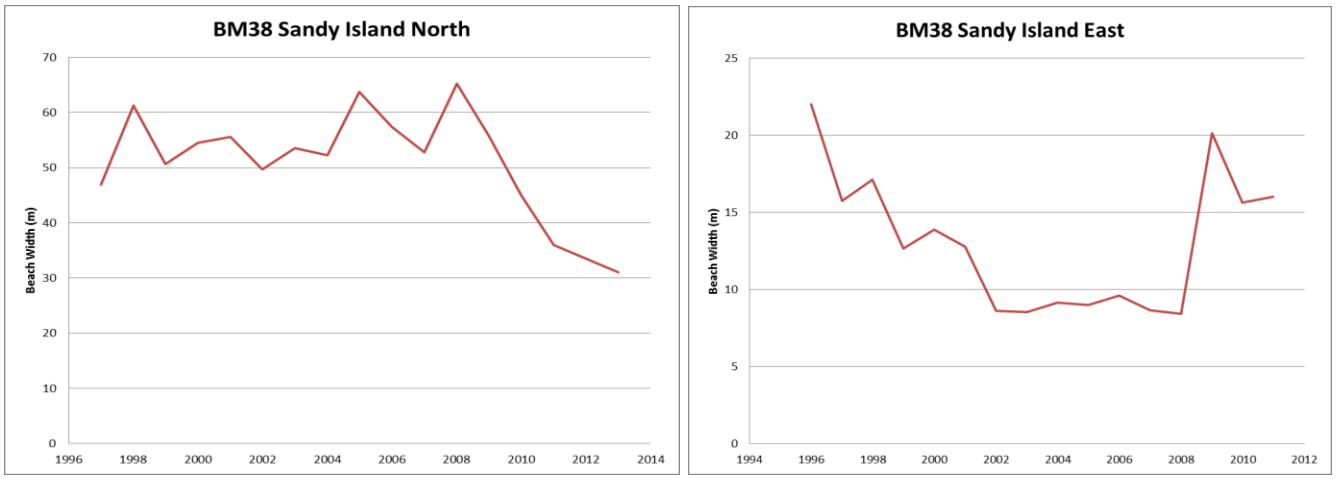

Figure 15: Mean annual beach width for two of the monitoring locations at Sandy Island illustrating potential south-easterly movement of sand following Hurricane Omar in 2008.

Prickly Pear East

Of the three monitoring locations on Prickly Pear some exhibit very large seasonal changes, with the 'central' location (BM40) recording one of the largest single erosional events during the study period, when in 2010 (following Hurricane Earl) it lost 52.3 m in beach width. Similar large seasonal changes can also be seen at the 'south' profile location (BM39), although of a lesser magnitude. (Figure 16). Despite their names, these two sites are situated on the relatively exposed northeastern side of Prickly Pear East, and so these changes are not surprising especially considering the strong ground seas that can affect the cays and access to them by boat. This can be corroborated in part by the more sheltered profile location known as 'Johnnos' (BM41) that has remained relatively stable aside from a notable though less dramatic erosion event again following Hurricane Earl in 2010 (Figure 17). Prior to this event, across the 12 year study period BM41 had a total increase in overall beach with of 6.4 m, but the two years after Hurricane Earl, there was a loss of 27m. The results at Prickly Pear East, where despite large losses BM39 is currently overall 4.8 m wider than when the study period commenced, suggest a shift in beach material as well as an overall loss, where sand is shifting towards the southeast.

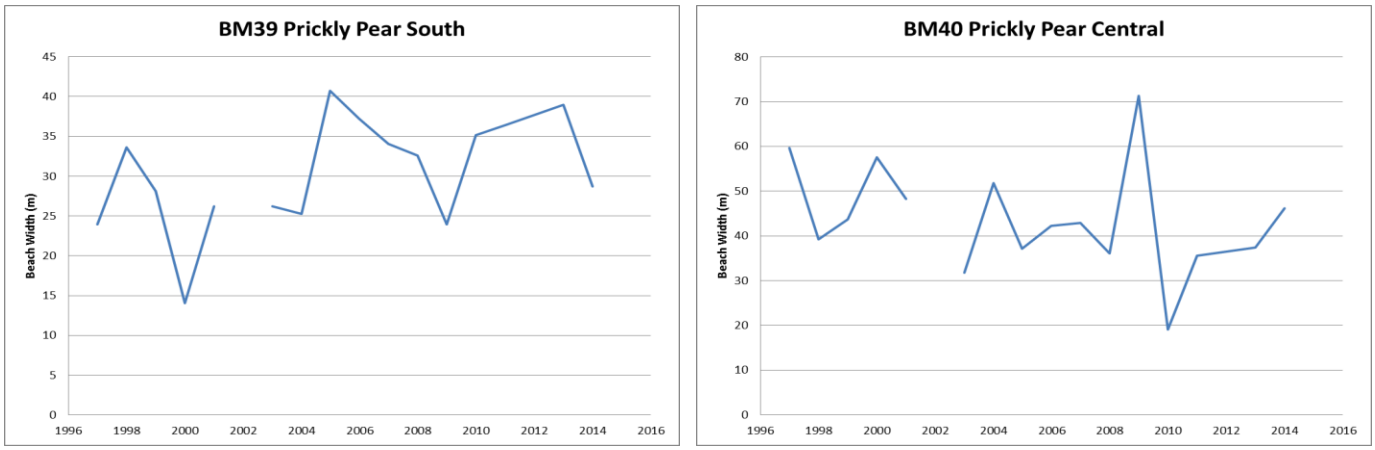

Figure 16: Mean annual beach width for the two south and eastern (central) monitoring locations on Prickly Pear East illustrating large seasonal changes not clearly linked to Hurricanes. Having said this erosion at BM39 potentially follows Hurricane Lenny in 1999 and a very large loss at BM40 follows Hurricane Earl in 2010.

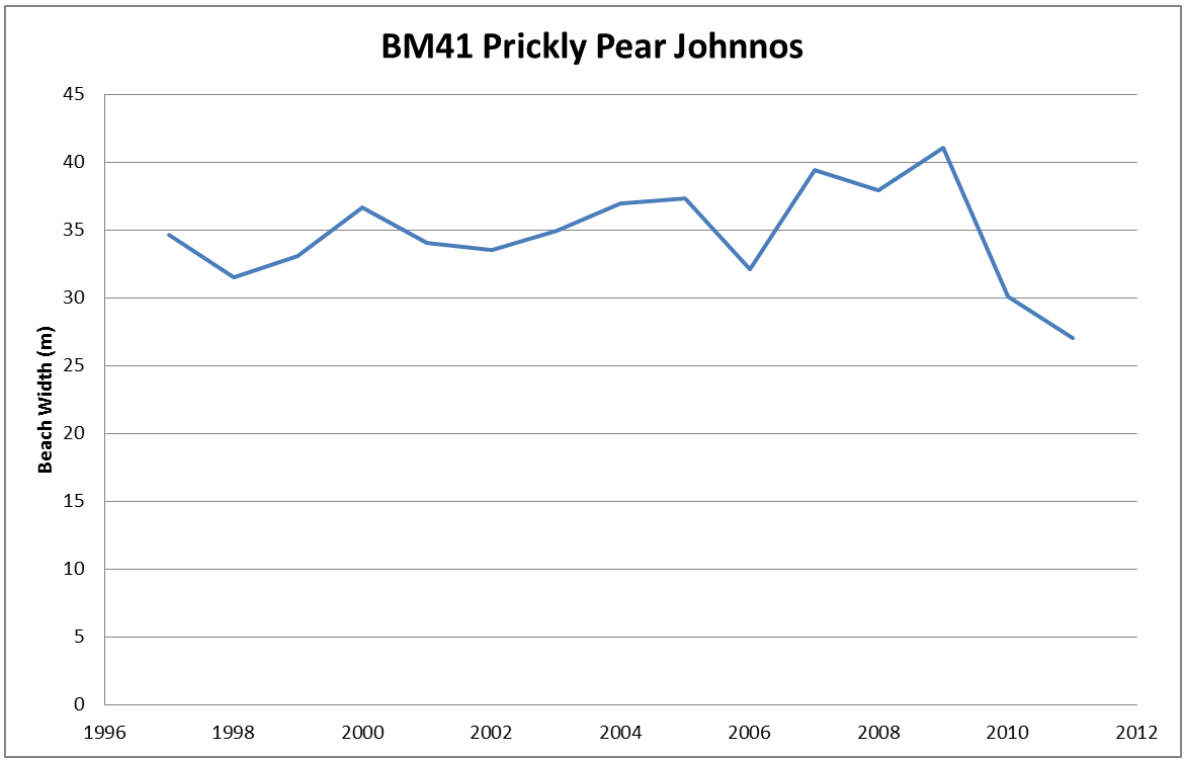

Figure 17: Mean annual beach width of the more sheltered northern monitoring location showing overall stability in beach width until Hurricane Omar in 2010. (It is however possible that subsequent ground swells will once again redeposit material here).

General Note

Although not part of the monitoring program, Windward Point Bay should be mentioned as over the years it has fallen victim to severe sand mining resulting in the loss of almost the entire beach (Plate 19). As with Sile Bay most of this mining took place in the dune areas and without their replenishment/storage function to balance erosional processes, the remaining sand gradually disappeared. Today, only a limited beach exists there and sand mining continues. Another incident of note occurred on an unmonitored beach at Forest Bay in 2008 (Plate 20). Here, a provisional development project began removing sand from shallow water areas in an attempt to create a beach and improve the area's development potential, although ecological concerns led to this work being stopped by Government. It is also worth noting that many of the beaches monitored are known for nesting turtle activity, in particularly Meads Bay, Barnes Bay, Rendezvous Bay, Limestone Bay, Shoal Bay East and the offshore cays.

Discussion

Based on the sites studied it appears that Anguilla is going through a period of an almost universal loss of beach width through erosional processes. Although there is a great deal of variety between beaches, and potential reasons behind the loss of material, what is clear is that hurricanes play the most significant natural role in this. However, there are other forces at play, many of which are anthropogenic, and these will be discussed below with reference to the case studies presented earlier.

Notwithstanding this, some brief notes on the data collected are needed. An extensive quality control check of the data was made in 2015, which resulted in removal of some profile measurements. Throughout this report reference is only made in terms of beach width, and another important result that can be yielded from such monitoring is beach area, or the volume of sand present on a beach. This information can be used to double check that a loss of width does in fact mean a loss of sand rather than a build-up of sand and increased beach gradient away from the littoral zone. Increases in such a way would have led to the historic accumulation of sand dunes at certain locations around the island. For the purpose of this report it was chosen to use beach width only as no such long terms build-ups were visually observed, and if they took place they were isolated events or seasonal in nature. It was therefore felt that including beach area as well as beach width would overly complicate analysis of such a long-term dataset and that such comparisons should only be made in future reports that may be produced which focus on individual beaches or even only individual profile locations.

Impacts of Hurricanes

The greatest natural cause of changes observed throughout the study were the impacts of hurricanes. Although general trends for each hurricane were different, the impact of each also varied from beach to beach, likely due to geographical or anthropogenic factors in the area (discussed later) and the individual hurricane's characteristics such as the direction from which if approached Anguilla. Some beaches seemed to be less affected by these storms (for example Captains Bay), with influences seemingly more seasonal and due to ground swells. Having said this, even these areas were influenced by certain storm events, with the most significant being Hurricane Earl in 2010 (Figure 4). Following this the second most damaging storm was Hurricane Lenny in 1999, and then Hurricane Omar in 2008. The damage caused by Hurricane Luis, which was a wake-up call for Anguilla in 1995 due to not having been hit by a major hurricane since Hurricane Donna in 1960, is not immediately obvious at many of the monitoring locations because it took place immediately after their establishment or resulted in the loss of the reference point.

The situation is however complex. Hurricane Lenny for example did not necessarily directly lead to a loss of beach width, but such losses were recorded a few months later, possible due to stronger than 'normal' ground sea season subsequently. This would not have been the result of the hurricane itself, but initial beach damage could have accentuated the effect of these ground swells. Furthermore, it appears many beaches were not able to recover back to pre-event levels as was discussed in the Limestone Bay case study earlier; or erosion began pre-hurricane and were then accentuated by it with no recovery yet recorded, as with Hurricane Omar at Meads Bay even following previous recovery from Hurricane Lenny. Similar complexities are seen with Hurricane Omar, except with this example it seems that erosion during the storm may have been exasperated by a particularly bad period of ground seas in March earlier that year (Plates 6 & 17). This initial removal of beach material seen at many beaches around the island may have given storm surges better access and allowed them to cause more damage that they would have done otherwise.

Similar patterns to this can be seen at other locations, where beaches were unable to recover to pre-event levels before another hurricane impacted. What is of interested is how, despite only being the third most damaging hurricane during this study, Hurricane Omar seems to have punctuated a period of increased erosion around a majority of the profile locations, with Hurricane Earl appearing as the 'nail in the coffin' two years later. As

documented by Cambers (2009), the erosional regime dominating most of the beaches around Anguilla reflects the situation found around much of the Caribbean, where across 8 eastern Caribbean countries a mean erosion rate of -0.5 m/yr^{-1} was recorded, with elevated rates in those islands impacted by a higher number of hurricanes.

The erosional regime that has been shown to be elevated by hurricanes is not predicted to reverse overtime (Cambers, 2009). In fact, based on recently published works by the Intergovernmental Panel for Climate Change (IPCC, 2013) the projection is that hurricanes will become more intense in the future, which combined with sea level rise and the predicted effects of ocean acidification on coral reefs paints a gloomy picture for low lying Caribbean islands such as Anguilla. The IPCC report describes a 0.19 m sea level rise between 1901 and 2010, with a projected increase of between 0.52 m and 0.98 m by 2100 depending on emission scenarios. With this being the case, policy makers need to take the threat of erosion very seriously and start implementing protective policy as described in the following subsection.

Sand mining at Sile Bay

The removal of beach material for the construction industry, a process known as sand mining, has been taking place on Anguilla since at least the 1980's, especially in the eastern end of the island. As mentioned in the previous case study for Sile Bay, this practice has led to an almost entire loss of beach material here (Plate 9), with a small retaining wall constructed after the event doing little to reverse the process (Plate 10). Sand mining also takes place along the coast east of Sile Bay towards Savannah Bay and up to Windward Point Bay, with both of the areas undergoing erosion (although Windward Point Bay – Plate 19 – is not part of this monitoring program so there are no quantitative data). It is likely that sand mining affects neighboring beaches through long-shore drift of sediments, but it is especially clear that sand mining is extremely damaging for the immediate area.

The danger of sand mining, or removing dunes to make way for beach front development, cannot be understated. The dunes, that have been built up though accretion processes over many decades (if not millennia), provide a sand store that can replenish beaches during times of increased erosion. When the regime changes once more the dunes rebuild. When these stores are removed the natural balance is destroyed and erosion results in the loss of the beach. Removing dunes also increases the chance of sea breaches during storm events that can flood properties or destroy sand bars that separate salt ponds from the ocean. If these salt ponds become connected to the sea not only is their sediment/nutrient trapping ability lost, but the sea can potentially encroach permanently landward. This sediment/nutrient trapping ability is of special significance to local marine habitat health as described in Wynne (2016). Dunes also provide habitat and food for marine birds and other animals.

One such example of concern at the time of writing is a proposed development at Cove Bay, where villas are planned to be constructed at the western end of the bay where currently large dunes separate the sea from Cove Pond. One of the profile locations here (BM14) has the second highest accretion rates of all the current mainland monitoring locations, although it is predicted for this to change, and all other sites at Cove Bay to increase in erosion rates if these dunes are removed. This is especially concerning based on the other bays in this area, as discussed in the following subsection. Given Anguilla's documented erosion rates over the past 20 years every effort needs to be made to conserve the remaining dunes and to design new beachfront developments is such a way as to ensure the long term viability of the sand dunes.

Note on regulations: Sand mining is essentially prohibited in terms of the removal of beach material under the Beach Protection Act, although this only goes as far as the vegetation line. Dunes behind the vegetation are mined in certain areas, although a new draft of the Physical Planning Act sets out to put regulations in place and give powers to authorities to stop the activity anywhere on the island should it be so desired. Coastal setbacks have not yet been included in this draft Act, which, based on the results of this study is seen to be essential. Within this setback zone it would be advisable to prohibit sand mining of any kind, which would then protect virtually all dune systems and the erosional 'buffer zone' that they create.

Coastal Development at Shoal Bay West

It is not clear what the makeup of this bay was like before coastal development dominated Shoal Bay West, but based on the fact that two of the four neighboring bays (Cove Bay and Rendezvous Bay) still have large dune formations it is likely such a situation was the case here also. Since monitoring started erosion has dominated the natural sand regime here, with accentuated events during hurricanes. With the fourth highest overall change per profile location at mainland sites across the study period, this bay illustrates clearly the dangers of coastal development that takes place right up to the vegetation line. Such development is not wise in any situation, as vegetation grows seaward over time, and so the vegetation line does not mark how far inland the sea comes, rather how far seaward plant life has managed to grow since the last storm surge. Combining this with the fact that a dune system may have been removed in order to undertake this development, it is no surprise what is occurring here.

Since its construction the beach has gradually eroded away (Plates 3 & 4) and with no dunes to replenish it storm surges often lead to the villa developments being almost undercut by the sea. As the swells wash up the beach and are stopped by the development it leads to greater backwash and the accentuated removal of material. It remains unclear if the eroded material remains in the bay, but prevailing currents and coastline morphology indicate it may have moved westwards and lost forever. However, some beach nourishment was undertaken here (Plate 5) and so the bay may have retained more material than it would have otherwise.

A similar situation involving potential dune removal, coastal development and changes to the natural regime has likely occurred in neighboring Maundays Bay. However, as discussed in the following subsection rigorous and regular beach nourishment has kept the beach in place.

Beach nourishment: Maundays Bay vs Barnes Bay

As with Shoal Bay West, it is thought, based on the morphology of neighboring bays that Maundays Bay once had extensive dunes that were removed to allow construction of a beach front resort development. Again, as with Shoal Bay West erosion has been prevalent over the study period (especially towards the west end of the bay), with accentuated periods during hurricanes that lead to the complete loss of the beach and, significant damage to the resort development (Plate 6). However, unlike Shoal Bay West, the resort owners were financially able to undertake rigorous and regular beach nourishment programs that dredged the displaced sand from the bay and placed it back on the beach (Plate 7). A vertical seawall was also constructed, and at one point sand brought in from Barbuda to help rebuild the beach.

Short term, these beach nourishment exercises appear to have been successful with periods of stability in between hurricane events. However, the stability does not last, and the next storm brings with it the need for further costly beach restoration efforts. This situation once again provides an example of why beach front developments on sand dunes and low sand terraces are not a good idea, especially if dune systems are removed during development, as described in the subsection above. Despite this, it does also illustrate how beach nourishment can restore the beach to its pre-storm condition. However, care should be taken in reviewing the long term impacts of this restoration since the offshore zone may become progressively deeper – allowing larger waves to reach the beach and subsequent erosion. Thus it does not mean that beach nourishment is a fix for all erosional processes: if erosion is taking place at a background level and nourishment attempted, the end result will simply be a continued background erosion rate.

Although not part of the current data, the result of this type of nourishment effort will be illustrated by activities that took place recently at Barnes Bay. Here a series of small offshore breakwaters were constructed for the new Viceroy (now Four Seasons) development, with sand dredged from offshore via an industrial suction dredger set up and pumped onto the beach behind them. Almost immediately this sand began to disappear, and after a year or so the dredging was abandoned. It remains to be seen as to the long term ’benefits’ of this multimillion dollar work, but

currently the rock breakwaters appear to be shifting and dredged sand not remaining or new sand building up. Two new profile locations were set up here in 2013 to monitor this, but it is as yet too early to draw conclusions. Initial results show a combined total reduction in beach width for the two locations of -3.8 m.

Erosion at Shoal Bay East and notes on shifting sand

It is not always obvious what is behind changes in erosional regime, and it is not always for direct anthropogenic reasons. Shoal Bay East is an example of this where it remains unclear the precise reasons for a prolonged period of increased erosion at its eastern end that increased following Hurricane Omar in 2008 (Plates 12-16). The current working theory is that it points to a possible degradation of surrounding reef areas and their ability to protect against ground swells. Indeed, the erosion here had already begun when monitoring in this area started in the mid-late 1990's, and reef monitoring conducted by DFMR beginning in 2006 suggested habitat degradation here was a cause for concern (Wynne, 2016). It is probable that the initial gradual erosion was due to this, and then the damage caused by Omar pushed the area into an increased erosional regime. At the time of writing this erosion continues with no signs of abating, but based on lessons learnt at other locations in Anguilla in is not recommended for beach nourishment to be implemented here. This would likely fail due to the fact that erosion has been occurring here gradually for a number of years, and is not due to a sudden loss caused solely by one storm event. Factors such as ongoing sea level rise may also be a factor. In terms of management strict protection of the reefs in the area is recommended. Over the last few years discussions have been had regarding artificial reef structures placed in the near-shore areas in an attempt to slow erosion, and while this *may* offer a solution[5] an air of caution cannot be emphasized enough as such an endeavor may exasperate the problem. Ocean dynamics are extremely complex and extensive investigations are required in such complex locations.

This complexity may also be confounded further as erosion in one part of a beach does not necessarily mean the beach is eroding as fast as the data suggest. Instead, sand may be building up in another (unmonitored) location along the beach and may signify shifting sand rather than erosion. This process is driven by long-shore drift and is responsible for sand bars, spits, tombolos and even the cuspate foreland that may lie underneath Shoal Point. It is interesting to note that a cuspate foreland, with similarities to Shoal Bay East, existed at Crane Beach on the southeast coast of Barbados up to the 1970s. Following Hurricane Donna in 1960, it was eroded over the years and has now disappeared such that there is now a small sand beach in front of the cliffs.

To a limited extent, such shifting sands are taking place at Shoal Bay East where accretion is occurring on the western end, while the beach erodes away at the eastern end. Erosion far outweighs accretion in this example, although in other monitoring locations shifting sands can be deduced from the data (for example Sandy Island and Prickly Pear East) and patterns of erosion somewhat match accretion in other areas. Having said this, both cays are still eroding more than they are accreting, so the situation is not that simple and remains a cause for some concern.

While the example at Shoal Bay East illustrates how erosional processes can vary naturally and are not necessarily caused by direct human influences such as irresponsible coastal development, it does provide an important example of how beach vegetation slows this process down. Along the coast of Upper Shoal Bay East dense sea grapes and other vegetation were present, and their root systems slowed erosion noticeably, although the rigor of the regime is still leading to a loss of land to the sea. The importance of beach vegetation cannot be overstated, as if a 'one off' erosion event takes place the vegetation will reduce the impact, and following the event the root structures will help promote natural accretion.

[5] Such a proposal would be a highly complex undertaking with a limited likelihood of success. Artificial reefs best function as fish aggregation areas with their role in reducing erosion limited and the subject of debate.

The case for coastal setbacks

As mentioned earlier Hurricane Luis in 1995 was a wake-up call for Anguilla, causing a great deal of coastal damage not seen since the last major Hurricane event 35 years previously. This lead to some major recommendations being made in terms of coastal development setbacks (Bythell *et al*., 1996) that were later adopted as 'guidelines' by the Department of Physical Planning when considering planning applications. With the coastal regime in Anguilla being one dominated by erosion, and with a rate higher than the average reported across the region, the need for these setbacks to become official policy cannot be understated. Despite the Government resolving to put in place measures to protect their coastline (Cambers, 2009), an official policy has not yet been adopted. The guidelines set were based on calculations that took into account historical changes, projected hurricane damage, projected coastline retreat, and ecological, planning and social considerations; ultimately grouping beaches into setback zones of 18 m, 30 m, 45 m, and 92 m. However, over the years the Department has found it necessary to customize on a site by site basis, which has resulted in developments still being permitted closer to the vegetation line than the guidelines suggest. Cambers (2009) goes on to describe how in 2007 work started on drafting a policy for the protection of coastal lands, but to date nothing has yet been finalized. In fact, a new draft of the Physical Planning Act recently circulated for review still made no mention of coastal setbacks. It is hoped that the current work will act as a catalyst and justify the need for setbacks and the development of multi-agency driven coastal zone management plan as recommended by Wynne (2016).

Conclusions and Recommendations

- Anguilla's beaches are eroding with the most significant periods of sand loss during or directly following four major hurricane events.
- Full recovery after hurricane events does not usually take place and any recovery is less apparent in areas of beach front developments or where developments and/or sand mining has removed dune systems.
- Beach nourishment is a costly undertaking and has had some success in Anguilla after storm events but it is not seen as a "permanent' solution to an ongoing natural erosional regime in an area.
- Increased erosion at Shoal Bay East is thought to be due to overall regime change in the area and probably at least in part driven by degradation of nearby reef systems. The presence of coastal vegetation has helped mitigate the overall rate of loss.
- To mitigate against erosion as much as possible coastal setbacks should be mandatory and follow those laid out in 1996 after Hurricane Luis. The removal of dune systems should be prohibited, along with sand mining within the prescribed setback zone.
- To monitor these changes the current beach monitoring program should continue unchanged, with the exception of reviewing the locations of Sile Bay profile sites. Regular reports, at a minimum of every five years, should be produced, and individual beach case studies published as necessary.

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Note: A supplementary document has been produced that contains beach profile graphs using the raw data for all reference points (split by changes) across the study period. These graphs include combined side-on beach cross-sections for each individual monitoring round along with graphic representation of beach width and beach area for each. Copies can be obtained by contacting fisheriesmr@gov.ai

Appendix I – Photograph Plates 1 to 20 Referred to in Main Text

Plates 1 (left) Looking westward across Barnes Bay during heavy storm swells following a major hurricane event in the 1990's (thought to be Hurricane Luis in 1995 but image is undated). Photograph courtesy of DFMR archives.

Plate 2 (right) Looking eastward across Barnes Bay in 2015 following significant beach nourishing and construction of small breakwaters. It should be noted that before this work the beach had recovered from the erosion events in the 1990's, but the new Viceroy development (renamed Four Seasons at the time of writing) desired a wider beach. Photograph courtesy of Dr. G. Cambers.

Plate 3 (left) Looking east across Shoal Bay West following Hurricane Luis in 1995. Photograph courtesy of Dr. G. Cambers.

Plate 4 (right) Looking west across Shoal Bay West following an erosion event in 1997. Photograph courtesy of Dr. G. Cambers.

Plate 5 Looking east across Shoal Bay West in January 2000 following Hurricane Lenny in November 1999. The extent of beach nourishment that took place is not known and may have only been minimal. Photograph courtesy of Dr. G. Cambers.

Plate 6 (left) Severe beach erosion at Maundays Bay following Hurricane Lenny in 1999. Much of the beach was washed away and villas undermined, leaving their access stairs as floating 'islands' in the wash zone. Photograph courtesy of Dr. G. Cambers.

Plate 7 (right) Beach nourishment taking place at Maundays Bay following one of the 1990's hurricane events. Photograph courtesy of DFMR archives.

Plate 8 Dolphinarium under construction at Sandy Point in June 2008. The sand spit just beyond the construction is much reduced from that seen on older maps. Since the photograph was taken the spit has begun to extend seawards again. Photograph courtesy of S. Wynne.

Plate 9 (left) Remains of beach at Sile Bay in 2015 following sand mining here back in the 1980's. Photograph courtesy of Dr. G. Cambers.

Plate 10 (right) Small retaining wall (also in top of plate 9) built in the 1990's in an attempt to halt beach erosion and retain remaining sand. Photograph courtesy of Dr. G. Cambers.

Plate 11 Captains Bay following some particularly strong ground seas in March 2008. Interestingly this event occurred prior to Hurricane Omar later that year, and may have been the reason such severe erosion occurred during the storm and also why it continued on into subsequent years. Photograph courtesy of DFMR archives.

Plate 12 Looking south down Upper Shoal Bay East at BM31 (Masons Fence) in December 2009 a year or so following the beginning of severe erosion in the area (refer to plate 16 for historical record). Photograph courtesy of S. Wynne.

Plate 13 (left) Status of erosion between BM30 and BM31 on 15th December 2009 at Upper Shoal Bay East following the onset of severe erosion seemingly punctuated by Hurricane Omar in 2008. Photograph courtesy of S. Wynne.

Plate 14 (right) Status of erosion between BM30 and BM31 on 15th February 2010 at Upper Shoal Bay East. The amount of beach material lost here during the two month period since Plate 13 was extremely concerning. Photograph courtesy of S. Wynne.

Plate 15 (left) Beach erosion at Gwens Reggae Bar, Upper Shoal Bay East, leading to the loss of numerous old coconut palms in February 2010. Photograph courtesy of S. Wynne.

Plate 16 (right) Taking a step back in time to the early 1990's when concerns were first raised about erosion at Upper Shoal Bay East, inspiring the construction of a pallet 'sand trap' fence. This fence was subsequently destroyed by weather conditions, but the image is a good historical reference for Plate 12 (Masons Fence). Although both images are looking in different directions they depict the same stretch of coast, also partially including that in Plates 13 & 14. Photograph would have been taken from the rough location pictured in Plate 15, and is courtesy of DFMR archives.

Plate 17 (left) Removal of stones at Crocus Bay uncovered by strong ground swells in early 2008. This material would have formed an important foundation for the beach here and a great defence against such sea conditions. Material was sold as aggregate. Photograph courtesy of DFMR archives.

Plate 18 (right) Tall wave cut sand cliff at Dog Island in October 2009. Such features are often present here during periods of strong ground swells. Photograph courtesy of S. Wynne.

Plate 19 (left) Loss of beach at Windward Point Bay following a number of years of sand mining in the area. Photograph courtesy of DFMR archives.

Plate 20 (right) Digging sand from within Forest Bay in April 2008 as an attempt to create a beach to convince investors for the potential of a new coastal resort development. Photograph courtesy of DFMR archives.

Appendix II – Details of Active Profile Locations

Beach	Site	GPS Code	Coordinates	Notes
Meads Bay	Malliouhana	BM01 MEADS	N18 11.170 W063 08.090	Site established on 23rd September 1992. Has had three changes. Site still ongoing. Profile lines up to the western end of Dog Island.
	Turtles Nest	BM02 MEADS	N18 10.875 W063 08.352	Site established on 23rd September 1992. Has had no changes. Site still ongoing. Profile lines up to the eastern end of Prickly Pear.
	La Sirena	BM03 MEADS	N18 10.750 W063 08.576	Site established on 23rd September 1992. Has had five changes. Site still ongoing. Profile lines up to the western end of Prickly Pear.
Barnes Bay	Mangoes	BM04 BARN	N18 10.509 W063 08.994	Site established on 21 September 1994. Has had three changes. Site still ongoing. Profile lines up to the western end of Prickly Pear.
	West of Mangos	BM05 BARN	N 18 10.467 W 06303.024	Site established on 6th April 2011. Has had no changes. Site still ongoing. Profile lines up to the western end of Prickly Pear.
Shoal Bay West	Villa 8	BM06 SBW	N18 09.807 W063 09.636	Site established on 23rd September 1992. Has had no changes. Site still ongoing. Profile lines up with the valley between the two largest hills on St. Martin.
	Villa 2	BM07 SBW	N18 09.902 W063 09.489	Site established on 23rd September 1992. Has had no changes. Site still ongoing. Profile lines up to the single antenna on hill on St. Martin.
	Trattaria	BM08 SBW	N18 09.875 W063 09.324	Site established on 23rd September 1992. Has had two changes. Site still ongoing. Profile lines up to center of small rocky outcrop.
	Altamar	BM09 SBW	N18 09.802 W063 09.240	Site established on 23rd September 1992. Has had four changes. Site still ongoing. Profile lines up to center of small rocky outcrop.
Maundays Bay	Villa 19	BM10 MAUN	N18 09.808 W063 08.889	Site established on 2nd May 1996. Has had one change. Site still ongoing. Profile lines up with the valley between the two largest hills on St. Martin
	Georgeis	BM11 MAUN	N18 09.918 W063 08.708	Site established on 2nd May 1996. Has had two changes. Site still ongoing. Profile lines up to the single antenna on hill on St. Martin.
	Water Sport	BM12 MAUN	N 18 09.892 W063 08.538	Site established on 2nd May 1996. Has had no changes. Site still ongoing. Profile lines up to small rocky outcrop.
Cove Bay	Cap Juluca Parking Lot	BM13 COVE	N18 09.930 W063 08.415	Site established on 6th April 2011. Has had no changes. Site still ongoing. Profile lines up to single antenna on hill on St. Martin.
	West of Smokey's	BM14 COVE	N18 10.241 W063 08.014	Site established on 21st September 1992. Has had two changes. Site still ongoing. Profile lines up to single antenna on hill on St. Martin.
	Smokey's	BM15 COVE	N18 10.264 W063 07.831	Site established on 21st September 1992. Has had three changes. Site still ongoing. Profile lines up with the valley between the two largest hills on St. Martin.
Rendezvous Bay	Bankie Banx	BM16 RND	N18 10.547 W063 07.090	Site established on 6th April 2011. Has had no changes. Site still ongoing. Profile lines up to the tip of Cul de Sac.
	Cuisin Art	BM17 RND	N18 10.634 W063 06.919	Site established on 8th June 1994. Has had three changes. Site still ongoing. Profile lines up to single antenna on hill on St. Martin.
	Great House	BM18 RND	N18 10.662 W063 06.742	Site established on 22nd February 1994. Has had two changes. Site still ongoing. Profile lines up to single antenna on hill on St. Martin.
	East of Great House	BM19 RND	N18 10.648 W063 06.604	Site established on 8th June 1994. Has had two changes. Site still ongoing. Profile lines up to tip of the second to last hill on St Martin.
	Far East of Great House	BM20 RND	N18 10.619 W063 06.499	Site established on 6th April 2011. Has had no changes. Site still ongoing. Profile lines up to tip of the second to last hill on St Martin.

Sandy Hill Bay	Sandy Hill Bay (South)	BM21 SHB	N18 13.274 W063 00.534	Site established on 24th September 1992. Has had four changes. Site still ongoing. Profile lines up to tip of the white concrete roof.
	Sandy Hill Bay (North)	BM22 SHB	N18 13.356 W063 00.537	Site established on 24th September 1992. Has had two changes. Site still ongoing. Profile lines up to the track down to the bay next to the yellow house.
Sile Bay	Sile Bay (East)	BM23 SILE	N18 14.349 W062 59.041	Site established on 24th September 1992. Has had one change. Site still ongoing. Profile lines up to the western end of mountain on Saba.
	Sile Bay (West)	BM24 SILE	N18 14.307 W062 59.116	Site established on 24th September 1992. Has had two changes. Site still ongoing. Profile points straight out to sea.
Savannah Bay	Savannah Bay (South)	BM25 SAV	N18 14.800 W062 59.227	Site established on 21st September 1994. Has had three changes. Site still ongoing. Profile lines up to the tip of bay.
	Savannah Bay (Central)	BM26 SAV	N18 14.948 W062 59.242	Site established on 21st September 1994. Has had four changes. Site still ongoing. Profile points straight out to sea.
	Savannah Bay (Junks Hole)	BM27 SAV	N18 15.078 W062 59.134	Site established on 21st September 1994. Has had two changes. Site still ongoing. Profile lines up to the tip of bay.
Captains Bay	Captains Bay	BM28 CAP	N18 15.823 W063 58.779	Site established on 22nd September 1992. Has had one change. Site still ongoing. Profile points straight out to sea.
Shoal Bay East	Shoal Bay East (South Gwens Reggae Grill)	BM29 SBE	N18 15.313 W063 01.490	Site established on 13rd May 1999. Has had one change. Site still ongoing. Profile lines up to the northern tip of Little Scrub.
	Shoal Bay East (Old Gwens Reggae Grill)	BM30 SBE	N18 15.324 W063 01.498	Site established on 13rd May 1999. Has had no changes. Site still ongoing. Profile lines up to the northern tip of Little Scrub.
	Shoal Bay East (Mason Fence)	BM31 SBE	N18 15.350 W063 01.553	Site established on 22nd September 1992. Has had two changes. Site still ongoing. Profile lines up to the northern tip of Little Scrub.
	Shoal Bay East (Lake Fence)	BM32 SBE	N18 15.435 W063 01.665	Site established on 22nd September 1992. Has had three changes. Site still ongoing. Profile lines up to straight out to sea.
	Shoal Bay East (Elodias)	BM33 SBE	N18 15.370 W063 01.753	Site established on 22nd September 1992. Has had two changes. Site still ongoing. Profile lines up to straight out to sea.
	Shoal Bay East (Madeariman)	BM34 SBE	N18 15.268 W063 01.878	Site established on 22nd September 1992 . Changes are unclear from datasheets and so has been excluded from analysis. Profile points straight out to sea.
	Shoal Bay East (Heartbroke)	BM35 SBE	N18 15.200 W063 02.020	Site established on 22nd September 1992. Has had one change. Site still ongoing. Profile lines up straight out to sea.
	Shoal Bay East (Zemi Beach)	BM36 SBE	N18 15.153 W063 02.181	Site established on 22nd September 1992. Has had one change. Site still ongoing. Profile lines up straight out to sea.
Limestone Bay	Limestone Bay	BM37 LIME	N18 14.037 W063 04.193	Site established on 27th September 1994 7. Has had no changes. Site still ongoing. Profile lines up straight out to sea.
Sandy Island	East Point	BM38 SANDY	N18 12.762 W063 07.093	Site established on 26th September 1994. Has had three changes. Site still ongoing. Profile lines up to the edge of Anguilla.
	North Point	BM38 SANDY	N18 12.762 W063 07.093	Site established on 26th September 1994. Has had two changes. Site still ongoing. Profile lines up to Seal Island
	West Point	BM38 SANDY	N18 12.762 W063 07.093	Site established on 26th September 1994. Has had three changes. Site still ongoing. Profile lines up to the tip of West End
Prickly Pear	South Point	BM39 PEAR	N18 15.867 W063 10.157	Site established on 20th September 1994. Has had one change. Site still ongoing. Profile lines up to the tip of Anguilla.
	Central Point	BM40 PEAR	N18 15.932 W063 10.215	Site established on 20th September 1994. Has had one change. Site still ongoing. Profile points straight out to sea.

	Johnno's	BM41 PEAR	N18 15.906 W063 10.293	Site established on 20th September 1994. Has had two changes. Site still ongoing. Profile lines up to the rocky outcrop closest to shore.
Dog Island	North Point	BM42 DOG	N18 16.412 W063 15.179	Site established on 17th January 2008. Has had one change. Site still ongoing. Profile lines up to the rocky outcrop in the bay.
	Central Point	BM43 DOG	N18 16.412 W063 15.178	Site established on 24th August 2011. Has had no changes. Site still on going. Profile lines up to the rocky outcrop in the bay.
	South Point	BM44 DOG	N18 16.346 W063 15.096	Site established on 10th July 2010. Has had no changes. Site still on going. Profile lines up to the rocky outcrop in the bay.
Scrub Island	North Point	BM45 SCRUB	N18 16.995 W062 57.346	Site established on 2nd May 2008. Has had no changes. Site still ongoing. Profile lines up to the tip of Shoal Bay Point.
	Central Point	BM46 SCRUB	N18 16.908 W062 57.342	Site established on 2nd May 2008. Has had no changes. Site still ongoing. Profile lines up to the tip of Shoal Bay Point.
	South Point	BM47 SCRUB	N18 16.807 W062 57.337	Site established on 2nd May 2008. Has had no changes. Site still ongoing. Profile lines up to the tip of Windward Point.
Meads Bay	Bamboo Restaurant	BM48 MEADS	N18 10.748 W063 08.613	Site established on 26th March 2013. Has had no changes. Site still ongoing. Profile lines up to eastern end of Prickly Pear.
ViceRoy	Alethea Restaurant	BM49 VRR	N18 10.750 W063 08.759	Site established on 26th March 2013. Has had no changes. Site still ongoing. Profile lines up straight out to sea.
Barnes Bay	Half Shell Restaurant	BM50 BARN	N18 10.621 W063 08.852	Site established on 26th March 2013. Has had no changes. Site still ongoing. Profile lines up to the western end of Dog Island.
	Villa 6	BM51 BARN	N18 10.587 W063 08.881	Site established on 26th March 2013. Has had no changes. Site still ongoing. Profile lines up with the western end of Dog Island.
Rendezvous Bay	The Reef West Point	BM52 RND	N18 10.219 W063 07.545	Site first establish on 1st July 2013. Has had no changes. Site still on going. Profile lines up to the valley between the two overlapping mountains on St Martin.
	The Reef East Point	BM53 RND	N18 10.267 W063 07.482	Site established on 1st July 2013. Has had no changes. Site still on going. Profile lines up to the edge of St Martin.
Sandy Point	Green Fence Pole	BM54 SANDP	N18 10.186 W063 05.793	Site established 1st July 2013 Has had no changes. Site still ongoing. Profile lines up to the beacon pole.
	Ferry Boat Inn Restaurant	BM55 SANDP	N18 10.255 W063 07.678	Site establish 1st July 2013. Has had no changes. Site still ongoing. Profile lines up to the beacon pole.
Crocus Bay	Main Restaurant	BM56 CRO	N18 13.229 W063 04.009	Site established on 13rd January 2014. Has had no changes. Site still ongoing. Profile lines up to the southern end of Dog Island.
	South of Beach Bar	BM57 CRO	N18 13.176 W063 04.029	Site established on 13rd January 2014. Has had no changes. Site still ongoing. Profile lines up to the southern end of Dog Island.
	Seine House	BM58 CRO	N18 13.154 W063 04.043	Site established on 13rd January 2014. Has had no changes. Site still ongoing. Profile lines up to the northern end of Prickly Pear.
Shola Bay East	New Gwens Reggae Grill	BM59 SBE	To be Obtain	Site established on 6th January 2015. Has had no changes. Site still ongoing. Profile points straight out to sea.
Barnes Bay	Cerulean Villa	BM60 BARN	To be Obtain	Site established on 7th January 2015. Has had no changes. Site still ongoing. Profile lines up to eastern end of dog island.