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Front Cover: The reef crest indicator species, *Acropora palmata*, on Gaulin's Reef, San Salvador Island. Gaulin's Reef is a classic bank-barrier reef that has shown remarkable resilience following two significant disturbances: El Niño-induced warming of the sea surface in 1998 and Hurricane Floyd in September, 1999 (see Peckol et al., this volume). Photo by Janet Lauroesch.

Back Cover: The oolite shoals of Joulter's Cay, north of Andros Island, Bahamas, site of the pre-meeting field trip. Photo by Ben Greenstein.

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COASTAL EFFECTS OF HURRICANE FLOYD ON SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Hurricane Floyd, a Category 4 storm with winds up to 155 mph, made a close encounter with San Salvador Island on September 13-14, 1999. In addition to inflicting severe damage to homes, tourist facilities, businesses, and infrastructure on the island, the storm also caused considerable beach erosion and coastal modification, mostly on the western and northern coasts. This paper reports and documents with photos the findings of a survey of coastal erosion effects on four areas of the San Salvador coastline: Coast Guard Beach, Rocky Point south to Cockburn Town and Fernandez Bay, South of Sugarloaf toward Grotto Bay, and Grotto Bay to Sandy Point. The western coast of San Salvador was most strongly affected by Hurricane Floyd. The storm resulted in extensive erosion of beach sand, severe scarping of the seaward-facing dune line, frequent overwashing, generation of much rock rubble, and widespread damage to vegetation. Many, if not most, of the developed areas of the San Salvador coastline are vulnerable to storm damage. The example of a threatened beach house at Sandy Point is documented and discussed in some detail.

INTRODUCTION

On September 13 and 14, 1999, Hurricane Floyd lashed the island of San Salvador with strong winds, heavy surf, and much rain. From 0600 to 1800 UTC (Coordinated Universal Time) on the 13th, Floyd was close to San Salvador and at the top end of Category 4 intensity (winds 131-155 mph) on the Saffir/Simpson Hurricane Scale. The eye passed 20 to 30 nautical miles northeast and north of San Salvador on the night of the 13th (Fig. 1; Pasch et al., 1999). After its encounter with San Salvador, this massive storm continued northwestward and later caused large-scale damage in the Abacos and very heavy rains in the mid-Atlantic region of the United States, resulting in disastrous flooding, loss of life, and catastrophic damage in eastern North Carolina.

Initial and largely speculative news reports from San Salvador indicated severe damage on the island from Hurricane Floyd. A team of researchers led by Douglas Gamble surveyed Hurricane Floyd damage in September, immediately after the storm, and again in late December 1999 – early January 2000 and documented significant and extensive damage to tourist facilities and island infrastructure (Gamble et al., 2000). However, this team found that damage to infrastructure and tourist

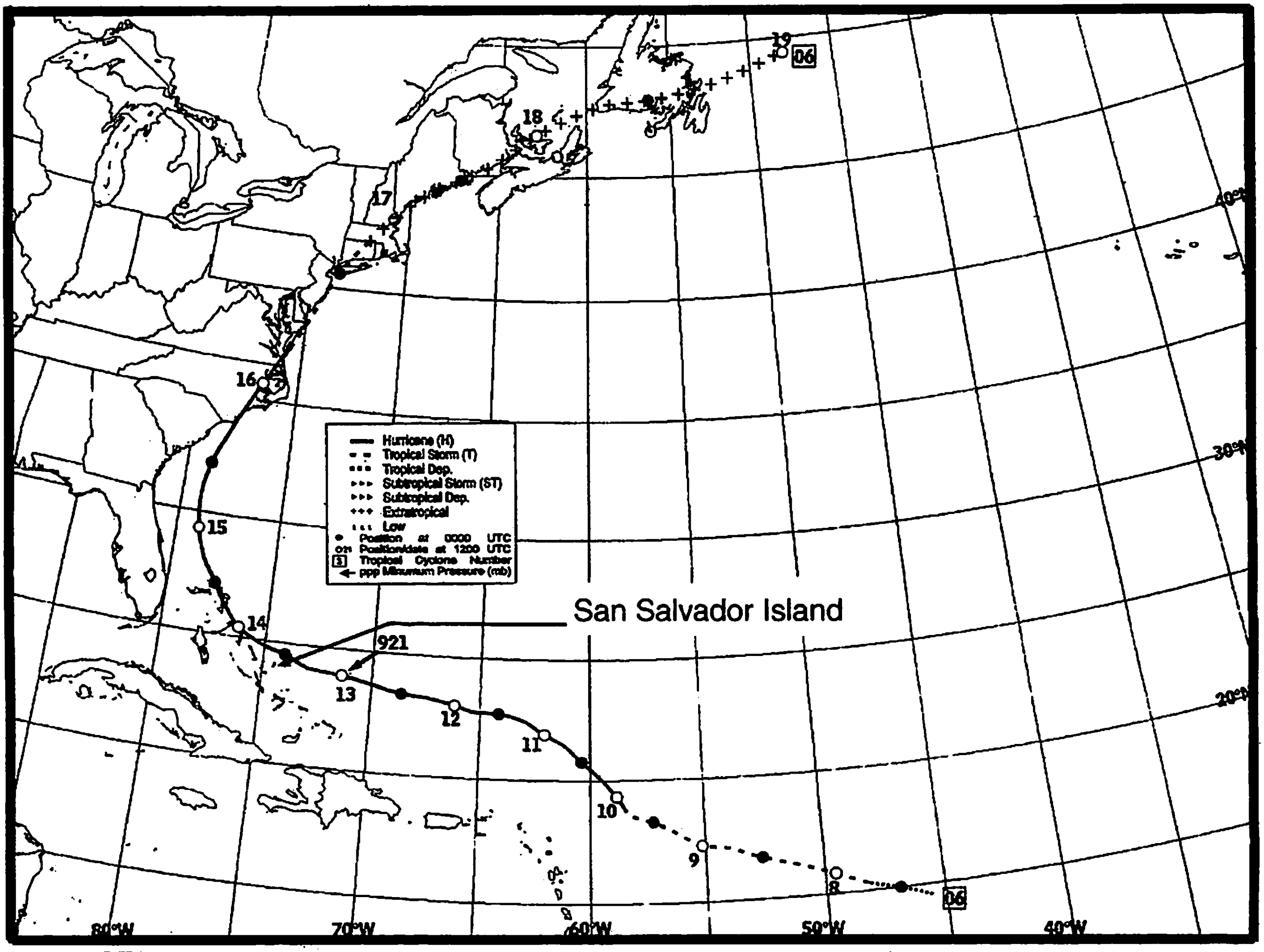

Figure 1. Best U.S. National Hurricane Center tracking positions for Hurricane Floyd, September 1999. Times are in UTC (Coordinated Universal Time) numbers. The black dot between positions 13 and 14 (13 and 14 September) represents the closest position of the hurricane's eye to San Salvador Island. The corrected local time for that position is 2000 (8 p.m.) Eastern Daylight Time on September 13, 1999. Modified from Pasch et al., 1999.

facilities was less than expected given the size and intensity of the storm and its close proximity to San Salvador. Gamble et al. (2000) discussed this apparent dichotomy in some detail and offered several hypotheses in explanation, as well as a useful comparison between the damage on San Salvador resulting from Hurricane Lili in October 1996 versus Hurricane Floyd.

In a personal account of Hurricane Floyd's encounter with San Salvador, Tom Goossens, former Facilities Manager for the Bahamian Field Station, reported that by 11 a.m. local time on Monday, September 13, 1999 storm winds were at about 70 mph and increasing. Conditions were bad throughout the afternoon, with local residents seeking the best shelters available. Many residents from the United Estates community took shelter in the large laboratory/auditorium building ("T" building) at the Bahamian Field Station. The greatest effects of the storm occurred during the night of September 13-14, with residents emerging the next day to survey the damage and begin the extensive clean-up operations (Goossens, public lecture, 2000; Gamble, et al., 2000).

Gamble et al. (2000) concentrated their survey efforts on assessing damage to tourism facilities and island infrastructure, such as water supply systems and roads. Their report made only passing mention of coastal erosion phenomena. The senior author has had a long-standing research interest in the beaches of San Salvador and their changes with time (see Brill et. al., 1993; Loizeaux et al., 1993; and Beavers et. al., 1995). With this background information available, Priscilla Delano and Meredith Barrett, two students enrolled in a Smith College carbonates geology field course, conducted a reconnaissance study of the beaches of San Salvador most affected by Hurricane Floyd. The study took place during the period January 10-19, 2000, with supervision and support from Professors Curran and White. Given that the greatest fury of the storm occurred during the night of September 13-14, and that virtually everyone on the island was under shelter during the storm, there apparently are no direct accounts or photographs of beach erosion actually taking place during the storm. However, we had no trouble "finding the storm" in January 2000, because beach erosion features, including extensive scarping, were present and obvious four months later. The purpose of this report is to provide a documented record of coastal erosion on San Salvador Island resulting from Hurricane Floyd.

COASTAL EFFECTS OF HURRICANE FLOYD

An initial reconnaissance of the island's beaches in January 2000 indicated to our survey team that beaches on the eastern side of the island had been only minimally affected by Hurricane Floyd. Our brief survey of East Beach showed little real change in morphology from that reported by Brill et al. (1993). Likewise, the beach along French Bay retained the more-or-less continuous dune scarp cut by Hurricane Lili in October 1996 (see Gamble et al., 2000, Fig. 6) but showed no significant new erosion. The story was different along the northern and western coasts of the island. Here it was obvious that the storm intensity had been great and coastal erosion significant. This observation was readily confirmed by Tom Goossens and by the local residents whom we interviewed regarding the storm's effects. As is clearly indicated by the Pasch et al. (1999) storm report and the Gamble et al. (2000) survey, the path of Hurricane Floyd past San Salvador (Fig. 1) generated the strongest winds and storm surge from the N-NW-W directions (Gamble et al., Fig. 6).

With this background information in hand, our team concentrated its beach survey efforts along the northern and western coasts of the island in four areas as shown in Figure 2. The methodology consisted of the student survey team walking the beaches in each area and making observations and notes on all beach erosion features that could reasonably be attributed to Hurricane Floyd. Methods were primarily those of detailed recording of observations, measurement of erosional features using a measuring tape and Jacob's staff, and extensive photo documentation. The principal findings of this January 2000 field reconnaissance study are presented in the following sections.

Area 1 - Coast Guard Beach

The storm surge from Hurricane Floyd generated and moved large amounts of rubble along the cliffs at the eastern end of Coast Guard Beach. Large boulders, up

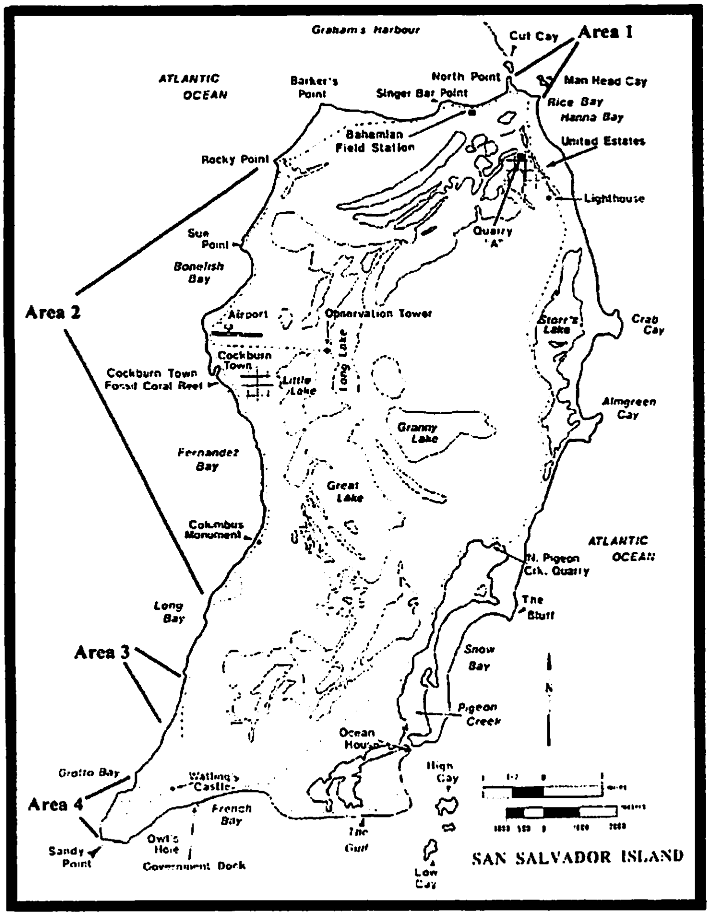

Figure 2. Index map to San Salvador Island showing the four coastal areas surveyed in January 2000 to document the effects of Hurricane Floyd.

to 1.25 m in diameter, were scattered about and the rocky headland area showed many fresh white surfaces where rock had been plucked from the cliffs (Fig. 3A). A bit farther to the west, the rocky coast gives way to a largely sandy shore with low, vegetated dunes that have been highly modified by human activity. Here overwash areas were obvious (Fig. 3B), and there was much dead vegetation, with plant roots projecting from the scarp cut by storm erosion. This scarp ranged from 0.2 to 1.8 m in height (Fig. 3C) and averaged about 1.2 m; the greatest scarp heights were toward the western end of Coast Guard Beach where the beach merges with the proximal end of the rocky North Point coast. Here the beach and dunes were well scoured by Hurricane Floyd storm waves, as indicated by the numerous old underground cables that were exposed by erosion (Fig. 3D).

Although we did not survey in detail the northern shoreline to the west of North Point and adjacent to the Bahamian Field Station, the same general set of storm effects remained obvious here in January 2000. These effects included scarping of the dunes to the west of the Government Dock, overwash areas, extensive damage to vegetation, and erosion to the rocky coast areas adjacent to the Bahamian Field Station dock.

Area 2 - Rocky Point South to Cockburn Town and Fernandez Bay

The beach area immediately south and leeward of Rocky Point was protected from severe storm erosion effects, but a low and continuous scarp had been cut into the dunes. This scarp gradually increased in prominence toward the Victoria Hill settlement and Sue Point, where it ranged in height between 0.8 to 1.5 m. Washover areas were present and extended 8 to 9 m inland from the scarp.

South of Sue Point, the northern, rockier part of the coast of Bonefish Bay exhibited much rock rubble and plant debris, with rock outcrops showing fresh surfaces of erosion. However, the Club Med beach along Bonefish Bay was not heavily eroded and did not exhibit a scarp. As reported by Gamble et al. (2000), the Club Med facilities suffered significant but not severe damage from the storm. It was noted that washover of sand from the beach was extensive, damaging the grass and garden areas of the resort.

Farther south toward the Riding Rock Inn, coastal damage was much more severe. Gamble et al. (2000) attributed this

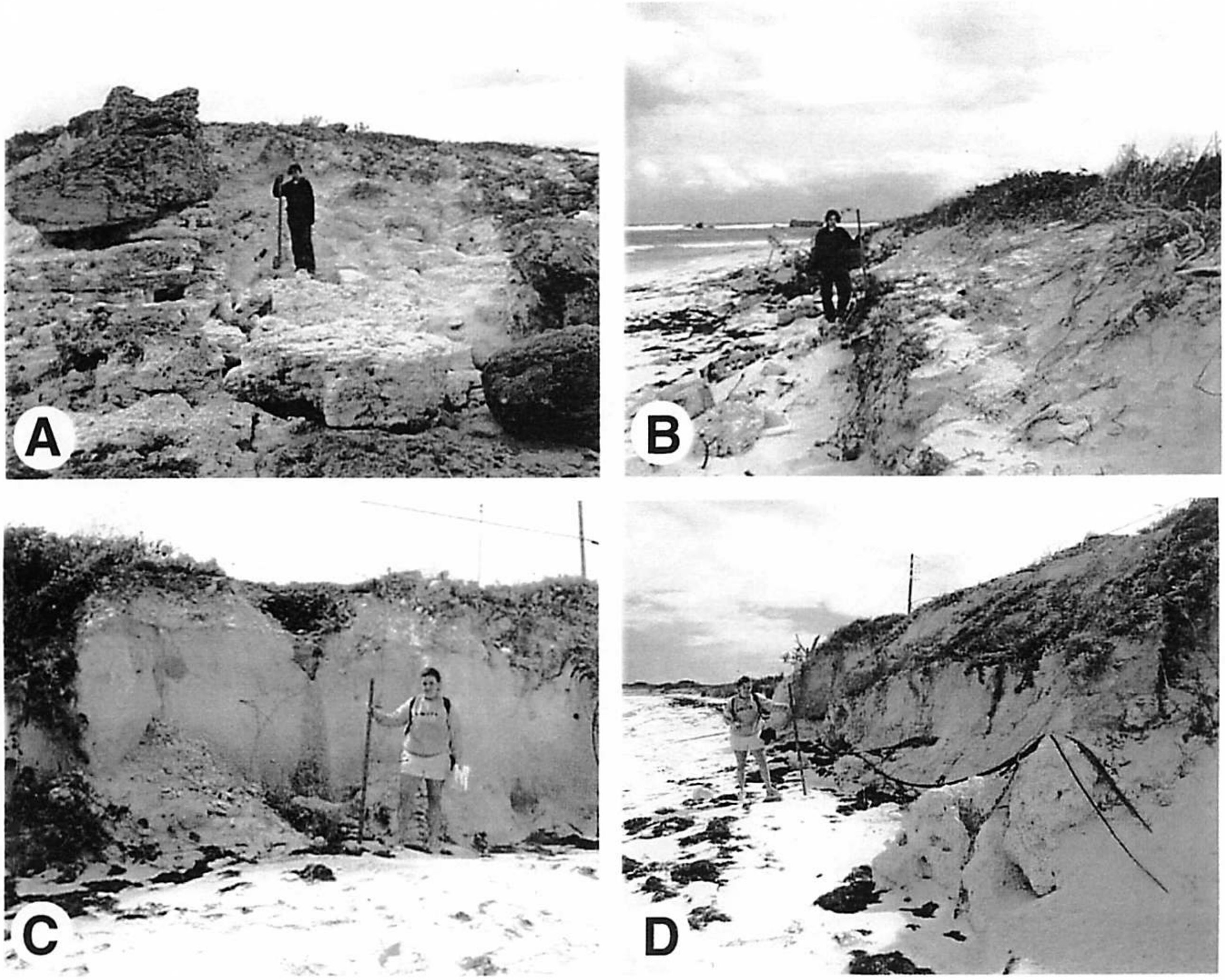

Figure 3. Storm erosion effects in Area 1 – Coast Guard Beach: A) Fresh white surfaces on outcrops indicated plucking of rock by strong wave action. B) Overwash of dunes caused erosion and extensive damage to vegetation. C) The scarp cut at the back of Coast Guard beach reached a maximum height of 1.8 m. D) Scarping at the western end of Coast Guard Beach exposed several old underground cables.

to the strong storm surge that affected this largely unprotected, west-facing reach of the coast. Here storm-deposited boulders littered the coast and rock rubble was extensive, along with much dead vegetation and many downed Australian pine (*Casurina*) trees. South of the Riding Rock Inn and marina property, the Cockburn Town fossil coral reef site gave ample evidence of the storm's powerful wave energy in the form of extensive new deposits of rock rubble and fresh outcrop surfaces (Fig. 4A). Walker et al. (this volume) documented many of the storm's effects in this area.

As reported by Gamble et al. (2000), the Riding Rock Inn received the most severe damage of the three tourism facilities that they surveyed. In January 2000, much damage was still in evidence here (Fig. 4B), and the back of the narrow beach was severely scarped, with the beach littered by boulders, rock rubble, downed trees, and vegetation debris.

→ *Figure 4. Storm erosion effects and damage in Area 2 - Rocky Point to Fernandez Bay: A) Much rock rubble littered the Cockburn Town Fossil Reef site and fresh exposure surfaces were numerous. B) Damage to Riding Rock Inn cottage units was severe, as seen in January 2000. C) An old, abandoned building in Cockburn Town, immediately adjacent to the shore, was extensively damaged. D) Jumbled grave sites in the cemetery immediately south of Cockburn Town. E) View looking north along the Queen's Highway bordering Fernandez Bay; the south end of the seawall is at the top left of the photo. All along this area, the base of the road was severely eroded, with the top of the road about 1.5 m above the beach. Note the highly scoured appearance of the beach. F) A low but continuous scarp was cut in sandy beach areas at the south end of Fernandez Bay. G & H) Extensive beach scouring and vegetation damage was present in the developed areas at the south end of Fernandez Bay.*

Damage to buildings in Cockburn Town proper also was extensive (Gamble et al., 2000). The town dock was largely destroyed and several of the older, abandoned buildings immediately adjacent to the coast were severely damaged (Fig. 4C). The cemetery immediately south of the center of Cockburn Town also was extensively eroded and damaged (Fig. 4D).

Continuing south from Cockburn Town along the Queen's Highway (main road paralleling the coast), a section of mixed rocky and sandy coast, debris and rock rubble was everywhere in evidence. South of Bamboo Point and close to the highway, it appeared that much beach sand had been eroded away, and there was a distinct scarp at the back of the beach. A bit farther south the seawall protecting the highway begins. This important seawall, the highway, and the main power lines running along the highway were severely damaged by the storm, as reported by Gamble et al. (2000). It was obvious that storm waters had crossed the road at many points, because red mangroves on the east side of the road were brown and stressed from salt water incursion and spray, and fresh rock rubble and sand lobes were visible. The seawall acted as a hard barrier to storm waves, and much sand in front of the wall was removed by erosion. The general effect was scouring of sand from the beach and the accumulation of rock rubble at the base of the damaged seawall and road, with development of a scarp of up to 1.5 m in height (Fig. 4E). At the southern end of Fernandez Bay, beyond the reach of the seawall and toward the Columbus Monument park area, severe scarping of the back of the beach continued to be the norm. Rock rubble was everywhere and downed trees and piles of vegetation were common (Figs. 4F-H).

Area 3 – South of Sugarloaf toward Grotto Bay

This section of coast is not developed and the highway is well back from the beach. A good thing, because the beach here was severely eroded, with much scarping and widespread overwash of dunes (Fig. 5A). The stripping away of sand from the beach and dunes extended well inland (15 to 20 m in many places) and exposed much beachrock and weakly lithified protodune material (Fig. 5B).

Area 4 - Grotto Bay to Sandy Point

The coastline in this area has been the subject of two beach dynamics studies (Loizeaux et al., 1993; Beavers et al., 1995), so the patterns of sediment movement and beach morphology are relatively well documented here. Sandy Point has the widest beaches and largest amount of sand of any coastal area on San Salvador, and it is an

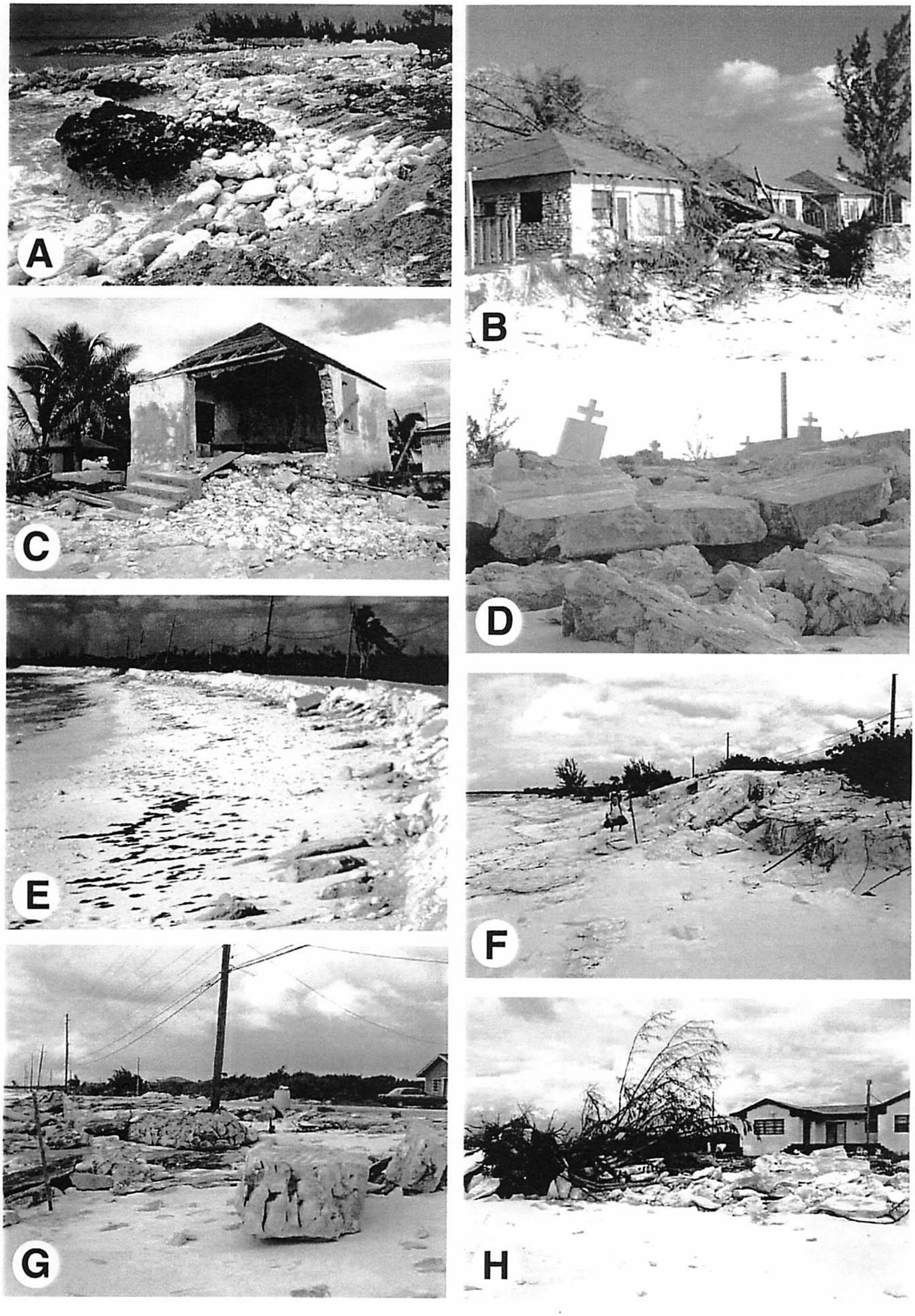
A
B
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Figure 5. Storm erosion effects in Area 3 – South of Sugarloaf toward Grotto Beach: A) Typical view of the scoured and scarped beach and dunes south of Sugarloaf community; the scarp averaged about 1 m height. B) Beach and dune scouring exposed much beachrock and weakly lithified protodune material; rock rubble was extensive.

area of highly active sand transport. As determined by Loizeaux et al. (1993), this is an event-driven system, with sand being transported west and north around Sandy Point under fair weather conditions (most predictably the spring and summer seasons) from the energy of waves generated by the prevailing easterly Trade Winds. Storms from the northwest generate strong waves that reverse the direction of sediment transport, with sediment moving north to south and around Sandy Point to the east. Such storms are most common during the fall and winter months, as weather fronts from the North American mainland push out across the Bahamas. However, the key word here is event-driven. Any storm generating waves from the northwest will move sand from north to south toward Sandy Point along this reach of coast, as well proved by Hurricane Floyd.

As previously documented, the strongest winds and waves from Hurricane Floyd were from the northwest quadrant. Resulting beach erosion was very severe along this northwestward-facing reach of coast, with much sand transport to the south and around Sandy Point. The rocky coast area immediately to the south of the Grotto Bay beach, and just beyond the picnic shelter (Profile Station #9 of Loizeaux et. al., 1993, and Beavers et al., 1995), has been shown to be very dynamic with respect to sand deposition and erosion. Floyd removed almost all of the sand from this area. Continuing to the south, the beach is narrow and somewhat steep, but it is well formed and typically has much sand. Hurricane Floyd removed a tremendous amount of sand from this area and cut a steep and continuous scarp, ranging from 0.7 to 1.5 m height, in the dune face at the back of the beach (Figs. 6A,B).

This section of beach has been partially developed, with several new houses having been built in the past few years. To at least some extent, all of these properties were damaged by Hurricane Floyd, and the seaward edge of all lots was moved notice-

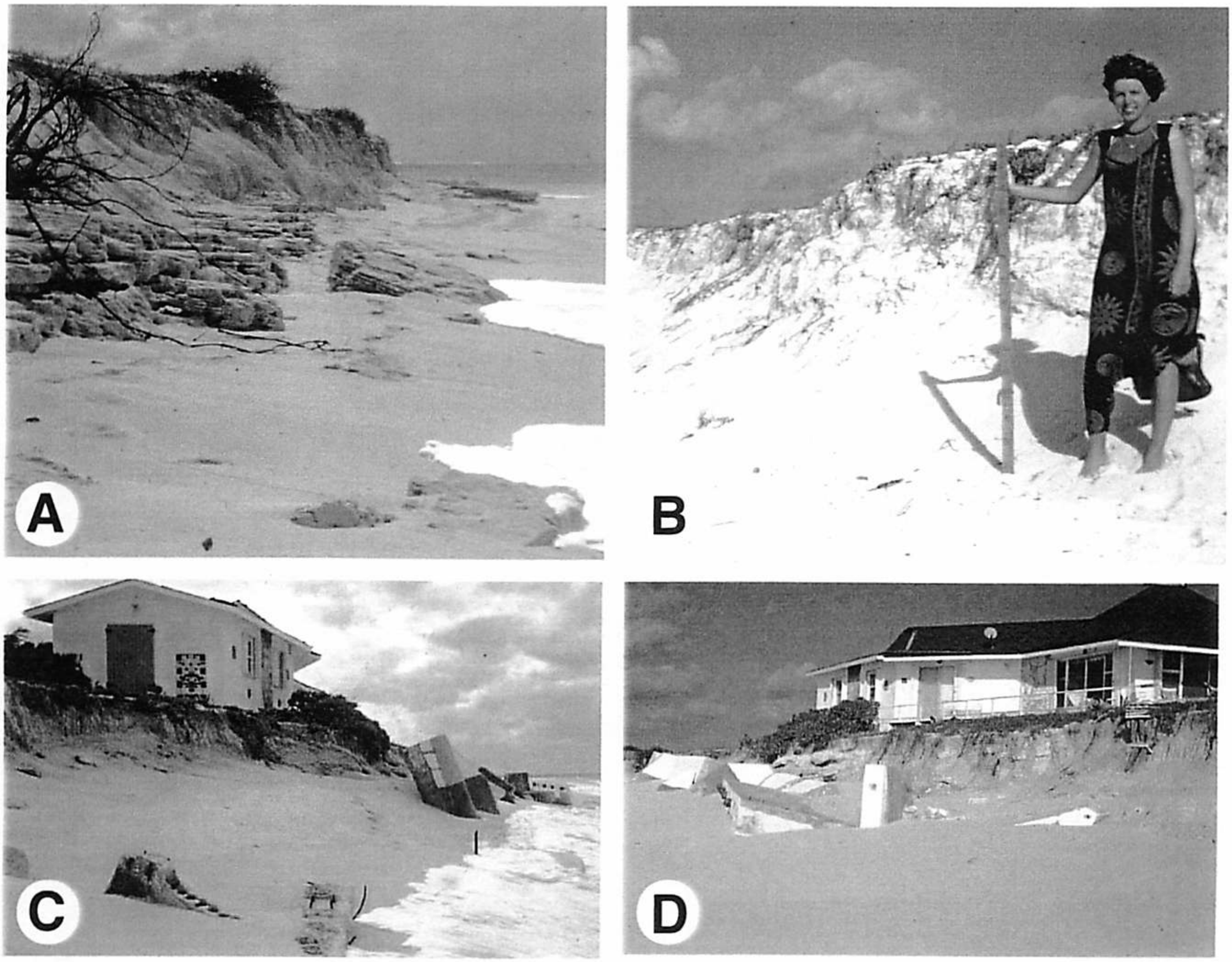

Figure 6. Storm erosion effects in Area 4 – Grotto Bay to Sandy Point: A) Severe beach erosion and scarping immediately south of the section of rocky coast at the south end of Grotto Beach. Note exposed beachrock and the steep scarp cut by wave erosion. B) A continuous scarp was cut into the dunes along the northwestward-facing beach between Grotto Bay and Sandy Point. C) The Savio house viewed from the north; note the remnants of the seawall destroyed by Hurricane Floyd and the vulnerable position of the building's foundation. On this day in January 2000, a weak northwest storm had generated waves that were washing to the base of the scarp. D) Savio house as viewed from the south on a fair-weather day in January 2000.

ably landward by the storm erosion and scarping! The most severely damaged and presently endangered property is the Savio house, located at the southern-most position toward Sandy Point. Prior to Hurricane Floyd, a seawall protected the front of the house. This seawall was flanked and undercut by storm waves and ultimately destroyed by Floyd (Figs. 6C,D).

Figure 7 shows beach profiles made in the early 1990s at a monitoring station located immediately south of the Savio house (Station #3 of Loizeaux et al., 1993). These profiles clearly illustrate the dynamic nature of sand accretion and erosion on this

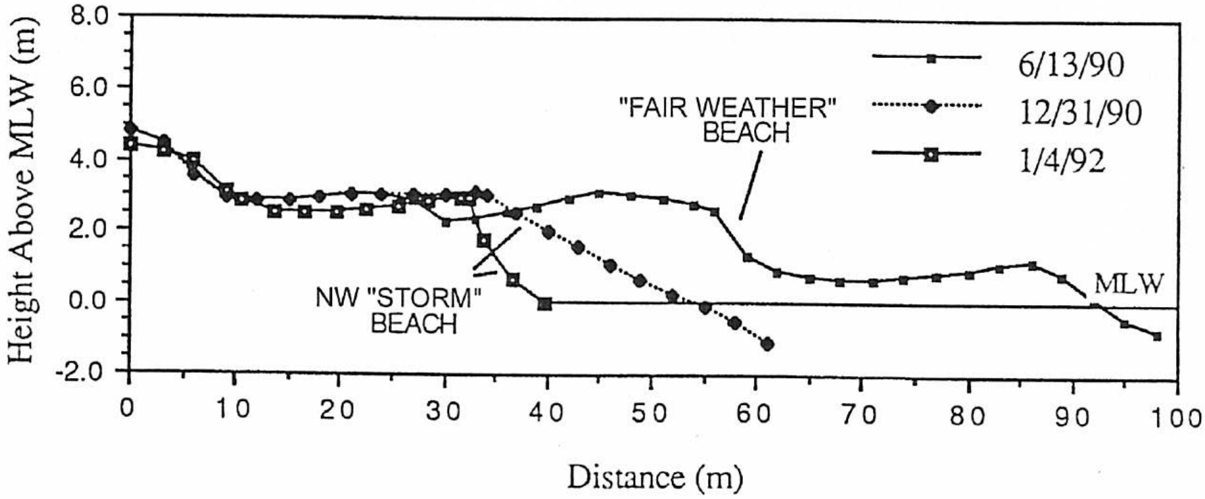

Figure 7. Data from Profile Station #3 of Loizeaux et al., 1993, located immediately to the south of the Savio house. These profiles reveal the dynamic nature of this section of beach, with sediment accretion under "fair weather" conditions generated by easterly Trade Winds versus erosion from the energy of northwest storm waves. Modified from Loizeaux et al. (1993).

section of beach. The views of the Savio house and seawall shown in Figure 8 reveal the waxing and waning of sand supply over time. Following Hurricane Floyd and the collapse of the Savio seawall, the future existence of the house was threatened. Any future northwest storm could generate waves that would cut away at the house's unprotected foundation. Mr. Savio faced a set of unwelcome choices: abandon the property, move the property landward, or attempt an engineering solution. He elected to do the latter, and, as of June 2000, a new seawall was under construction (Fig. 9). This seawall was being constructed of interlocking PVC sections set in a deep trench cut into the beach and anchored with steel girders.

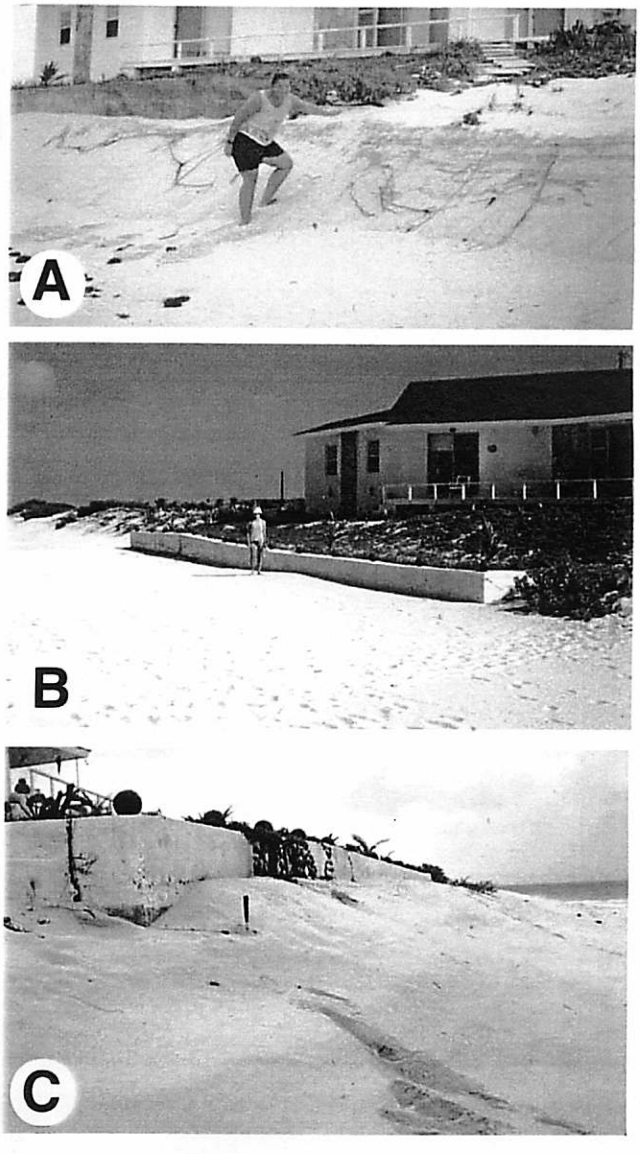

Figure 8. Early 1990s views of the variable conditions of sand supply at the Savio house. A) June 1992 – a scarp was present from a recent northwest storm, but sand was in good supply. B) January 1993 – a prolonged period of fair weather had generated plenty of sand on the Savio beach. C) January 1994 – the beach was steep in front of the Savio seawall, but sand was in good supply.

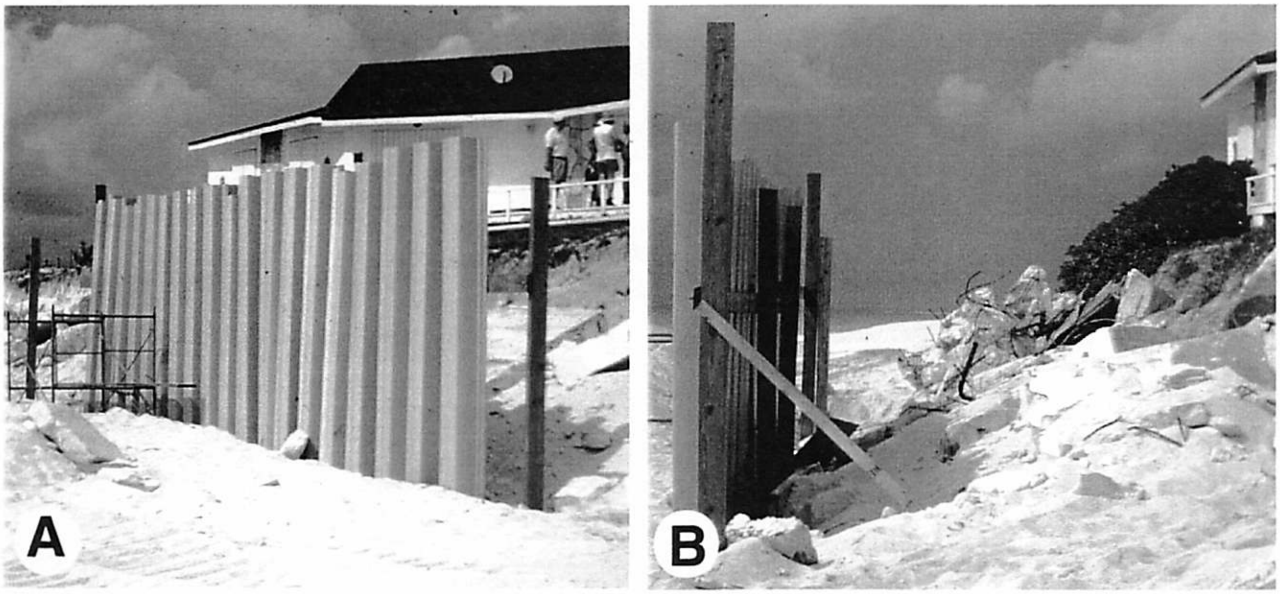

Figure 9. Following Hurricane Floyd, Mr. Savio had to take action to protect the foundation of his house. In June 2000 a seawall was under construction. A) Front view of the seawall, made of interlocking PVC sections. B) View of the seawall construction from the south.

Time will tell how this plan works out, but one thing is certain – the waves of future storms will continue to be a threat to this property and to other properties located in vulnerable positions along San Salvador's coasts.

BRIEF SUMMARY AND CONCLUSIONS

This paper has documented much of the coastal effects of Hurricane Floyd on San Salvador Island. The northern and western coasts of the island were most affected, with the severest erosion and scarping along the island's west coast. Here the storm caused extensive erosion of beach sand, severe scarping of the seaward-facing dune line, frequent overwashing, erosion of rock outcrops and generation of much rock rubble, and widespread damage to vegetation. In addition to these coastal effects, the storm caused much damage to buildings and infrastructure, as documented by Gamble et al. (2000). Given that the scarp eroded in the dune line by Hurricane Lili in October 1996 is still quite obvious at French Bay and elsewhere along the southern coast of the island, it can be predicted that the dune scarps and other coastal erosion effects so evident on San Salvador in January 2000 will remain as a reminder of Hurricane Floyd for many years to come.

In this time of rising sea level, prudent selection of construction sites is a must for most coastal regions. Hurricane Floyd clearly demonstrated the vulnerability of developed areas along San Salvador's western coast, notably Club Med, Riding Rock Inn, and Cockburn Town proper. Sections of The Queen's Highway south of Cockburn Town now are highly vulnerable to wave erosion from any storms from the northwest or west.

The Sandy Point area is one of the most dynamic sections of coastline on San Salvador. Construction sites in this area must be chosen with care and set well back from the active beach. The Savio house at

Sandy Point was severely threatened following collapse of its seawall during Hurricane Floyd. Remedial measures have been taken. Nature now has the next call.

ACKNOWLEDGMENTS

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