Robinson, E. et al. P.S. 2012. Shoreline changes and sea-level rise at Long Bay, Negril, western Jamaica. *Caribbean Journal of Earth Science*, Volume **43**, 35-49. Available online: 2nd July 2012. © Geological Society of Jamaica.

Shoreline changes and sea-level rise at Long Bay, Negril, western Jamaica

EDWARD ROBINSON, SHAKIRA KHAN, RICHARD COUTOU AND MONIQUE JOHNSON

Marine Geology Unit, Dept. of Geography and Geology, University of the West Indies, Mona, Kingston 7, Jamaica. http://www.mona.uwi.edu/geoggeol/MGU/

ABSTRACT. The 300 to 700 m wide beach barrier system at Negril is backed by a wide expanse of wetland (the Great Morass) underlain by peat deposits exceeding 12 m deep in places, effectively limiting present and future development to the barrier itself. 200 locations along the barrier were leveled to establish that its highest parts are between 1.5 and 2 metres above sea-level. Aerial photographs and satellite imagery covering the period from 1971 to 2008 were used to determine historical shoreline changes at 66 shore-normal beach transects, spaced at 100 m intervals. For this period the average annual shoreline retreat for the whole of Long Bay as measured by us was about 23 cm/yr. This contrasts with average values some four times higher quoted by other sources. From 1971 to 1991 retreat averaged 0.07 m/yr for the whole bay. From 1991 to 2008, a time of accelerating hotel development, average retreat rose to 0.4 m/yr. At two "hot spots" near the centre of the bay historical rates between 1991 and 2008 reached as much as 1-2 m/yr. A "coolspot" between the hotspots showed shoreline accretion between 1971 and 2003, followed by recession. The accretionary tendency is attributed to the breakwater effect of the sheltering shallow reef opposite this point. The degree of beach nourishment for the bay is unknown and has been ignored.

For projections of possible shoreline changes into the future two approaches were examined. The first ignored possible effects of accelerated sea-level rise (SLR) and used a simple extrapolation of historical rates of loss into the future. This yielded a cumulative average shoreline retreat for the whole bay (base date 2008) 1.5 to 3 m by 2015, 5 to 9 m by 2030, 10 to 17 m by 2050, and as much as 25 m by 2050 for the "hot spots". The second included SLR effects, based on published projections by the IPCC and others, and employed a direct empirical correlation of loss rates with the historical and projected rates of SLR. This increased projected retreat to as much as 12 to 21 m by 2050 and up to 30 to 55 m for the "hot spots. For comparison the Bruun Rule was used to estimate future shoreline recession with future SLR at 11 surveyed shore-normal profiles along the bay. These indicate averaged values for the whole bay of 7 to 12 m by 2050.

We suggest the adoption of simple semi-quantitative evaluations of coastline changes, such as a Coastal Vulnerability Index (CVI) and an Estimated Hazard Area (EHA), concepts developed in the United States for its coastlines, for coastal planning and management purposes at Negril and elsewhere.

Key words: Negril, Jamaica, beach erosion ....

1. INTRODUCTION

For a number of years the beaches at Long Bay and Bloody Bay, Negril (**Figure 1**), have been experiencing erosion problems. In response to the concerns raised by the public and private sectors the Department of Geography and Geology (DOGG), University of the West Indies (UWI), in conjunction with the Coastal Zone Unit of the Nation Environment and Planning Agency (NEPA), undertook a sedimentological and sociological investigation of the problem, funded by the Coastal Waters Improvement Project (CWIP) of the United States Agency for International Development (USAID) and NEPA (DOGG, 2002; Mitchell et al., 2002). NEPA continued a monitoring programme for several years (McKenzie, this volume). A further study was carried out by Smith Warner International (SWI) for the Negril Coral Reef Preservation Society (NCRPS), funded by the Environmental Foundation of Jamaica (EFJ), to examine the oceanography and beach responses of the system and to propose engineered solutions to mitigate the problems (SWI 2007; see also this volume). In 2008 the Marine Geology Unit, UWI, carried out a survey to generate elevation and cross-profile data for the barrier and to examine past and possible future

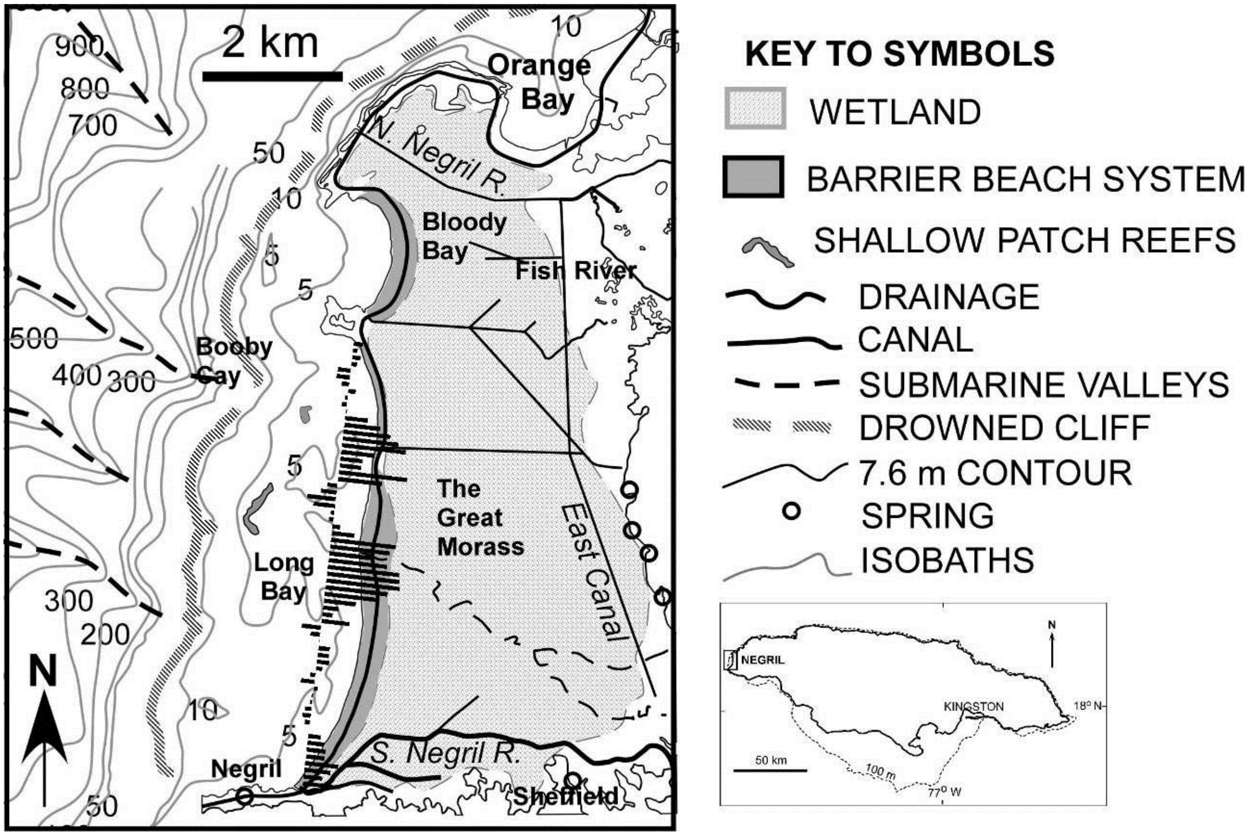

Figure 1 Location and major physical features of the Negril region. The set of horizontal bars normal to the Long Bay coastline indicate the shoreline changes since 1971 (bars extending to the right indicate erosion; those extending to the left indicate accretion. See text and figure 5 for discussion (transect locations described in Appendix 2). Dashed line, course of the Middle River.

changes in shoreline positions between 1971 and 2003 (MGU 2008; Khan et al. 2009). Most recently the United Nations Environment Programme (UNEP) completed a Risk and Vulnerability Assessment Development Project (RiVAMP) using the Negril Environmental Protection Area for a pilot assessment (UNEP 2010).

With current concerns over the rate and magnitude of future sea-level rise, Negril stands out as an area at considerable long-term risk (Mitchell et al. 2002; Robinson & Khan in Mahlung in press). Many elevations there are substantially lower than the magnitude of sea-level rise projected by some authorities over the rest of this century, and extensive general elevation data are in many instances confusing or questionable.

The main purpose of this paper is to evaluate the potential for future changes in the shoreline position, based on the observed shoreline changes in the past thirty seven years (1971-2008) and the several published projections of sea-level rise (SLR) over the twenty-first century. We also suggest the use of Erosion Hazard Areas (EHAs) similar to those defined by the Federal Emergency Management Administration (FEMA) of the United States (Crowell & Leatherman 1999) as an aid to Coastal Management of the Negril Environmental Protection Area.

Existing Situation

The resort areas of Long Bay and Bloody Bay are built on a narrow strip of low-lying land (mainly sand) between the sea and the Great Morass, forming a barrier beach system (**Figure 1**). The Negril beaches are divided into the two segments of Long Bay and Bloody Bay by the limestone promontory at Point Village (**Figure 1**). The morass is a low, more or less level wetland, underlain for the most part by peat of varying thickness. The peat exceeds 12 m in some places in the southwestern part of the wetland (Robinson, 1983 appendix 1; Robinson & Hendry, this volume). Elevations over most of the morass do not exceed one metre. A survey of the Negril Morass and near-shore region carried out in the 1950s (Town & Country Planning Development Order for Negril, 1959) showed elevations tied to a datum at 96.16 ft. below mean sea-level (MSL). When corrected these indicate morass elevations nearly everywhere below one metre above MSL except in the southeast corner.

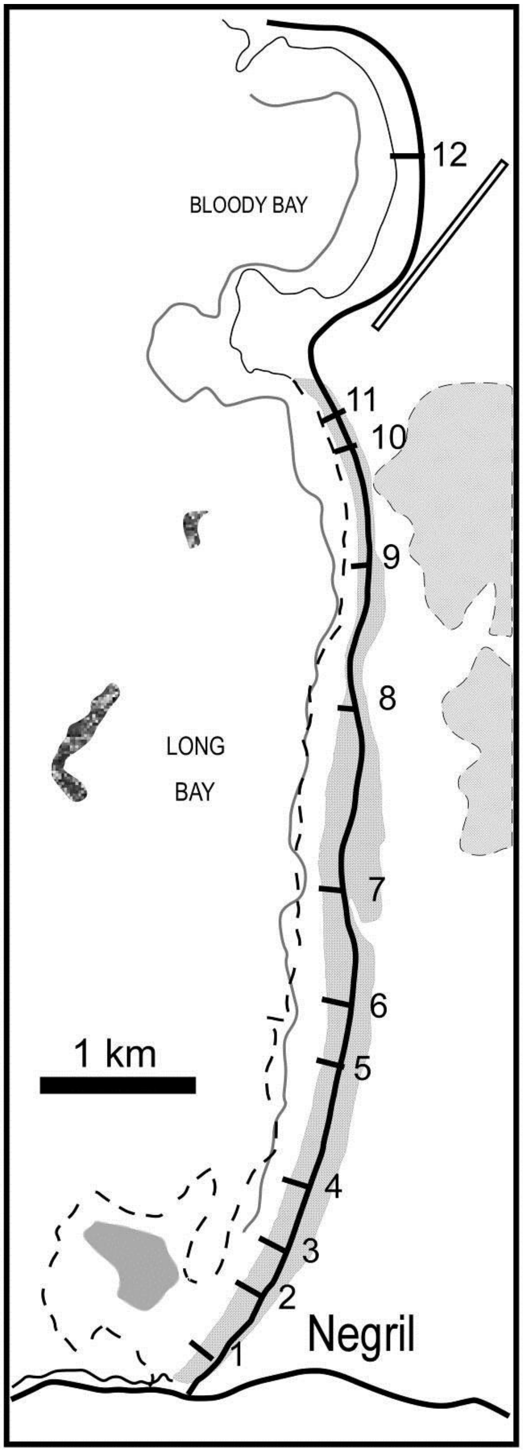

Figure 2 Long Bay Negril showing barrier beach (long grey strip) and positions of 12 levelled cross-profiles to evaluate shoreline changes using the Bruun Rule. Grey hatched area in the Great Morass (upper right) are identified from aerial photographs as being permanently flooded. The grey shading offshore of Negril (bottom left) is identified as a zone where offshore dredging has taken place (see text). Arrow marks position of datum used for leveling.

Subsequent construction of the eastern canal (**Figure 1**) has probably resulted in lowering of elevations over parts of the morass (Robinson 1999). Aerial survey photographs show large parts of the north-central region of the Morass to be water-logged (**Figure 2**). The load-bearing capacity of peat deposits for construction purposes is essentially zero, thus limiting building expansion into the morass area and restricting further development to the coastal strip.

This relatively narrow barrier beach complex, consists of unconsolidated to poorly consolidated carbonate sand overlying limestone bedrock, clay or peat deposits at depth (Hendry, 1982; Mitchell et al., 2002). The active beach at Long Bay is 6.4 km long, and backed by a strip of sand, forming, in places, low relief beach ridges and originally with extensive forest cover, as evidenced by aerial survey photographs dating from 1940. The arcuate Bloody Bay, 1.5 km across, has a continuous beach, backed by low beach ridges on which the forest cover was still largely preserved as recently as 1999. There is a notable absence of a storm berm/aeolian dune complex behind the beach along both bays (DOGG, 2002; Mitchell et al. 2002) and the presence of a beach ridge complex suggests that the barrier has been prograding until relatively recent times (Robinson & Hendry, this volume). Geologically, the Long Bay beach is divided into two segments near the centre where limestone bedrock is exposed in the swash zone (just north of transect 8, **Figure 2**). Geological evaluation of the barrier system was undertaken by Hendry (1982).

Study of the distribution and characteristics of the beach sediments by a team from the Department of Geography & Geology, UWI, suggested that the main source of beach sand lay in the near-shore seagrass beds and that the supply of available sediment was probably controlled by the health of the sediment-producing organisms in these beds, principally the calcareous algae and the foraminifera (DOGG, 2002; Mitchell et al. 2002).

Climate Change and SLR

It is generally accepted that sea level is rising, and that this rise will continue into the foreseeable future. The internationally researched publication (AR4, IPCC, 2007) suggested, conservatively, that the rise could be in the region of 0.18 m to 0.59 m over the next century. Since then several researchers have suggested that SLR by the year 2100 could be more than twice the amount projected by the IPCC, perhaps as much as 1.6 m (e.g. Rahmstorf, 2007; Rignot et al., 2008; Rohling et al., 2008; Richardson et al. 2009). Global records indicate a rise of about 10 cm since 1970 (Richardson et al. p.8 fig. 1). The

IPCC's AR4 report suggested that SLR in the region near to Jamaica would approximate to the global average (IPCC, 2007, chapter 11, p. 915 and figure 10.32) and this has been accepted for the purposes of this paper. It is also possible that, over the much longer term, the actual rate of local SLR could be modified by isostatic/ tectonic movements in the Negril region, the Long Bay beach complex and Morass being situated on a recently down-faulted block (Hendry, 1987; Hendry & Robinson this volume).

In response to SLR, where there is an adequate supply of sediment from the near-shore and back beach areas, and in the absence of hardened structures, the beach will change its position in space as sea level rises, migrating upwards and inland. This would probably result in the beach system eventually transgressing over the morass. However, the highway and existing and planned future built environment will inhibit this, and lead to increased vertical incision, accompanied by loss of the beach. In the following projections of future shoreline changes we have excluded factors such as the impact of present and future built structures, chemical and thermal effects on the ocean, and carbonate production levels, as well as the effects of tides and currents. Zhang et al. (2002; 2004) discounted the impact of severe storms in the analysis of long term effects of SLR and we do not address this factor.

4. METHODS

Field Survey

A survey was carried out along the Norman Manley Boulevard, Long Bay, between the Craft Market in the south and the entrance to Hedonism II at Point Pen to ascertain the general elevation of the road above sea level, using standard leveling procedures. Two hundred elevation points were measured tied to a datum established just north of the Craft Market (Appendix 1). Positioning was effected using WAAS-enabled geographic positioning systems (GPS) with a positioning error of up to 5 m. Initially a National Land Agency survey marker near the Negril Craft Market was to be used as the datum, but a careful search and conversations with local persons and personnel from the Negril Coral Reef Protection Society (NCRPS) failed to identify such a marker, and it is presumed destroyed. The new mark was tied to local sea-level based on observations carried out over the three days of our visit (May 19-22, 2008). Twelve cross-sections from the main road, or where possible the morass edge, to the sea were also levelled, and the profiles tied to the main road survey (**Figure 2**). Our elevation data indicated that the highest parts of the barrier system do not exceed about 2 metres ASL.

Aerial Survey and Satellite Imagery

Determination of shoreline position on aerial and satellite imagery depends on defining and identifying specific indicators on the beach that are visible on the images used, and relating these to the beach itself. The high water line, or as proxy, the wet/dry line has been widely employed as an indicator of the shoreline position (Boak & Turner, 2003) although GPS (Pajak & Leatherman, 2002) and LIDAR (e.g. Harris et al. 2006) methods are now increasingly in use as providing more precision. However, for the white sand of tropical carbonate beaches here and in similar situations in other parts of the world, the beach toe, the lowest point on the beach face, has frequently proved to be the most easily seen indicator of the shoreline position on modern aerial/ satellite imagery (Coyne et al. 1999; Fletcher et al. 2003). At Long Bay this feature is readily visible on satellite imagery and the more recent aerial photographs (vertical and oblique) and so was used by us.

The edge of the vegetation cover behind the beach was used to mark the back of the beach, but the extent of this cover frequently depends on human interference with the natural vegetation, and so can be a poor indicator of the position of the rear of the active beach. Because the vegetation line is easily identifiable, even on older photographs that cannot be used for beach toe identification, it is used by us in this paper to identify the rear of the beach. The beach width is therefore defined as the distance between the beach toe and the vegetation line (Coyne et al., 1999, fig. 3).

Data on the historical shoreline changes were developed using aerial photo images from 1971 and 1991, and satellite imagery up to January 2008, rectified (point-to-point method) using the georeferenced 2003 IKONOS imagery of the Negril area as the reference image. Older aerial survey photographs of 1980, 1968, 1961, 1953 and 1940 were rejected because of relatively poor definition (excessive contrast and inferior resolution) preventing reliable identification of the beach toe. Beach toe and vegetation line positions were digitized for Long Bay on each rectified image and profile lines were then added to the images approximately 100 m apart, totalling 66 locations for Long Bay. Their locations are described in Appendix 2. An example is given at **Figure 3**. The intersections of the digitized shorelines were identified and measured for each location. The tide state was not taken into account, but on the relatively steep Long Bay beaches this might

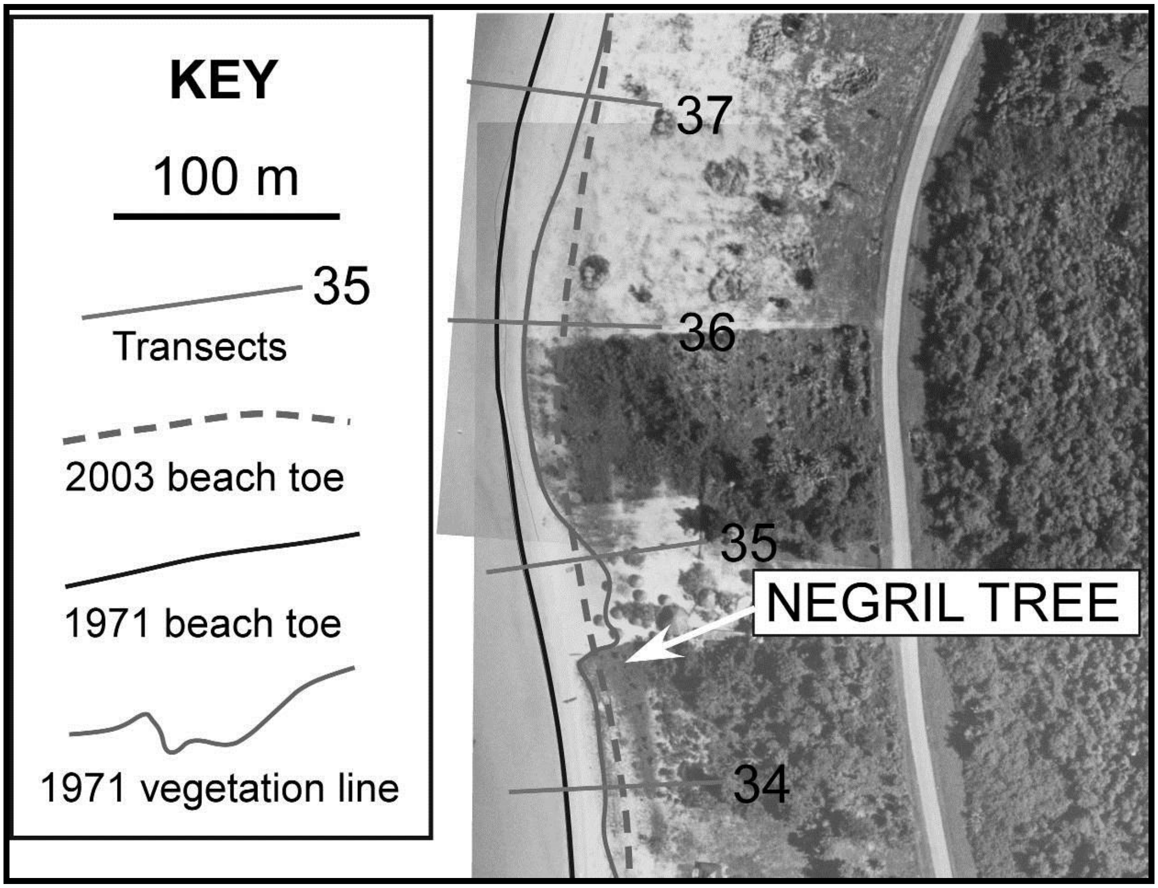

Figure 3. Portion of 1971 aerial photograph indicating shorelines and position of the "Negril Tree" now (2009) in the swash zone.

introduce positioning errors of up to about 4 m.

We judged the quality of the 1961 aerial photographs to be about equal to that of the 1968 and 1980 series. They were used to examine the vegetation line and, as the earliest photos available to us that include the highway, were also used to carry data points from one photo set to another. The 1971 low-level aerial photographs of Long Bay, generated by the late Jack Tyndale-Biscoe, are much superior in level of detail to any others we have seen from that general time period, and we have used these as the main reference for historical changes (**Figure 3**). These photographs were generated before significant development had taken place along Long Bay. The vegetation line on them provides what is probably the most reliable indication of the rear of the active beach so this line was used as the reference for all shoreline changes for all the dates examined. Extensive modification of the vegetation line has taken place in more recent years.

Projections of Future Shoreline Position

In projecting future shoreline positions for Long Bay two methods were adopted. The first one used empirical correlations of changes in past shoreline positions and sea-levels to estimate the possible locations of future shorelines (Crowell et al., 1999; Fletcher et al. 2003,). The second uses the so-called "Bruun Rule" to calculate the positions of future shorelines, based on the concept that each particular beach strives to maintain the shape of its equilibrium profile as sea level rises (Zhang et al., 2004, fig. 1; Masselink and Hughes, 2003, fig. 8.3). Both methods have their critics as well as their supporters (Dubois, 1975; Pilkey & Cooper, 2004; Nicholls & Stive, 2004).

3. RESULTS

Historical Shoreline Changes

Figure 3 shows two of the digitized shorelines at transects 34 to 37. Transects 34 and 35 encompass the "Negril Tree", near "Footeprints" (now, 2009, in the swash zone) as it was in October 1971. The bar graphs (**Figure 4a-c**) summarise changes along each of the 66 transects for each time period between the image "snapshots" and the total changes for the 37 years of observations (Figure 4d) which average 23 cm/yr. These graphs indicate

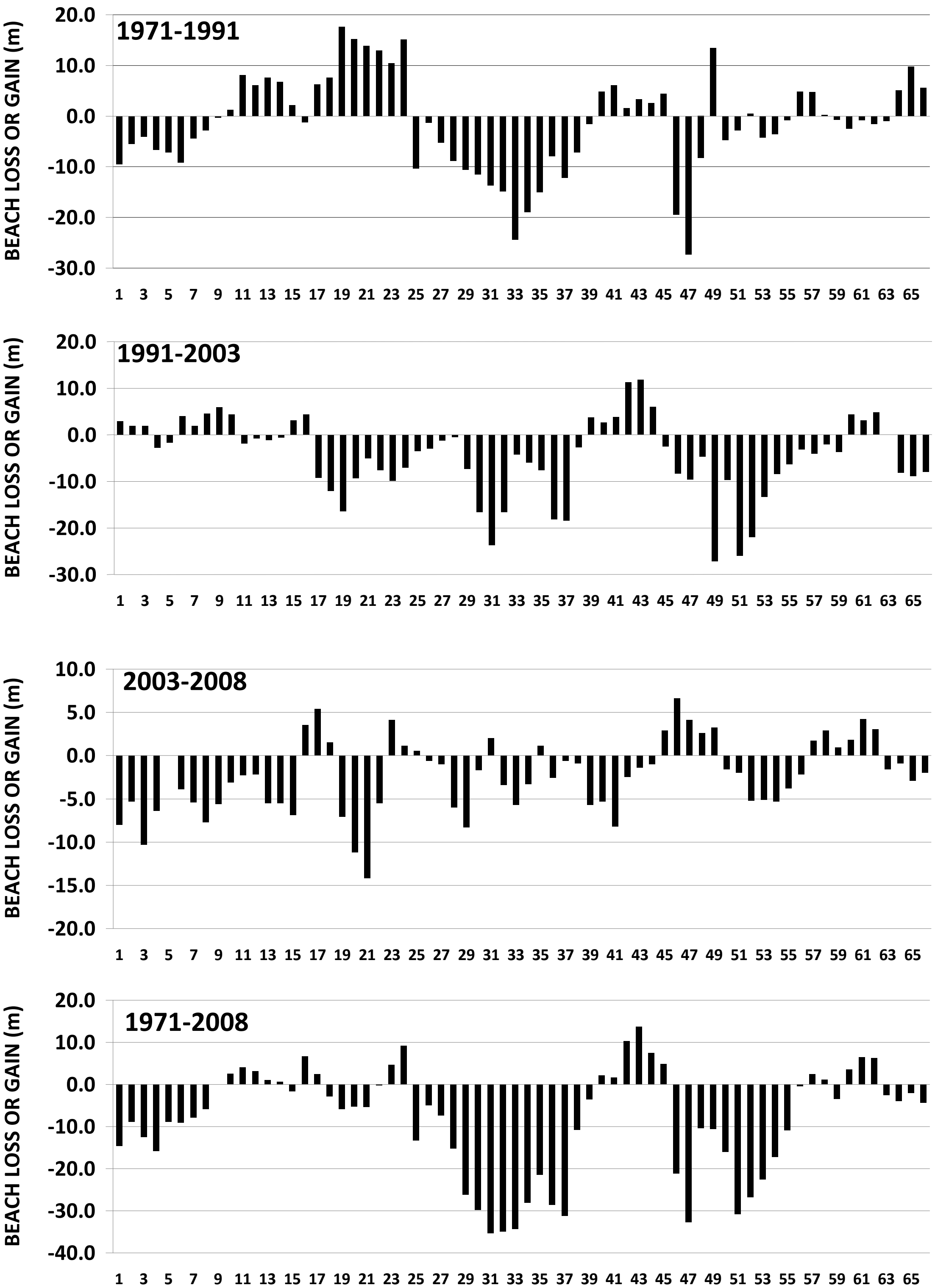

Figure 4. Bar graphs indicating relative recession or progradation of the shoreline between 1971 and 2008 for each of the 66 measured transects (see also figure 1).

the significant differences in the shoreline response in different parts of the bay (see also **Figure 1**) and highlight two areas near the centre of the shoreline that have experienced unusually high rates of

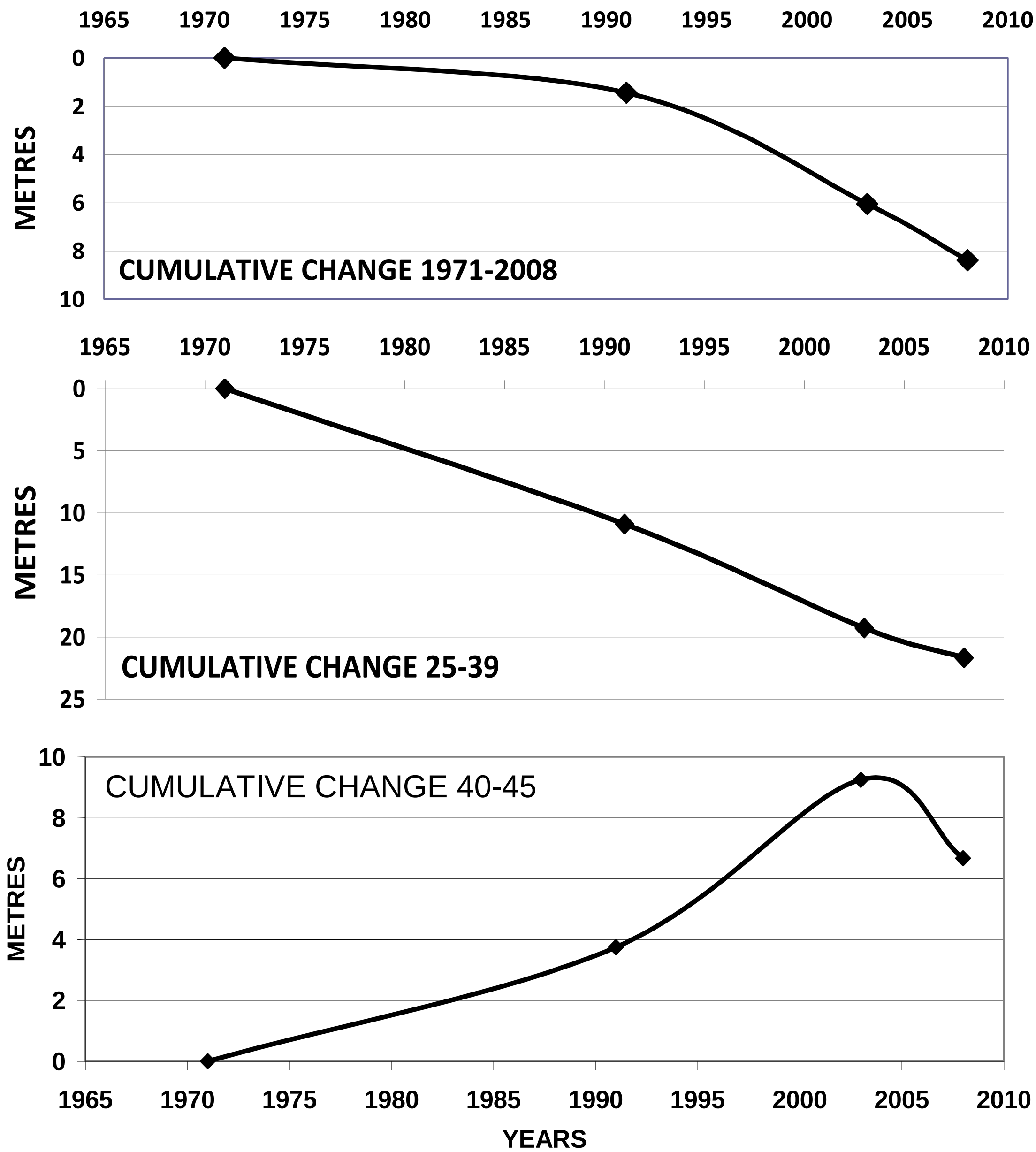

Figure 5. Trends in shoreline change averaged: top, for Long Bay as a whole; middle, for the erosion "hotspot" between transects 25 and 39; bottom, for a region where accretion has been dominant, between transects 40 and 45.

recession (transects 25-39 and 46-55). Sandwiched in between these two "hotspot" zones is a stretch of shoreline, a "coolspot" (transects 40-45) that has seen steady accretion, only reversed in the last few years. A third zone dominated by erosion is that at the southern end of Long Bay (transects 1-11) where net recession up to some 15 m has occurred. A zone of fluctuating changes is encompassed by transects 12 to 24. All transect locations are listed in **Appendix 2**.

Trends in past shoreline change (Figure 5)

For the period 1971 to 1991 the amount of recession was relatively small at about 1.5 m for the whole of Long Bay, an average recession rate of 7 cm per year (**Figure 5**), but figure 4a highlights the recession, up to nearly 28 m that occurred in the middle part of Long Bay at that time. This was balanced by accretion in other areas. For the period 1991 to 2003, covering a time of accelerating hotel development, the average annual recession increased nearly four times to 0.4 m/yr over the

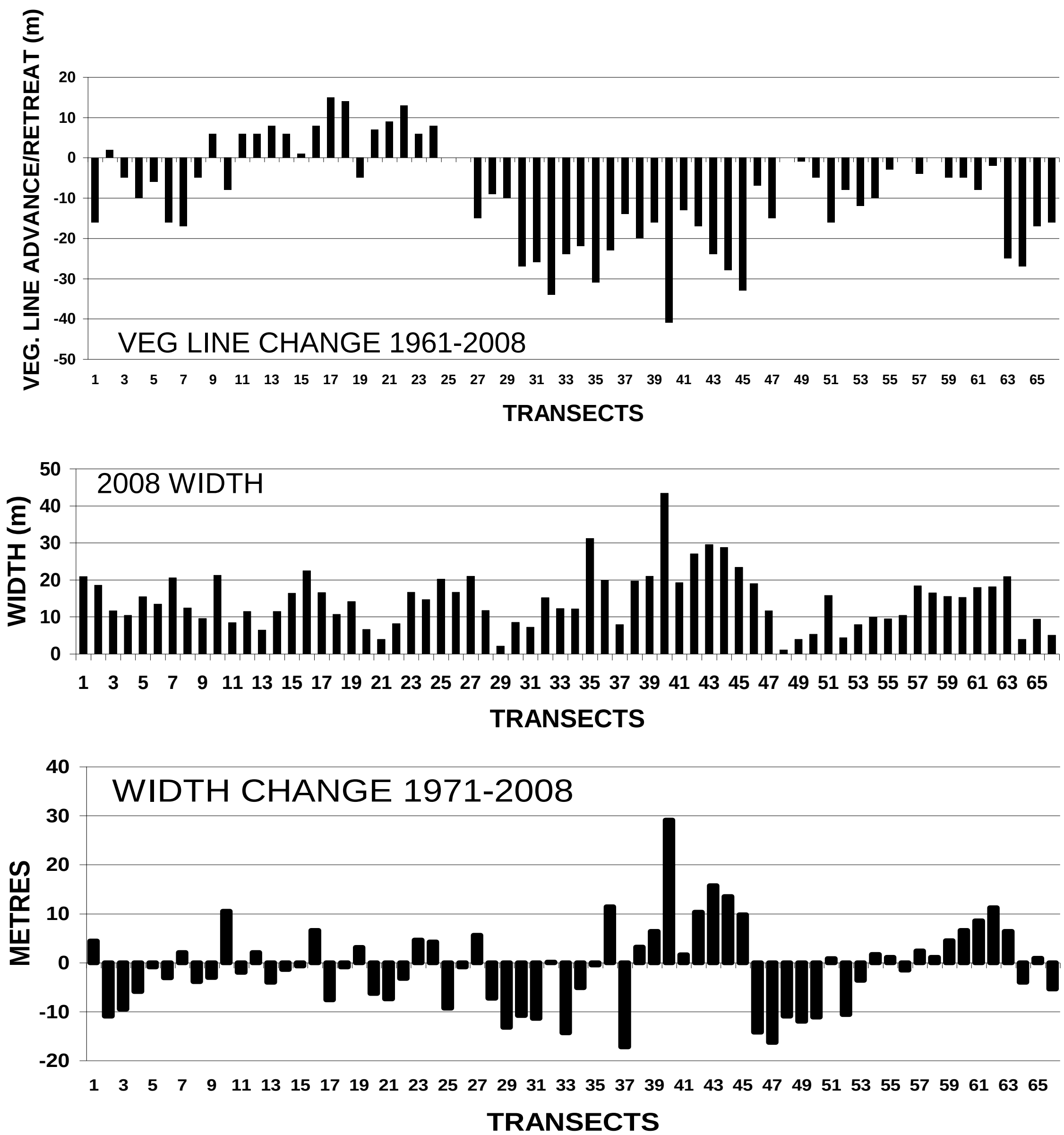

Figure 6. Changes in beach width, 1971-2008, as defined by changes in the positions of the beach toe and the vegetation line.

previous 20 years, giving an average retreat of 4.8 m for the whole Bay. In the main "hotspot" (transects 25-39) the higher recession rate already experienced in the first twenty years continued (**Figure 5**) reaching as much as 1 to 2 m per year, but was reduced after 2003. This slight reduction coincides in time with the reversal from accretion to recession experienced by the "coolspot".

Beach Widths (Figure 6)

As beach width is dependent on both the shoreline position and the vegetation line at the rear of the beach, width trends do not necessarily correlate with trends in shoreline change. On **Figure 6** the vegetation line changes have been indicated from aerial photography of 1961 up to 2008. The changes probably have much to do with the construction behind the beach and clearing of inactive parts of the barrier system to extend the beach width, as the barrier itself is also composed of easily utilised beach sand. The coastwise distribution of the changes in **Figure 6** suggests that much of the vegetation loss has to do with these factors. An important additional factor, difficult to monitor by remote sensing, is the degree of beach nourishment that has occurred. Such nourishment need not be at the waterline but can also be carried out as part of the back beach development.

Future Projections

For any one point along the beach **Figure 4d** indicates the mean annual rate of recession over the thirty seven-year period 1971 to 2008. Will this shoreline recession continue into the future? In the following paragraphs projected values are suggested. These are subject to errors of largely unknown size, due to possible future changes in shoreline structure and dynamics, and variations in SLR, so that the figures given must be treated with caution, merely indicating likely general trends.

Using Historical Shoreline Data Only

These projections have been made without reference to SLR or any other physical and possible future engineered mitigation. They follow the same procedure that has been adopted by FEMA to indicate erosion hazard areas (EHAs) that should be monitored for their vulnerability to future impacts of natural hazards (Crowell et al. 1999). The EHAs were constructed by projecting current erosion rates to suggest a shoreline position in 60 years time. In arriving at these projections a mean value of change may be applied to the whole coastal cell, in this case Long Bay, or more detailed analysis of changes in different sectors of the cell can be carried out, usually targeting "hotspots" of above normal rates of shoreline change.

We use a simple end-point rate calculation to project the average situation for the whole of Long Bay, assuming no hardened engineering structures are present, for the years 2015, 2030 and 2050, assuming future rates of change will be similar to those of the past 37 years (1971-2008). Negative values are recession/erosion; positive values progradation/accretion. The mean rate of past coastline change was -8.4 m in 37 years. This translates to -0.23 m/yr (from **Figure 5; Table 1**).

However, the available data suggest that the recession rate increased over the period 1991 to 2008 (**Figure 5**) so that use of the end points for the higher rate may be advisable for future projections. Mean coastline change from 1991 to 2008, -6.9 m in 17 years, translates to -0.41 m/yr (**Table 1**).

These projections are based on mean rates for the whole bay. If one looks at the situation for the "hot spots" in the central part of the bay, say, between profiles 25 and 39, the mean total shoreline change there for the period 1971 to 2008 was 21.7 m in 37 years (sum of values for profiles 25 to 39 divided by the number of profiles), or -0.59 m/yr (Table 1).

Using Historical Shoreline and SLR Data

While the projections made above, assuming present day shoreline change rates, may be reasonably valid for the near-future, i.e. for 2015 and, perhaps, 2030, they are clearly less reliable as one progresses into the more distant future.

In this situation it may be more appropriate to link future recession to the rate at which sea-level is rising and is expected to rise in the future (Leatherman, 1990), based on our observations of past shoreline changes during the SLR that has taken place over the period 1971-2008. For this report we have used SLR values approximating the high side of projections published by the IPCC (2007; "AR4 high" in tables below) as well as the higher projections suggested by Rahmstorf (2007; "Rahmstorf high" in tables below; see Richardson et al. 2009 for more discussion). Projected sea-level rise values are approximate, taken from graphics of IPCC 2007 and Rahmstorf 2007. The IPCC projected values are for the A1F1 scenario of the IPCC. This describes a future of rapid economic growth, the rapid introduction and use of new and more efficient technologies, with technological emphasis on fossil fuels. This scenario is likely to accelerate global warming more than most other modelled scenarios and so is more

Table 1. Changes in Coastline

Mean rate of past coastline change = -8.4 m in 37 years (-0.23 m/yr					
Change (metres)	1971-2008	2008-2015	2008-2030	2008-2050	2008-2100
Whole bay	-8.4	-1.6	-5.1	-9.7	-21.2
Mean coastline change from 1991 to 2008, -6.9 m in 17 years, translates to -0.41 m/yr					
Change (metres)	1991-2008	2008-2015	2008-2030	2008-2050	2008-2100
Whole bay	-6.9	-2.9	-9.0	-17.2	-37.7
Mean total shoreline change for 1971 to 2008 was 21.7 m in 37 years (-0.59 m/yr)					
Change (metres)	1971-2008	2008-2015	2008-2030	2008-2050	2008-2100
Hotspot	-21.7	-4.1	-13.0	-24.8	-54.3

Table 2. Projected shoreline recession (metres) for the "hot spot" and whole of Long Bay at Negril using historical rates of shoreline erosion and sea level rise data.

Change (metres)	2008-2015	2008-2030	2008-2050	2008-2100
AR4 SLR projection	0.02	0.07	0.14	0.46
Whole bay shoreline change	-1.7	-5.9	-11.7	-38.6
Hotspot shoreline change	-4.3	-15.2	-30.4	-99.8
Rahmstorf high SLR projection	0.03	0.12	0.25	0.95
Whole bay shoreline change	-2.5	-10.1	-21.0	-79.6
Hotspot shoreline change	-6.5	-26.0	-54.3	-206.2

likely to promote rapid sea-level rise. In this respect we are looking at possible "worst case scenarios" for future shoreline changes at Long Bay.

Sea-level rise, 1971-2008 (Richardson et al. 2009, p. 8, fig.1) was about 0.10 m. Total mean shoreline change, 1971-2008 (whole bay) was -8.38 m and for the hotspot, -21.7 m. Therefore average change rates for the whole bay, based only on sea-level rise, are -8.38 m per 0.10 m rise, or 83.8 m recession per metre rise. For the hotspot between transects 25 and 39 the average change was -21.7 m per 0.10 m rise, or 217.0 m recession per metre rise averaged for the hotspot. **Table 2** below summarises the information.

Projections using the Bruun Rule

The Bruun Rule equation may be expressed as

$$\mathbf{R = S \times (L/(B+h))}$$

where **R** is the amount of recession,
S is the vertical rise in sea-level,
L is the width of the shoreface to the closure depth,
h is the water depth at the closure depth,
B is the height of the berm or highest part of the beach.

Smith Warner (SWI, 2007 Appendix p. 94) suggested closure depth values at Negril of 2.99 m (mean) and 3.12 m (RMS). Closure depths ranging from 2.8 m to 16.2 m for various localities have been summarized in Masselink & Hughes (2003, table 8.1). In this paper we use a closure depth value of 3 m for the Bruun Rule equation. We also examined the location, at about 3 m depth, of the boundary between the clean, mobile sand carpet in front of the beach and the seagrass beds of the shelf, which help in trapping and stabilizing the sediments. This might better define the position of the closure depth.

Table 3 indicates projected shoreline erosion distances in metres at the surveyed cross-profiles in **Figure 2** for future years 2015, 2030, 2050 and 2100, based on projected sea-level rise as suggested by the IPCC (2007) and by Rahmstorf (2007), using a 3 m depth of closure. The same SLR values used in Table 1 are used in Table 2.

4. DISCUSSION

Variation in Values of Projections

Our value for the net average shoreline recession for the whole of Long Bay between 1971 and 2008 is 8.4 m or about 23 cm per year. This rate is significantly lower than the average erosion rate for the whole of Long Bay of about 1 metre per year recently published by UNEP (2010) for the period from 1968 to 2006. Reasons for the differences remain to be debated but in our own analysis of aerial photograph imagery, as stated above, we rejected the 1968 aerial photos as being of inferior resolution. In particular it was not possible to pick out the position of the beach toe with any degree of precision. Only the seaward limit of the sand carpet in front of the beach is well defined. On the other hand the low level aerial survey images produced by J. Tyndale-Biscoe in October 1971 and used by us clearly show the beach toe as well as the wet-dry line.

The future erosion distances using the Bruun Rule are conservative compared with projections using evidence from the historical changes discussed previously and SLR. Also the projected values bear little relative relationship to those of adjacent transects obtained using the historical data. Further work is needed to evaluate the discrepancies, but the historical changes result from real physical processes at work in Long Bay, including SLR, whereas the Bruun Rule equation, although incorporating SLR does not take into account many of these processes, particularly the influence of long shore sediment transport and the nature of bedrock. It is possible that disturbance of near-shore sea-grass and a reduction in the carbonate productivity of the shelf area following accelerated development are leading to a reduced sediment budget, promoting the higher recession values observed since 1991. It is also tempting to link the increased recession since 1991 at least partially with the global increase in SLR recorded by Richardson et al. (2009, fig.1).

Table 3. Projected shoreline recession (metres) for twelve surveyed profiles at Negril using the Bruun Rule equation. Projections are made from a 2008 start date, the date of the surveys.

	A1F1	Scenario	IPCC Projection				Rahmstorf Projection			
NEGRIL at 2008		2008	2015	2030	2050	2100	2015	2030	2050	2100
SLR in metres		0	0/02	0.07	0.14	0.46	0.03	0.12	0.25	0.95
12. Bloody Bay			2	5	11	35	2	9	19	72
11. Sandals			1	4	9	29	2	7	16	59
10. Our Past Time			2	5	11	35	2	9	19	73
9. North UDC Beach			1	2	5	15	1	4	8	32
8. South UDC Beach			1	4	9	29	2	7	16	32
7. Conch Hill			1	2	4	14	1	4	8	29
6. Sun			1	3	7	21	1	5	12	43
5. Waves			1	4	8	25	2	6	14	51
4. Fishermans			1	3	7	22	1	6	12	46
3. Barry's			1	3	6	19	-1	5	11	40
2. Shields			0	1	3	10	1	2	5	20
1. Public			1	2	4	14	1	4	8	29
Mean values			1	3	7	21	1	5	12	42

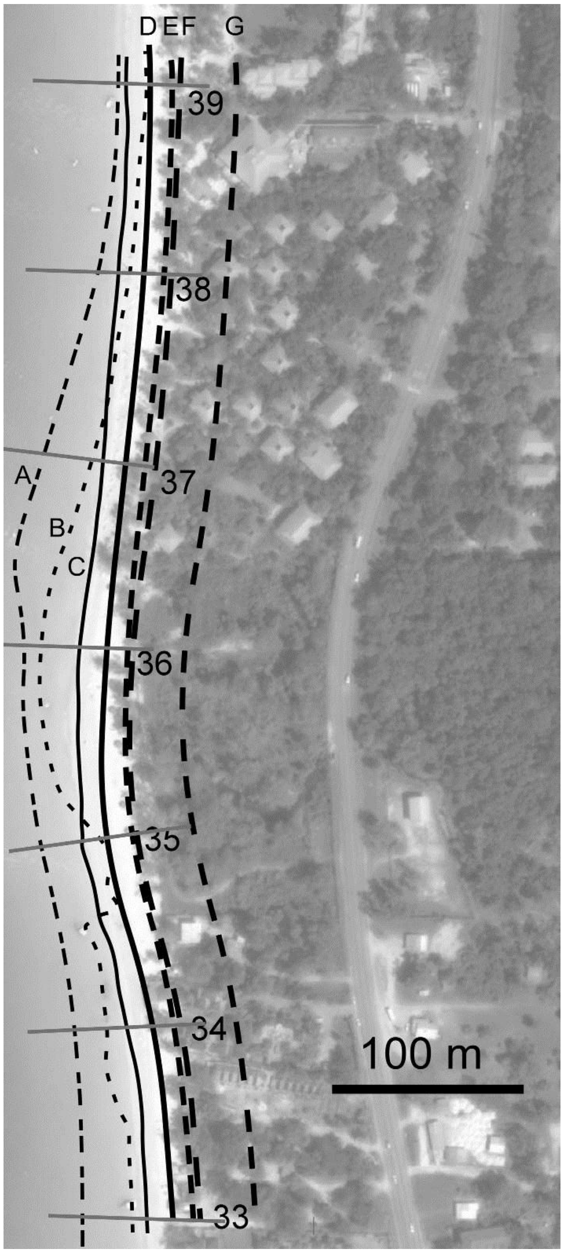

Figure 7. Portion of the "hotspot" coastline embracing transects 33 to 39 superimposed on the satellite imagery for 2003. A, 1971 shoreline; B, 1971 vegetation line; C, 2008 shoreline; D, 60 year EHA based on whole bay average shoreline recession; E, 60 year EHA based on average for the "hotspot"; F, projected future "hotspot" shoreline by 2030 using Rahmstorf high estimate of sea-level rise; G, projection for 2050 same basis.

Without close monitoring and control of waste materials, the increase in tourist-related activities and associated built structures inevitably leads to increased pollution of the near-shore region by uncontrolled runoff (some grey water, unconnected sewage devices, shower-heads in the beach zone), inadvertent pollution from beach food preparation areas, and destruction/removal of sea-grass beds (DOGG 2002). Some beach areas have been artificially widened. This can lead to erosion due to extension of unconsolidated sand in zones that have been added to the active beach area (DOGG, 2001). Although the sand in such zones may not be affected by everyday oceanographic conditions, severe storms can quickly remove such material.

The position of the two hotspots in the middle of the bay behind the only significant stretch of shallow coral reef in the bay (**Figures 1, 2**) strongly suggests that the reef may act as a natural detached breakwater promoting accretion in the "coolspot" area discussed above. This may be at the expense of erosion in the hotspots on either side (e.g. Montgomery, 1992, fig.7.11). The more southerly of the two hotspots coincides with the exit of the Middle River of the Negril Morass before beach front development took place (**Figure 1**). More speculatively some of the persistent erosion here may be a result of some part of the overall Negril development process, which included the construction of the now derelict drainage canal system along the eastern side of the morass. The canal diverted most of the natural flow of the Middle River. Similarly the drain just south of the Anglican Youth Centre which exits to the sea near transect 51 may have influenced sedimentation within the other hot spot between beach lines 45 and 55 in the UDC Beach Park.

Using EHAs for Coastal Management

Figure 7 shows a portion of one of the hotspots of the Long Bay coastline on which are superimposed EHA limits based on average projected recession to 2068 for the whole bay (line D) and as averaged for the hotspot (line E). As mentioned above the EHAs are constructed based on the most reliable calculation of recession rates in the past, using the current shoreline as the reference (Crowell et al. 1999). No account of SLR is taken into consideration. For the high recession rates of the North American Atlantic coast these lines would be well inland of the present coast. At Negril, where recession rates are much lower, the EHA limits are still close to the beach itself.

For coastal management purposes, we suggest using as planning guides the limits of estimated recession based on linking recession rates to SLR. On **Figure 7** line F indicates this limit for recession at this hotspot by 2030 and line G for 2050. Following the use of a Coastal Vulnerability Index (CVI) to evaluate the relative vulnerability of various sections of the coastline (Robinson and Khan, in press, section 4.5.5), the plotting of limits such as these at Negril and elsewhere, would provide a simply calculated, semi-quantitative reference for planning development near the beach, in this case over the next 22 years (**Figure 7**, line F) and the next 42 years (**Figure 7**, line G). These limits should be revised at frequent intervals, say every ten years, in the face of revision of actual and expected shoreline recession.

In the case of the "coolspot" between transects 40 and 45, where progradation has dominated the 37 year period under investigation, none of the projection methods described above can be used in a meaningful manner. However, it is most unlikely that the shoreline will accrete indefinitely in the face of sea-level rise. **Figure 5** already suggests this. For such stretches of coastline, the implementation of the mean value for the whole of the coastal cell, in this case Long Bay, may be more appropriate for management and planning purposes, and frequent monitoring of shoreline change trends should be undertaken.

5. CONCLUSIONS

The main conclusions are:

1) Most of the southern part of the Long Bay barrier system on the seaward side of the main road is less than 2 metres above sea-level.

2) Net averaged shoreline recession for Long Bay from 1971 to 2008 was 8.4 m but in hotspots near the centre of the bay averaged as much as 28 m with maxima around 35 m.

3) Based on the net historical recession (erosion) observed, averaged for the whole of Long Bay for the period 1971-2003, possible erosion scenarios into the future, base-year 2008, and without including possible effects of SLR, are 1.6 m by 2015, 5.1 m by 2030 and 9,7 m by 2050.

4) Based on the higher net historical rate observed for the shorter period 1991 to 2003, future projections are 2.9 m by 2015, 9 m by 2030 and 17.2 m by 2050.

5) For the "hot spot" over the observed period 1991 to 2008 between profiles 25 and 39, the future projections for mean net erosion, rounded to the nearest metre, are 4 m by 2015, 13 m by 2030 and 25 m by 2050.

6) If it assumed that past shoreline changes are directly linked to past SLR and that future changes will follow the same relationship, mean projections for the whole of Long Bay, base year 2008, are likely to be 2 to 3 m by 2015, 6 to 10 m by 2030 and 12 to 21 m by 2050.

7) For the "hot spot" between profiles 25 and 39 similar calculated projections are for shoreline retreat of 4 to 7 m by 2015, 15 to 26 m by 2030, 30 to 54 m by 2050 and over 200 m by 2100.

8) The projections for coastal recession at Long Bay along the 11 cross-section lines, averaged using the sea-level dependent Bruun Rule are about one metre by 2015, 3-5 m by 2030 and 7 to 12 m by 2050. These compare quite well with our projections, based on historical analysis, that ignore the effects of sea-level rise, but are only half our values for future projections that include the factor of SLR.

8) The discrepancies may be due to such factors as variation in long-shore sediment supply (not considered for the Bruun Rule), changes in the Great Morass drainage characteristics (including diversion of the flow of the Middle River) and changes in the carbonate sediment supplies from the shelf.

9) The application of easily calculated guidelines such as Coastal Vulnerability Indices (CVIs) described by Robinson & Khan (in press) and estimates of possible future shoreline scenarios, such as the EHAs used by FEMA and those discussed in this paper, would provide a useful semi-quantitative scientific basis for the planning and management of coastal development.

Acknowledgements. The Environmental Foundation of Jamaica provided funding and vehicular support for this project. Mr. Ray Arthur, of the Negril Chamber of Commerce, provided much valuable background information on past erosion and storm events at Negril. The National Land Agency provided draft elevation maps of the Negril area. Imagery from which data for the 2008 shoreline position was generated, was provided by GeoInformatics Ltd. Low-level aerial photographs provided by J. Tyndale-Biscoe Ltd. were used to identify the shoreline position for October 1971.

REFERENCES

Bjork, S. 1983. *Environmental feasibility study of peat mining in Jamaica.* Report to the Petroleum Corporation of Jamaica, 102 p.

Boak, E.R. and Turner, I.I. 2005. Shore definition and detection: a review. *Journal of Coastal Research*, **21**(4): 688-708.

Coyne, M.A., Fletcher, C.H. and Richmond, B.M. 1999. Mapping coastal erosion hazard areas in Hawaii: observations and errors. *Journal of Coastal Research*, Special Issue **28**, 171-184.

Crowell, M. and Leatherman, S.P. (Eds.) 1999. Coastal Erosion Mapping and Management. *Journal of Coastal Research* Special Issue **28**, 196 pages.

Crowell, M., Honeycutt, M. and Hatheway, D. 1999.

Coastal erosion hazards study: phase one mapping. *Journal of Coastal Research*, Special Issue **28**, 10-20.

DOGG, 2002. *Beach sand resource assessment Negril, Jamaica: Final report on Phase 1 by the Department of Geography & Geology to NEPA/USAID's CWIP programme*, 80 pages.

Dubois, R.N. 1975. Support and refinement of the Bruun Rule on beach erosion. *Journal of Geology*, **83**, 651-657.

Fletcher, C., Rooney, J., Barbee, M, Siang-Chyn, L. and Richmond, B. 2003. Mapping shoreline change using digital orthophotogrammetry. *Journal of Coastal Research*, Special Issue **38**, 106-124.

Haggstrom, M. 1982. *Water balance for the Great Morass of Negril and the Lower Morass of the Black River, Jamaica.* Swedish Meteorological and Hydrological Institute Report to the Petroleum Corporation of Jamaica, 42 pp.

Harris, M., Brock, J., Nayangandhi, A. and Duffy, M. 2006. *Extracting shoreline from NASA airborne topographic lidar-derived digital elevation models. U.S. Geological Survey Open File Report OFR* 2005-1427, Reston VA,

Hendry, M.D. 1982. *The structure, evolution and sedimentology of the reef, beach and morass complex at Negril, western Jamaica.* Report to the Petroleum Corporation of Jamaica, 1-185.

Hendry, M.D. 1987. Tectonic and eustatic control on late Cenozoic sedimentation within an active plate boundary zone, west coast margin, Jamaica. *Geological Society of America Bulletin*, **99**,718-728.

Hendry, M.D. and Digerfeldt, G. 1989. Palaeogeography and palaeoenvironments of a tropical coastal wetland and offshore shelf during Holocene submergence, Jamaica. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **73**, 1-10.

IPCC, 2007 (Solomon, S. et al.; Eds.). *Climate Change 2007: the Physical Basis, Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, 996 pages.

Khan, S., Robinson, E., Coutou, R. and Johnson, M. 2009. Beach erosion and sea-level rise at Long Bay, Negril, Western Jamaica. *Abstract and presentation, IGCP Project 405, UNESCO/IUGS; Quaternary Land-Ocean Interactions-Driving Mechanisms and Coastal Responses, Myrtle Beach, South Carolina USA, October 25-31, 2009*, p 41-43

Leatherman, S.P. 1990. Modeling shore response to sea-level rise on sedimentary coasts. *Progress in Physical Geography*, **14**(4), 447-464.

Masselink, G. and Hughes, M.G. 2003. *Introduction to Coastal Processes and Geomorphology*; Arnold, 354 pp.

MGU (Marine Geology Unit) 2008. *Draft final report on a survey of elevations and beach changes at Negril, Jamaica*. Prepared for the Environmental Foundation of Jamaica, 1B Norwood Avenue, Kingston 5, July 27, 2008, 47 pages.

Mitchell, S., Khan, S., Maharaj, R. and Robinson, E. 2002. Carbonate beach sediment composition at a tourist beach, Negril, Jamaica. *In:* **O.T. Magoon, L.L. Robbins & L. Ewing, (Eds.)**, *Carbonate Beaches, 2000*, American Society of Civil Engineers: 204-217.

Montgomery, C.W. 1992. *Environmental Geology*, 3rd Edition, Wm. C. Brown, Dubuque USA, 466 pages.

Nicholls, R.J. & Stive, M.J.F. 2004. Society and sea level rise requires modeling. Science, 303.

Pajak, M.J. and Leatherman, S. 2002. The high water line as shoreline indicator. *Journal of Coastal Research* **18**(2), 329-337.

Pilkey, O.H. and Cooper, J.A.G. 2004. Society and sea level rise. *Science*, **303**, 1781-1782.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science*, **315**, 368-370.

Richardson, K. and 11 others 2009. *Synthesis report from Climate Change Copenhagen*, 39 pages.

Rignot, E. et al., 2008. Recent Antarctic ice mass loss from radar interferometry and regional climate modeling. *Nature*, doi:10.1038/news.2008.438.

Robinson, E. 1983. *Jamaica peat resource utilization project: resource survey.* Report to the Petroleum Corporation of Jamaica. 79 pages, maps, appendices.

Robinson, E. 1999. *Preliminary assessment of possible environmental impacts of a proposal to desilt drainage channels near Springfield, Westmoreland, Jamaica*. Report to the Coastal Water Improvement Project (CWIP), NEPA/USAID,

Robinson, E. and Khan, S.A. (in press). Coastal Resources, including Human Settlements. *In:* **Mahlung, C. (Ed.)**, Chapter 4, Section 4.5, *Second Communication of Jamaica to UNFCCC*, Meteorological Service of Jamaica.

Rohling, E.J. et al. 2008. High rates of sea-level rise during the last interglacial period. *Nature Geoscience*, **1**, 38-42.

SWI (Smith Warner International Ltd.), 2007. *Preliminary engineering report for beach restoration works at Negril.* For the Negril Coral Reef Preservation Society, 1-115; Appendices 1-108.

Town & Country Planning Development Order for Negril, 1959.

UNEP 2010. *Linking Ecosystems to Risk and Vulnerability Reduction: the Case of Jamaica,* RiVAMP Pilot Assessment, 96 pages.

Zhang, K., Douglas, B.C. and Leatherman, S.P. 2002. Do storms cause long-term beach erosion along the U.S. east barrier coast? *Journal of Geology*, **110**, 493-502.

Zhang, K., Douglas, B.C. and Leatherman, S.P. 2004. Global warming and coastal erosion. *Climate Change*, **64**, 41-58.

APPENDIX 1. Location of datum for the field surveys.

See figure 2 for location. MGU waypoint station 678, degree. Coordinates: W78.33721 N18.30627

APPENDIX 2. Locations of transect lines used to estimate shoreline changes. Surveyed cross-profiles in (brackets). The entries in boldface are those located within the "hot spots" as defined in the text.

Transect	Locality Description
1	North Pier of South Negril River
2	Negril Craft Market
3	Public Beach access, (Cross profile 1)
4	Public beach
5	Public beach
6	Private property
7	North of Coral Seas/ Sunset on the Beach Hotel, (Cross profile 2)
8	Travellers Beach Resort
9	Mariners Negril Beach Resort
10	Beach House Villas
11	Barry's Beach, (Cross profile 3)
12	North of Bar-b-barn and Ben-Harr-Ver House
13	North of Legends and Jamaica Tamboo
14	Merrill's III
15	Fisherman's Beach/ Sea Tech water sports, (Cross profile 4)
16	Merrill's I
17	Alfred's Ocean Palace, North of Negril Gardens
18	Trombone
19	Roots Bamboo Beach
20	Fun Holiday Beach Resort
21	Westlea Cabins
22	N. of Rondel Village, S. of Boat Bar and Mariposa
23	Waves Beach, (Cross profile 5)
24	Nirvana
25	Charela Inn
26	Coco La Palm
27	Sun Beach, (Cross profile 6)
28	N. of Chances Restaurant, S. of Moondance Villas
29	Beachcomber hotel
30	Crystal Waters
31	Negril Tree House
32	?
33	Conch Hill, (Cross profile 7)
34	Footeprints
35	South end of Swept Away property
36	Swept Away property
37	Swept Away Resort
38	Swept Away
39	S. boundary of Beaches Negril, N. of Swept Away
40	Beaches Negril, front of main pool
41	Beaches Negril
42	Northern side of Beaches Negril
43	Cosmos Bar and Grill
44	Long Bay Beach Park
45	Long Bay Beach Park, (Cross profile 8)
46	Long bay Beach Park wooden huts (yellow)
47	Negril Beach park
48	Negril Beach park
49	At beach edge, Cross profile – base point
50	Negril Beach Park
51	North side of bridge
52	Negril Beach park
53	Negril Beach park
54	North of UDC Beach park, (Cross profile 9)
55	UDC Beach park
56	Private property, south of Cool Running's water park
57	Opposite Cool Running's water park, parking entrance
58	Front of Beaches Resort Main entrance
59	Front of Beaches main swimming pool
60	North end of Beaches
61	Our Past Time, (Cross profile 10)
62	Front of Sandals maintenance building
63	Sandals, (Cross profile 11)
64	Sandals Main entrance
65	North of Sandals Main swimming pool
66	Northern end of Sandals

Revised Manuscript Accepted: 14th February 2012