University of Puerto Rico
Mayagüez Campus
Faculty of Arts and Science
Department of Geology

Spatial and Temporal Changes of the Coastal Morphology adjoining the Manatí River in Puerto Rico, using Remote Sensing Techniques

Yesenia Marie Rivera-López
yesenia.rivera7@upr.edu
440-14-6653

Advisor: Fernando Gilbes Santaella
Department of Geology
University of Puerto Rico – Mayaguez Campus

GEOL 4049
12.06.18

ABSTRACT

On an island where most of the population lives within 7 km of the sea, awareness must be created among vulnerable communities at coastal zones. After the struck of Hurricane María, with winds of 249 kmh/155 mph (Pasch et al., 2018), the coast of La Boca in Barceloneta and its community was one of the most affected areas. Through this study, we address a coast section from the municipalities of Barceloneta and Manatí. Migrations of shorelines were quantified by using techniques of remote sensing. Also, an analysis of sand samples were conducted. As results, [1] we assume several depositional events have occurs, due to differences of grain sizes at a same site, [2] geomorphology at the north coast of Puerto Rico has variations features along every five to ten km and [3] reflectance measurements curves change with composition and let us characterize beaches as carbonates or by their content of dark minerals. Due to the morphology changes observed, the coastal erosion at the area of study is associated to: [1] short-term and [2] long-term effects. Short-term take place with the effects of atmospheric events (e.g. Hurricane María), while long-term effects represents the influence of depositional events conducted by drainage patterns and/or sea level changes.

INTRODUCTION

Several studies in Puerto Rico have observed a significant coastal erosion in the Rincon's coast. Through this study, we will address the coast adjoining the river-mouth of the Río Grande de Manatí (Manatí River) which, also, borderlines the municipalities of Barceloneta and Manatí [see **Figure 1**]. After the struck of Hurricane María, with winds of 249 kmh/155 mph (Pasch et al., 2018), the coast of La Boca in Barceloneta and its community was one of the most affected and highly damaged areas [see **Figure 2**]. The severe erosion in La Boca continues to affect and damage the community and infrastructure. On an island where most of the population lives

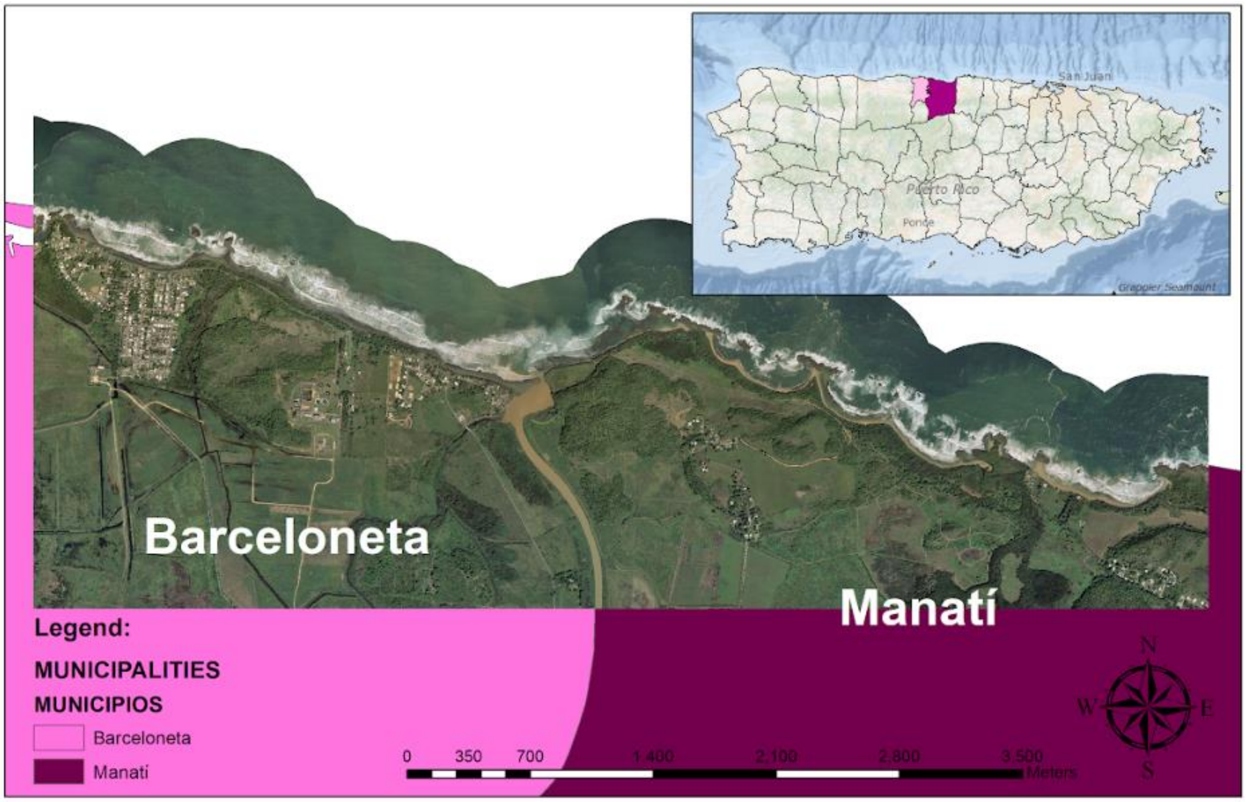


Figure 1. Area of Study, Municipalities of Barceloneta and Manatí
The aerial photograph presented is the area of study.

Figure 2. Coastal Conditions and Infrastructure of La Boca community
La Boca, Barceloneta, presented highly damages after the struck of Hurricane María.

within 7 kilometers of the sea, awareness must be created among vulnerable communities with chances of experiencing destruction of their homes due to coastal loss by atmospheric events (Rodríguez et al., 1994).

Purpose and Scope

This study produced a quantification of the morphology changes of the coast at the municipalities of Barceloneta and Manatí, Puerto Rico, measured by aerial photographs and analysis sands. An analysis through almost 100 years is presented of the coastline's changes from La Boca to the Manatí River continuing to several beaches along the Manati's coast. The hypotheses of this study are: [1] land use and atmospheric events affects the deposition of sediments in the study site, affecting the erosion pattern in the coastline and [2] mineral content in sand compositions can be related to a unique reflectance curve. Responsible factors for erosion at coastal environments are: [1] increase of infrastructure, [2] dam constructions and [3] tropical storms and hurricanes (Thampanya et al., 2006). Using the techniques, such as aerial photographs, radiometric measurements and image analyses was keys to conduct this research (Stafford and Langfelder, 1971).

Objectives

An aerial photography survey was used: [1] to measure coastal changes and [2] to quantify coastal loss through time. This work follows the methodology by Stafford and Langfelder (1971) to evaluate its applicability in beaches of Puerto Rico. Other objectives are [3] to observe if there are other geological features that have been eroded or formed through the years and [4] to analyze the composition of sand near the river-mouth and the berm.

Photogeology and Remote Sensing

The use of aerial photographs in geology is defined as photogeology and has been used since 1930s for geologic interpretations, research and exploration purposes (Nath et al., 2018). Aerial photographs are a cost-efficient tool of remote sensing focused on mapping and classifying features. These are an ideal collection of data, because it records the location of sites through time -permanently- at each photo taken. That let us study long-term geological processes and how areas, including coastal environments, have changed. Aerial photos are taken more frequent than modifications made to maps and therefore they are better updates to the real conditions. The integration of remote sensing techniques is becoming a reality to model predictions for future changes of our environments (Hugenholtz et al., 2012; Stafford and Langfelder, 1971; Andres et al., 2018).

METHODS

Description of Study Area

The coast of Puerto Rico can be classified by its sand composition, which will be influenced by the sediments reaching the beaches. Beaches are categorized by: [1] wave height, [2] type of sand (grain sizes), [3] color of sediments and [4] submarine currents. The composition of sediments changes throughout the whole coast of the island (Chiqués, 2005). The north coast receives waves generated in the Atlantic Ocean, winds with a predominant direction from the east and its currents directions are dominantly to the west region (Morelock and Taggart, 2005).

The area of study considers the north coast, including -specifically- the northern of street 681 which merge with 684 (Boca Ave.), Barceloneta to Punta Boquilla at Manatí. This research divided the area of study in two sections: [1] La Boca, Barceloneta (starting from the Manatí

River to the west) and [2] Manatí (from Río Grande de Manatí to the east) [see **Figure 3**]. The area of study was selected due to their proximity of urban activities [see **Figure 4**] and because La Boca experienced a severe damage to infrastructure after the impact of Hurricane María.

Manatí River

The hydrological basin of Manatí River origins from the Cordillera Central at an elevation of ~273 meters above sea level, covers the north and central regions of Puerto Rico and lies in an alluvium floodplain. It flows north and empties, in Barceloneta, to the Atlantic Ocean [see **Figure 5**] (DRNA 2012; Briggs, 1965).

La Boca (to the west)

According to Briggs (1965) La Boca covers [1] beach sand with a composition of volcanic rocks fragments, quartz grains and smalls amounts of magnetite, [2] beach rock cemented by calcite and [3] dunes sand similar to adjacent beach sands.

Manatí (to the east)

The Manati's coast, covered in the study, consists of [1] beach sand of calcium-carbonates with forms of polished shell fragments, also [2] beach rock cemented by calcite and [3] cemented dunes of calcite (Briggs, 1965).

Field Work

The first trip to La Boca included a walk by the river-mouth of the Manatí River and the community. Sand samples were collected using a sediment core, extracted near the berm and river-mouth in the west area of the site. These sand samples were collected in order to verify if sediments from the top and bottom of the same area are identical or have experienced changes.

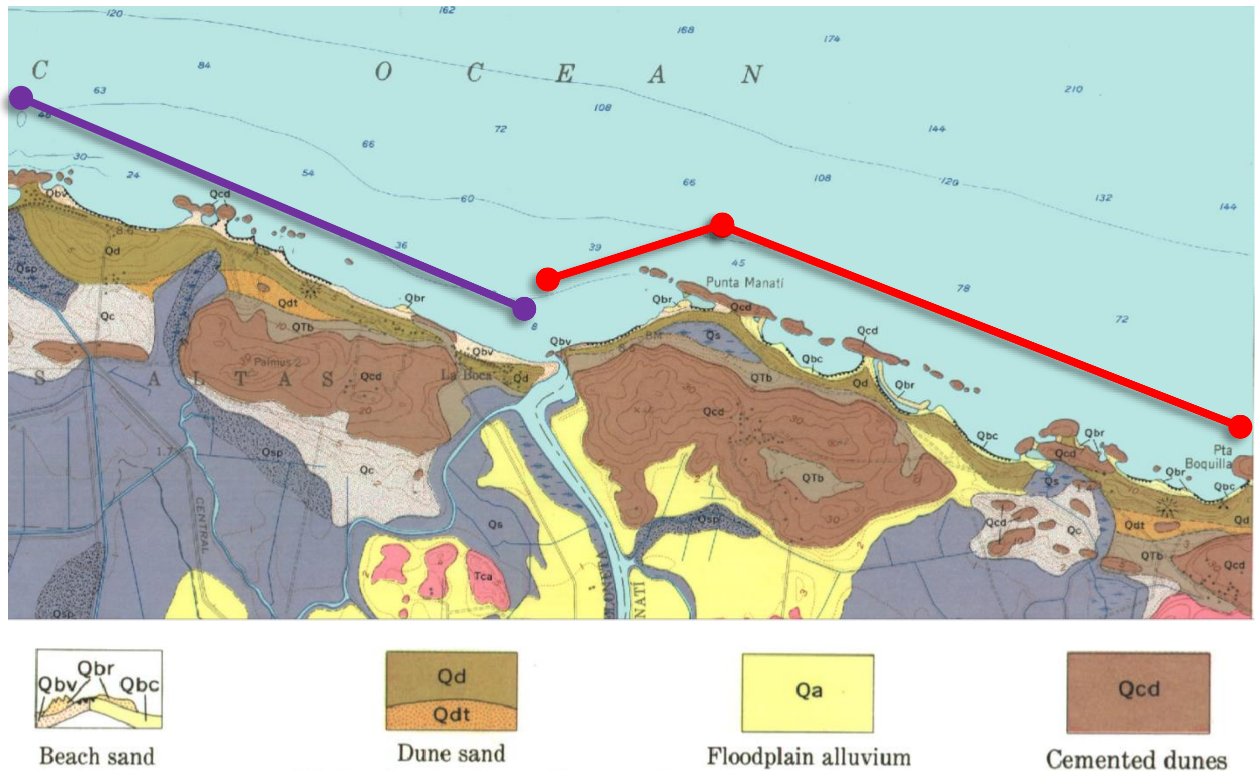


Figure 3. Area of Study

This research divided the area of study in two sections:

[1] La Boca, Barceloneta, starting from the Manatí River to the west (purple line) and

[2] Manatí, from Río Grande de Manatí to the east (red line).

(from Briggs, 1965; edited)

Figure 4. La Boca 1930-1993-2010-2017.
Urban growth at the community of La Boca, Barceloneta.
Aerial photographs from 1930 (top-left), 1993 (top-right),
2010 (bottom-left) and 2017 (bottom-right).

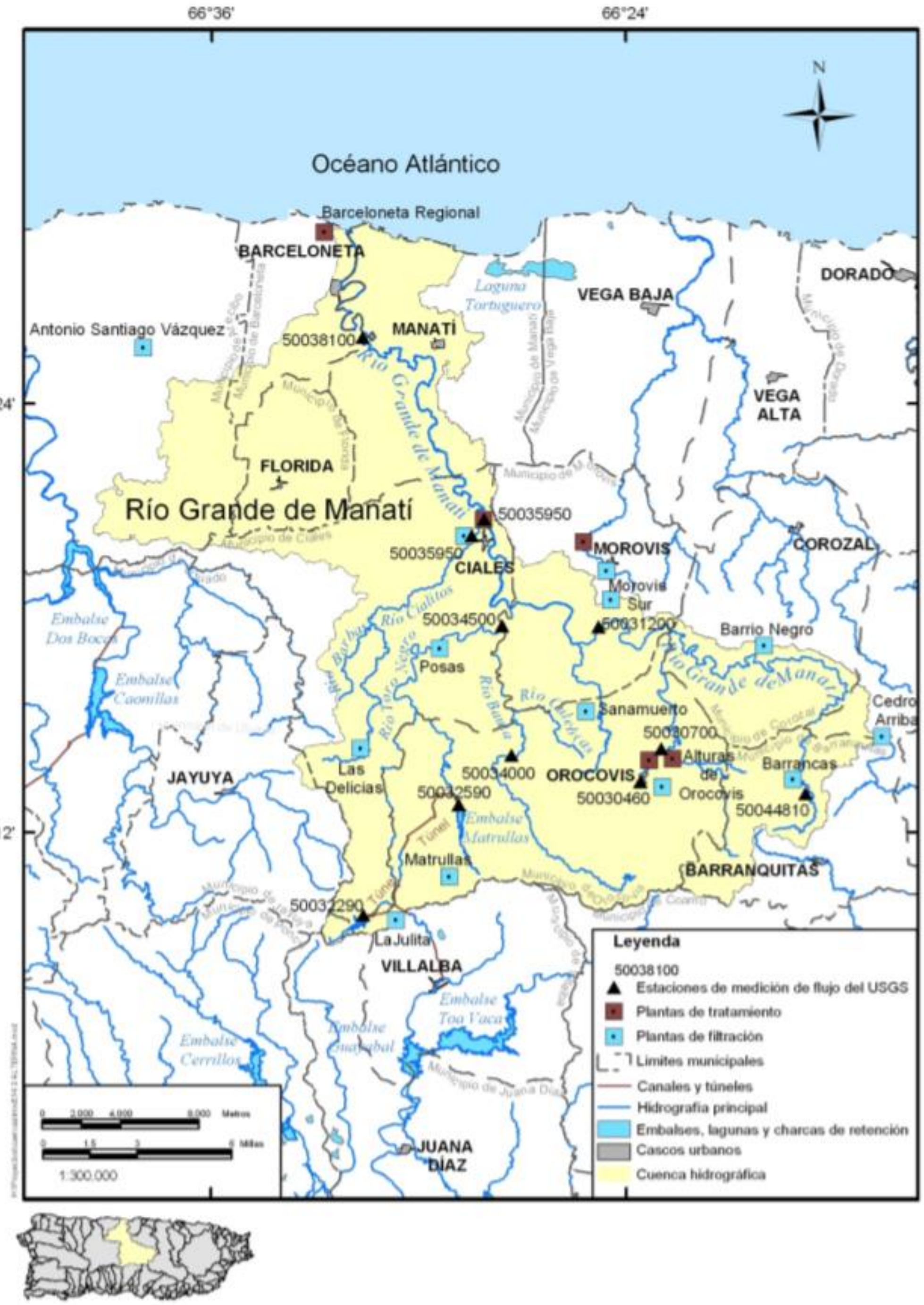


Figure 5. Hydrological Basin of the Manatí River

The hydrological basin of Manatí River (yellow area) origin from the Cordillera Central; it covers the north and central regions of Puerto Rico.

(from DRNA: http://drna.pr.gov/historico/oficinas/saux/secretaria-auxiliar-de-planificacion-integral/planagua/inventario-recursos-de-agua/cuencas-hidrograficas/Cuenca%20del%20Rio%20Grande%20de%20Manati.pdf/view)

Also, fifteen samples of sand were collected along the coast from five different stations; nine samples are from the western section of the Manatí River while the other six correspond to the eastern section [see **Figure 6**]. The visited stations where divided into three segments: [1] marine-terrestrial line, [2] high-tide shoreline and [3] shoreline; one sand sample of each segment were collected [see ***Aerial Photographs Analysis***, for detailly description of the stations and segments].

Reflectance Measurements. Reflectance measurements of the collected sand (fifteen samples) were measured using the GER 1500.

GER 1500. A field portable spectroradiometer [see **Figure 7**] that generates radiance measurements at different wavelengths. It has a spectral range from 350 to 1050 nm, visible to near-infrared [see **Figure 8**] (from Spectra Vista Corporation: https://www.spectravista.com/ger1500/).

Laboratory Work

Sand Samples. The used sand samples correspond to the ones collected near the berm and river-mouth at La Boca, Barceloneta. Tree different layers of composition were observed, and 100 grams were used to run the analyses from each layer. The first layer measured 0.453 meter, 2^{nd} layer distance was 0.685 meter and the 3^{rd} layer distance was of 0.965 meter [see **Figure 9**].

Sieving. Grain size was quantified by sediment sieving, described by Folk (1980), which consists of a set of nests (sieves) placed from the size of the mesh progressively smaller down the stack. The sizes of the testing sieves went from 4 millimeters (-2 phi) to 0.26 mm (2 phi).

Figure 6. All Samples of Sand

Sand samples collected along the coast of the area of study (top).

A composition of mostly dark minerals is observed at La Boca, Barceloneta (middle).
La Boca - Samples 1, 2 and 3 (A.B.C.)

In the other hand, Manatí is characterized for a content of carbonates (bottom).
Samples 4 and 5 (A.B.C.)

Figure 7. GER 1500 Portable Spectroradiometer
The GER 1500 is the instrumentation used as part of the field work.
We obtained reflectance measurements from the 15 sand samples collected

(from Spectra Vista Corporation: https://www.spectravista.com/ger1500/)

Figure 8. Visible Electromagnetic Spectrum
The results of reflectance percent, for the 15 sand samples collected, will be from 400 to 900 nm.
The visible light region starts at 400 nm and finish on 700 nm, at 780 nm starts the near infrared.

(from NASA 2010: https://science.nasa.gov/ems/09_visiblelight)

0.435 meter

0.685 meter

0.965 meter

Figure 9. Sand Samples collected near the Berm and River-Mouth
Same minerals fragments were identified at each thin section.
Highly percent of the composition consist of lithic fragments.

Thin Sections. Thin sections were prepared to observe composition and characteristics of the same sands used for sieving. The sand samples were polished and six thin sections were produced. The thin sections' thickness was -more or less- 0.030nm.

Aerial Photographs Analysis. Aerial photographs from the years [1] 1930, [2] 1993, [3] 2010 and [4] 2017 were downloaded through different sources: [1] Porto Rico 1930 Georeferenced, [2] EarthExplorer, [3] Geological and Environmental Remote Sensing Laboratory (GERS Lab) and [4] Hurricane MARIA Imagery (from NOAA Remote Sensing Division), respectively. The analysis of the aerial photographs were completed using the ENVI software.

Environment for Visualizing Images (ENVI). It is a software of image analysis and data statistics, considered a useful resource for time-series analysis and detection of changes (from HARRIS Geospatial Solutions: https://www.harrisgeospatial.com/SoftwareTechnology/ENVI.aspx).

According to the methodology presented by Stafford and Langfelder (1971), the following steps were used to achieve a coastal loss survey through time [see **Figure 10**].

1. Selection of primary points, which included -mostly- roads. These points were the same -consistent- at each photo evaluated. Eighteen primary points were stablished; eleven (1 to 11) from La Boca, Barceloneta and seven corresponding to the Manatí section (12 to 18) [see **Figure 11**].
2. Three reference points were defined:

    [maritime-terrestrial] defined as the boundary observed between vegetation/land and sand

    [high-tide shoreline] refers to the high water-line observed, is the closer water-line to the maritime-terrestrial boundary

    [shoreline] where the wave was observed

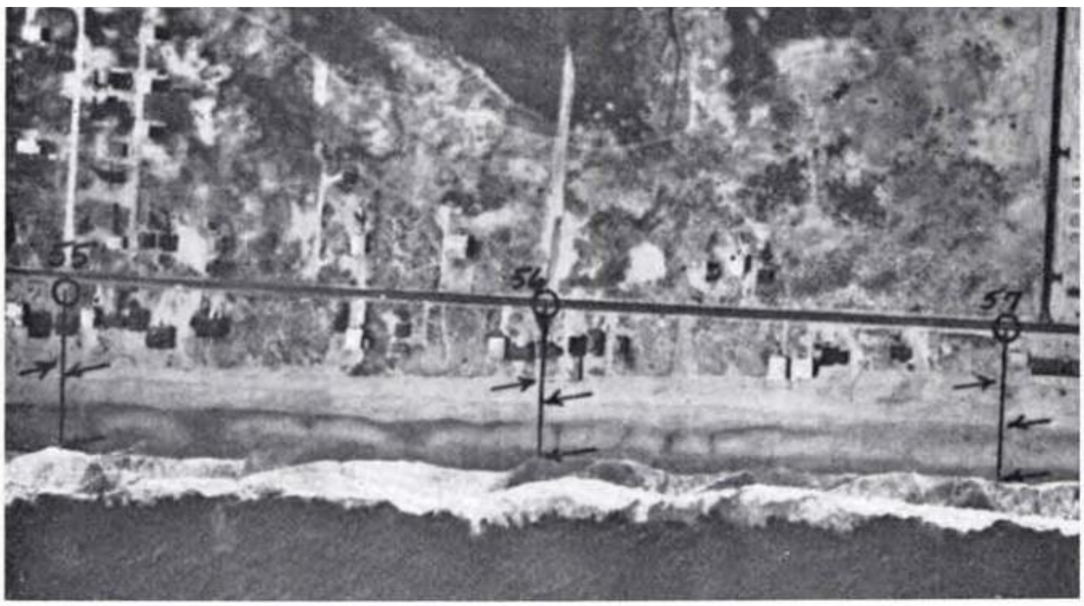


Figure 10. Reference Points Established

Primary points are marked with a circle. Arrows pointing west refers for high-tide shoreline and shoreline. We will follow the methodology by Stafford and Langfelder to see if it can be applied to beaches in Puerto Rico. The measurements will be taken using the ruler tool.

(from Stafford and Langfelder, 1971)

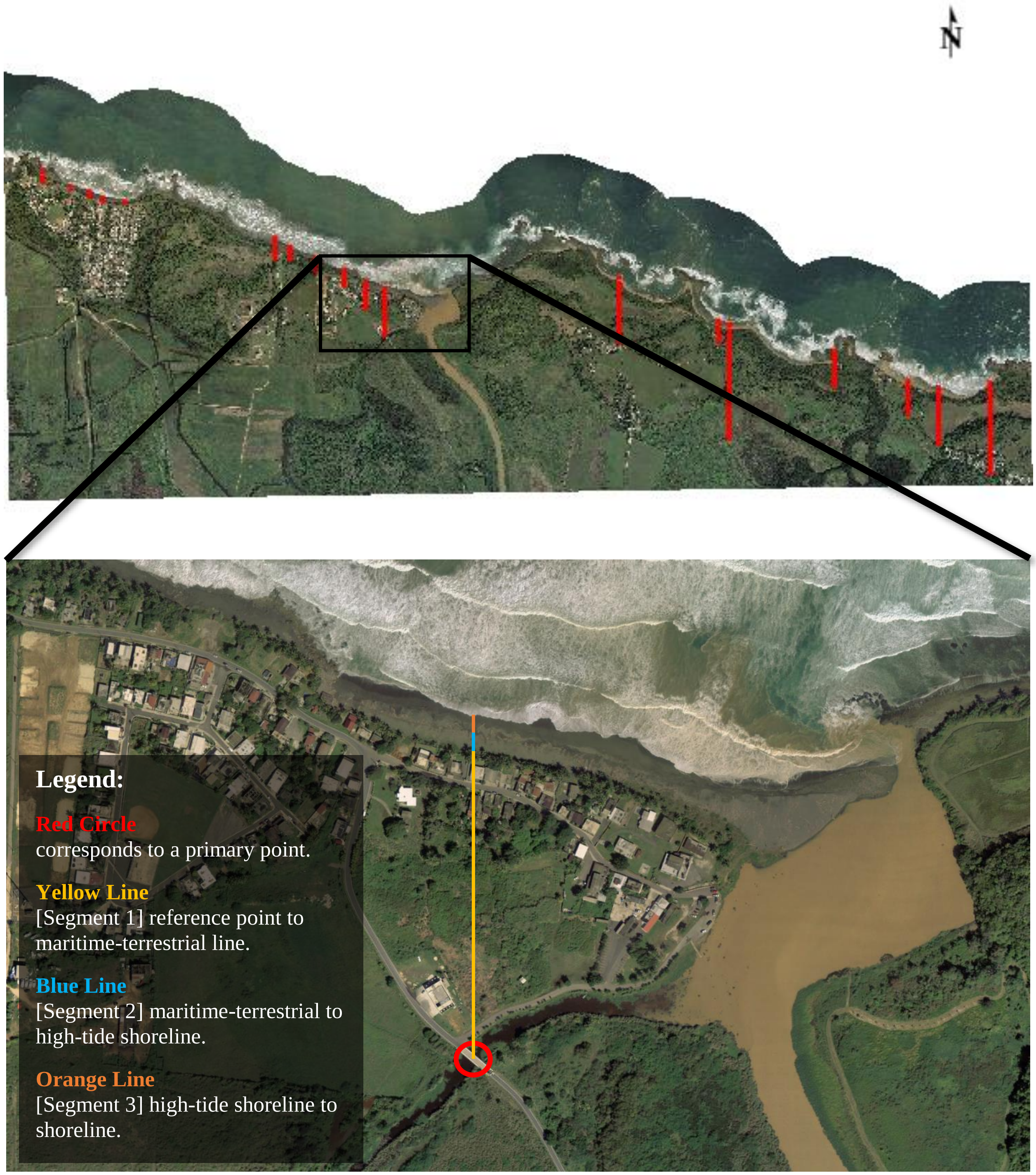


Figure 11. Primary and Reference Points Selected (2010 Aerial Photo)
Each segment was measured from south to north. The first 11 segments correspond to La Boca, Barceloneta and the other 7 for the Manatí coast; a total of 18 points were stablished. These segments were consistent at each aerial photo evaluated.

3. Using the ruler tool from ENVI a straight line was draw from:

   [Segment 1] reference point to maritime-terrestrial line

   [Segment 2] maritime-terrestrial line to high-tide shoreline

   [Segment 3] high-tide shoreline to shoreline

   The ruler tool shows the measurements for each segment in meters and, also, the total distance (which follow as: total distance = segment 1 + segment 2 + segment 3).

4. The measurements from each segment were copied to Microsoft EXCEL software. Coastal changes were created using a bar chart. Four bar charts were plotted; two from La Boca and two from Manatí. For each section, one bar chart corresponds to the high-tide shoreline values while the other to the shoreline measurements.

Reflectance Measurements Analysis. For measurements' interpretation, by exanimating the wavelength produced from the field work, the GER 1500 software were used. The GER 1500 measures the radiance (measurement of the light reflected by the surface of the object).

$$\%Reflectance = \frac{object\ radiation}{standar\ radiation} \times 100. \qquad \text{(eq. 1)}$$

In this study:

object radiation refers to the radiance from the sand and the

standard radiation is the radiance from the gray standard card.

The card used reflects 50 percent of sunlight, ∴ eq. 1 is adjusted to:

$$\%Reflectance = \frac{object\ radiation}{standar\ radiation\ (2)} \times 100. \qquad \text{(eq. 2)}$$

The following steps were used to analyze the reflectance measurements:

1. The reflectance measurements produced by the GER 1500 were extracted from the GER 1500 software and copied to Microsoft Excel Software.

   * Two reflectance measurements for each sand samples were collected that includes, also, two reflectance measurements from the gray card; a total of 60 measurements were produced and extracted.

2. The obtained measurements have to be converted from radiance to reflectance (eq.1).
3. Scatters charts of reflectance (%) *vs.* wavelength (nm) were created for each of the five stations where sand samples were collected. Three more charts were plotted for comparisons of the previous results; a total of eighteen scatters charts were produced.

RESULTS

Laboratory Analyzes

Sand Samples.

Grain Size Distribution. The grain sizes distribution for the samples were highly different at each layer and are shown in **Figure 12**.

[0.435 meter] Greater distributions of very coarse sand sediments were present (44%).

[0.685 meter] This layer has a highly average distribution of coarse sediments (47%).

[0.965 meter] Showed a good distribution along sediments: very coarse sand (31%), granules (30%) and coarse (29%).

Table 1 present details on phi scale, size of grains and sediments percent.

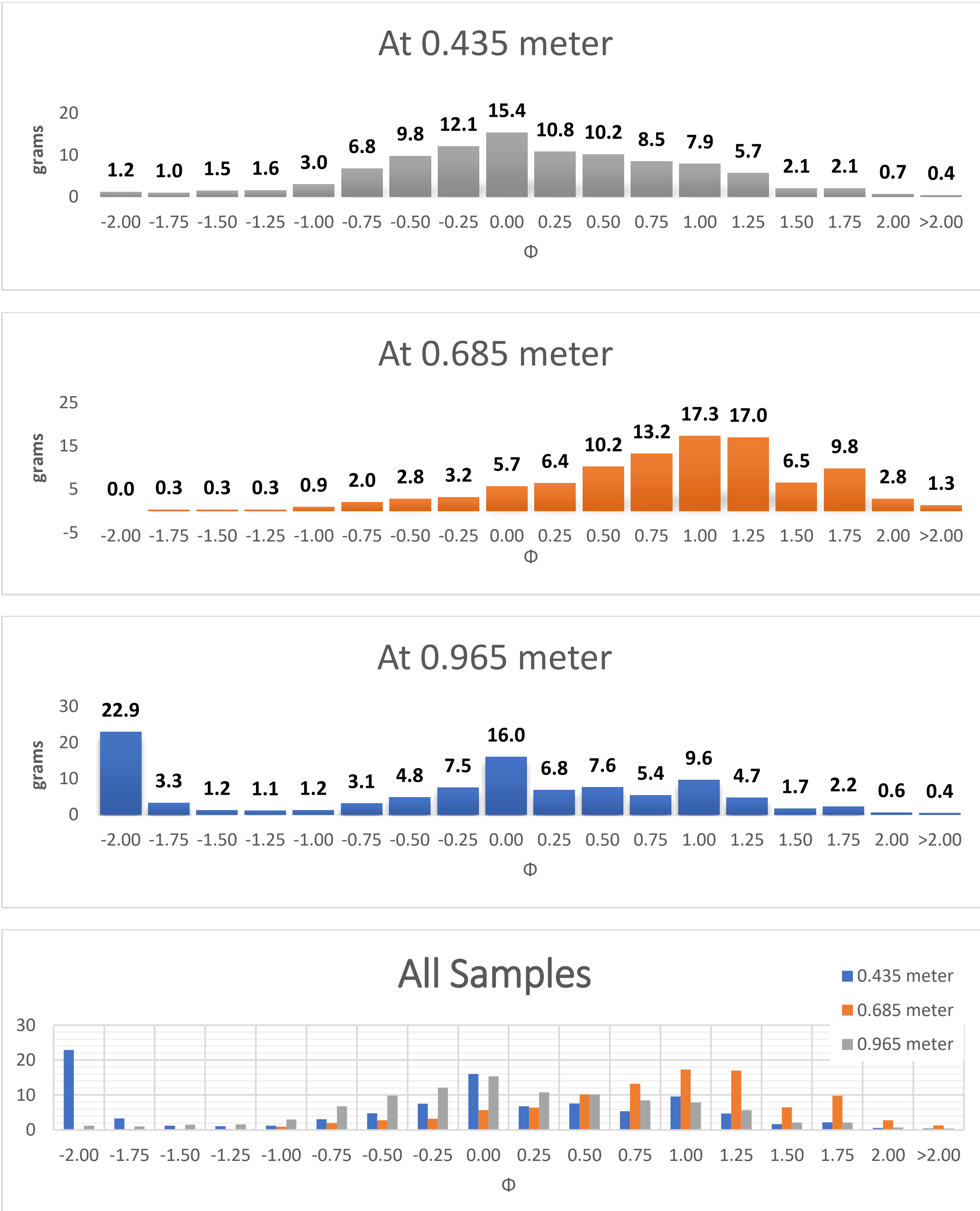


Figure 12. Grain Size Distribution

Sand samples correspond to the ones collected near the berm and river-mouth at La Boca**.**
At 0.435 meter, a 44% correspond to very coarse sand sediments (gray).
At 0.685 meter, a 47% was of coarse sediments (orange).
At 0.965 meter, 31 % of very coarse sand, 30% of granules and 29% of coarse (blue).

Sediment Name	Size (mm)	Φ Scale	0.965 m		0.685 m		0.435 m	
			(g)	Sediment	(g)	Sediment	(g)	Sediment
Granules	4.0000	-2.00	22.9	30%	0.0	2%	1.2	8%
	2.3636	-1.75	3.3		0.3		1.0	
	2.8482	-1.50	1.2		0.3		1.5	
	2.3784	-1.25	1.1		0.3		1.6	
	2.0000	-1.00	1.2		0.9		3.0	
V.C.S.	1.6818	-0.75	3.1	31%	2.0	14%	6.8	44%
	1.4142	-0.50	4.8		2.8		9.8	
	1.2500	-0.25	7.5		3.2		12.1	
	1.0000	0.00	16.0		5.7		15.4	
Coarse	0.8409	0.25	6.8	29%	6.4	47%	10.8	37%
	0.7071	0.50	7.6		10.2		10.2	
	0.5946	0.75	5.4		13.2		8.5	
	0.5000	1.00	9.6		17.3		7.9	
Med. S.	0.4204	1.25	4.7	9%	17.0	36%	5.7	11%
	0.3536	1.50	1.7		6.5		2.1	
	0.2973	1.75	2.2		9.8		2.1	
	0.2500	2.00	0.6		2.8		0.7	
Fine S.	<0.2483	>2.00	0.4	0%	1.3	1%	0.4	0%
		TOTAL	100.1	100%	100.0	100%	100.8	100%

Table 1. Grain Size Distribution (from Figure 12)

Mineral Composition. In the analysis of each thin section same minerals fragments were identified. Slightly differences observed, through the thin sections, were quantities' variations of each minerals.

[0.435 meter] Highly percent of the composition consist of lithic fragments. Lots of plagioclase were observed and some have clearly polysynthetic twinning. Also, amphiboles were identified (hornblendes). As secondary minerals, there were lots of chlorite. Less quantities of minerals' fragments were found of quartz and magnetite. Very low fragments of carbonates were present (mostly shells) and, also, a few algae and bivalves. **Figure 13**.

[0.685 meter] A lot more alterations were present at this sample. Still a highly percent of lithic fragments. There were more quantities of plagioclase, and chlorite and highly percent of ferromagnesian minerals (pyroxenes, amphiboles and olivine) and magnetite. Almost cero percent of quartz were found. Algae and bivalves' fragments were present, very low content of carbonates. **Figure 13**.

[0.965 meter] Lots of oxides were present at this layer. Less quantities of ferromagnesian minerals were identified. Still a high percent of plagioclase. **Figure 13**.

Aerial Photographs. **Figure 14** and **15**. In the boundaries defined [1] high-tide shoreline and [2] shoreline, values were obtained and extracted to produce four bar charts: two for La Boca in Barceloneta in **Figure 16** and two for the Manatí's coast section, **Figure 17**. The results showed pattern migrations to marine-terrestrial boundary known as transgressions and, also, seaward migrations defined as regressions.

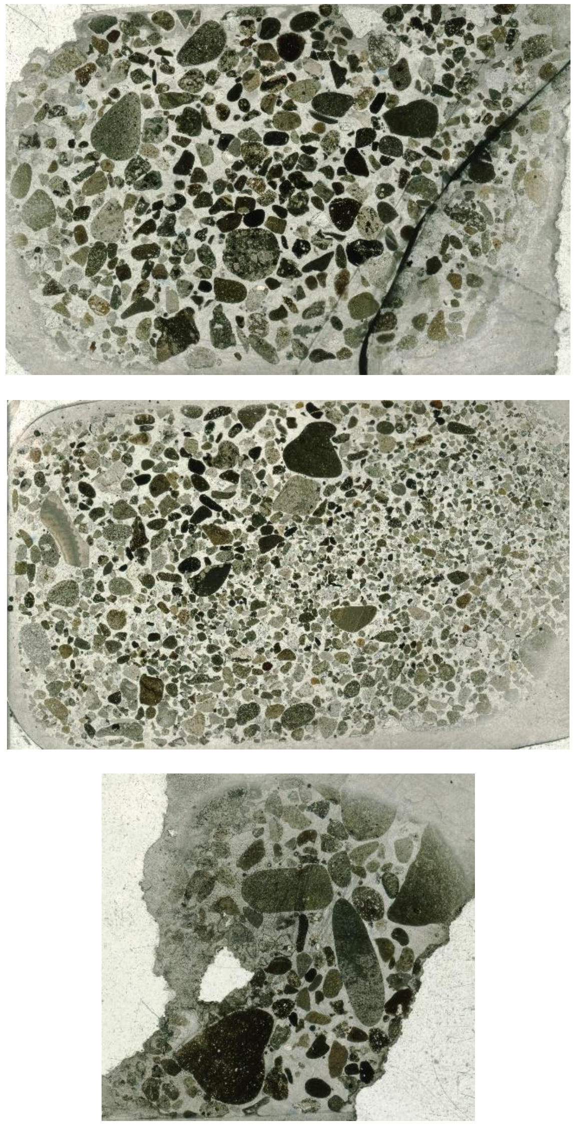


Figure 13. Thin Sections
Sand samples correspond to the ones collected near the berm and river-mouth at La Boca**.**
Samples from 0.435 meter (top), 0.685 meter (middle) and 0.965 meter (bottom).
The thin sections' thickness was -more or less- 0.030nm.
Highly percent of the composition consist of lithic fragments. Slightly differences observed, through the thin sections, were quantities' variations of each minerals.

(scanned by Pedro León)

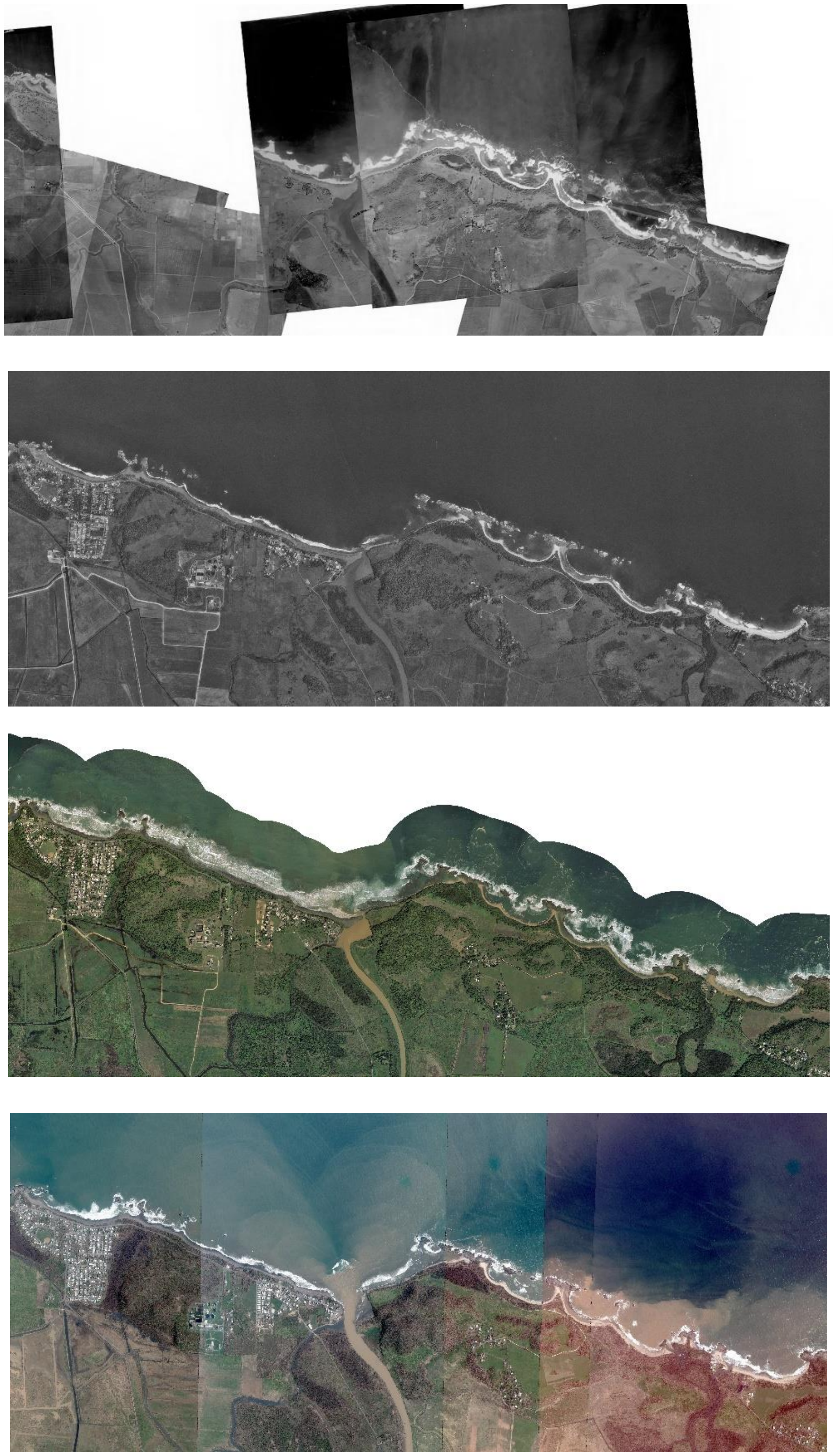


Figure 14. Aerial Photographs
From 1930 (top), 1993 (middle-top), 2010 (middle-bottom) and 2017 (bottom).

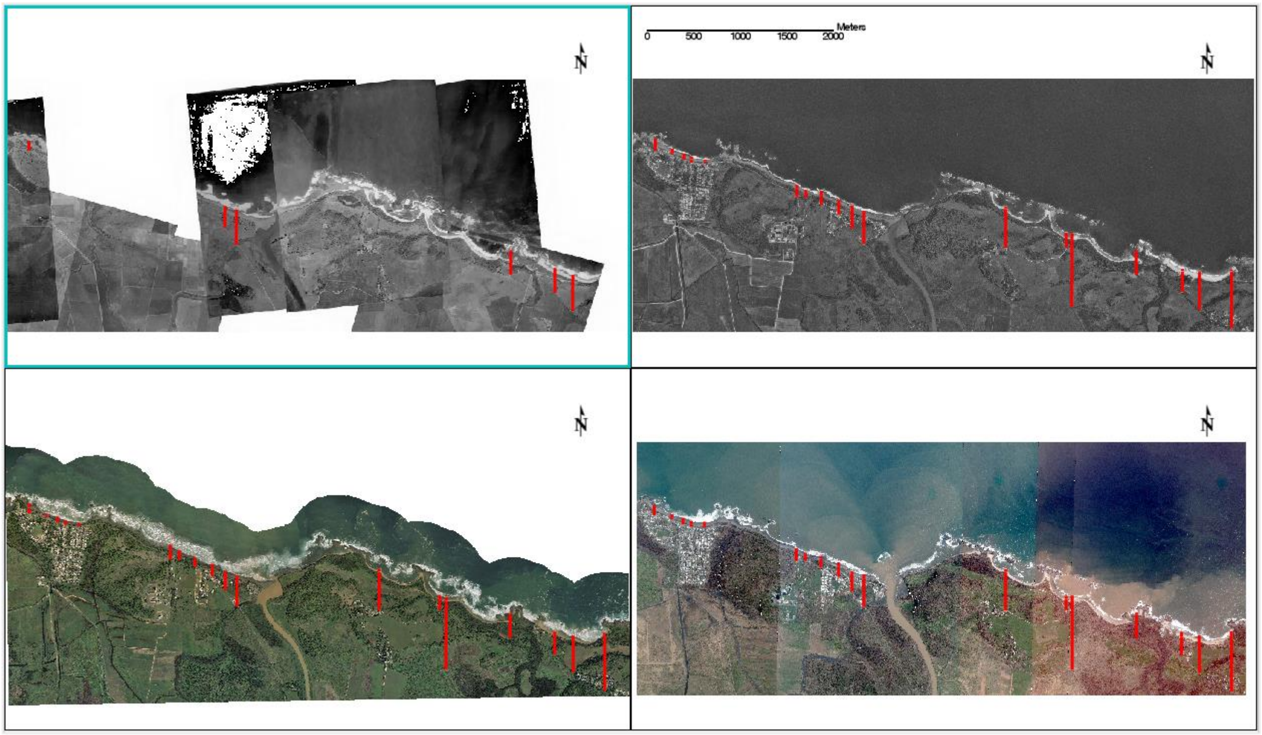
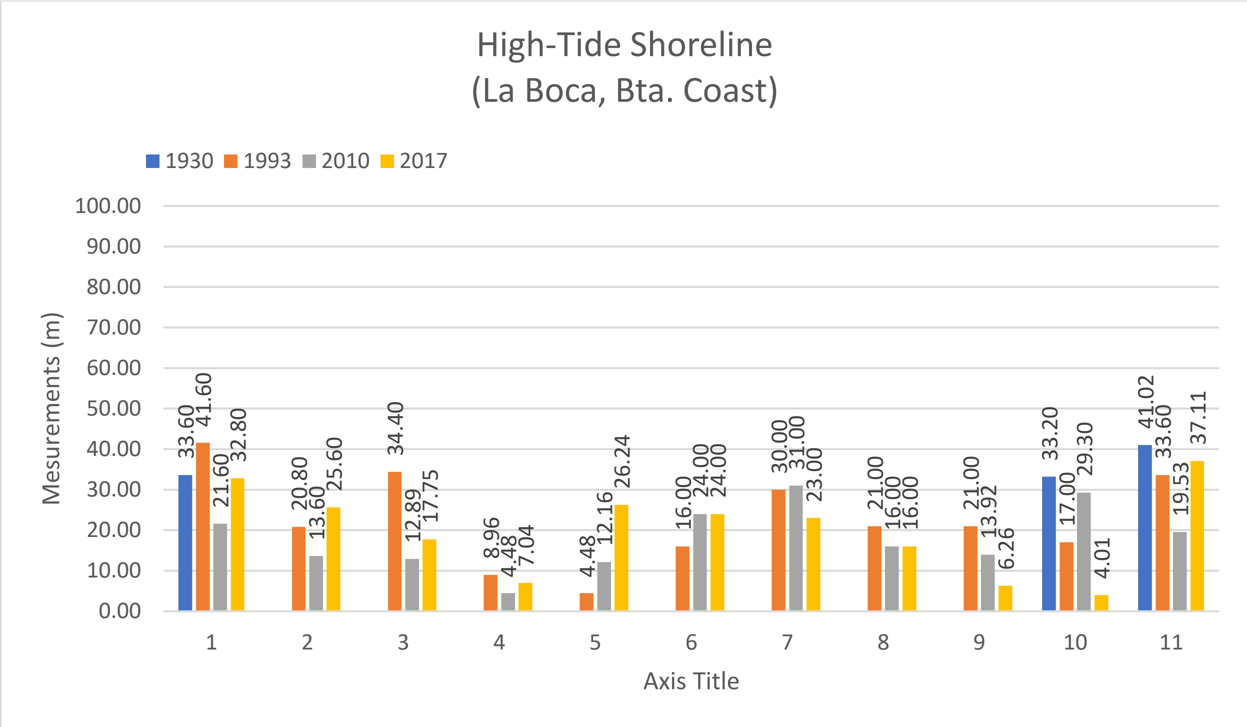


Figure 15. Aerial Photographs with linked-views at ENVI
For details of reference points see **Figure 11**.
Aerial photographs from 1930 (top-left), 1993 (top-right), 2010 (bottom-left) and 2017 (bottom-right).



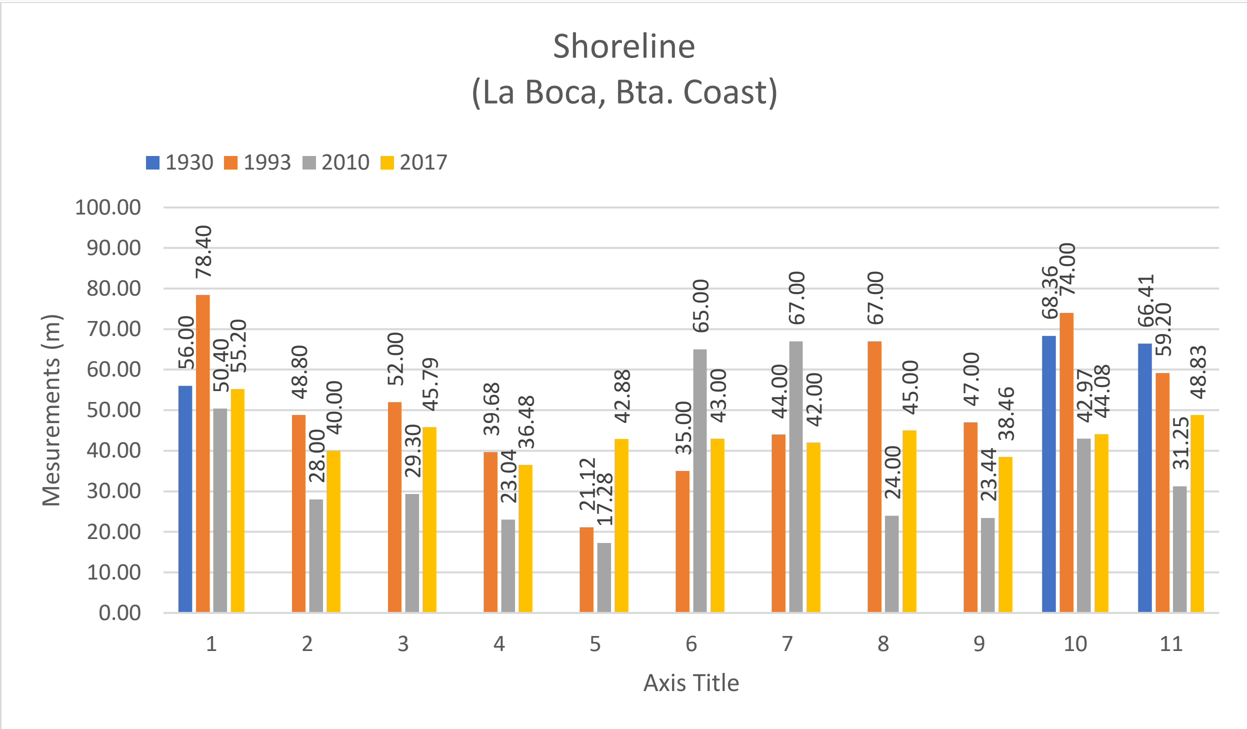
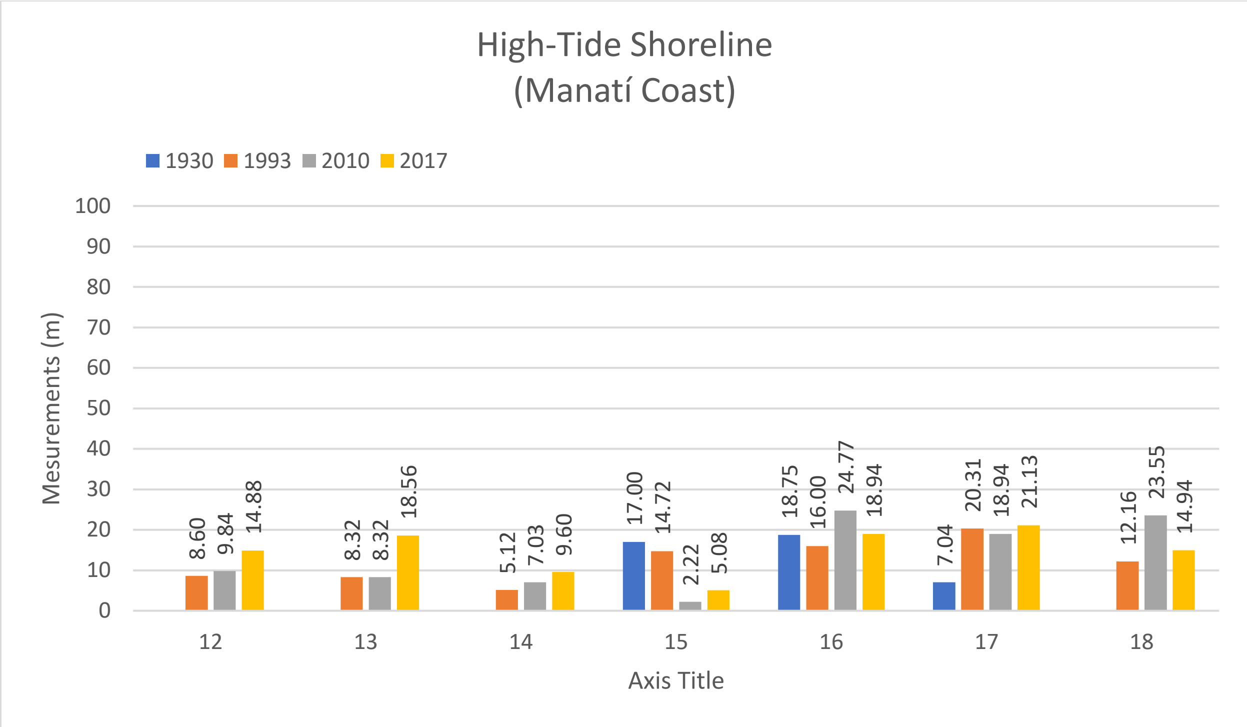


Figure 16. Results of High-Tide Shoreline and Shoreline at La Boca, Barceloneta.
At each year, La Boca presented patterns of transgressions and regressions.



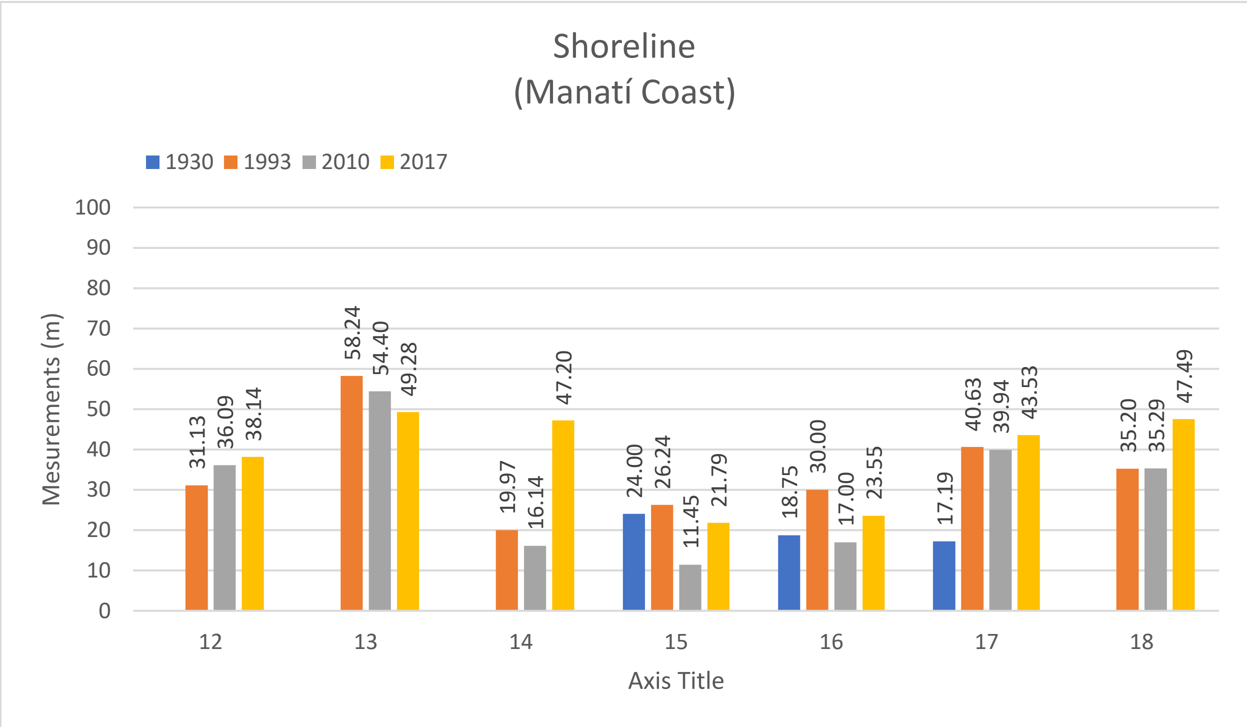


Figure 17. Results of High-Tide Shoreline and Shoreline Manatí.
If there were an event of transgression, almost the whole coast presented it;
the same occurred at the site if there were a regression event, was consistent at the coast.

The results from La Boca, Barceloneta correlated along with simple observations made through the aerial photographs for each year available; the migrations of shorelines were accurate. For the results of Manatí, three reference points (out of seven) do not seems to have correct measurements; the points are 15, 16 and 17. These show correct migrations of the shorelines, but the values of transgressions and regressions do not are accurate to the observations. A possible factor for these errors is the position were the aerial photographs were taken (associated to geometric distortions due to Earth’s surface).

La Boca presented a combination of transgressions and regressions events, at each year, along the whole coast. Manatí, does not presented a combination of events along its coast; there were significantly transgressions or regression events.

Reflectance measurements. Charts of reflectance measurements from the five stations visited are shown in **Figure 18**. Curves of magnitudes correlated along each section evaluated, at La Boca in and Manatí. The values obtained along La Boca were lower compared with the magnitudes results from Manatí. Lower magnitudes curves correlated with sand composition of dark minerals while higher magnitudes corresponded to higher amounts of carbonates.

DISCUSSION

The analyses of thin sections show that sand composition has not change -at least- through the first 0.965 meters of deepness, but there are have been percent’s changes (by increase or decrease) of certain minerals at each layer. We can assume several depositional events have occurs at this site, due to the layers observed and the results of grain sizes. Types of sand can be named at each layer by the average quantity and distribution of grains’ sizes.

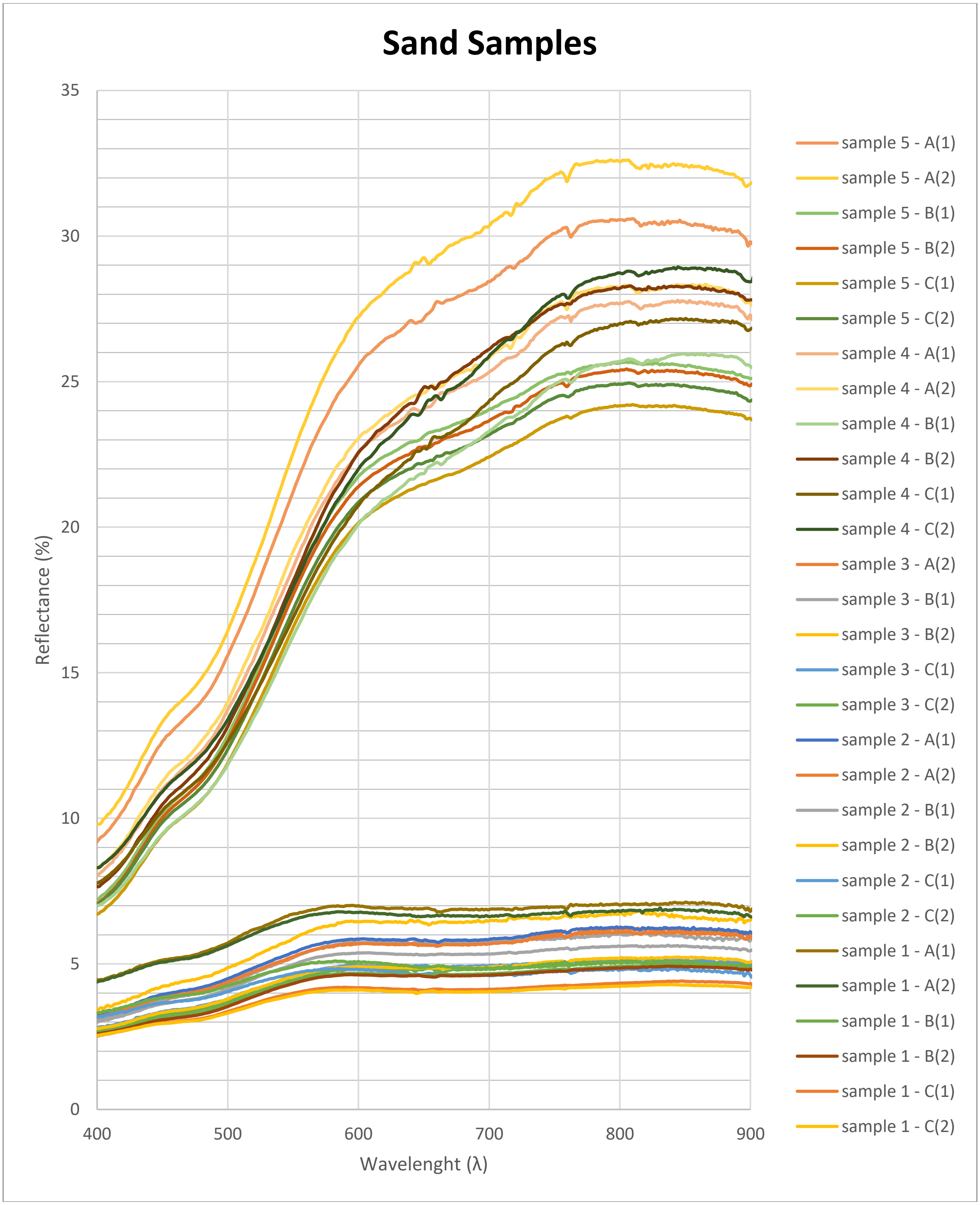


Figure 18. Results of all Reflectance Measurements of La Boca, Bta. and Manatí
The values obtained along La Boca were lower compared with the magnitudes results from Manatí. Lower magnitudes curves correlated with sand composition of dark minerals while higher magnitudes corresponded to higher amounts of carbonates. For details, see **Figure 6**.

The Manatí River seems to transport the same sediments and lithic fragments eroded from the same source through the decades. The rock fragments show a sphericity of roundness and well-roundness and a flattened surface, which its associated to a long depositional history. The sphericity is influence and controlled by the drainage of the Manatí River. The Manatí River serves as a source of sand for the beach at La Boca, Barceloneta by transporting all the terrigenous sediments and lithic fragments eroded at the Cordillera Central to its river-mouth. The flattened surface is mostly influence by waves, once the rock fragments reach the beach.

By just observing the aerial photographs, we know the area of study it is influenced by drainage patterns (greatly by the Manatí River), winds' direction and waves' distribution due to the geomorphology exposed. A long-term aerial survey of a section of the north coast at La Boca in Barceloneta and Manatí was accomplished. Patterns of transgression and regression were present at the shoreline. Both coasts were measured and quantified. The interaction between the sediments' source will define the shoreline migrations by transgressions or regressions events. After the struck of Hurricane María (2017) the community at La Boca, Barceloneta experienced a highly erosion of its coast in some areas while, on the other hand, there were a relative regression at Manatí's coast.

Definitely reflectance measurements curves change with composition. Even-thought grain size does not affect directly with same mineral composition, there were a slightly increase in magnitude curves with finer grains [at the shoreline] on the same station of sand collected. Using remote sensing techniques of radiometric measurements, let the user determine sand composition and an approximately range of grain sizes. Higher curves, at same minerals compositions, correspond to finer grains while lower curves represent very coarse sands. By the results obtained, we proved curves of reflectance let us characterize beaches as: [1] carbonates content or [2] by their abundant of dark minerals.

CONCLUSION

The western coast of the Manatí River does not have a significant influence of carbonate fragments besides as it occurs to the eastern side where sediments are derived from marine ecosystems. La Boca at Barceloneta has an abundant content of highly weathered lithic fragments while the section of Manatí presented a vastly abundant of bio-clast fragments. Due to the eolanites geomorphology of the beaches at Manatí, bio-clasts fragments do not have a strong opportunity to migrate.

The geomorphology shows that the north coast of Puerto Rico has variations features along every five to ten km -approximately-. These variations define beach systems along the north coast. Due to the morphology changes observed, the coastal erosion at the area of study is associated to: [1] short-term and [2] long-term effects, because this coast has experienced both. Short-term take place with the effects of atmospheric events (e.g. Hurricane María), while long-term effects represents the influence of depositional events conducted by drainage patterns and/or sea level changes. Events of shoreline erosion are common and natural, the real problems at coastal environments are the infrastructure and dams' constructions which highly affects the process of transportation and deposition of sediments.

Sand beaches have a correlation between its sand content and the curves of reflectance *vs.* wavelength for the visible range of the spectrum. It is possible to characterize beaches by [1] carbonates or [2] dark minerals; and, also, determine an approximately range of grain sizes. The distribution of grain sizes let us have a general idea of the sand's depositional history that can be attributed to the influence of energy changes during depositional events.

Further Work

As a second phase, for this study, we will run a methodology that let us establish correlations between radiometric measurements obtained by the GER 1500 and pixel values from the 2017 aerial photographs. The aerial photos from 2017 are necessary, because are the only ones that includes band values (from red, blue and green). The pixel values incorporated with $y = mx + b$ should let us obtain similar plots like the ones -previously presented- of reflectance *vs.* wavelength. The results obtained using pixel values, should correlated with the extracted values from the GER 1500 software. Also, we will compare minerals spectral signals with the curves obtained. On the other hand, we will use the Digital Shoreline Analysis System (DSAS), a software extension to ArcGIS, to compare the results obtained of transgressions and regressions. The results obtained by DSAS will be compared; measurements errors will be calculated to determinate the effectives of the methodology applied at this research.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the Department of Geology at the University of Puerto Rico – Mayagüez Campus and the GERS Lab. Thanks to my mentor, Dr. Fernando Gilbes, for the guidance through the research. Special thanks to Luis Cuba, Wanda López, Adriana Rivera and Luis Rivera for the help of collecting sand samples and measurements on the field. To Lauryn Martínez for the help on the identification of minerals and to César Rodríguez for the tutorials with GIS. Thanks to Dr. Wilson Ramírez for its knowledge, ideas and suggestions; and to Ernesto for all the questions he asked which let me question more the features of my area of study. Also, special thanks to Catherine Pérez, Jennifer Toledo, Giovanni Nin and Dra. Lizzette Rodríguez for the support to make this possible.

CITED REFERENCES

Andres, L., Boateng, K., Borja-Vega, C., and Thomas, E., 2018, A Review of In-Situ and Remote Sensing Technologies to Monitor Water and Sanitation Interventions: Water, v. 10, p. 756, doi: 10.3390/w10060756.

Briggs, R., P., 1965, Geological map of the Barceloneta quadrangle, Puerto Rico: U.S. Geological Survey, scale 1:20,000, 1 sheet.

Chiqués, G., M., 2005, Spectral Characterization of Sandy Beaches in Western Portion of Puerto Rico [Master thesis]: Mayagüez, University of Puerto Rico, 65 p.

Folk, R. L., 1980, Petrology of Sedimentary Rock: Texas, Hemphill Publishing Company, 190 p.

Hugenholtz, C. H., Levin, N., Barchyn, T. E., and Baddock, M. C., 2012, Remote sensing and spatial analysis of aeolian sand dunes: A review and outlook: Earth-Science Reviews, v. 111, p. 319-334, doi: 10.1016/j.earscirev.2011.11.006.

Nath, B., Niu, Z., and Acharjee, S., 2018, Pre-earthquake Anomaly Detection and Assessment through Lineament Changes Observation Using Multi-temporal Landsat 8-OLI Imageries: Case of Gorkha and Imphal: Multi-purposeful Application of Geospatial Data, p. 149-171, doi: 10.5772/intechopen.72735.

Rodríguez, R. W., Web, R. M. T., and Bush, D. M., 1994, Another Look at the Impact of Hurricane Hugo on the Shelf and Coastal Resources of Puerto Rico, U.S.A.: Journal of Coastal Research, v. 10, p. 278-296.

Sesli F. A., Karsli, F., Colkesen I., and Akyol N., 2008, Monitoring the changing position of coastlines using aerial and satellite image data: an example from the eastern coast of Trabzon, Turkey: Environmental Monitoring and Assesment, v. 153, p. 391-403, doi: 10.1007/s10661-008-0366-7.

Stafford, D. B., and Langfelder, J., 1971, Air Photo Survey of Coastal Erosion: Photogrammetric Engineering, p. 565-575.

Thampanya, U., Vermaat, J. E., Sinsakul, S., and Panapitukkul, N., 2006, Coastal erosion and mangrove progradation of Southern Thailand: Estuarine, Coastal and Shelf Science, v. 68, p. 75-85, doi: 10.1016/j.ecss.2006.01.011.

Pasch, R., J., Penny, A. B., and Berg, R., 2018, Hurricane Maria: National Hurricane Center Tropical Cyclone Report (AL152017), 48 p., https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf.