FINAL REPORT

A geomorphologic assessment at selected beach sites using imagery analysis (1936-2007) and beach profiling techniques (2009-2010): as a tool to define coastal indicators for management applications.

Playa Vega Baja, Playa Piñones, Loíza; Playa Fortuna, Luquillo; Playa Punta Santiago, Humacao; Playa Salinas, Salinas and El Maní, Mayagüez

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To submit

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STUDY SUMMARY

A geomorphic assessment was done in selected study beaches in Puerto Rico. These sites are: Playa Puerto Nuevo at Vega Baja, Playa Piñones at Loíza, Playa Playa Fortuna at Luquillo, Playa Humacao at Humacao, Playa Salinas at Salinas and Playa Maní at Mayaguez. This study includes an evaluation of historical subaerial beach, beach profile and width changes studies. Historical subaerial beach changes were done using vertical aerial photo from 1936 to 2010 (long-scale study). Beach profile and width were measured using field techniques during on August, September, October, November and December 2010 (short scale study). Data collection was done during normal conditions and after occurrences of storm systems (both Tropical and Extratropical). Permanent profile stations were located on beaches: protected by natural barriers 2) semi protected by natural or man-made barriers 3) exposed to direct impact of waves and swells. This evaluation helps to identifying possible effects of the presence of these barriers causing beach changes in these sites. Also, study sites were located in beaches near communities that may have high vulnerability to natural risk as storm surge, flooding, tsunami, swells, among others. Historical beach changes showed loss of sand in all study sites during 2007 period. Major beach changes were observed at Playa Fortuna, Luquillo and Playa Humacao. Major loss of sand was measured in Playa Fortuna. Minor beach changes were identified in Playa Piñones, Playa Salinas and Playa El Maní. Short scale beach assessment indicated elevation and width suffered changes in all beaches included in this study. Major loss of sand was measured in Fortuna Beach at Luquillo from August to December 2010. Dissipate profile was observed in this beach after the occurrence of storm systems nearby Puerto Rico waters (both Tropical and Extratropical). Minor subaerial beach changes were measured at Vega Baja Beach and Playa Salinas from August to December 2010. Final result showed that geomorphic indicators as eolianites, beach rock, coral reef, sand deposits, rocky shorelines found in beach systems acts a barrier that protect beach plain from erosion processes. Man-made structure as dock, housing and deforestation affect sediment sources and transportation that feed beach systems. Due to these results, these may use as a coastal indicators to define the degree of coastal protection in study sites. These data will helpful to understand the role of natural and man-made variables affecting the geomorphic dynamic in the coast. A detail list of each indicators founded in each site will be includes in this study.

INTRODUCTION

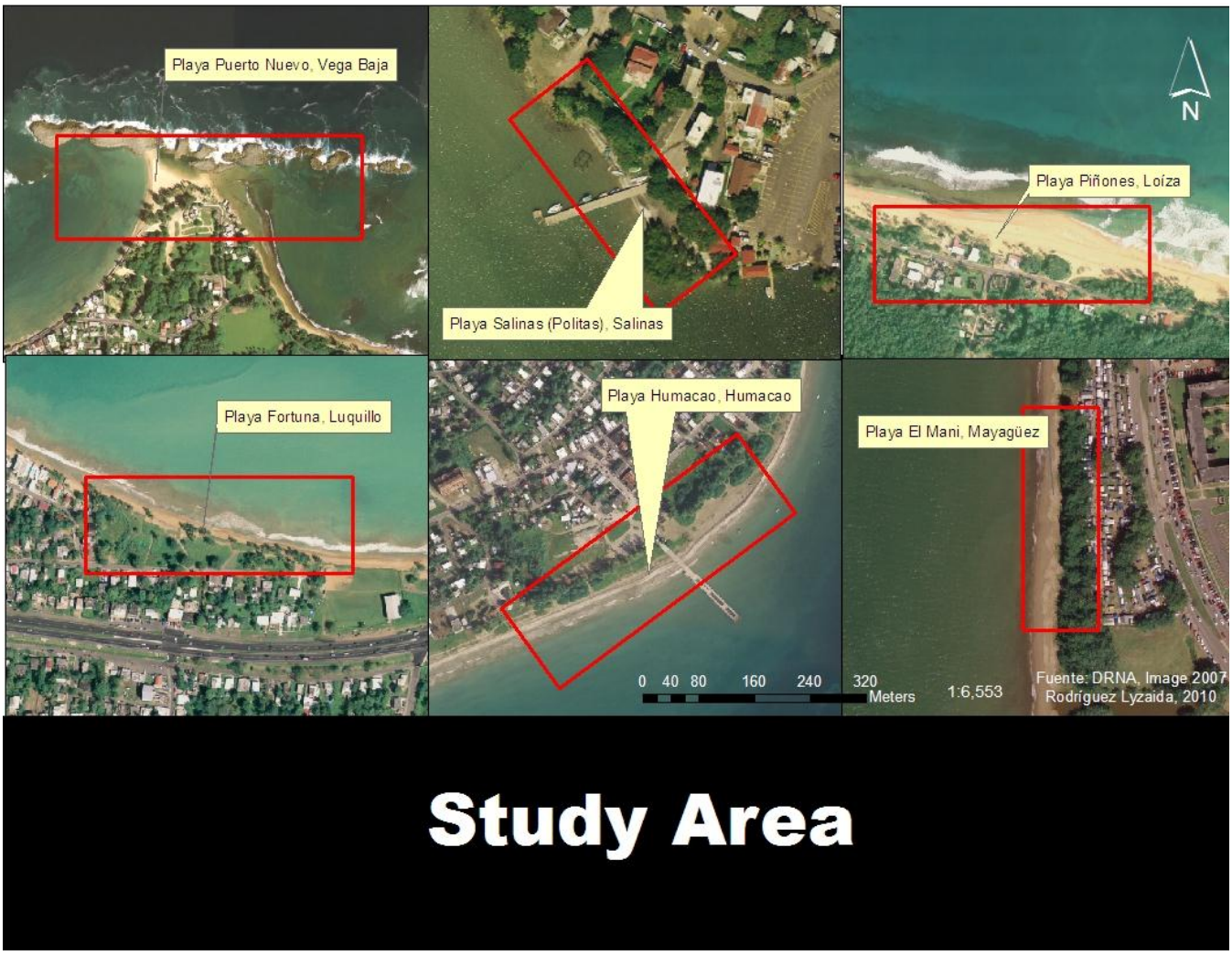
This study was conducted as a petition from The Coastal Zone Division from the Environmental Natural Resources Department (DRNA) as a part of their goal to identify coastal vulnerability/risk and its impact in local communities at Puerto Rico. Also, this study follow the objectives as called for President Barak Obama‘s June 12, 2009 Memorandum related with Ocean, Coastal and Great Lakes Planning. Final results acquired in this scientific study may use to identify geomorphic, oceanographic and anthropogenic coastal indicators that help to understand coastal system and be more effective in Coastal and Marine Spatial Planning as defined by the Interagency Ocean Policy Task Force. “This recommended framework places sound science and the best available information at the heart of decision-making and would bring Federal, State, and tribal partners together in an unprecedented manner to cooperatively develop coastal and marine spatial plans (CMS Plans). This process is designed to decrease user conflict, improve planning and regulatory efficiencies, decrease associated costs and delays, engage affected communities and stakeholders, and preserve critical ecosystem functions and services.” (The White House Council on Environmental Quality, Final recommendations of the Interagency Ocean Policy Task Force, July 19, 2010).

The study includes a detail geomorphic assessment of six selected beach sites in Puerto Rico from August to December 2010. The main objective of this study is defines in detail geomorphic behavior based in historical subaerial beach changes, beach profile and width changes in selected geographical sites. Long term geomorphic changes were done using aerial photos of selected sites from 1936 to 2007. Possible changes in beach configuration were related with natural and anthropogenic events occurred in the areas. Also, short term geomorphic assessment (beach profile and width) were evaluated using field techniques from August to December 2010. Permanent stations were located in protected, semi protected and non-protected areas by natural and /or man-made barriers. The main objective of this evaluation is underlying possible effects of barriers defining beach morphology in the sites.

STUDY AREA

Geomorphic assessments were done in six selected study sites. These are Playa Puerto Nuevo at Vega Baja, Playa Piñones at Loíza, Playa Fortuna at Luquillo, Playa Humacao at Humacao, Playa Salinas at Salinas, and Playa Maní at Mayaguez from August to November 2010.

Figure 1. Beach Study Sites



Playa Puerto Nuevo at Vega Baja

Study site was located from latitude 18˚29’27” to 18˚29’ 32.5” North to Longitude 66˚23’50” to 66˚23’56.3” West (NAD 83 Datum). Playa Puerto Nuevo is located in the municipality of Vega Baja on the north-central coast of Puerto Rico. The beach is oriented northwest and north. The beach is defined as a mixed biogenic and terrigenous beach where sediments come from Río Cibuco (located eastward to the study site) and marine platform sources. The area may classify as protected and semi protected coastline from the direct impact of seas and swells arriving from North Atlantic. Presence of eolianite and beachrock offers protection to the beach and shoreline located in the site.

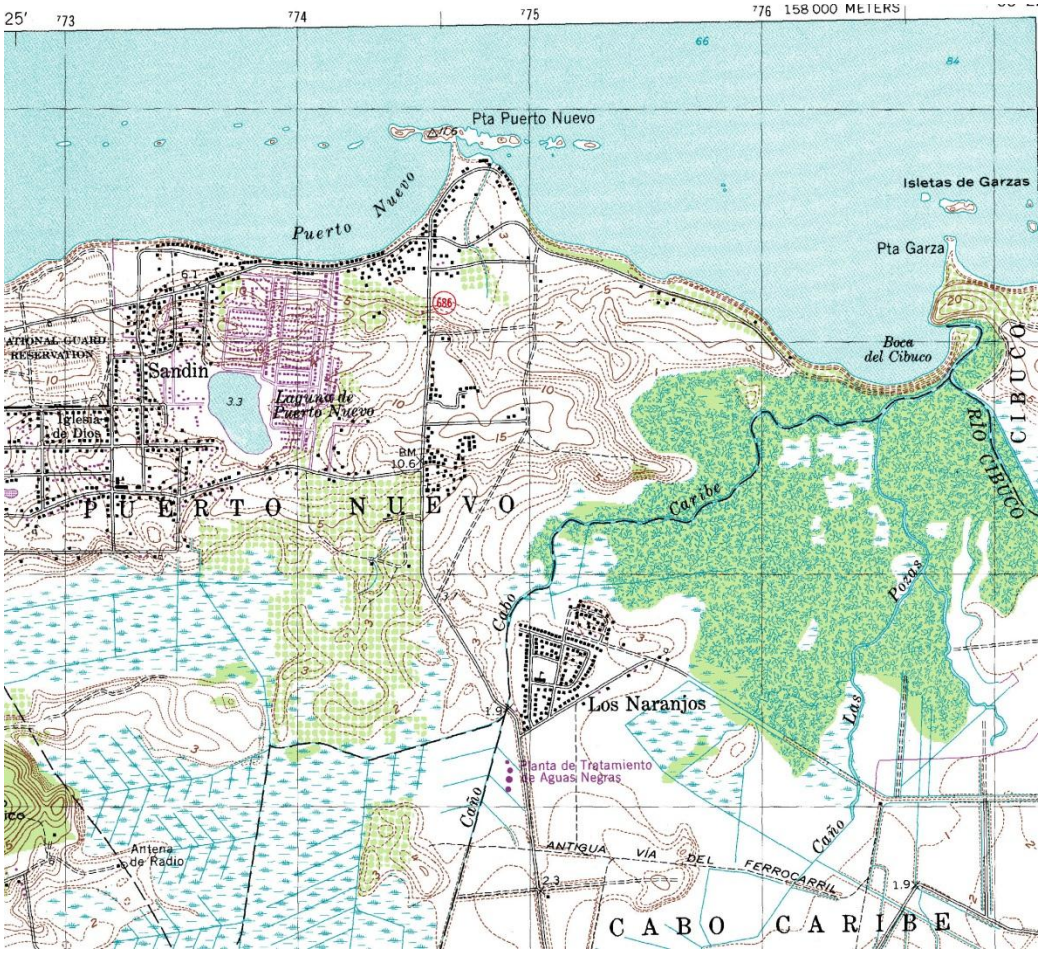


Figure 2. Topographic Map, Source: US Geological Survey (USGS). Topographic map showed eolianites on the northward to the beach.

Playa Piñones at Loíza

Study site was located from latitude 18˚27'3.2" to 18˚27' 3.9" North to Longitude 65˚57'24.7" to 65˚57'28.5" West. Playa Piñones is located in the municipality of Loíza in the northeast coast of Puerto Rico. The beach is oriented to the northeast. The beach is defined as a biogenic beach. Few terrigenous types of sediment were observed in the beach coming from Rio Grande de Loíza discharge during field study. Dunes, vegetated dunes, eolianites and beachrock were identified in the study site. Dunes protect the beach and offer sand sources to feed the beach. Eolianite and beachrock protect shoreline from the direct wave attack approaching from Atlantic Ocean.

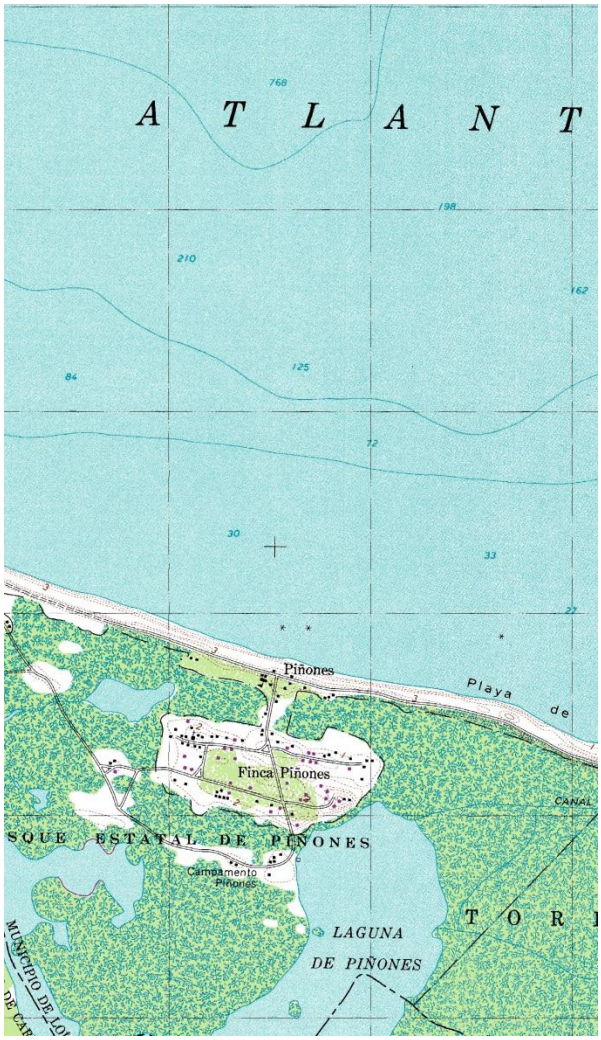


Figure 3. Carolina Topographic Map. Source US Geological Survey.

Playa Fortuna at Luquillo

Study site was located from latitude 18˚22’48.6” to 18˚22’ 52.5” North to Longitude 65˚44’26.7” to 65˚44’39.4” West. Playa Fortuna is located in the municipality of Luquillo in the northeast coast of Puerto Rico. The beach is oriented to the north. The beach can be defined as a biogenic beach with low terrigenous sediment patches. The area is exposed to seas and swells approaching from the North Atlantic. Dunes and beachrock were not found in the site. Housing, recreational areas were found near beach stations selected in this study.

Figure 4. Luquillo Topographic Map. Source US Geological Survey.

Playa Humacao at Humacao

Study site was located from latitude 18˚09’46.7” to 18˚09’ 50.4” North to Longitude 65˚44’35.9” to 65˚44’44” West (NAD 83 Datum). Playa Humacao is located in the municipality of Humacao on the east coast of Puerto Rico. The beach is oriented southeast. The beach is defined as a mixed biogenic and terrigenous beach. The area may classify as protected coastline by cays and man-made structures.

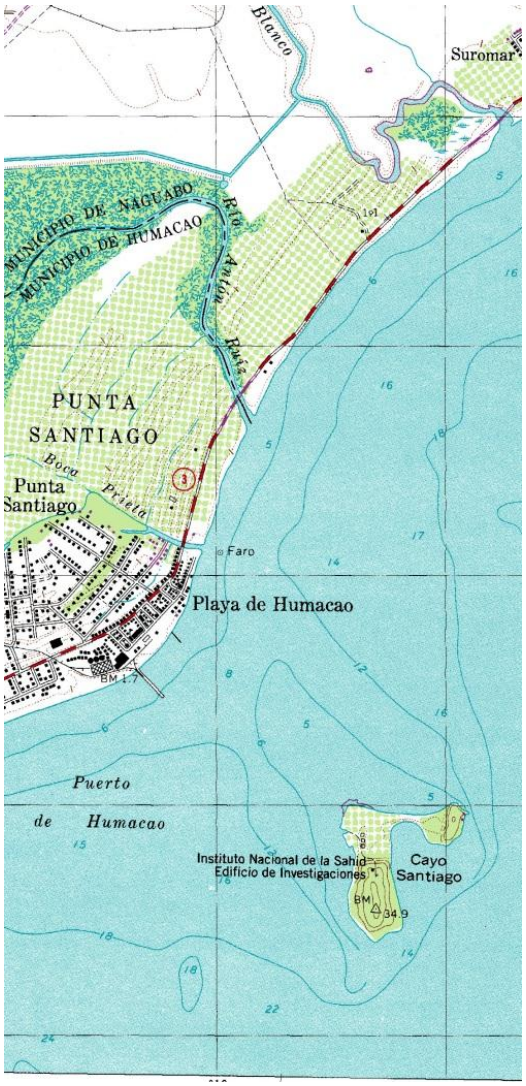


Figure 5. Naguabo Topographic Map. Source US Geological Survey.

Playa Salinas at Salinas

Study site was located from Latitude 17˚53’33.8” to 17˚57’ 36.1” North to Longitude 66˚17’52” to 66˚17’53.7” West. Playa Salinas is located in the municipality of Salinas on the south coast of Puerto Rico. The beach is oriented southwest. The beach is defined as a mixed biogenic and terrigenous beach. The beach is protected by mangrove island, mangrove shoreline, and cays. Seagrass beds and coral were found in the nearshore area.

Figure 6. Salinas Topographic Map. Source US Geological Survey.

Playa Maní at Mayagüez

Study site was located from Latitude 18˚13’53.8” to 18˚29’ 32.5” North to Longitude 66˚23’50” to 66˚23’56.3” West. Playa Maní is located in the municipality of Mayagüez on the west coast of Puerto Rico. The beach is oriented west. The beach is defined as a terrigenous beach. Barriers as a beachrock among others are not observed in the beach. The backbeach beach is protected by vegetation.

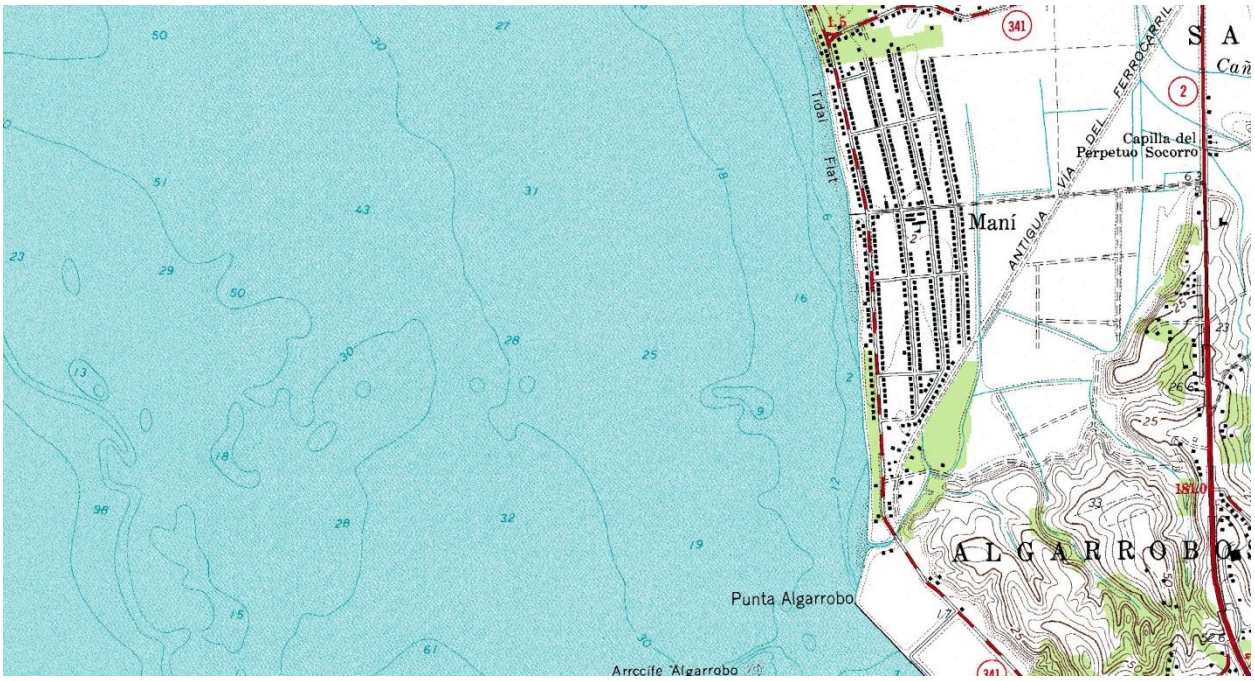


Figure 7. Mayaguez Topographic Map. Source US Geological Survey.

GENERAL SOCIO-ECONOMIC PROFILE OF COMMUNITIES LOCATED NEAR BEACH SITES INCLUDE IN THIS STUDY

Included is a general socio-economic profile of communities located near beach systems included in this study. The profile includes demographic variables as community population, median age, education level, poverty level (%), household income, occupancy type, median rent for 2000. This data was acquired from CENSUS data through “Encuesta de la Comunidad”.

Playa Puerto Nuevo at Vega Baja

This study site is located in Puerto Nuevo Barrio at Vega Baja in the north coast of Puerto Rico. This area has approximately 340 family units with a total population of 5,493 in 2000. Median age is 33.8 years old. Median Educational level in members of this community is mainly high school degree. Forty seven percent (47%) living in poverty level. Median household income is $16,808. Major infrastructure are using as a recreational area (62.8%). Residences are mainly use for rent or are vacant. Median rent is $329.00. Housing occupancy in Puerto Nuevo Barrio is 78.82%.

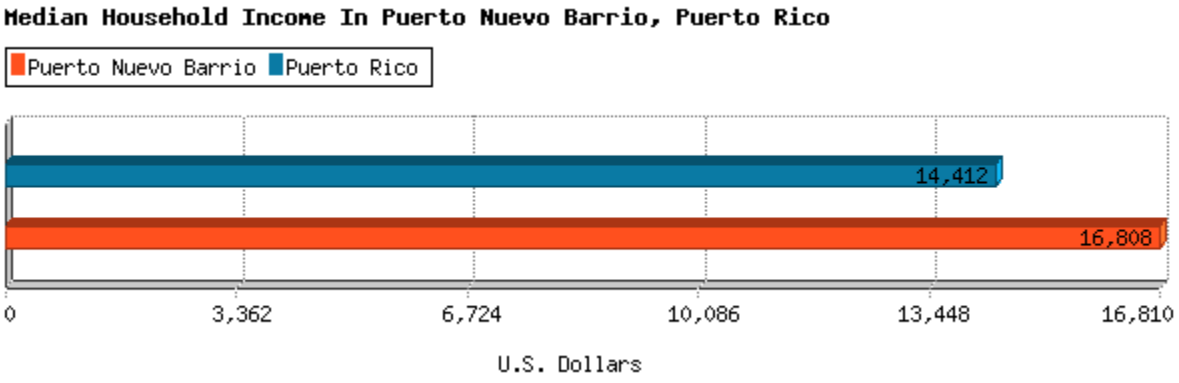


Figure 8. Median Household Income in Puerto Nuevo Barrio, Vega Baja, PR (2000). Source: Encuesta de la Comunidad, 2000.

Playa Piñones at Loíza

This study site is located in Barrio Torrecilla Baja at Loíza in the northeast coast of Puerto Rico. This community has a total population of 1,209 in 2000 (Encuesta de la Comunidad, 2000). Median age of this population is 31 years old. Educational level in members of this community is mainly high school degree. Sixty nine percent (69%) living in poverty level (entire Island 49%). Median household income is $7,138. Major infrastructure are using for rent and recreational area. Median rent of housing is $425. Housing occupancy in Torrecilla Baja Barrio is 89%.

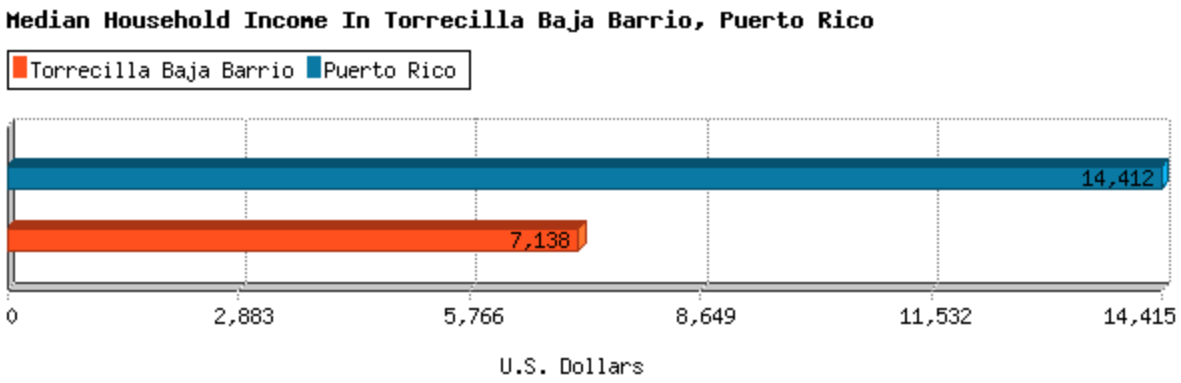


Figure 9. Median Household Income in Torrecilla Baja, Loiza, PR (2000). Source: Encuesta de la Comunidad, 2000.

Playa Humacao at Humacao

This study site is located in Punta Santiago Community at Humacao in the east coast of Puerto Rico. This community has a total population of 5,083 in 2000 (Encuesta de la Comunidad, 2000). Median age of this population is 30 years old. Educational level in members of this community is mainly high school degree. Fifty percent (50%) living in poverty level that is upper than Island level (49%). Median household income is $13,271. Major infrastructure are using for recreational area. Median Rent in the community is $297. Housing occupancy in Punta Santiago is 78.42%.

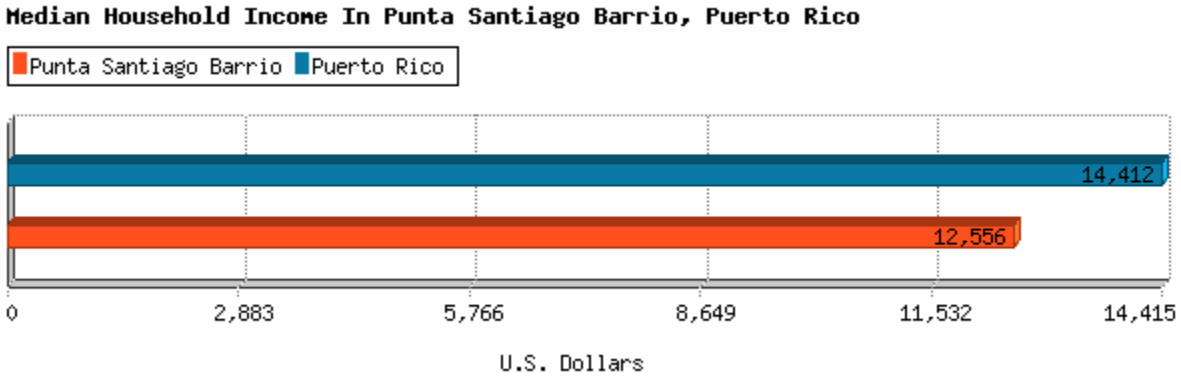


Figure 10. Median Household Income in Punta Santiago, Humacao, PR (2000). Source: Encuesta de la Comunidad, 2000.

Playa Salinas at Salinas

This study site is located in Playita Community at Salinas in the southeast coast of Puerto Rico. This community has a total population of 673 in 2000 (Encuesta de la Comunidad, 2000). Median age of this population is 33.6 years old. Educational level in members of this community is mainly high school degree. Fifty nine percent (59%) living in poverty level that is upper poverty level of the entire Island (49%). Median household income is $11,328. Major infrastructure are using as a recreational use. Median rent in the community is $202. Housing occupancy in Playita Community is 80%.

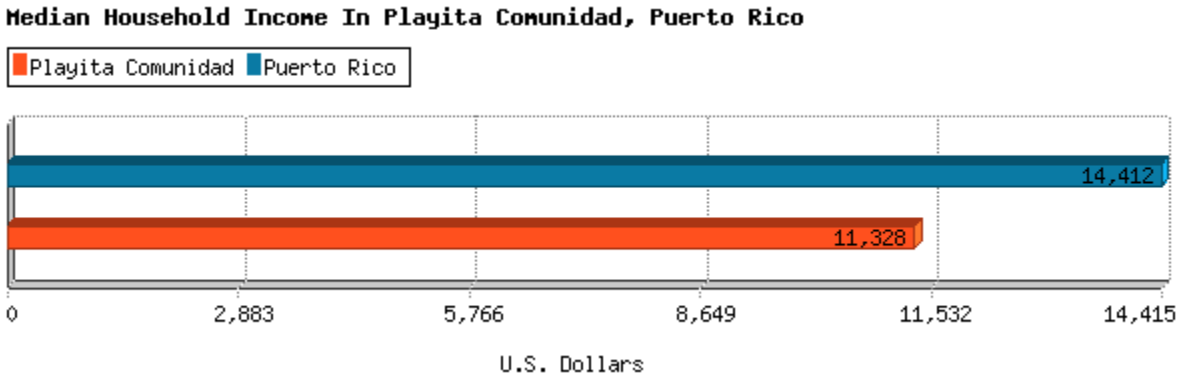


Figure 11. Median Household Income in Playita Comunidad, Salinas, PR (2000). Source: Encuesta de la Comunidad, 2000.

El Maní at Mayaguez

This study site is located in Barrio Algarrobo at Mayaguez in the west coast of Puerto Rico. This community has a total population of 4792 in 2000 (Encuesta de la Comunidad, 2000). Median age of this population is 38 years old. Educational level in members of this community is mainly high school degree and bachelor degree. Forty percent (40%) of this population living in poverty level that is under poverty level of the entire Island (49%). Median household income is $17,210. Major infrastructure are using for sale and recreational area. Median rent in the community is $422. Housing occupancy in Algarrobo Barrio is 87.7%.

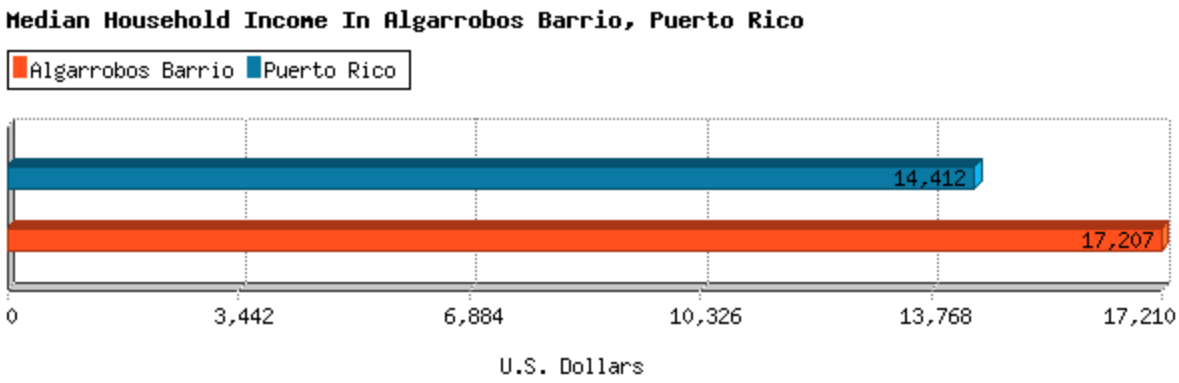


Figure 12. Median Household Income in Algarrobos Barrio, Mayagüez, PR (2000). Source: Encuesta de la Comunidad, 2000.

METHODOLOGY

An integration of remote sensing (historical aerial photographs evaluation), Geographic Information System (GIS) and field work (profile measures and field observation) were done to assess beach geomorphic process in selected coastal sites. As a final step, an identification of coastal indicators was done based on scientific data acquired. A list of recommendation was done to guide planners and users to understand beach system included in this study.

Historical shoreline evaluation

Vertical historical aerial photo were acquired from DRNA Coastal Zone Division. These photos were scanned in 600 dpi with 100% (Personal communication, Cuadrado, 2010). Digital distorted aerial photo were rectified and georeferenced using Arc GIS software. Control point as infrastructure and roads (one and second level control points) were selected in each photo for rectification process. North American 1983 datum (NAD 83) was used as base datum in the georectification process (degree, minutes and seconds format).

Subaerial beach was used as an unit to define historical changes between study areas. Subaerial beach is defined as beach plain extent from vegetation line or dune base to wet line (beach swash zone). The wet line was used as an indicator for define seaward limit of subaerial beach (shoreline). The use of wet line is a useful indicator to easily identification of shoreline due to its dark color in the aerial photograph. Historical shoreline changes studies will be done for selected coastal sites according to availability of the photos.

Table 1.Aerial Photographs selected for evaluate historical beach dynamic (1936 to 2010)

Beach	Year								
	36	50	51	63	71	77	87	97	2010
Puerto Nuevo	x	x	*	X	*	x	*	X	x
Piñones	*	*	x	X	x	x	x	X	x
Fortuna	*	x	*	X	*	x	x	X	x
Humacao	x	x	*	X	x	*	*	x	x
Salinas	*	*	x	X	*	x	x	x	x
Maní	*	*	x	X	*	*	x	x	x

*data no available

Polygons were defined using the criteria of definition of the subaerial beach described above. Polygons were measured in square meters using ArcGIS tool to evaluate changes between photos. Final maps were prepared showed study site and polygons for evaluate qualitative changes in morphology between periods.

Beach profiles

Elevation (meters) and subaerial beach width (meters) were measured for all selected beach sites. Beach orientation and profile locations were defined using a Global Positioning System (GPS) GARMIN Oregon 550t Model. Beach elevation and width were measured using a level, calibrated rod and metric tape. The boundaries of profile studies were from the vegetation line and/or dune base to a distance from the shoreline. This distance was variable according to accessibility to the submarine beach (wave action). Three beach profile station were selected in each beach system (Table x). The presence or absence of natural barriers as eolianita, beachrock, mangrove, coral reef, seagrass and algae beds was one of the criteria used to defined beach stations. Permanent profile stations were located on beaches: protected by natural barriers 2) semi protected by natural or man-made barriers 3) exposed to direct impact of waves and swells. This information is very helpful to evaluate the possible relation between beach profile dynamic and the degree of protection of the beach. Profiles were measured before and after occurrence of storm systems nearby Puerto Rico waters. Detail beach monitoring was done after the passage of Tropical System Danielle, Earl, Igor, and Tomas.

Table 2. Location of beach profile stations included in this study.

Beach Profile Station	Latitude	Longitude	Municipality	Presence of barriers
VBP1	18˚29’32.3”N	66˚23’50.1”W	Vega Baja	Yes: eolianite BR
VBP2	18˚29’32.3”N	66˚23’51.8”W	Vega Baja	Yes: eolianite BR
VBP3	18˚29’27”N	66˚23’56.4”W	Vega Baja	No: exposed
PBP1	18˚27’4.2”N	65˚57”29.5”W	Loíza	Yes: dunes, BR
PBP2	18˚27’3.3”N	65˚57’27.6”W	Loíza	Yes: dunes, BR
PBP3	18˚27’3.2”N	65˚57’27.1”W	Loíza	No: exposed
FBP1	18˚22’48.7”N	65˚44’26.8”W	Luquillo	Yes: protected
FBP2	18˚22’49.6”N	65˚44’31”W	Luquillo	No: exposed
FBP3	18˚22’52.4”N	65˚44’39.5”W	Luquillo	No: exposed
HBP1	18˚09’46.7”N	65˚44’44.1”W	Humacao	Yes: dock
HBP2	18˚09’49.6”N	65˚44’37.8”W	Humacao	Yes: dock
HBP3	18˚09’50.4”N	65˚44’35.9”W	Humacao	No: exposed
SBP1	17˚57’36”N	66˚17’53.6”W	Salinas	Yes: mangrove
SBP2	17˚57’34.7”N	66˚17’52.5”W	Salinas	No: exposed
SBP3	17˚57’33.6”N	66˚17’52.2”W	Salinas	Yes: mangrove
MBP1	18˚13’57.6”N	67˚10’23.7”W	Mayaguez	No: exposed
MBP2	18˚13’56.0”N	67˚10’23.7”W	Mayaguez	No: exposed
MBP3	18˚13’53.8”N	67˚10’23.6”W	Mayaguez	No: exposed

BR= beachrock

Figure 13. Beach Profile stations at Playa Puerto Nuevo, Vega Baja, 2010.

Figure 14. Beach Profile 2, Playa Puerto Nuevo, Vega Baja

Figure 15. Beach Profile stations at Piñones, Loíza, 2010.

Figure 16. Beach profile station 1 at Playa Piñones.

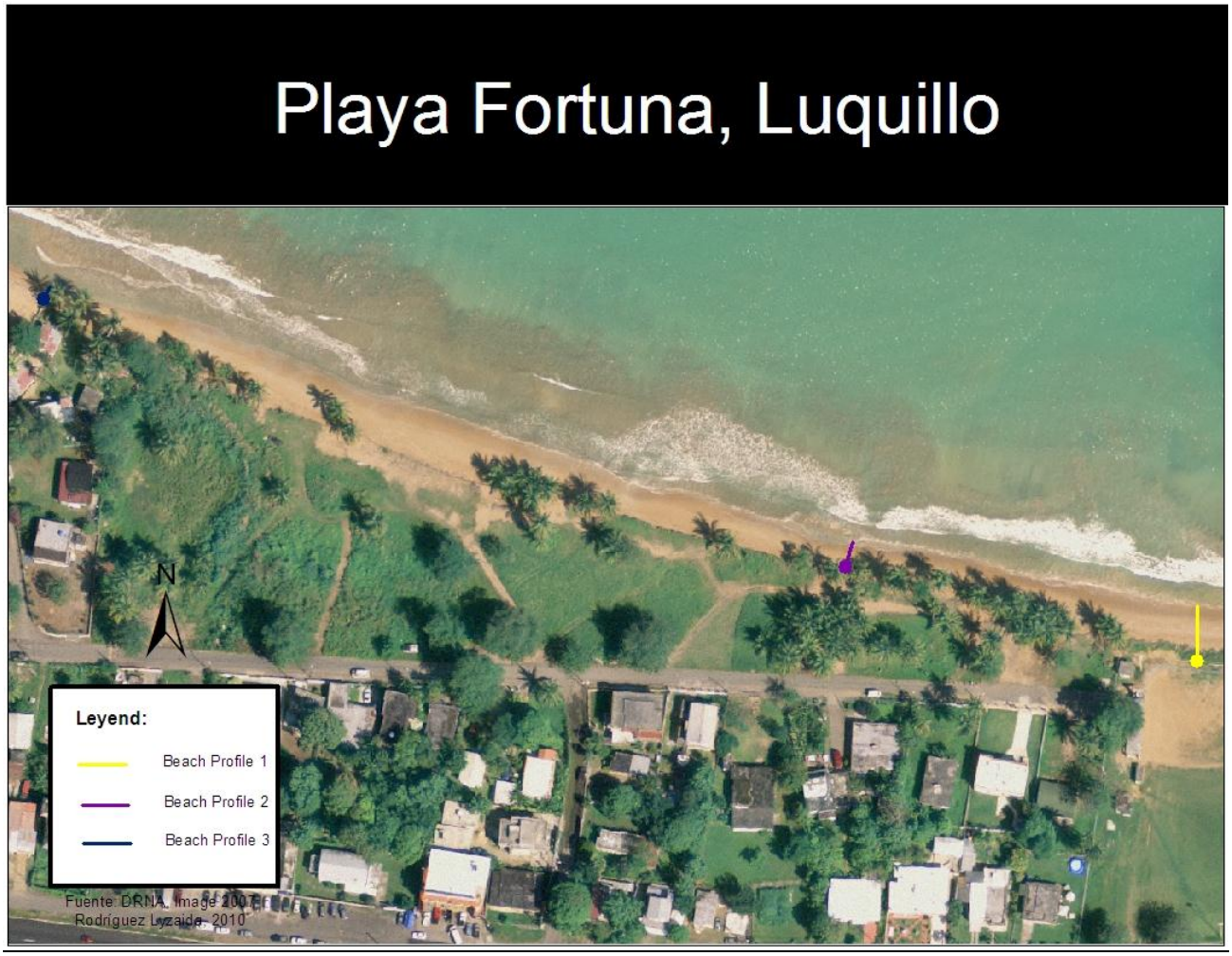


Figure 17. Beach Profile stations at Playa Fortuna, Luquillo, 2010.

Figure 18. Beach Profile station1 at Playa Fortuna.

Figure 19. Beach Profile stations at Playa Humacao, Humacao, 2010.

Figure 20. Beach Profile station 1 at Playa Humacao.

Figure 21. Beach Profile stations at Playa Salinas, Salinas, 2010.

Figure 22. Beach Profile station 1 at Playa Salinas.

Figure 23. Beach Profile stations at Playa El Maní, Mayaguez, 2010.

Figure 24. Beach Profile station at Playa El Maní.

RESULTS

Long term evaluation: Historical subaerial beach changes

An evaluation of subaerial beach deposits showed loss of sand in all study sites for 2007 period (Table x). Major losses of sand were found in Playa Fortuna (36,047m²) and Playa Humacao (7,105m²) during this period. Minor sand losses were observed at Playa Salinas (410 m²). Accretion was measured in all study sites located on the south and west coast of the Island (Playa Humacao (6,897 m²), El Maní (6,301 m²) and Playa Salinas in 1997. No data are available for evaluate beach sites on the north coast for this period. Each beach site showed diverse morphology and measures in subaerial beach between periods.

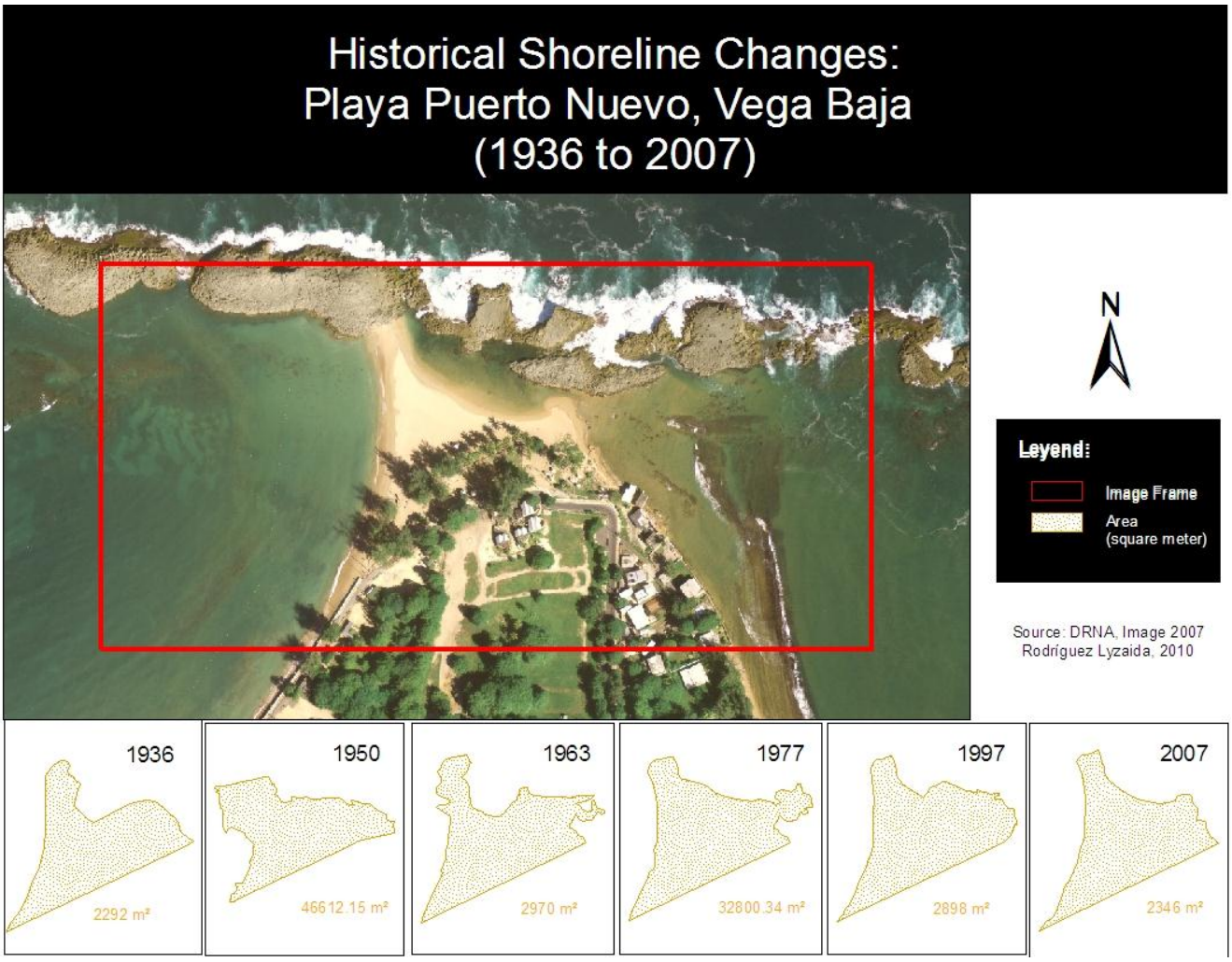
Table 3. Sand loss (m²) in subaerial beach measured in aerial photographs by year.

Study Site	Sand loss (m²) by period							
	1936	1950	1963	1971	1977	1987	1997	2007
Puerto Nuevo		+44320	-43642		+29830	-29902	n/a	-552
Piñones	n/a				-984	-1424	n/a	-746
Fortuna	n/a					22394	n/a	-36047
Humacao		n/a		-1184	n/a		+6897	-7105
Salinas	n/a			n/a		-503	+246	-410
Maní	n/a		+3654	-827	-1680	-1999	+6301	-6718

-erosion + accretion

Playa Puerto Nuevo at Vega Baja

Shift from erosion to accretion was observed at Playa Puerto Nuevo. Accretion was measured in beach during 1950 and 1977. Extensive sand deposits were seen in landward site of eolianites. This barrier apparently acts as a barrier that traps sediment inshore. Major morphology changes were identified in the northeast beach site where eolianite were discontinuous. No data was found to identify possible causes of produce extensive sand accumulation in the site but it may related with swells and seas occurrence in the area. Important sand losses in subaerial beach were observed starting from 1987. A decrease in sediment loss was found in 2007. No data are available to identified possible causes of reduction of sand loss.



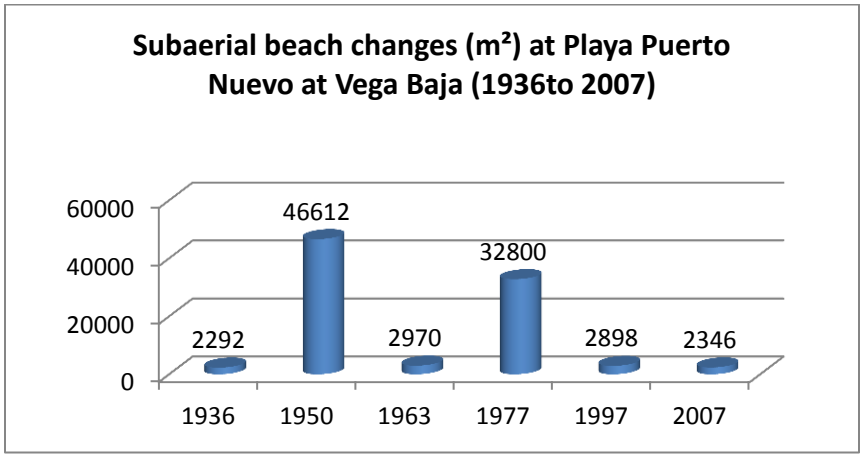


Figure 25. Subaerial beach deposit changes at Plata Puerto Nuevo at Vega Baja (1936-2007)

Playa Piñones at Loíza

Continuous loss of sand was measured in Playa Piñones from 1977 to 2007. Subaerial beach changes are from 746 to 1424 m² approximately each ten years. Cuspate beach morphology was formed on the northeast site of the subaerial beach during 2007. This deposit is composed of coarse sand which has been molded by constructive waves emanating from two different directions.

Playa Fortuna at Luquillo

Important sand accumulation was measured in Playa Fortuna during 1987 (22,394 m²). Shift from accretion to major erosion was identified in the subaerial beach during 2007 (36,047m²). Major loss of sand was measured in the northwest side of the beach plain where major housings were found it.

Playa Humacao at Humacao

Shift from erosion to accretion and vice versa was observed in Playa Humacao at Humacao from 1971 to 2007. Major beach accretion was identified during 1997. Major loss of sand was measured in 2007.

Playa Salinas at Salinas

Accretion was measured in Playa Salinas during 1963. Shift accretion to erosion was measured in Playas Salinas in 1987. Loss of sand may related with man-made activities as housing, dock construction in the area after 1978. Erosion was observed in subaerial beach during 2007 (410m²).

Playa El Maní at Mayaguez

Continuous erosion was observed in Playa El Maní, except for 1997 period where accretion was found it. Major loss of sand was measured during 2007 (6,718m²).

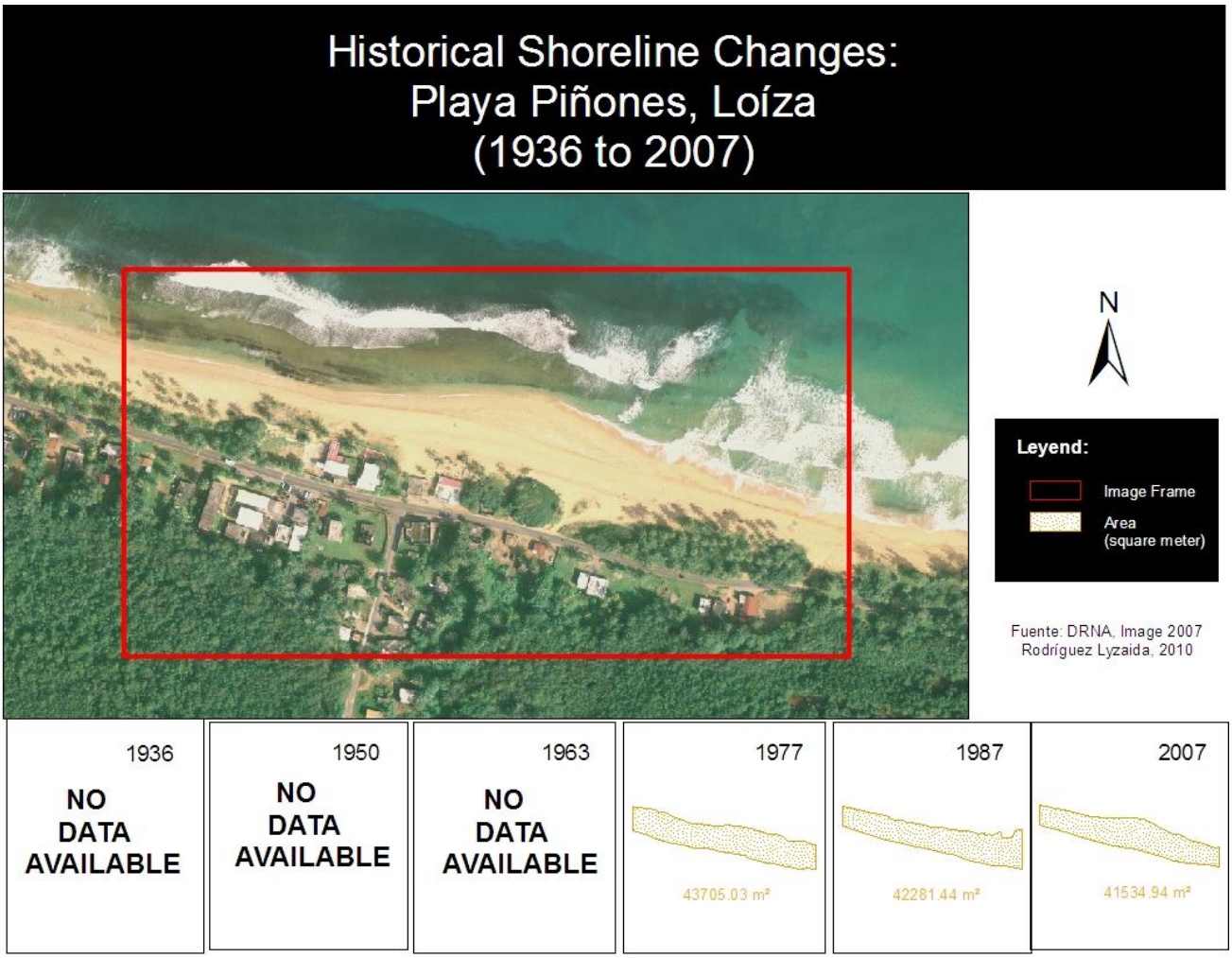


Figure 26. Subaerial beach changes at Playa Piñones.

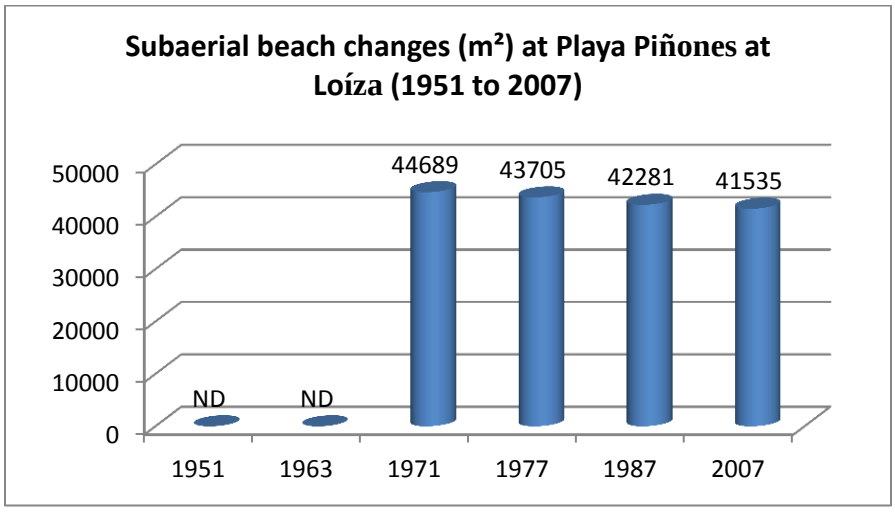
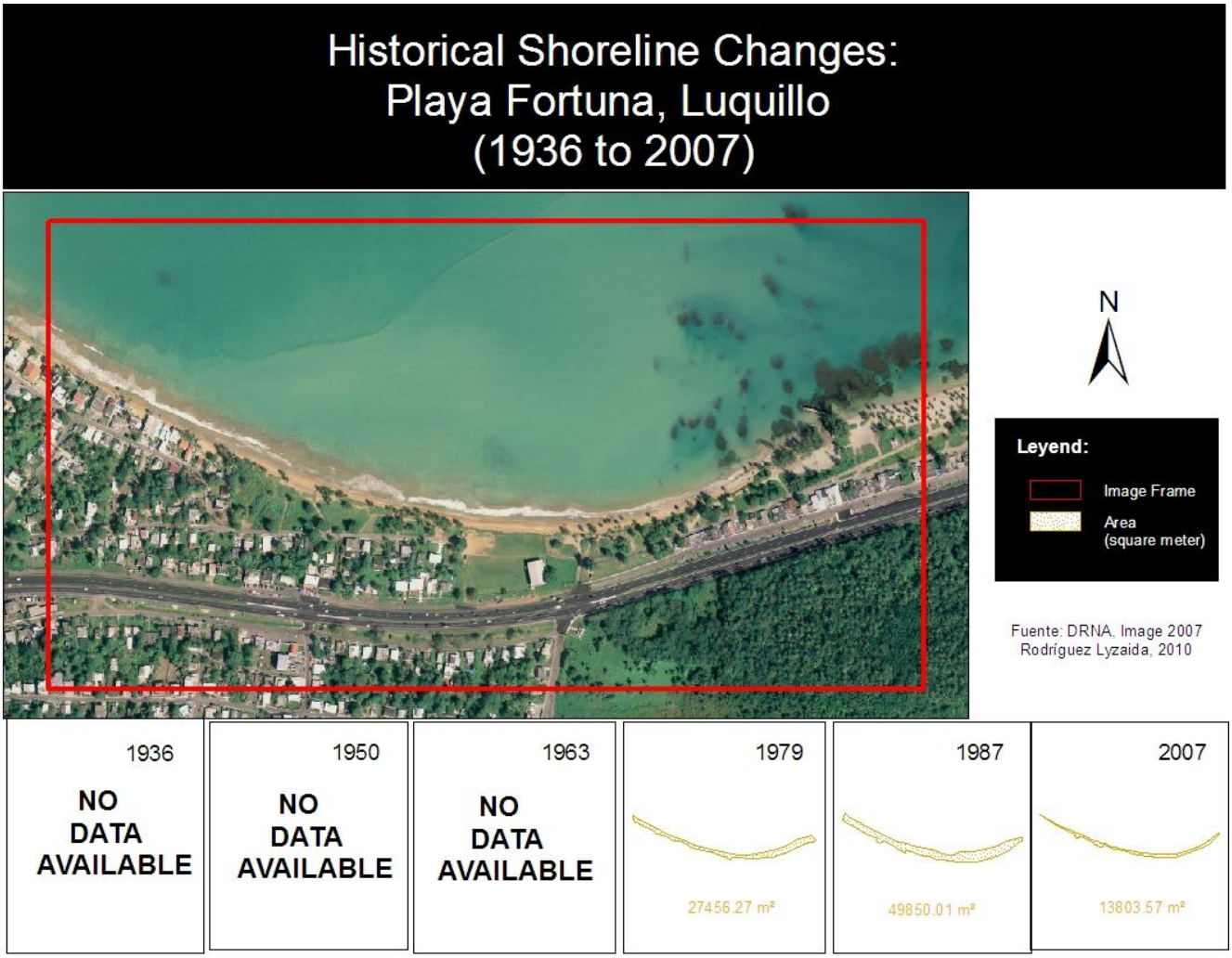


Figure 27. Subaerial beach changes at Playa Piñones.



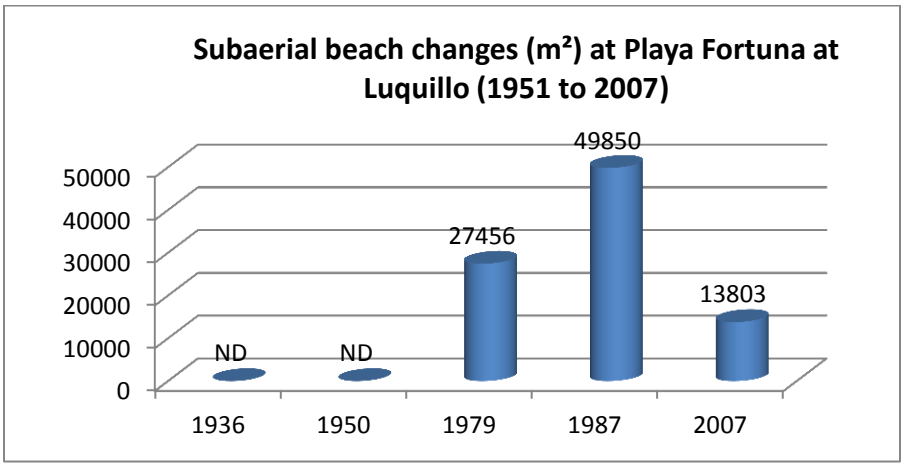
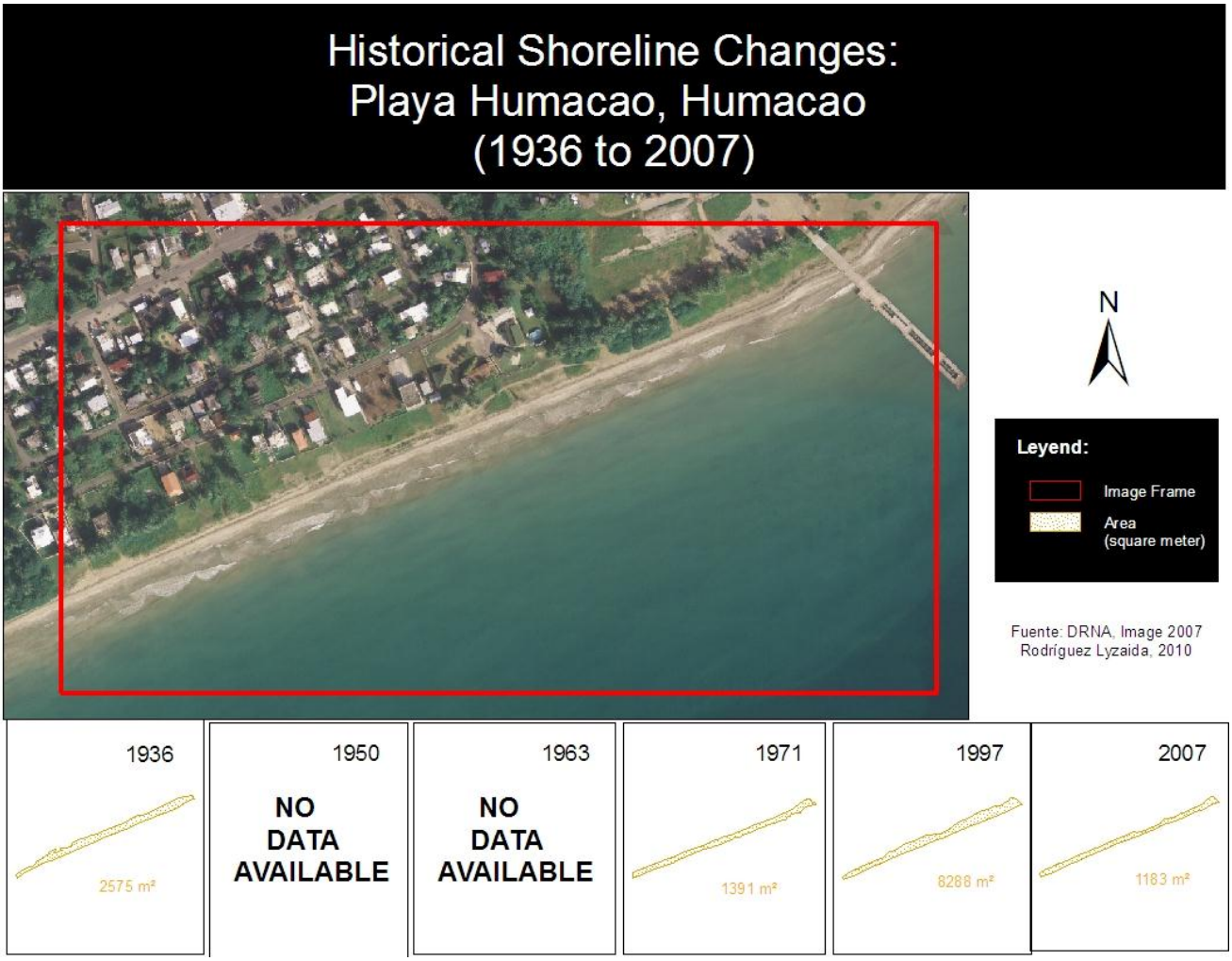


Figure 28. Subaerial beach changes at Playa Fortuna



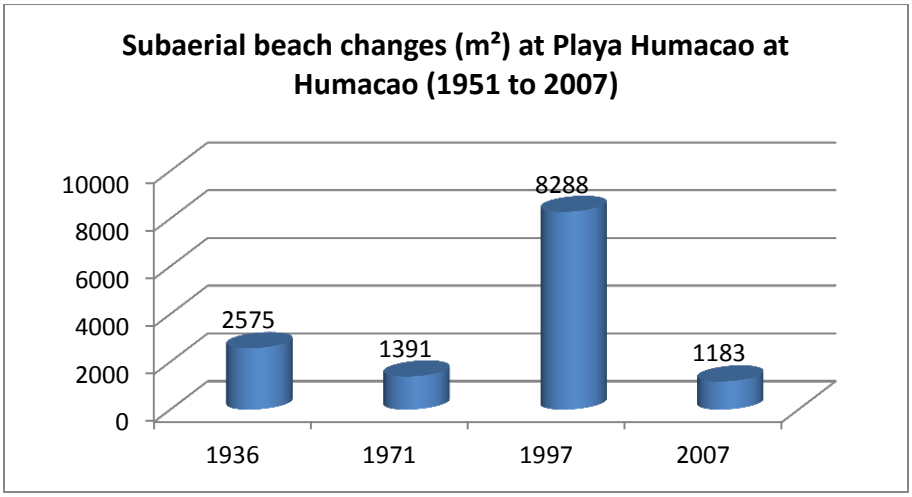
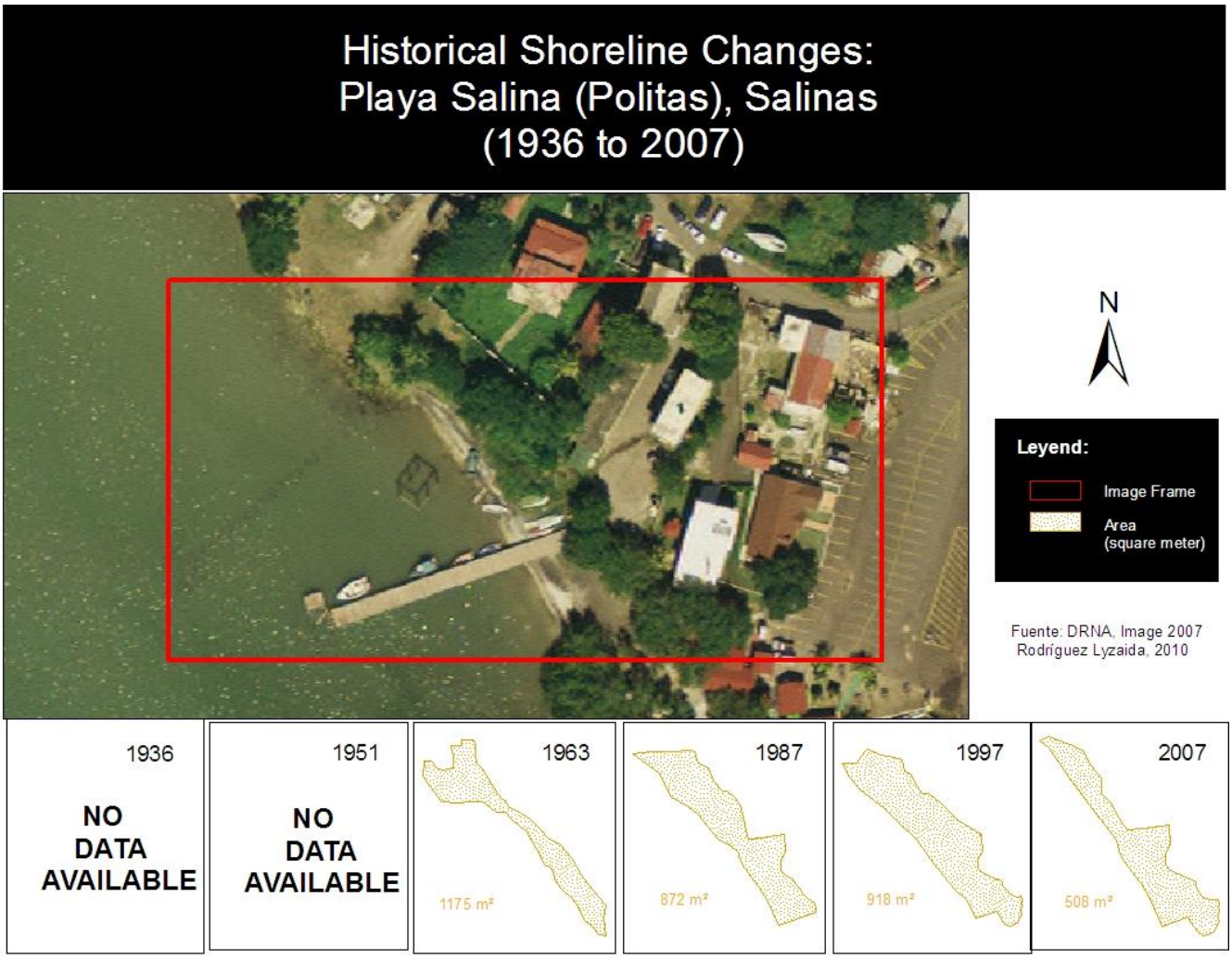


Figure 29. Subaerial beach changes at Playa Humacao



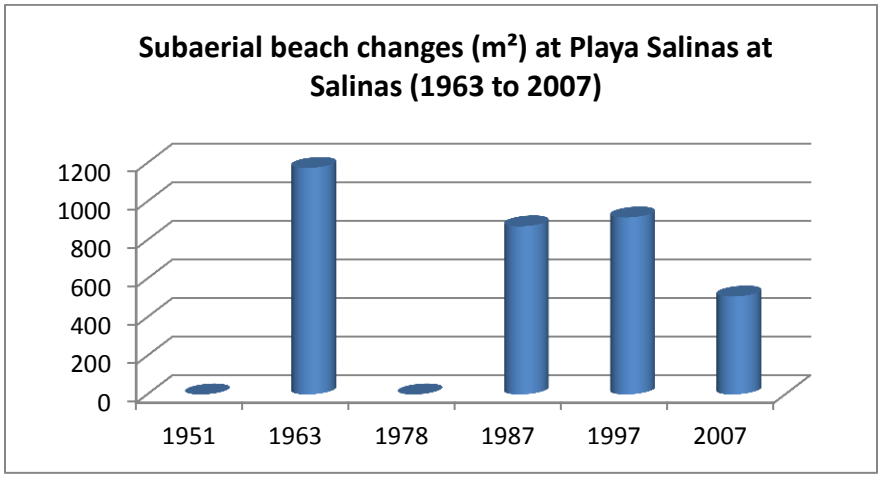
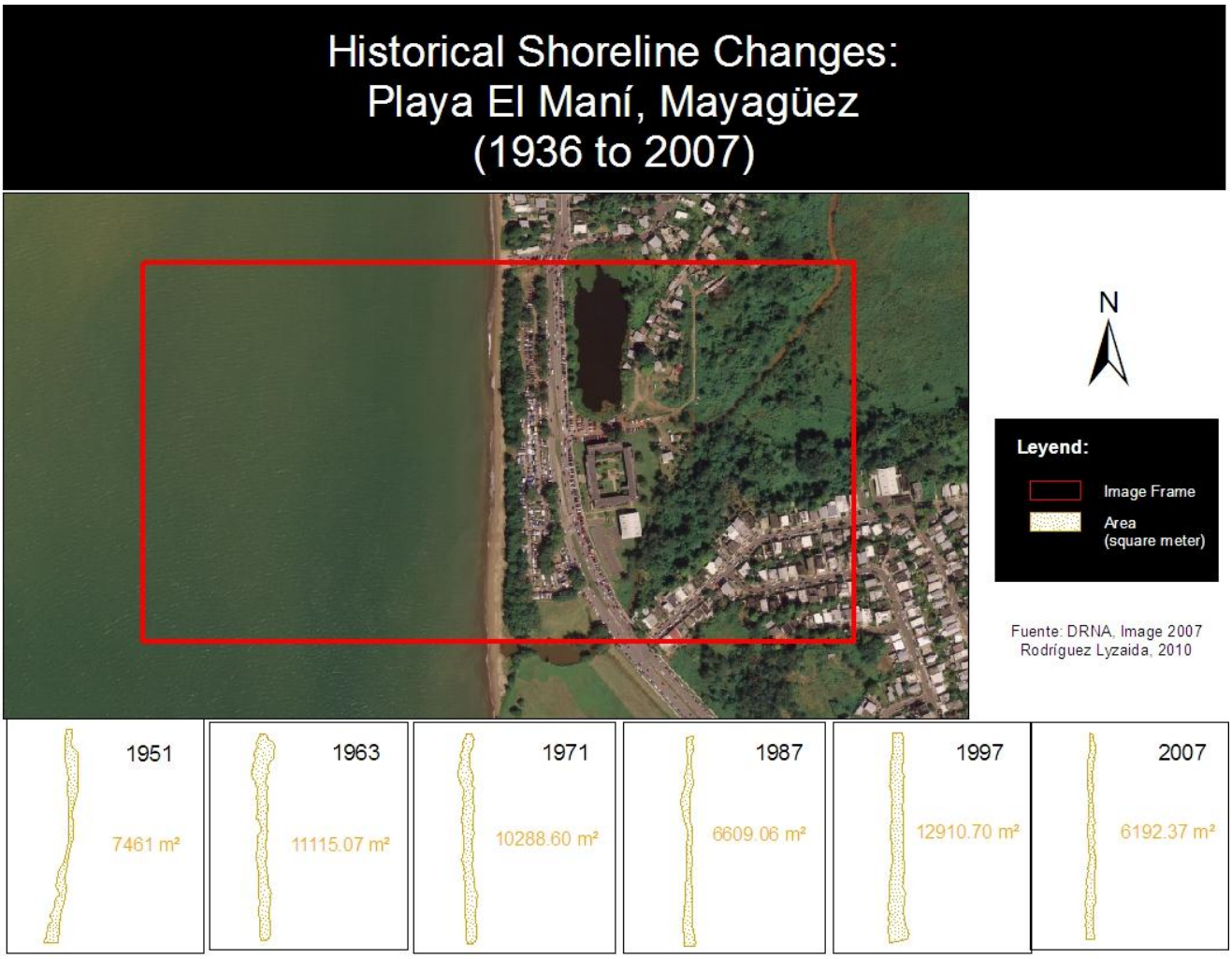


Figure 30. Subaerial beach profile at Playa Salinas



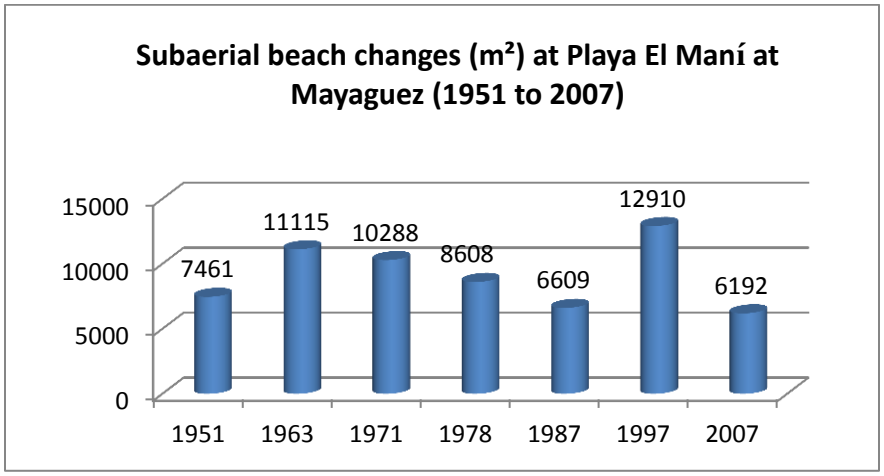


Figure 31. Subaerial beach profile at Playa El Maní

Short Scale Study: Beach Profile

Beach profile changes were diverse in beach system included in this study. Major beach profiles measured were mainly transitional (intermediate between summer and winter profile). Major loss of sand was found at Playa Fortuna, Luquillo. Loss of sand was caused by high waves produced by both tropical and extratropicales storms in the area. Minor beach changes were identified at Playa Salinas on the south coast of Puerto Rico. This beach is protected by mangrove shoreline, seagrass beds and coral found it the neashore area. Accretion and erosion were measured in study sites after the occurrence of Storm systems nearby Puerto Rico waters. Loss and gain of sands were diverse according storm trajectory, beach orientation and degree of coastal protection. Hurricane Danielle causes accretion in Playa Piñones and Playa Salinas during August. Loss of sand was identified in Playa Puerto Nuevo, Playa Fortuna and Playa Humacao in this same period. Hurricane Earl causes erosion at Playa Puerto Nuevo and Playa Fortuna. In other way, Hurricane Igor produces accretion in many beaches as Playa Puerto Nuevo, Piñones (BP2 and BP3), Playa Humacao (BP1 and BP3) and Playa El Maní. Hurricane Tomas produce accretion in beaches located in the south and east coast. Extratropical swells produce erosion or accretion in study beaches according wave approach and beach orientation.

Figure 32. Erosion at Playa Fortuna, Luquillo (December 2010)

Table 4. Beach profile changes after occurrence of Storm Systems nearby Puerto Rico waters.

BP Station and Orientation (degrees)	Storm System H=Hurricane TS= Tropical Storm ES= Extratropical Storm						
	Danielle (H)	Earl (H)	Igor (H)	Otto (TS)	Tomas (H) S	Tomas (H) N	ES
PNuevoBP1 (58°)	NC	NC	NC	NC	NC	NC	erosion
PNuevoBP2 (5°)	erosion	erosion	accretion		erosion	ND	accretion
PNuevoBP3 29.8°	erosion	erosion	accretion	erosion	erosion	ND	accretion
PinonesBP1 (20°)	accretion	erosion	erosion	erosion	ND	ND	accretion
PinonesBP2 (13°)	accretion	NC	NC	NC	NC	NC	NC
PinonesBP3 (ND)	accretion	accretion	accretion	erosion	ND	erosion	accretion
FortunaBP1 (20°)	erosion	erosion	erosion	erosion	ND	erosion	erosion
FortunaBP2 (6°)	erosion	erosion	erosion	erosion	ND	erosion	Erosion
FortunaBP3 (ND)	erosion	erosion	erosion	erosion	ND	erosion	erosion
HumacaoBP1 184°	erosion	ND	accretion	ND	accretion	ND	erosion
HumacaoBP2	erosion	ND	erosion	ND	erosion	ND	erosion
HumacaoBP3	erosion	ND	accretion	ND	accretion	ND	NC
Salinas BP1 (241°)	accretion	NC	NC	NC	accretion	ND	NC
Salinas BP2 (247°)	Erosion	NC	NC	NC	NC	ND	NC
Salinas BP3 (249°)	accretion	NC	erosion	ND	NC	ND	Erosion
ManíBP1 (ND)	ND	ND	accretion	ND	erosion	ND	Accretion
ManíBP2 (ND)	ND	ND	accretion	ND	erosion	ND	Erosion
ManíBP3 (ND)	ND	ND	accretion	ND	erosion	ND	Accretion

Playa Vega Baja at Vega Baja

Beach profiles were measured in three stations from August to December 2010. Beach width varies from 25 to 120 meters of length. Loss of sand was observed mainly after the occurrence of swells during October 2010 in beach profiles stations located on the eastern site of the beach. Accumulation of sand was identified in profile 1 located on the western site of the beach

- Beach profile 1: No changes were found in profiles from August to October 2010. Danielle, Earl and Igor do not cause erosion in this site due to the protection done by an eolianite located to the northwest. This eolianita protect the site from storm waves approaching from the northwest. Major profile changes were measured from October to December during a swell event during December. It is possible profile change in this station depends of wave direction due to eolianite location. Storm trajectory may an important variable producing changes profile between stations.

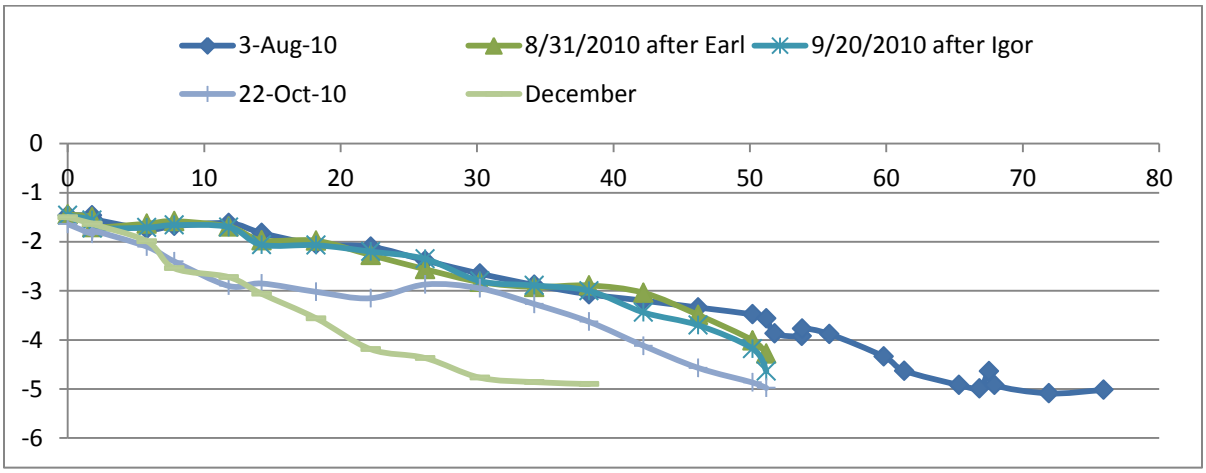


Figure 33. Beach profile 1 at Playa Puerto Nuevo (length in meters)

Figure 34. Beach profile 1 at Playa Puerto Nuevo (August 2010). This barrier protects the station from waves approaching from northwest.

- Beach profile 2: Loss of sand was found in this site except for sand accumulation was observed during the occurrence of Igor in September. Sand accumulation may produce by eolianite during waves approaching from north and northeast. Erosion was mainly occurred during the occurrence of Hurricanes Danielle and Earl. Hurricane Tomas produce erosion after trajectory changes to the northwest (after November 11). Loss of sand may produce of waves approaching from northwest during the period that storms systems where located northwest site of Puerto Rico waters.

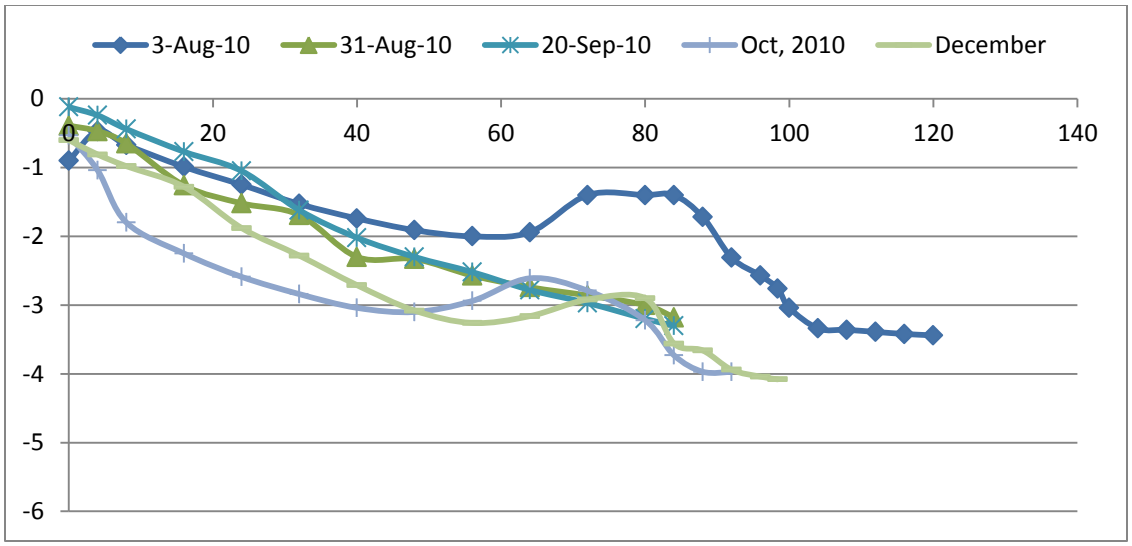


Figure 35. Beach profile Station 2 at Playa Puerto Nuevo.

Figure 36. Beach profile 2 at Playa Puerto Nuevo (October 2010). The site is protected by an eolianite system. This barrier protect the profile from waves approaching from north and northeast

- Beach profile 3: A dissipates beach profile was identified in station 3. This station is complete exposed to wave and swells approaching from North Atlantic waters. This station is the most eroded dissipative profile from the beach system. As well station 2, this station suffers accretion after the occurrence of Hurricane Igor in September. Sand accumulation may relate with waves approaching from north and northeast. Major loss of sand was measured after the occurrence of swell event during December.

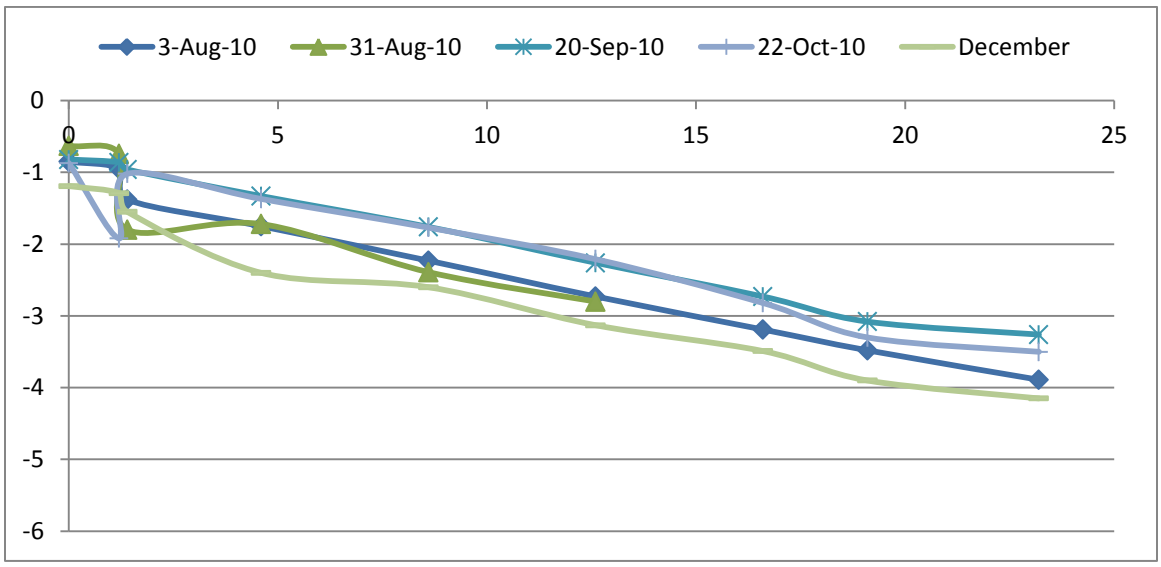


Figure 37. Beach profile Station 3 at Playa Puerto Nuevo.

Figure 38. Beach Profile 3 at Puerto Nuevo Beach (September 2010).

Playa Piñones, Loíza

Major changes in beach profile were observed in stations that are exposed to seas and swells. Minor changes in elevation were measured in profile station protected by dunes, beachrock and eolianite. Apparently, the presence of this natural formation protects profile from direct wave approach. Loss of sand was observed after the occurrence of swells activity during October 2010.

- Beach Profile 1. Sand accumulation was occurred after the occurrence of Hurricane Danielle. Major erosion was identified during the occurrence of Hurricane Earl and Igor.

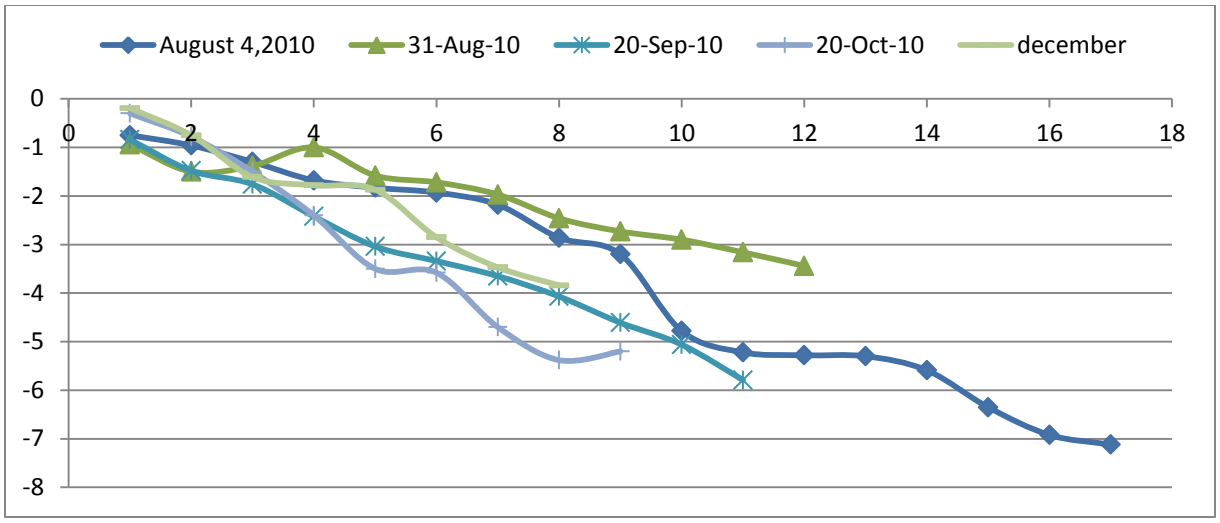


Figure 39. Playa Piñones, Loíza, Beach Profile 1(length in meters)

Figure 40 . Beach Profile 1 at Playa Piñones (August). Station showed dunes and beachrock.

- Beach profile 2: Minor beach profile changes were observed from August to December 2010 in this station. Minor changes may relate with degree of coast protection due by the presence of dunes, vegetated dunes, beachrock and eolianites. Accretion was measured after occurrence Hurricane Danielle. Minor profile changes were measured from September to December 2010.

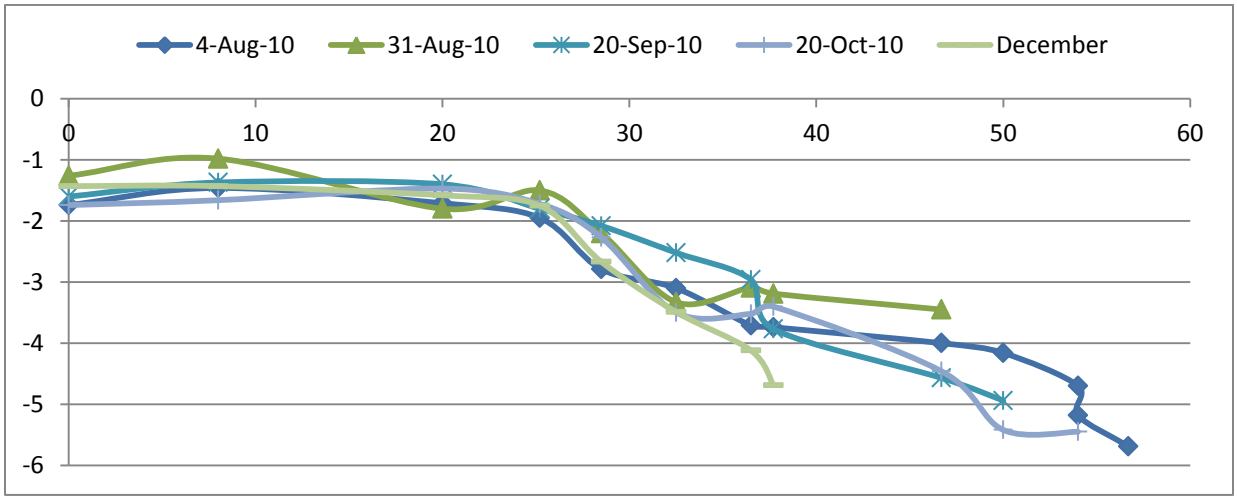


Figure 41. Playa Piñones, Loíza, Beach Profile 2 (length in meters)

Figure 42. Beach Profile 1 at Playa Piñones (August). Station showed dunes and vegetated dunes and beachrock.

- Beach profile 3: Accretion was measured after occurrence of Hurricanes Danielle and Earl. Loss of sand was continuous until October. Shift from erosion to accretion was observed after the occurrence of swell event. This station is less protected that station 1 and 2.

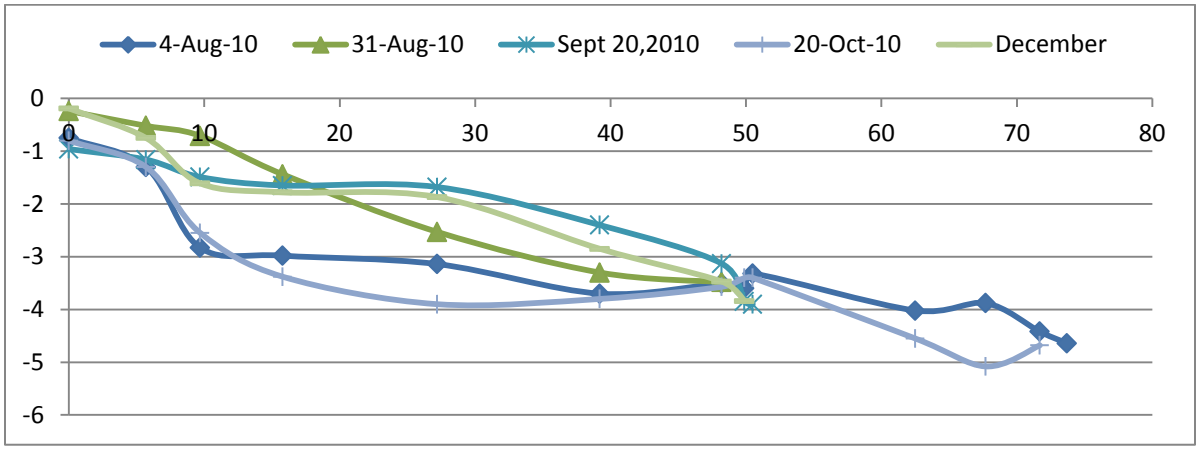


Figure 43. Playa Piñones, Loíza, Beach Profile 3 (length in meters)

Playa Fortuna at Luquillo

Loss of sand was observed in all beach profile station after the occurrence of storm systems. This beach is exposed to the seas and swells approaching from North Atlantic. Major erosion was found after the occurrence of swell event on December. Also, major erosion was measured in station. Infrastructure as residences, roads, recreational facilities suffered important damaged during the occurrence of storm systems.

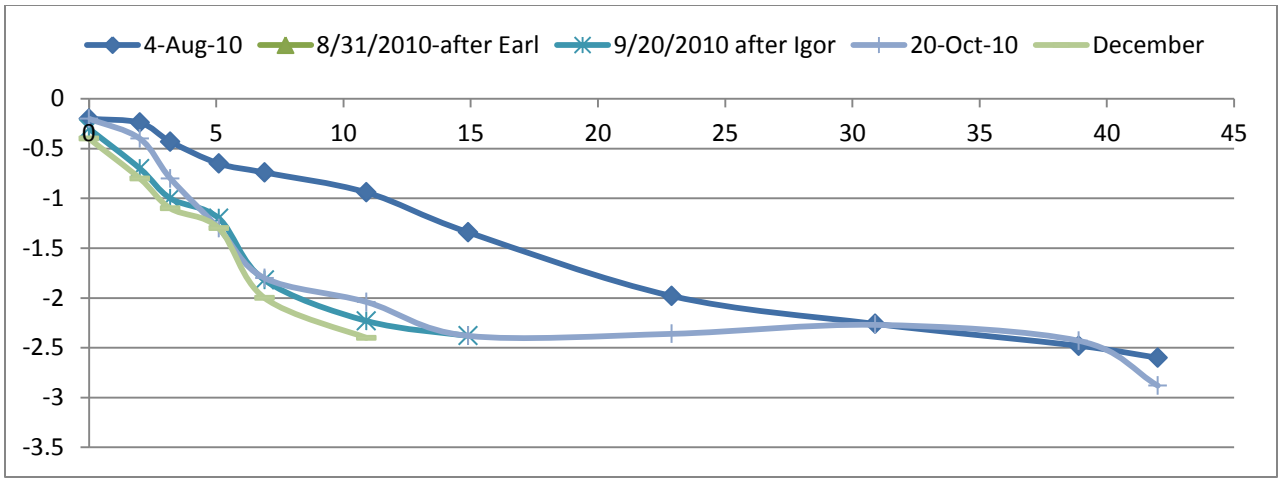


Figure 44. Playa Fortuna, Luquillo, Beach Profile 1 (length in meters)

Figure 45. Beach profile 1 at Playa Fortuna. Dissipative profile was observed near to recreational infrastructure in the study site during August 2010.

Figure 46. Beach profile 1 at Playa Fortuna. Major erosion was occurred near to recreational infrastructure in the study site.

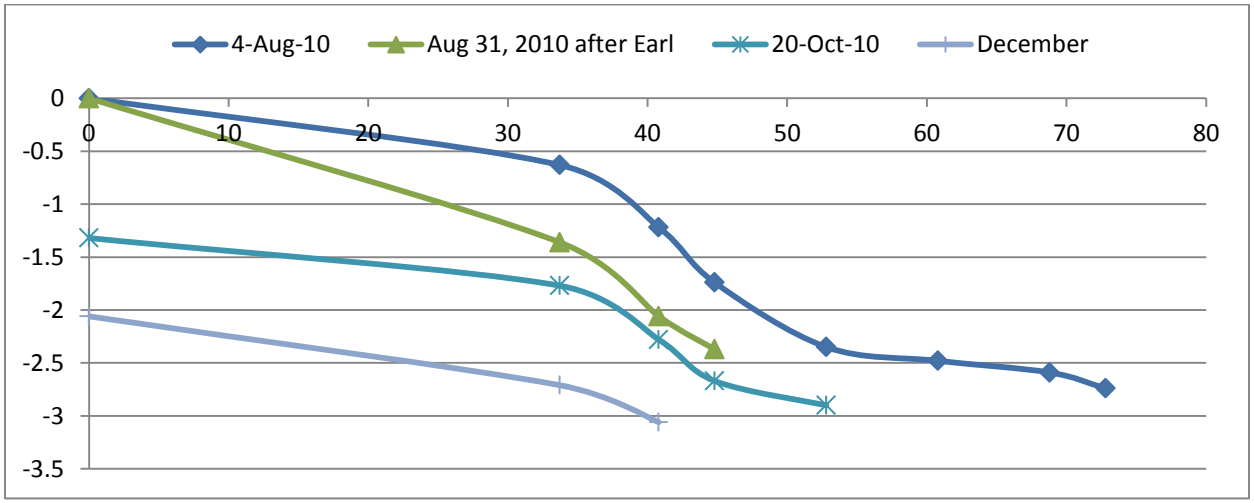


Figure 47. Playa Fortuna, Luquillo, Beach Profile 2 (length in meters)

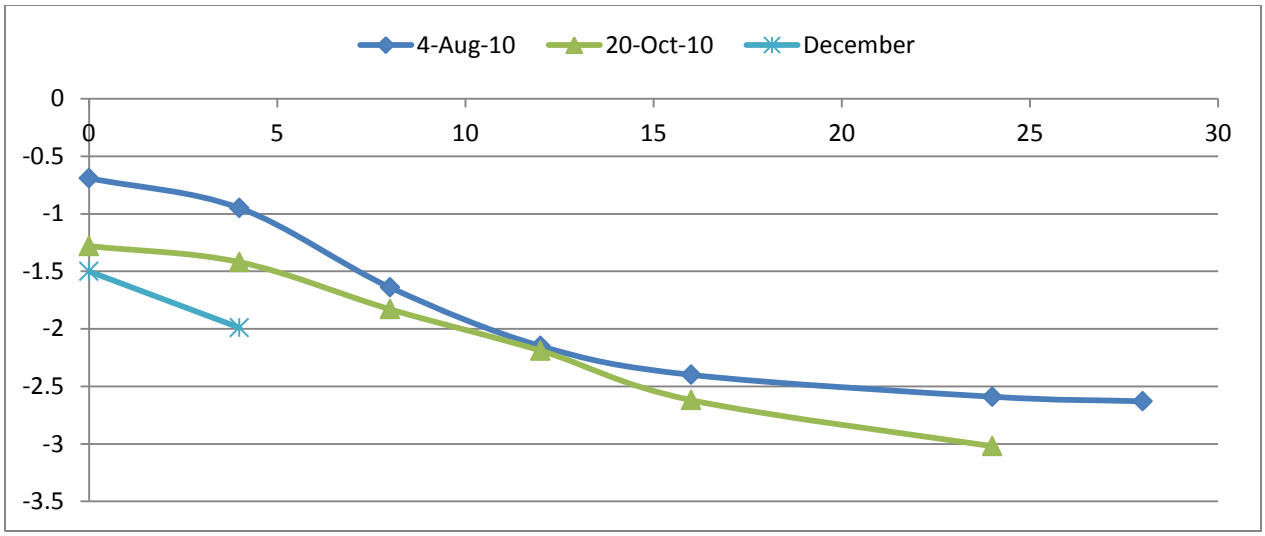


Figure 48. Playa Fortuna, Luquillo, Beach Profile 3 (length in meters)

Figure 49. Extreme subaerial beach loss at Playa Fortuna (December 2010).

Figure 50. Severe erosion was measured in Playa Fortuna beach during December 2010 due by high swells.

Playa Humacao at Humacao

Major loss of sand was identified in all beach stations after the occurrence of Hurricane Danielle. Dissipate profiles were observed after the occurrence of high storm waves. Shift from erosion to accretion was observed in station 2 and 3 after the occurrence of Hurricane Earl and Igor during September. Minor beach changes were measured in beach station 2 and 3 during December. Profile changes between stations possible relate with the dock structure located in near station 2. This dock has a concrete base that may blocks sediment transport to the longshore path.

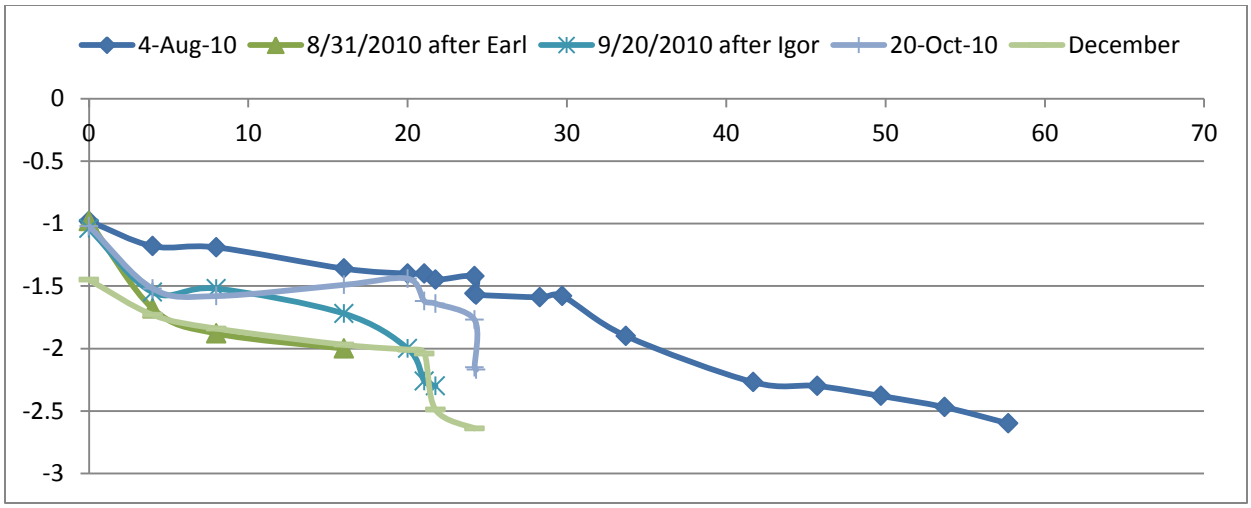


Figure 51. Playa Humacao , Humacao, Beach Profile 1 (length in meters).

Figure 52. Beach station1 at Playa Fortuna (August 2010)

Figure 53. Beach profile station 1 at Playa Humacao (August and December 2010)

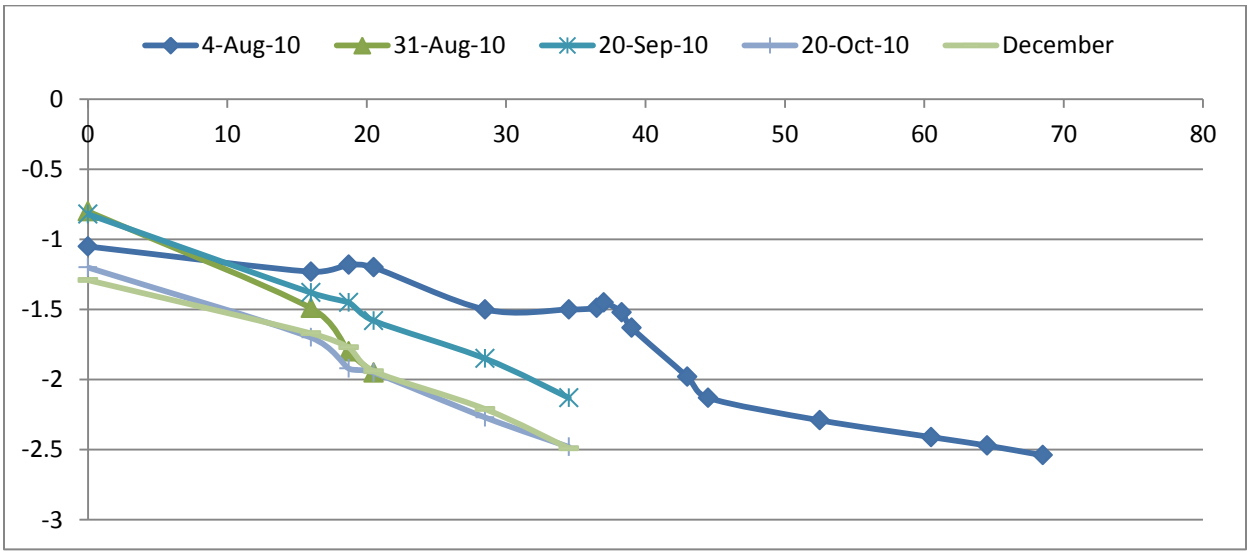


Figure 54. Playa Humacao, Humacao, Beach Profile 2 (length in meters)

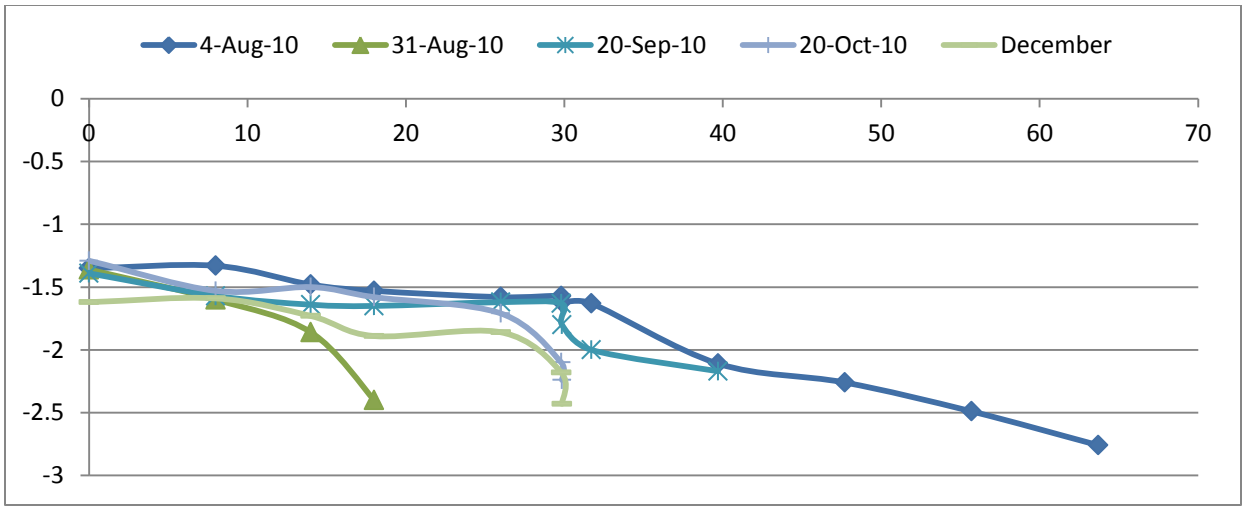


Figure 55. Playa Humacao, Humacao, Beach Profile 3 (length in meters)

Figure 56. Dock structure located to the southward station 2.

Playita Salinas at Salinas

Minor changes were measured in beach profiles at Playa Salinas between periods. This may related with degree of protection due by the presence of mangrove shoreline and seagrass bed in the nearshore area. Loss of sand was observed in station 3. This station is oriented to the southeast. Beach profiles 1 and 2 were oriented to the southwest.

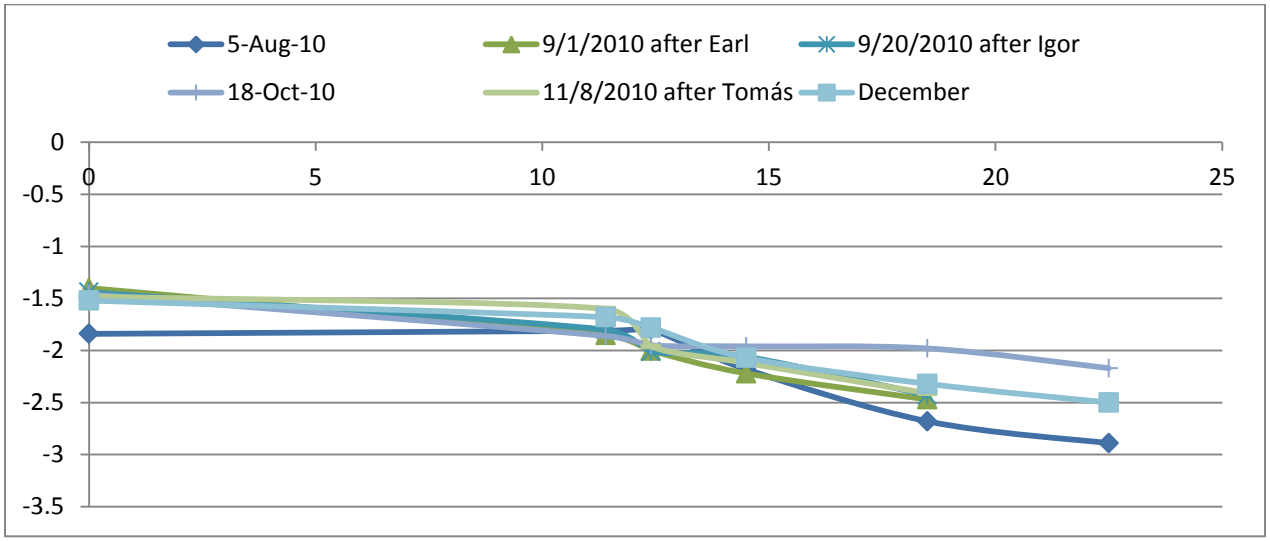


Figure 57. Playita Salinas, Salinas, Beach Profile 1 (length in meters).

Figure 58. Beach profile 1 at Playa Salinas (August)

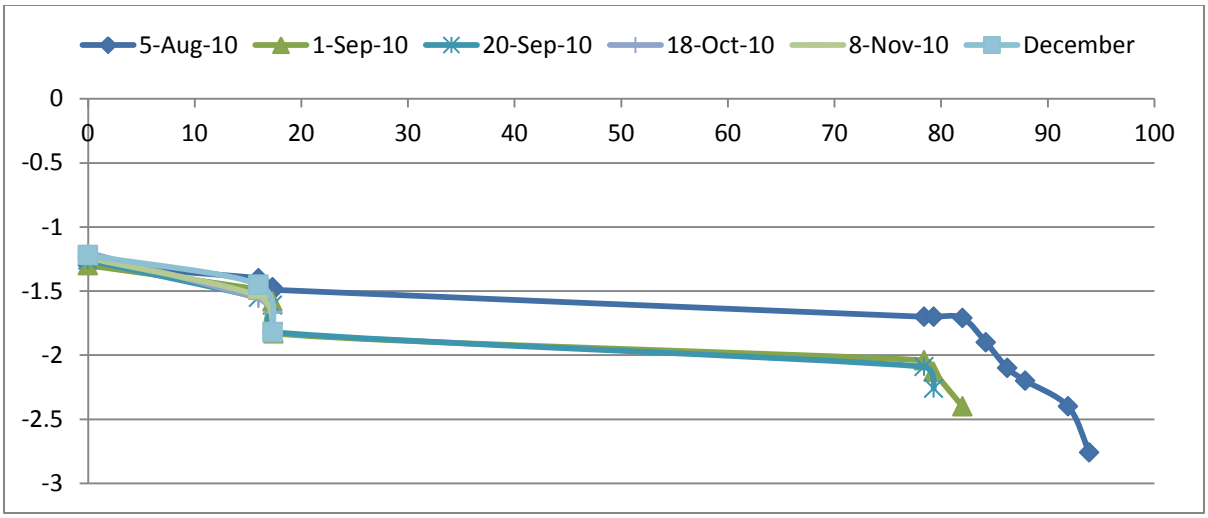


Figure 59. Playita Salinas, Salinas, Beach Profile 2 (length in meters)

Figure 60. Beach profile 2 at Playa Salinas (December 2010)

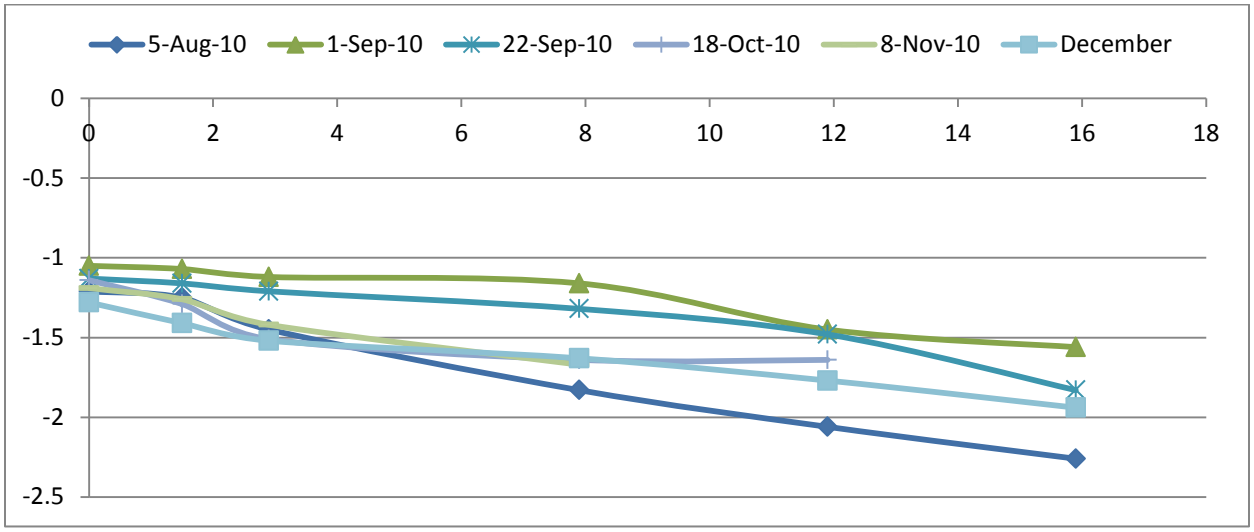


Figure 61. Playita Salinas, Salinas, Beach Profile 3 (length in meters)

Figure 62. Beach profile 3 at Playa Salinas (October). It is Beach station 3 is protected by mangrove shoreline.

Playa Mani at Mayaguez

Accretion was measured after occurrence Hurricane Igor. This storm system may produce waves that approach to west coastal areas. Loss of sand was found after the passage Hurricane Tomas. Vegetation located on the back beach area suffered significant damages.

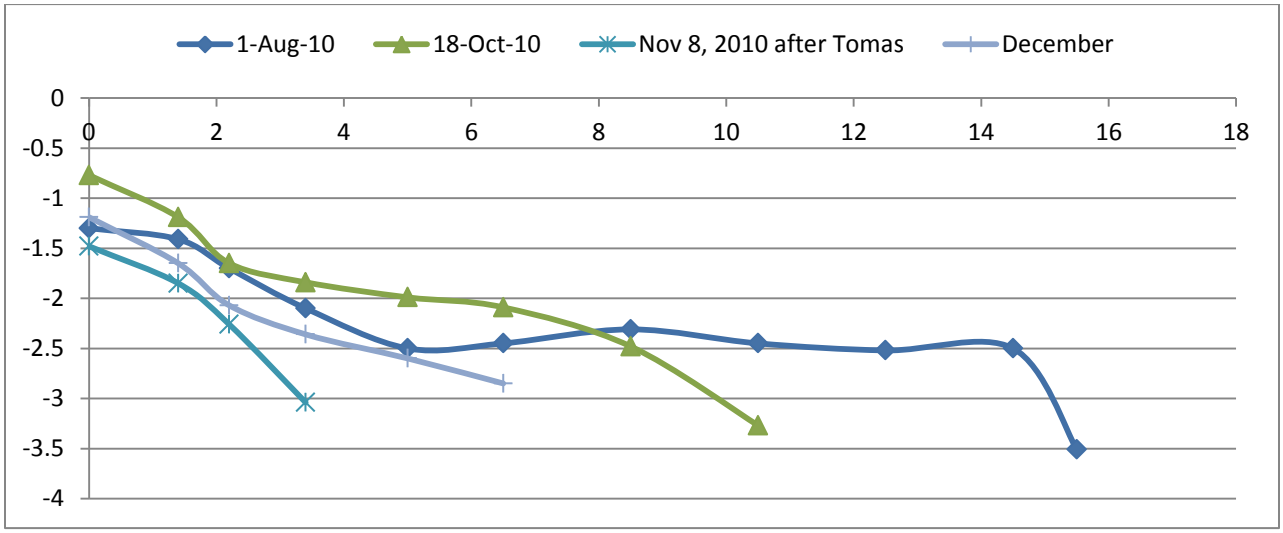


Figure 63. Playa Maní, Mayaguez, Beach Profile 1 (length in meters)

Figure 64. Beach profile 1 at Playa El Maní (August 2010)

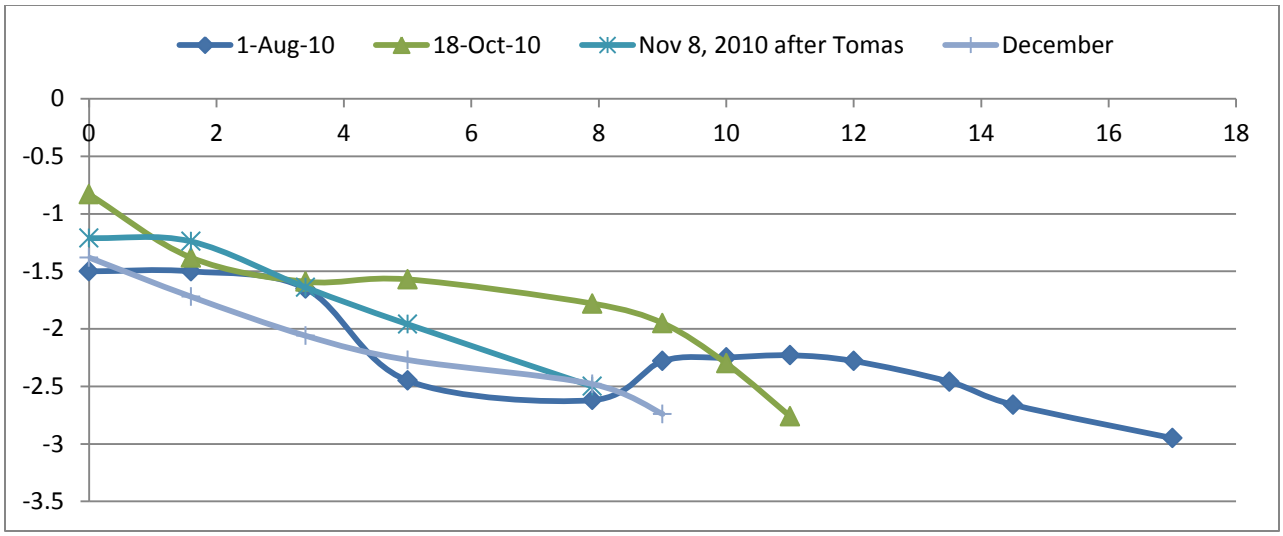


Figure 65. Playa Maní, Mayaguez, Beach Profile 2 (length in meters)

Figure 66. Beach profile 2 at Playa El Mani.

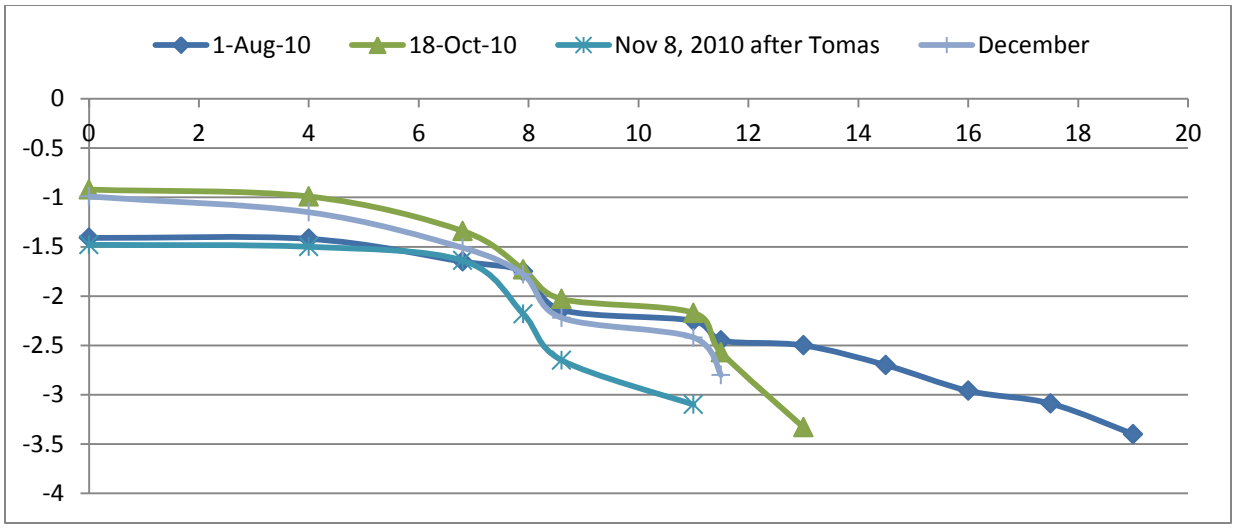


Figure 67. Beach profile 3 Playa El Maní (length in meters)

Figure 68. Playa El Maní.

Short Scale study: Beach Width

An evaluation of beach width (meter) was done for all beach sites selected in this study from August to December 2010. Beach width is measured from the vegetation line and/or dune base and/or infrastructure to wet line during mean low tide (MLT). Beaches with wider plains were identified in Playa Puerto Nuevo (20 to 120m) and Playa Piñones (20 to 70 m). Playa Salinas (7-26m) and Playa El Maní (4-21m) showed narrower beach plain in this study. Major width changes (meters) were identified at Playa Fortuna through study period. These changes are observed mainly northward site of the beach where housing develop are found it. These changes occurred from August to December 2010 (5 months). Beach width changes may relate with passage of Tropical Storms nearby coastal sites. Minor beach width changes were found on Playa Puerto Nuevo and Playa Piñones through study period (Figure 1 and Table x).

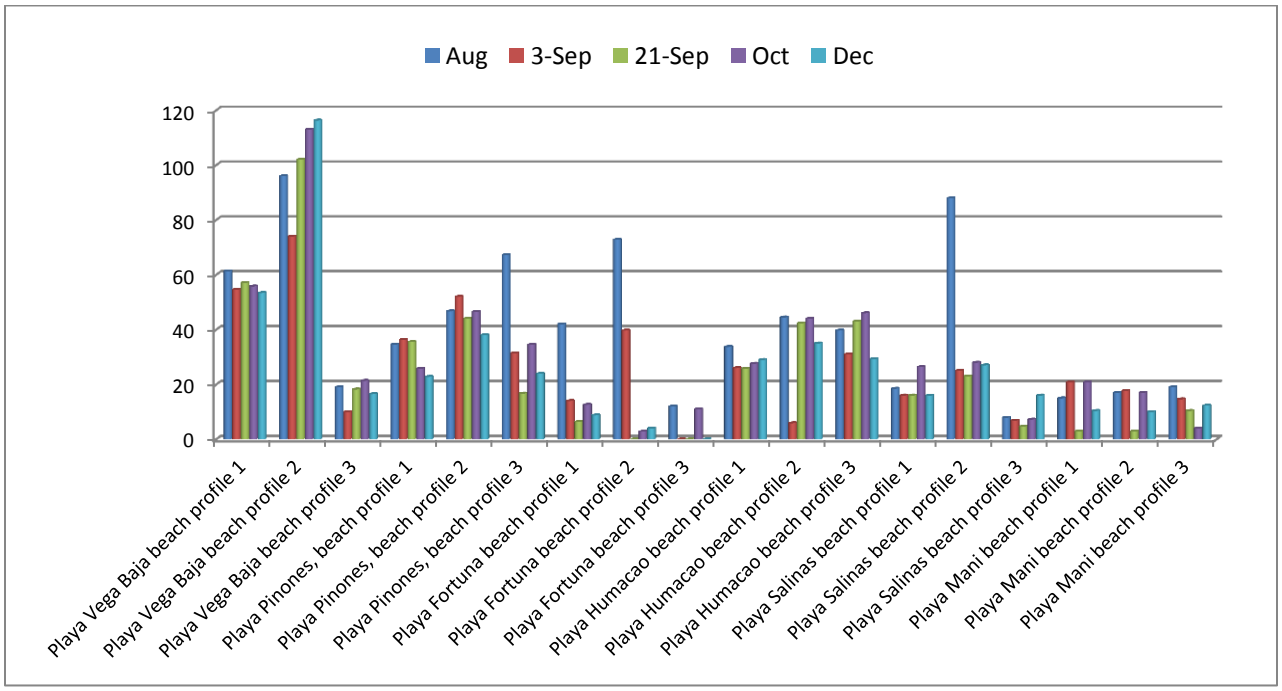


Figure 69. Beach width (m) to selected beach sites by period.

Table 5. Beach profile characteristics by study site.

beach site	Bearing degrees	With protection	Beach width (meters) by period				
			Aug 3-4	Aug 31-2 Sept	Sept 20	Oct 20	Dec
Playa Puerto Nuevo BP1	58	Yes	61.33	54.6	57.1	55.8	53.4
Playa Puerto Nuevo BP2	5	Yes	96	74	102	113	116.3
Playa Puerto Nuevo BP3	29.8	No	19	10	18.2	21.36	16.5
Playa Piñones, BP1	20	No	34.6	36.3	35.5	25.8	22.8
Playa Piñones, BP2	13	Yes	46.7	52	44	46.5	38
Playa Piñones, BP3		No	67.2	31.4	16.7	34.5	23.9
Playa Fortuna BP1	20	Yes	42	14	6.35	12.6	8.75
Playa Fortuna BP2	6	No	72.8	39.7	n/a	2.8	4
Playa Fortuna BP3		No	12	n/a	n/a	11	0
Playa Humacao BP1	184	Yes	33.71	26	25.76	27.6	29
Playa Humacao BP2		Yes	44.5	5.9	42.34	44	35
Playa Humacao BP3		No	39.7	31	43	46	29.3
Playa Salinas BP1	241	No	18.5	16	16	26.36	15.94
Playa Salinas BP2	247	Yes	87.9	25	23	28	27
Playa Salinas BP3	249	Yes	7.9	6.84	4.68	7.24	16
Playa Maní beach BP1		Yes	15	20.8	2.9	20.8	10.4
Playa Maní beach BP2		No	17	18	2.9	17	10
Playa Maní beach BP3		No	19	15	10.4	4	12.3

Playa Puerto Nuevo

Playa Puerto Nuevo showed the widest plain of beaches selected in this study(100 to 120 meter of width). Station 2 is the wider beach profile in the system due to the presence of eolianites. Accretion was measured in station 2 especially during high seas and swells events produced by Igor and extra tropical storms. Station 3 is the narrower beach profile in this geomorphic system. This station is exposed to the direct impact of swells and seas from North Atlantic.

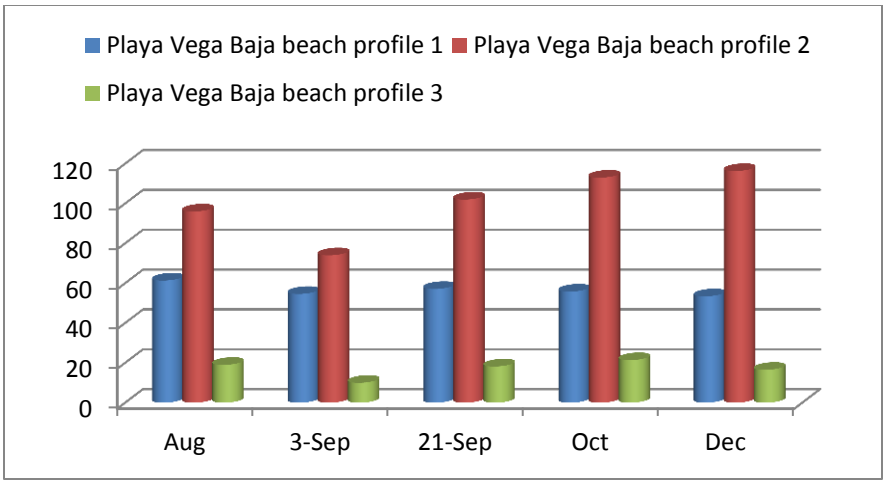


Figure 70. Beach width (m) in Playa Vega Baja (August to December 2010).

Figure 71. Beach Station 2 at Playa Puerto Nuevo. The beach is protected by an eolianite.

Playa Piñones

Playa Piñones showed a beach width extension ranges from 30 to 70 meters. Station 3 showed major changes in beach width (m) from August to December 2010. Major changes were observed during the occurrence of Hurricane Earl near Puerto Rico waters during September 2010. This station is more exposed to seas and swells arriving from Atlantic Ocean than other stations. Minor beach width changes were measured in beach profile 1 due to the presence of vegetated dunes and beach rock. Apparently, the presence of beach rock produces protection to the subaerial beach in this site.

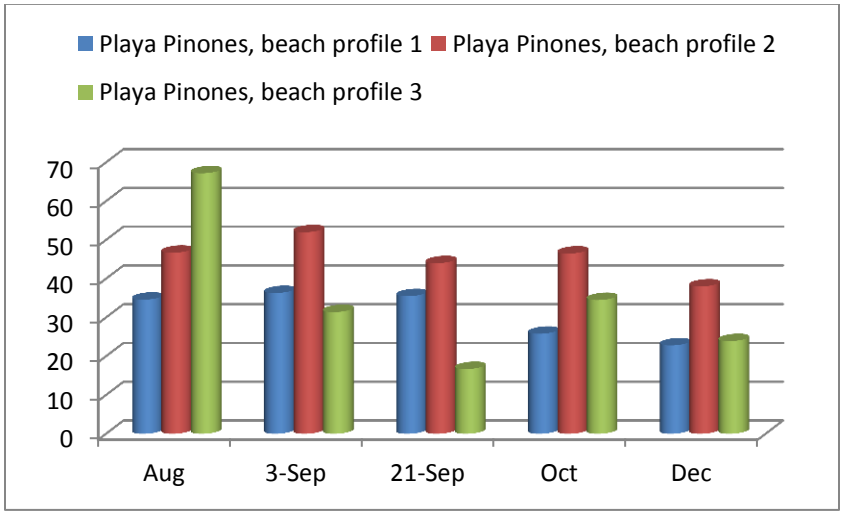


Figure 72. Beach width (m) in Playa Piñones (August to December 2010).

Figure 73. Beach profile Station 1 at Playa Piñones. The beach is protected by beachrock and Eolianites.

Playa Fortuna

Playa Fortuna showed extreme beach width changes from August to December 2010. This beach suffered extreme erosion events in all beach stations during this period. Major changes were measured in beach profile statins 2 and 3 during extreme swells produce by Tropical (Danielle and Earl) and Extra tropical (December event) Storms. Major continuous erosion was identified in areas near to residences and other types of infrastructures.

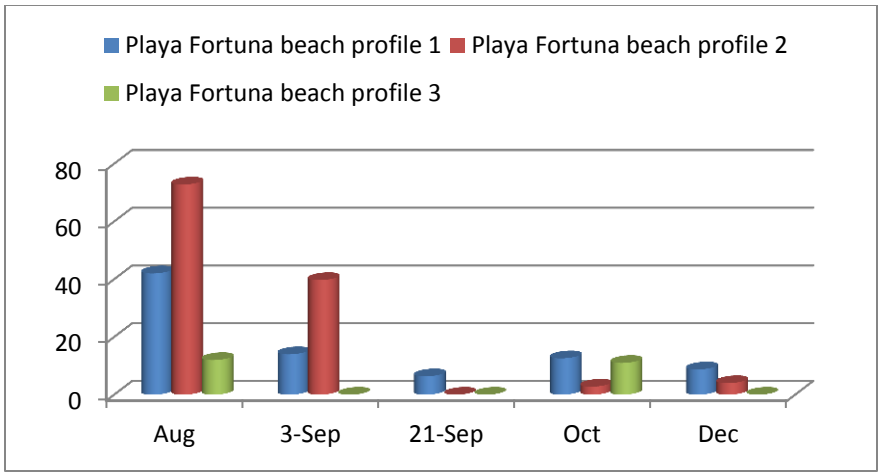


Figure 74. Beach width (m) in Playa Fortuna (August to December 2010).

Figure 75. Beach Profile Station 1 at Playa Fortuna before impact of Storm waves.

Figure 76. Beach Profile Station 1 at Playa Fortuna after the occurrence of extreme swell event on December 2010.

Playa Humacao

Playa Humacao showed beach width ranges from 10 to 45 meters. Beach width is wider to the northward side of the beach (station 2 and 3). Wider subaerial beach plain may produces by the presence of infrastructure located near station 2. This dock acts apparently acts as a barrier that block sediment transport to the south (station 1). Station 1 is the narrower beach plain found in this area.

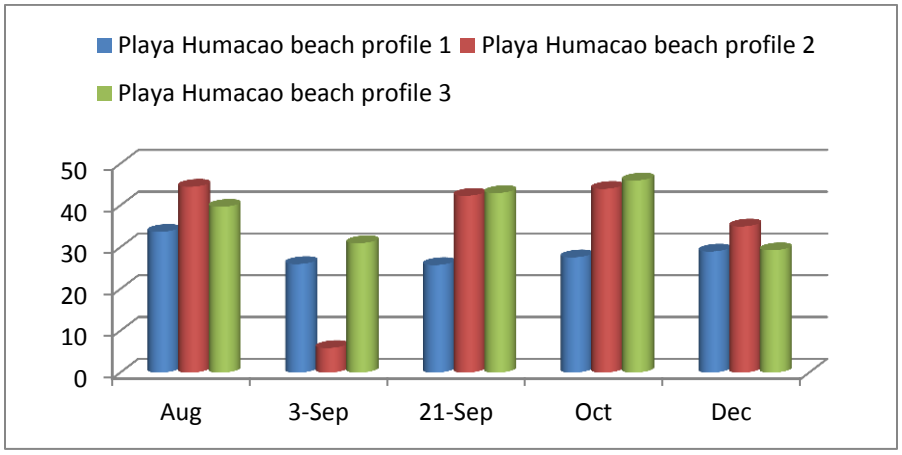


Figure 77. Beach width (m) in Playa Humacao (August to December 2010).

Figure 78. Beach profile Station 2 at Playa Humacao. The dock apparently blocks sediment transport to the south (beach station 1).

Playa Salinas

Playa Salinas showed diverse type of natural and made barriers as mangrove shoreline, seagrass and algae beds, dock and land vegetation. Major loss of subaerial beach was measured in station 2 at Playa Salinas. This station is protected by mangrove shoreline and seagrass beds in the nearshore. Erosion was caused the occurrence of high waves approaching to the site. Hurricanes Earl produces high waves in the southeast nearshore that apparently impact seagrass and algae beds in the area. Significant amount of seagrass and algae were deposited in the beach shoreline. Hurricane Tomas produced high waves arriving from the southwest due to its trajectory during December. Wave approach and magnitude cause that mangroves were not produce an effective protection to the study site. It is possible that high waves that produce damage in seagrass beds cause a change in bottom morphology in the area. This may produce changes in wave refraction in the nearshore zone. The presence of a dock structure apparently does not block sediment transport among stations.

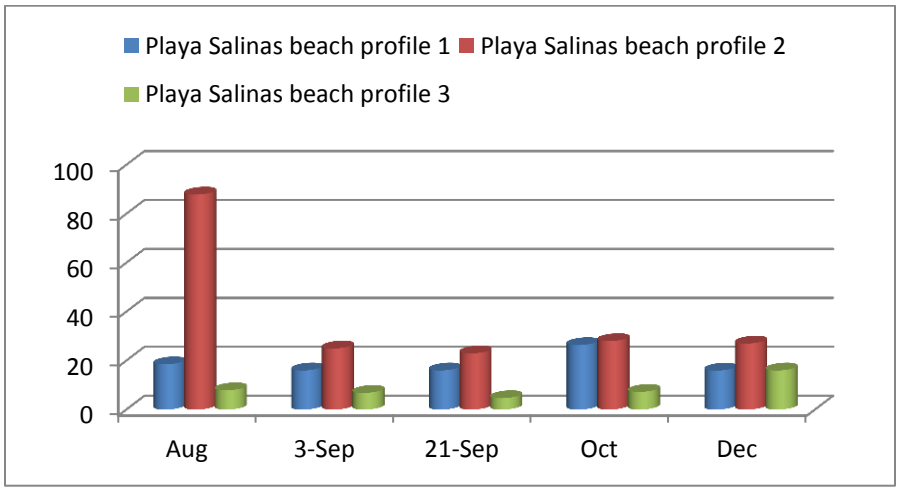


Figure 79. Beach width (m) in Playa Salinas (August to December 2010).

Figure 80. Mangrove shorelines at station 2 at Playa Salinas.

Figure 81. Beach profile Station 1 at Playa Salinas.

Figure 82. The dock located between station 1 and 2 apparently do not block sediment transport to the west. This dock was build-up with an open base that may do not block sediment transport.

El Maní

Playa El Maní showed a narrow subaerial beach with ranges from 4 to 20 meter of width. Major erosion was measured after the occurrence of Hurricane Igor on September 2010. Shift from accretion to erosion was observed among stations from August to December 2010. This shift may relate with changes in wave direction approach to the study area. The beach is exposed to direct wave approaching from northwest and west.

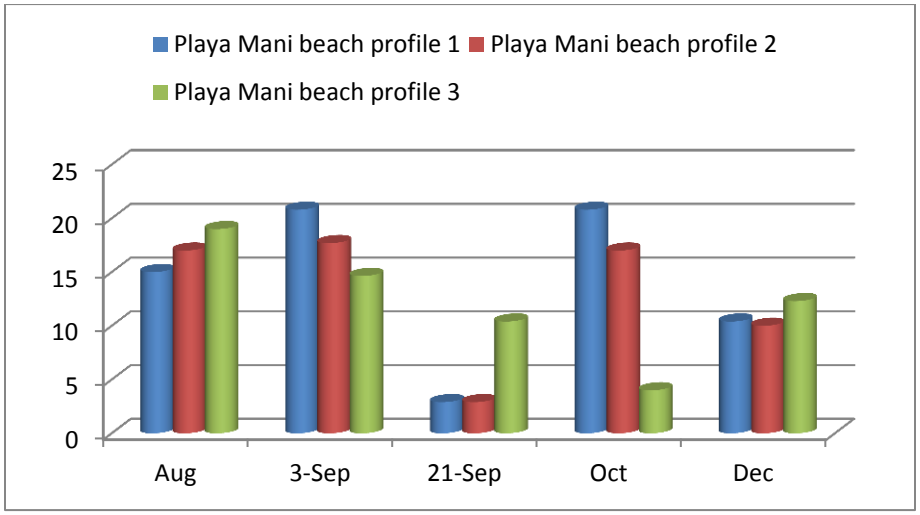


Figure 83. Beach width (m) in Playa El Maní (August to December 2010).

Figure 84. Playa El Maní at Mayaguez (west coast of Puerto Rico)

IDENTIFICATION OF COASTAL INDICATORS TO MANAGEMENT APPLICATION

Coastal indicators were derived from geomorphic assessment done in this study in six beaches at Puerto Rico. The identification of coastal indicators permits attaining better understanding of coastal processes and how users and their activities may alter it. Major government initiatives to identify coastal indicators are based in ecological point of view to apply to continental coastal areas (Keeley, D. 2005 and Harrington, 2007). In this study we are focusing in defining geomorphic, oceanographic and anthropogenic indicators as variables that are altering local and regional coastal processes causing beach changes in a Tropical Island. Included is a list of coastal indicators identified in this study.

Coastal Indicator 1. Natural Barriers

- Eolianite: Sedimentary rock (sandstone). Eolianite protect beach system from high waves and swells. The degree of protection apparently depends of barrier extension and orientation. According data includes in this study, eolianites acts a barrier that trap sediment to the inshore causing beach accretion (Playa Puerto Nuevo study).
- Beachrock: Sedimentary rock (sandstone or conglomerate). Beachrock may reduce wave energy in the nearshore area causing less erosion. As well eolianites, the degree of coastal protection produces by beachrock will depend of barrier extension, high and orientation (Playa Piñones study).
- Dunes: Dune deposits have a dual function in the beach system. This deposit reduces wave impact in the backbeach and acts as sediment reservoir that feed beaches during erosion events (Playa Piñones study).
- Vegetated dunes: As well non-vegetated dunes, these deposits reduce the impact in the backbeach. But it is possible that these deposits do not act as a sediment reservoir due to permanent vegetation (Playa Piñones study).
- Mangrove shorelines: Mangroves shoreline apparently is the most protective coastal indicator according data collected in this study. But, we need more information to support this observation because other variables can operate in the system that may cause this result.
- Seagrass beds: Seagrass beds cause reduction of wave energy. This indicator produces a degree of protection to the shoreline (Playa Salinas study). The presence of seagrass bed

protects beach from erosion event. Also seagrass bed is a habitat of invertebrates that are sources of biogenic sediments. This type of sediment can feed beach systems.

- Cays: Cays are geomorphic features that may affect wave approach to the shoreline. The presence of this indicator may cause both erosion/or accretion depend of wave distribution along shoreline. More studies are necessary to understand the specific role of cays in the nearshore. Preliminary evaluation indicates that presence of cays may affect shoreline according its orientation and wave direction (Playa Humacao, Punta Santiago).

Indicator 2. Anthropogenic barrier

- Dock with concrete cement: This indicator block longshore transport (Playa Humacao study)
- Dock with open base: This indicator do not block longshore transport (Playa Salinas study)
- Housing along shoreline exposed shoreline: Indicates loss of sand and properties. High coastal vulnerability to direct wave impact during both Tropical and Extratropical Storms (Playa Fortuna study)
- Housing along protected shoreline: No data available to conduct evaluation.
- Recreational facilities near exposed shoreline: Indicates loss of sand and recreational areas. High coastal vulnerability to direct wave impact.
- Recreational facilities in protected shoreline: No data available to conduct evaluation.
- Abandoned concrete structures in exposed shoreline: This type of infrastructure may block sediment transport according infrastructure location along shoreline (Playa Salinas study).
- Abandoned concrete structures in protected shoreline: No data available to conduct evaluation.

Indicator 3. Beach Orientation: Degree of orientation. Bearing defined by a line perpendicular to the shoreline.

- Beach Orientation in protected shoreline:
    - North (0º) to northeast: Erosion may cause by waves from Tropical Systems (Playa Puerto Nuevo study).
    - East (90º) to southeast: Erosion may cause by waves from Tropical Systems (Playa Humacao study)
    - South (180º) to southwest: Erosion may cause by waves approaching from southwest. Storm systems passing along south coast of the Island (Playa Salinas and Playa El Maní study)
    - West (270º) to northwest: No data available to conduct evaluation.
- Beach Orientation in non-protected shoreline
    - North (0º) to northeast: Erosion was caused by waves approaching from north and northeast due to the occurrence of Extratropical and Tropical Storms (Playa Piñones BP3)
    - East (90º) to southeast: Erosion was caused by waves approaching from southeast, south due to the occurrence of Tropical Storm. Waves approaching from the north and northwest are less effective causing erosion.
    - South (180º) to southwest: erosion may cause by waves approaching from extratropical storms (El Maní study).
    - West to northwest (360º): No data available to conduct evaluation.

Indicator 4: Wave direction: Erosion or accretion was occurred in beaches according to the relation between beach orientation and wave direction.

- North
- Northeast
- East
- Southeast
- South
- Southwest
- West
- Northwest

Indicator 5: Storm Systems

- Trajectory: It is the more important indicator found based on this study.
- Translation velocity
- Magnitude

GENERAL MANAGEMENT RECOMMENDATIONS

Included is a list of management recommendations based on detail results found in this study.

- Housing structures will not allow to build-up near to exposed shorelines areas (eg. Playa Fortuna).
- Recreational facilities will not allow to build-up near to exposed shoreline areas (eg. Playa Fortuna).
- Recreational facilities located in non-protected shoreline should be evaluate to decide which type of management will apply based on specific process occurred in the site. This evaluation will do by agency in charge of recreational facilities.
- Dock with concrete base will be reconstructed to permit sediment longshore transport through the beach.
- Abandoned concrete infrastructure will be removed from coastal sites especially near to beach system.
- Beach plain was not recommended to be cleaning using vehicles or other techniques that remove the natural profile configuration.
- An intensive education process will conduct to teach communities about the effect of waves cause by extratropical storms and its effect in beach systems and infrastructures.
- Risk profile studies will conduct in community areas to understand the risk vulnerability. This study will include detail risk profile based on published data analysis and community perception (questionaries).
- An intensive education process will conduct to teach communities about the effect of waves cause by Tropical Storm passing nearby Puerto Rico waters and its effect in beach systems and infrastructures.
- Educational material related with the importance of extratropical storms causing properties damage and possible loss of life will prepare by DRNA. Study data indicated that many erosion problems in beaches were caused by extratropical storms.
- DRNA still conduct continuous beach monitoring to extract detail information of all indicator and variables included in this study. Permanent stations will define using concrete bench marks.
- DRNA still conduct studies in other communities located near high risk coastline as Punta Uveros, Levitown, Arecibo, Manatí, Isabela, Naguabo and Arroyo .

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