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**Shoreline Change at Playa Jayuya, Fajardo, Puerto Rico using
Digital Shoreline Analysis System (DSAS)**

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Abstract

This research in shoreline change was developed at Playa Jayuya in Las Cabezas de San Juan Natural Reserve in Fajardo, Puerto Rico. Working with remote sensing analysis of high resolution aerial photography and satellite images from 1962 and 2010. The images and aerial photographs were used to calculate shoreline rate- of- change statistics from multiple shoreline position using ESRI ArcGIS 10.1 software and its extension from the United States Geological Survey (USGS), The Digital Shoreline Analysis System (DSAS) version 4.3 and developed by Thiehl (2009). The statistical analysis used were Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), and End Point Rate (EPR). The analysis revealed and averaged erosion rate of -0.10 m/year. DSAS tool was of great use developing the statistical analyses. However, some problems were encountered when transects were located near curved areas.

Keywords: Shoreline, DSAS, Aerial Photographs, GIS, Fajardo

1. Introduction

In order to develop a coastal management project as well as land use, and planning strategies to conserve the area it is crucial to understand processes related with shoreline changes (Bush et al., 2013). One of the most dynamic environments on Earth are the coasts (Bush and Yung, 2009). Coastal zones are exposed, in long and in short terms, to wave break and currents, high tides and low tides, climate change, and natural disasters such as cyclones and storms (Bush and Yung, 2009). Although, coastal zone is a broad term, it includes all land and water areas which are affected by marine processes (Bush and Young, 2009). In this case Puerto Rico's shoreline suffers from constant erosion and deposition (Thieler et al., 2007). Shoreline change is define as the movement or position variation of any shoreline markers such as dune lines, beaches, etc. (Bush

and Young, 2009). Shoreline change information analysis is a basic step in order to make decisions on short-terms and in long-terms erosion rates, hazard and risk consideration, and coastal planning (Bush and Young, 2009). For this reason, the evolution and behavior of Playa Jayuya shoreline will be quantified using transects to enhance a better understanding of its shore dynamic. Transects are segments used to capture shoreline change distance and statistical rate between shorelines (Bush et al., 2013). The best ways to monitor shoreline change is using aerial photography, remote sensing surveying, and geographical information system (GIS) (Bush and Young, 2009; Avinash et al., 2010). This because it reduces some errors and, in some cases, achieved in absence of field investigation (Avinash et al., 2010).

Rodriguez et al. (2009) state that the Geographic Information System (GIS) show the spatial and temporal evolution of dynamic processes as well as the factors that controls their behavior. GIS software has several uses depending on the coastal zone need (Rodriguez et al., 2009). In this case, the shore of Playa Jayuya is going to be delineated in order to detect the changes in the shoreline position. For instance, GIS is going to be used to determine the evolutionary tendencies to define the shore behavior (Rodriguez et al., 2009). This is one of the most important or useful characteristics of GIS (Rodriguez et al., 2009).

The Digital Shore-line Analysis System (DSAS) is an extension or application of the Environmental System Research Institute (ESRI) Geographic Information System (ArcGIS) software (Thieler et al., 2007). DSAS is a free software with focus on the calculation of rate-of-change statistical analyses (Thieler et al., 2007). DSAS reads the shoreline position with GIS, and applying the user specifications, it calculates several measurements of change such as; average-of-rate, and linear regression (Bush and Young, 2009). Besides, using DSAS for coastal environment, it is also useful to compute other boundary or change problems (Thieler et al., 2009).

Puerto Rico has distinctive shoreline types (Kaye, 1959). The northeaster shore of Puerto Rico is full of off shore small islands (Kaye, 1959). During the past 500 years has suffer from deposition to erosion, meaning that the erosion is the dominant activity in beaches and in coastal areas (Morelock, 2000). Some causes of erosion may be change in sea level, erosion of barrier reefs and eolimates, man activity, and maturity of coastal systems (Morelock, 2000). Unconsolidated shores are more exposed to erosion than those located in rock stretches (Bush et al., 1996).

Several shoreline change projects have been develop in the coast of Puerto Rico. However, slightly nothing been said of the northern part of Puerto Rico, especially at Cabezas de San Juan. For this reasons the objectives of this research are:

- a. Use DSAS to determine shoreline change at Playa Jayuya located in Las Cabezas de San Juan Nature Reserve.
- b. Compare aerial photography from different years to determine temporal changes in shoreline.

2. Study Area

Playa Jayuya is part of Las Cabezas de San Juan Nature Reserve. It is located in the northeastern part of the Fajardo municipality. With longitude $65^{\circ}37'19.79''$ W and latitude $18^{\circ}22'56.72''$ N, (Figure 1 and figure 2). The analyzed area comprehends approximately 470 m. The area included in the reserve has been classified as part of the northern Cretaceous section (Weaver et al. 1999). Las Cabezas de San Juan reserve is surrounded by five beaches including Playa Jayuya.

The reserve general geology has two sections, the first is divided in volcanic breccia and tuffaceous sandstone and siltstone, from marine deposit origin (Weaver et al. 1999). The second,

it is composed of alluvial deposits, terraces, beach, lagoons, swamp, dune deposits, and coastal eolianites (Weaver et al. 1999). Playa Jayuya, has a pre- Columbian archeological site (Weaver et al. 1999). There are artifacts from the Igneri Indian culture in addition to bones, ceramic vessel, and human activity (Weaver et al. 1999).

3. Methodology

3.1 Sample Description

The study was performed using 2 aerial photo from 1962 (figure 3) and other from 2010 (figure 4), provided by the Geological and Environment Remote Sensing (GERS) Laboratory. The 2010 photo has a spatial resolution of 1 foot. The photograph from 1962 is in black and white. The datum used for the photographs and digitalized objects is NAD 1983 State Plane Puerto Rico and Virgin Islands FIPS 5200 and the units are in meters. The aerial photograph was georeferenced in ArcMap using the 2010 photo and using as reference the building closer to the shore.

3.2 Shoreline Change

Shoreline change at Playa Jayuya was analyzed using ESRI ArcGIS 10.1 software and its extension, the Digital Shoreline Analysis System (DSAS) version 4.3. The photos shoreline was delineated and digitized as a shapefile using ArcMap (figure 5). The shoreline proxy used to delimitate the area was the boundary between the sand and the water. This because the significant error displacements due to high relief topography has to be minimized (Moore 2000).

All shorelines were digitized through shapefiles and later staked in order to visualize and compare the change. Although, it is possible to note the change in shoreline true the staking of shapefiles, it is necessary to develop quantitative analyses in order to have more accurate conclusions. These calculations or statistics used in this study were the Net Shoreline Movement (NMS), Shoreline Change Envelope (SCE), and End Point Rate (EPR) (Table 1). In this step,

graphs and tables were developed in order to obtain rate of change of the coastline. DSAS allowed to create transects and the rate of change of the shoreline was analyzed at different points in meters per year. Transect spacing selected was 20 m and 120 m in length. The spacing and length were determined after observing several options in order to cover all interested site area. In order to compare and analyze the shorelines, all the individual shapefiles were converted into a feature class and append together. The baseline was established using the buffer method, one of the three available, of the 2010 existing shoreline. The buffer was of 25 meters and created as a polygon file in ArcMap and therefore was change to a polyline using a tool called Polygon to Line. When the shorelines and baseline were all in a personal geodatabase file, the maps, and tables identifying the areas of deposition and erosion were produced.

4. Results and Discussion

4.1 Shoreline Change

A shoreline erosion from 1962 to 2010 is most visible in the east part of Playa Jayuya. However, there are exemptions were deposition was also occurring. The End Point Rate (EPR) analysis for the area gave a mean average of -0.10 m/year with a standard deviation of 0.16 m/year (figure 6). EPR divides the distance of the shoreline movement by the time elapse between the oldest and the youngest (Thieler et al., 2009). In order to determine the shoreline net movement the NSM analysis was used which reports the distance between the oldest and youngest shorelines for each transect (Thieler et al., 2009). The Net Shoreline Movement (NSM) was -4.8 meters with a standard deviation of 7.6 meters (figure 7). In addition, in order to represent the total change in shoreline position the Shoreline Change Envelope (SCE) analysis was used. It measures the distance between the shoreline farthest from and closest to the baseline (Thieler et al., 2009). It also represents the total change in shorelines regardless of its dates. The SCE mean value was 6.5

meters and a standard deviation of 6.1 meters (figure 8). It is possible to note the variation between shorelines was due primarily by the erosion or accretion. The highest ERP of Playa Jayuya is of -0.38 m/year in the second transect, east to west. The NSM, as well, exposes the erosion predominantly in the east area. The EPR and the NSM analysis present a deposition true transects 23 to 26 which is a least in comparison with the erosion. The highest deposition rate was of 0.16 m/year.

The erosion in Playa Jayuya may be due to the presence of beachrocks. This because it forms a natural wall against deposition (Kaye, 1959). In this cases wave erosion takes over the uncemented sand behind the beachrock and new sand cannot be deposited (Kaye, 1959). In Puerto Rico it is common to see this features along the north coast (Kaye, 1959). A beachrock is cemented sand along the intertidal zone in which the cement consists geminately of CaCO_3 (Kaye, 1959).

5. Conclusion

The shoreline of Playa Jayuya is being eroded at a rate of -0.10 m/year all tough in some areas deposition also occur. The highest deposition rate was of 0.16 m/year this in the west area. The EPR and the NSM analysis showed value similarities but with different units. The erosion of the shoreline seems to be by natural causes. It may be produced by the appearance of beachrocks in the intertidal zone. This research was possible with the use of ArcGIS system. It is accessible and relatively easy to use. In addition, DSAS tool was an extension for the program and useful in determining shoreline change. The problem presented with DSAS was the application of transects in curved areas because transects in some cases overlapped the shorelines. However, the calculation and statistics seems to be efficient and well developed.

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Figures

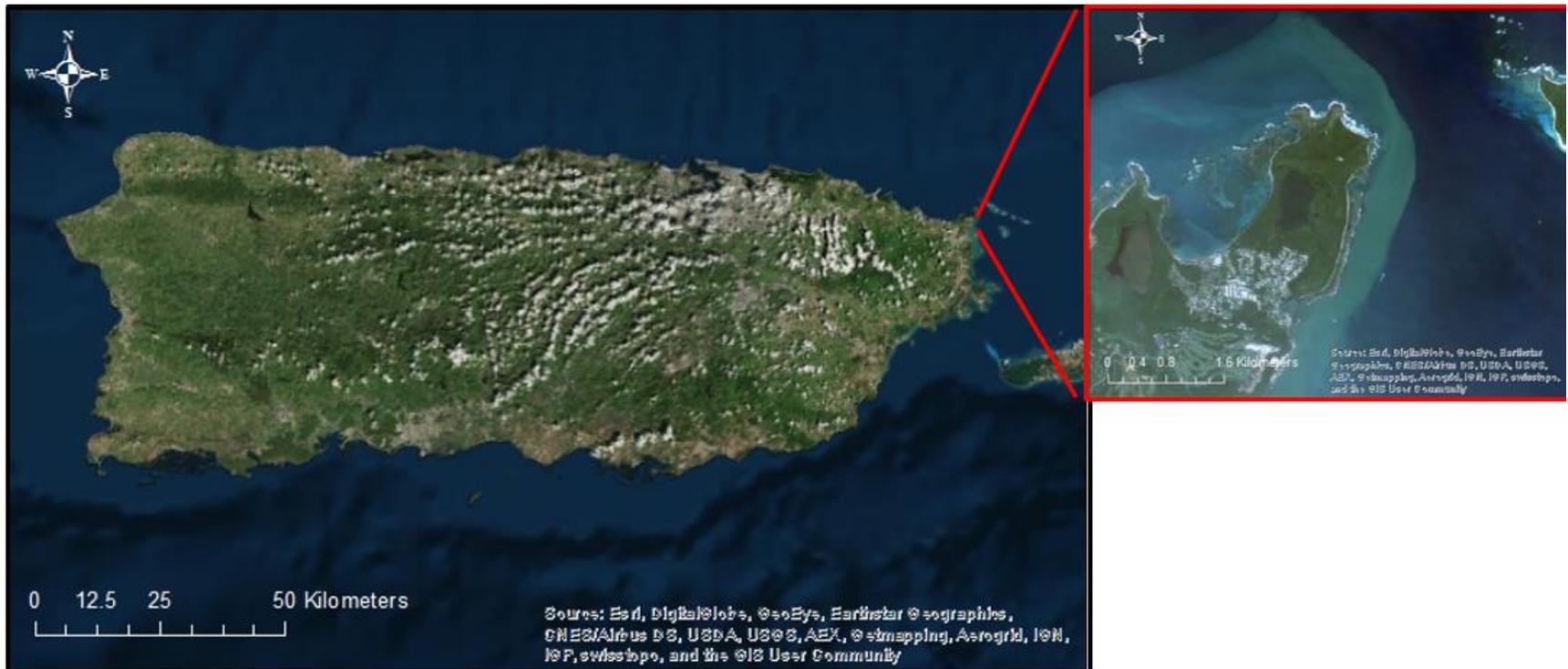


Figure 1: Location of Las Cabezas de San Juan Reserve with longitude $65^{\circ}37'19.79''$ W and latitude $18^{\circ}22'56.72''$ N where the beach is located



Figure 2: Image of the shoreline analysis location, Playa Jayuya, situated in Fajardo Puerto Rico. The red dot is where the archeological site is found. The photo was taken in 2012 by the Conservation Trust of Puerto Rico.

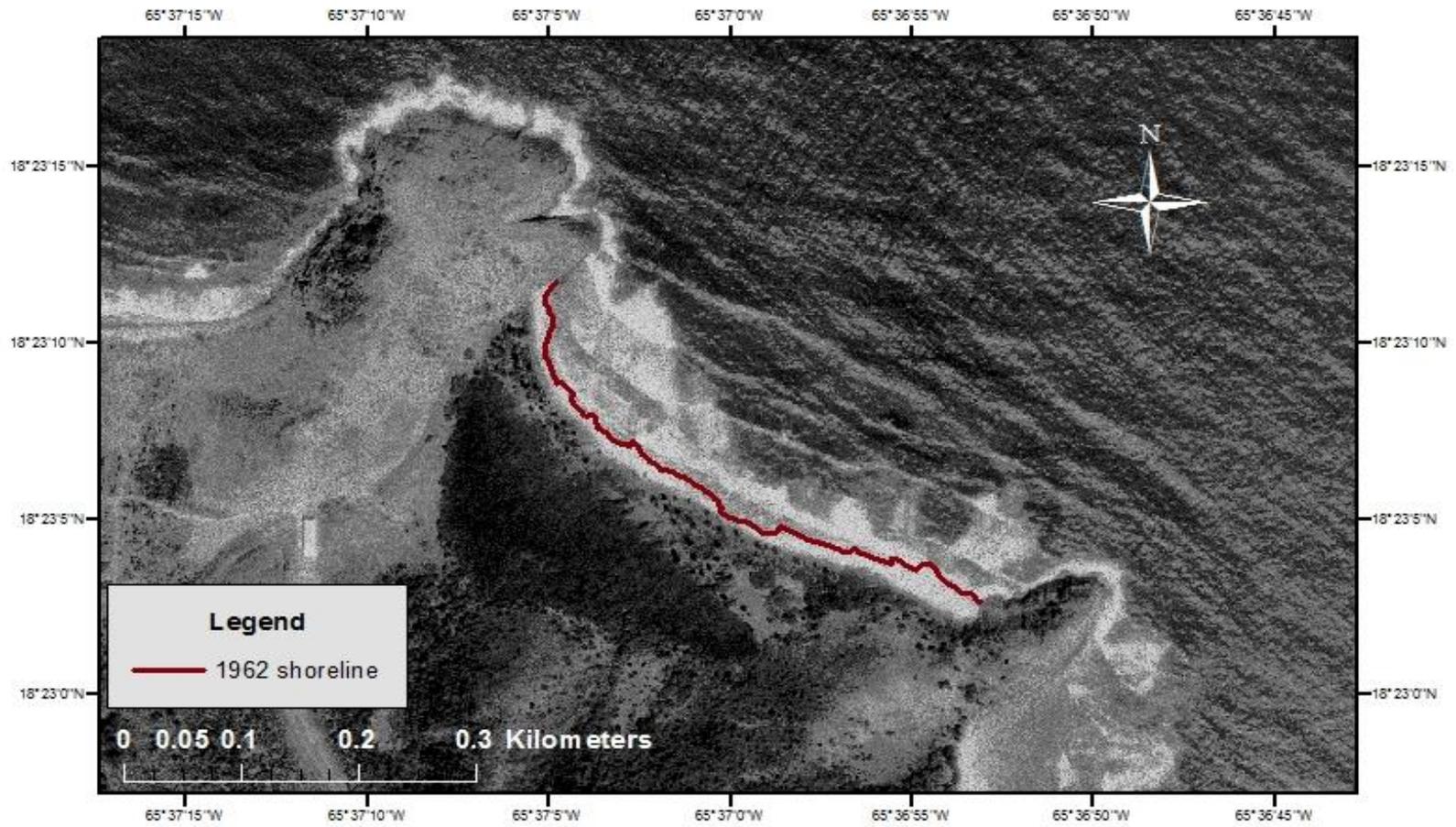


Figure 3: 1962 Black and white aerial photograph of Playa Jayuya, Fajardo Puerto Rico. Photograph obtained from Earth Explorer.



Figure 4: 2010 true color photograph of Playa Jayuya, Fajardo Puerto Rico. Image provided by GERS Lab. These



Figure 5: Image displaying the shorelines of 1962 (green) and 2010 (blue), baseline, and transects.

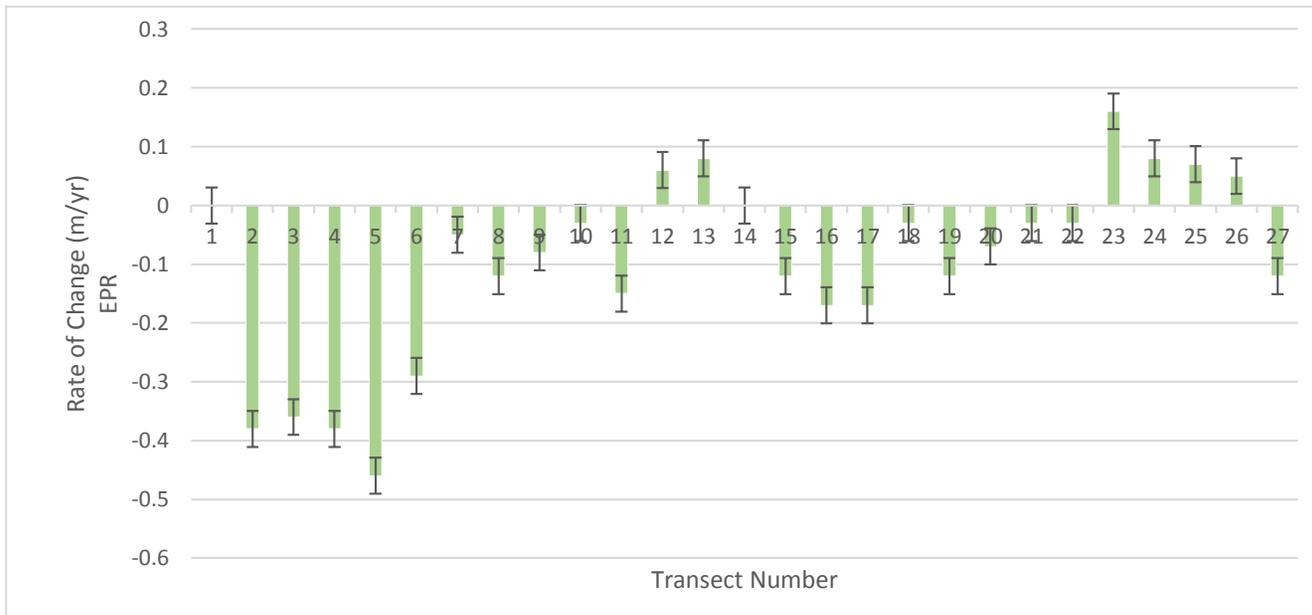


Figure 6: Graph of End Point Rate of Change (EPR) analysis with units in m/year with standard error bars. It represents the rate of distance movement of the shorelines. Note that most of the values are the negatives indicating erosion.

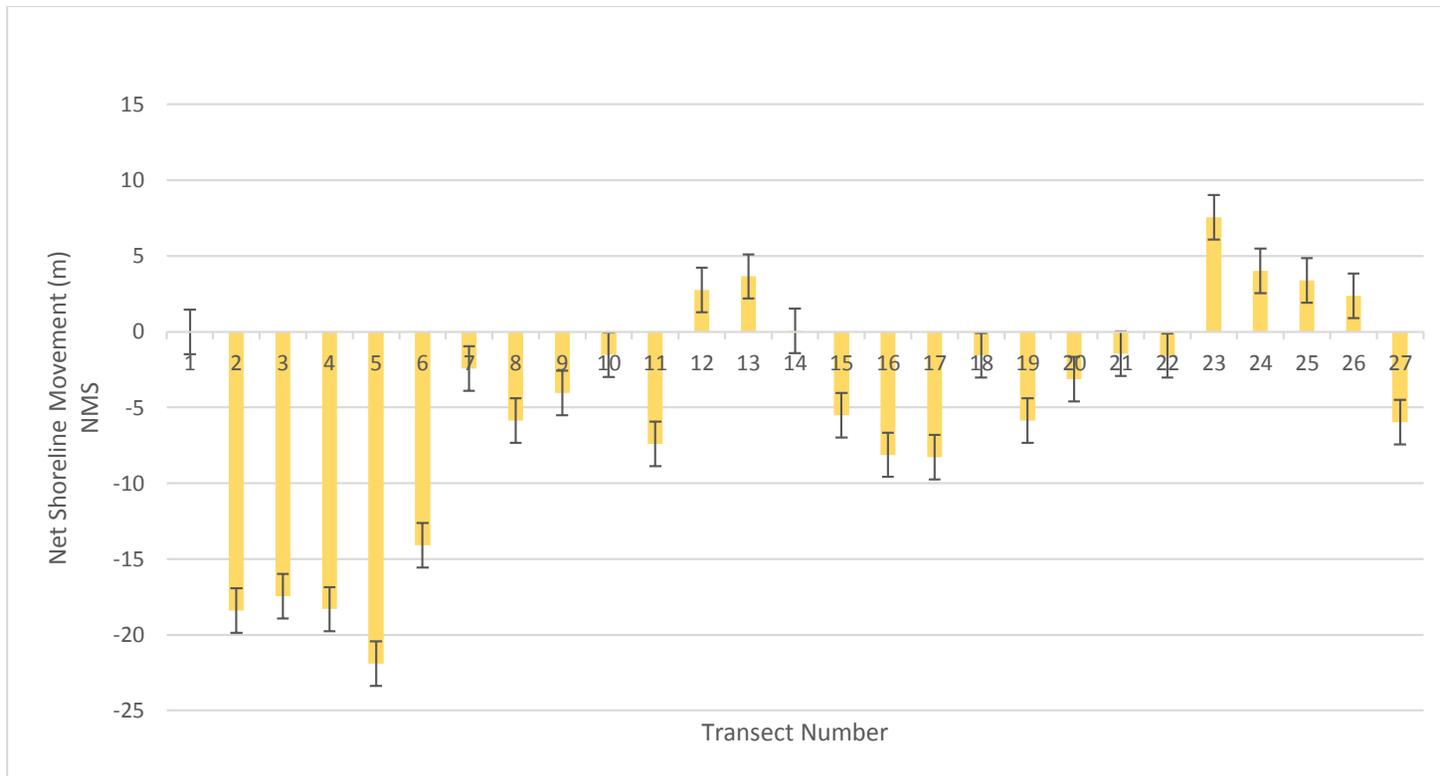


Figure 7: Graph of Net Shoreline Movement (NSM) analysis with units in meters with standard error bars. It represents the distance between shorelines in each transect. Note that the most of the values are negatives indicating erosion.

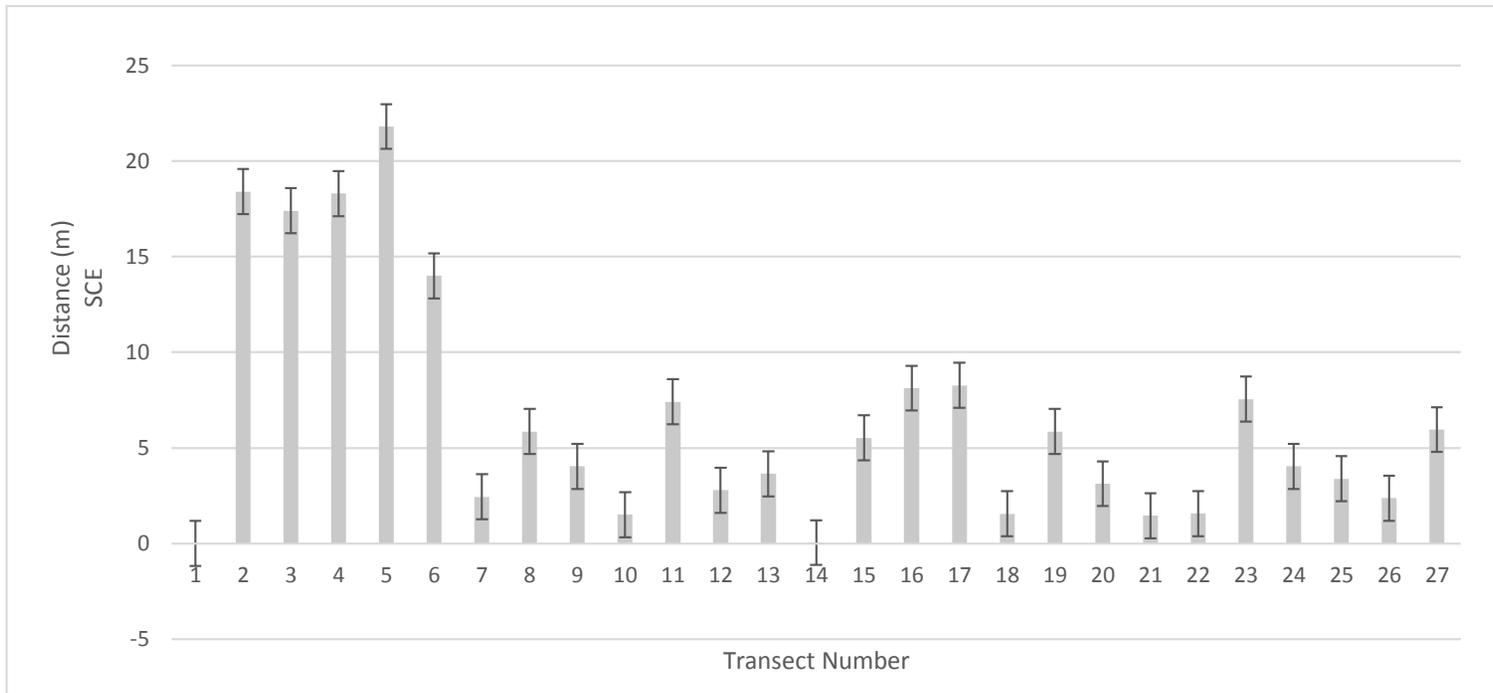


Figure 8: Graph of Shoreline Change Envelope (SCE) analysis with units in meters with standard error bars. It represents the distance between shorelines and the baseline.

Table of statistics of shoreline Change in Playa Jayuya, Fajardo, Puerto Rico			
object identifier	NMS	EPR	SCE
1	0	0	0
2	-18.4	-0.38	18.4
3	-17.44	-0.36	17.4
4	-18.31	-0.38	18.3
5	-21.89	-0.46	21.8
6	-14.08	-0.29	14
7	-2.44	-0.05	2.44
8	-5.86	-0.12	5.86
9	-4.04	-0.08	4.04
10	-1.51	-0.03	1.51
11	-7.41	-0.15	7.41
12	2.76	0.06	2.79
13	3.65	0.08	3.65
14	0.05	0	0.05
15	-5.52	-0.12	5.52
16	-8.12	-0.17	8.12
17	-8.27	-0.17	8.27
18	-1.55	-0.03	1.55
19	-5.85	-0.12	5.85
20	-3.13	-0.07	3.13
21	-1.46	-0.03	1.46
22	-1.57	-0.03	1.57
23	7.55	0.16	7.55
24	4.03	0.08	4.03
25	3.39	0.07	3.39
26	2.37	0.05	2.37
27	-5.96	-0.12	5.96

Table 1: Table of statistics for each transect created by DSAS.