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Spatial and Temporal Shoreline Changes at Playa Jayuya: Las Cabezas de San Juan Nature Reserve in Fajardo, Puerto Rico

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1. Abstract

Several shoreline change projects have been develop in the coast of Puerto Rico. However, slightly nothing been said of Las Cabezas de San Juan. The main objective of this study was to use DSAS to determine the spatial and temporal shoreline changes of six different sections of Playa Jayuya in Las Cabezas de San Juan Natural Reserve in Fajardo, Puerto Rico using several high resolution aerial photographs from 1930, 1950, 1962, 1994, and 2010. The 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 Thieler (2009). The statistical analysis used were Net Shoreline Movement (NSM), End Point Rate (EPR), and Simple linear Regression (LRR). The analysis revealed a long term (80 years) averaged erosion rate for all the beach of -0.120 m/year and an average net shoreline movement of-9.69. In addition, short term (1930-1950, 1994-2010) analysis were developed. An average rate of change from 1930 to 1950 reveled a -0.292 m/yr and an average (NSM) of -6.09 m. For 1994 to 2010 the average rate of change was -0.012 m/yr and an average (NSM) of -0.189 m. The Playa Jayuya is most likely eroding as a result of natural causes because there are no human modifications, such as jetty or sea walls. It may be the result of physical processes and its geologic setting.

Keywords: DSAS, GIS, Fajardo Puerto Rico, Shoreline analysis, Playa Jayuya

2. Introduction

Several shoreline change projects have been developed on the coast of Puerto Rico. However, very little can be said of the northern part of Puerto Rico, especially at Cabezas de San Juan Nature Reserve. For this reason the main objective of this study was to use

DSAS to determine the spatial and temporal shoreline changes of different sections of Playa Jayuya using high resolution aerial photographs. Shoreline change information analysis is a basic step in order to make decisions on short-term and long-term erosion rates, hazard and risk consideration, as well as coastal planning (Bush and Young, 2009). This study of shoreline change analysis was conducted in Playa Jayuya at Las Cabezas de San Juan Natural Reserve in Fajardo, Puerto Rico (Figures 1 and 2) and was an extension of my previous work (Santiago, 2015; Figure 3). The aerial photographs were used to calculate shoreline rate- of-change statistics from multiple shoreline positions divided in sections or reaches (Sections A-F), in order to provide better information of the erosion rate and where the beach is more susceptible. The study was developed 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 (Thieler et al., 2009). DSAS is a free software with focus on the calculation of rate- of- change statistical analysis using digital vectors (Thieler et al., 2007). DSAS reads the shoreline position GIS-generated, and applying the user specification, it calculates several measurements of change such as; average-of-rate, and linear regression (Bush and Young, 2009). In addition, using DSAS for costal environments utility, it is also useful to compute other boundary or change problems (Theiler et al., 2009).

In order to develop costal management projects as well as land use and planning strategies to preserve the area, it is crucial to understand how shoreline changes and why (Bush et al., 2013). One of the most dynamic environments on Earth are the coasts (Bush and Young, 2009). This because coastal systems are exposed to climate change, rainfall and river discharge, in addition to wave break and currents, high tides and low tides and natural seasonal disasters such as cyclones and storms (Bush and Young, 2009). The tides in Puerto

Rico average about a foot and are semidiurnal (two tidal cycles daily) in the north coast and diurnal (one tidal cycle daily) in the south coast (Kaye, 1959). The terms coastline and shoreline differ in scale meaning; the difference is that coastline is that when referring to the boundary of land and water at a local scale and when talking about a regional scale is called shoreline (Bush and Young, 2009). Although, coastal zone is a broad term which includes all land and water areas which are affected by marine processes (Bush and Young, 2009). Shoreline change is defined as the movement or position variation of any shoreline markers such as dune lines, beaches, etc. (Bush and Young, 2009).

Puerto Rico's shoreline suffers from constant erosion and daily deposition (Thieler et al., 2007). For this reason, the evolution and behavioral history of Playa Jayuya shoreline was quantified by constructing shore- perpendicular transects and dividing the beach in sections in order to understand shoreline erosion or aggradation and to produce a better understanding of its coastal dynamics. Thieler et al. (2005) indicates that measurement transects that are cast by DSAS from the baseline will intersect the shoreline vectors providing location and time information used to calculate rates of change. The baseline is constructed by the user and serves as the starting point for all transects. In this case the baseline was created delimitating the vegetation line of the 2010 aerial photograph and later generating a buffer of 10 m. 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 error and in some cases can be achieved in the absence of field investigation (Avinash et al., 2010).

A previous study by Santiago (2015) showed that shoreline erosion from 1962 to 2010 is most visible in the east part of Playa Jayuya. However, deposition was also occurring at the west area of the beach. Several analyses were conducted using DSAS such as End Point Rate (EPR), which divides the distance of the shoreline movement by the time elapse between the oldest and the youngest (Thieler et al., 2009). The EPR analysis resulted in a mean average value of -0.10 m/year with a standard deviation of 0.16 m/year. Another analysis used was the Net Shoreline Movement (NSM), which reports the distance between the oldest and youngest shorelines for each transect (Thieler et al., 2009). The NSM was -4.8 meters with a standard deviation of 7.6 meters. 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. The highest EPR 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 highest deposition rate was of 0.16 m/year.

2.1 Study Area

Playa Jayuya is part of Las Cabezas de San Juan Nature Reserve (Figures 1 and 2). It is located in the northeastern part of the Fajardo municipality. With longitude 65˚37’19.79” W and latitude 18˚22’56.72” N. The analyzed area is approximately 470 m long. 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’s general geology has two sections, the first is divided in to a volcanic breccia and tuffaceous sandstone and siltstone, from marine deposit origin (Weaver et al., 1999). The second 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 with artifacts from the Igneri Native American culture in addition to bones, ceramic vessels, and human activity (Weaver et al. 1999).

3. Methodology

Shoreline change at Playa Jayuya was analyzed using ESRI ArcGIS 10.1 software and the Digital Shoreline Analysis System (DSAS) version 4.3. The shoreline position from 1962 and 2010 were used in a previous study. In this case a most complete search of aerial photographs was done in order to expand the temporal analyses. Photos from 1930, 1950, 1962, 1994, and 2010 were used and georeferenced using ArcMap with datum: NAD 1983 State Plane Puerto Rico and Virgin Islands FIPS 5200 and units in meters. Most aerial photographs were obtained from EarthExplorer website and the 2010 aerial photograph was provided by the Geological and Environmental Remote Sensing Laboratory (GERS Lab). Each shoreline from every photograph was delineated using ArcMap tools. The shoreline proxy used to delimit the area was the boundary between the sand and the water. (Moore, 2000). This phase of the project was considered the most important because it was going to expose the rate of change in shoreline through the years.

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 have a quantitative and more accurate result of change. In this step the DSAS software was used to create transects and analyze the different points to calculate rate-of-change at the specified time interval (Thieler and Danforth, 1994). For each transect DSAS provides a calculation (Bush and Young, 2009). DSAS allowed to create transects and the rate of change of the shoreline was analyzed at different points in meters per year (Thieler et al., 2009). The nominal spacing between transects was 10 meters and the length of transects was 70 m (Figure 4). The spacing and length were determined after testing several options in order to cover all interested site area and avoiding the crossing of transects with each other.

The baseline buffer, which is the starting point from all transects, was generated of 10 m from the 2010 vegetation line 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 were produced. The calculations or statistics used in this study were:

1. **Net Shoreline Movement (NMS):** Calculates the distance between the oldest and youngest shorelines for each transect in meters (Figure 5) (Thieler et al., 2009).
2. **End Point (EPR):** Reports a rate in meters per year when the distance between the oldest and youngest shoreline are divided by the time elapse in each transect in meters per years (Figure 6) (Thieler et al., 2009).
3. **Simple linear Regression (LRR):** It is determined by fitting a least-squares regression line (a line that summarizes the relationship between the two variables) to all shoreline points for a particular transect. The linear regression rate is the slope of the line with formula $y= a + bx$ in meters per year. This calculation provides the standard error of the slope with the user-selected confidence interval of 95% (Figure 7) (Thieler et al., 2009).

Graphs and tables were developed in order to obtain the changes of the coastline. The shoreline uncertainty, in this case a value of +-3 m, was incorporated into the calculations for the standard error, and confidence intervals, which are computed for the simple linear regression (Thieler et al., 2009). The uncertainty value account both for positional uncertainties associated with natural influences over the shoreline position (wind, waves, tides) and measurement uncertainties (for example, digitization or global-positioning-system errors) (Thieler et al., 2009). In order to express the uncertainty associated with rate of change statistic a 95- percent confidence interval was selected. Also, the analyses of 6 smaller sections of the shoreline allowed a better interpretation of the spatial changes (Figure 4). Other current study at Playa Jayuya has also located six stations in order to construct beach profile analyses. The sections used in this study covers those same stations. This will facilitate the comparison of both studies in the future.

4. Results

The study area was divided in six distinct sections (Figure 4). There are total of 52 transects and each section has nine transects, except for section F which has only seven.

- Section A from transect 1 to 9 (Figure 8) has a long term (80 years) erosion rate of -0.198 meters per year and an average shoreline movement of -15.68 m (Table 1). This values indicates that the section A is eroding at a much higher rate. The simple linear regression for section A presents an average rate of erosion of -0.20 per year, value similar to the one given by the EPR. Although, Thieler et al. (2009) indicate that the simple linear regression tents to underestimate the rate of change relative to other statistics such as EPR. Section A has a short term average erosion rate of -0.425 m/yr (Table 2) from 1930 to 1950 (Figure 9) and from 1994 to 2010 (Figure 10) has an average erosion rate of 0.007 m/yr.
- Section B from transects 10 to 18 (Figure 11) has a long term average erosion rate of -0.06 meters per year and an average net shoreline movement of -5 meters. The

simple linear regression average was of -0.047 meters per year (Table 3). From 1930 to 1950 section B has a short term (Table 4) average erosion of -0.265 m/yr (Figure 12) and from 1994 to 2010 has an average erosion rate of -0.018 m/yr (Figure 13)

- Section C from transects 19 to 27 (Figure 14) reported an average erosion rate of -0.08 meters per year with an average linear regression of -0.059 meters per year and an average net shoreline movement of -6.39 (Table 5). Section C reported a short term erosion rate from 1930 to 1950 (Table 6) of -0.338 m/yr (Figure 15) and from 1994 to 2010 reported an average erosion rate of 0.012 m/yr (Figure 16).
- Section D from transects 28 to 36 (Figure 17) is the second section with higher erosion values, presenting a long term average erosion rate of -0.14 meters per year, an average liner regression of -0.136 meters per year, and an average net shoreline movement of -11.51 meters (Table 7). Section D reported short term (Table 8) erosion rate from 1930 to 1950 of -0.323 m/yr (Figure 18) and from 1994 to 2010 of -0.051 m/yr (Figure 19).
- Section E from transects 37 to 45 (Figure 20) had an average erosion rate of -0.12 meters per year, an average linear regression rate of -0.11 meters per year, and an average net shoreline movement of -10.1 meters (Table 9). Section E has a short term erosion rate (Table 10) from 1930 to 1950 (Figure 21) of -0.251 m/yr and from 1994 to 2010 (Figure 22) of -0.005 m/yr.
- Section F from transects 45 to 52 (Figure 23) had a long term average erosion rate of -0.13 meters per year, an average linear regression of -0.126 meters per year, and an average net shoreline movement of -10.46 meters (Table 11). Section F has an

average erosion rate (Table 12) from 1930 to 1950 of -0.076 m/yr (Figure 24) and from 1994 to 2010 of -0.024 m/yr (Figure 25).

5. Discussion

The shoreline change data are discussed in the context of long term (80 years) and short term (1930- 1950, 1994- 2010) trends within the sections identified in the study. It is limited by the lack of detailed knowledge of the local geologic framework and sediment thickness. The shoreline changes are interpreted to reflect a variety of potential underlying causes, such as: climate change, rainfall and river discharge, in addition to wave break and currents, high tides and low tides and natural seasonal disasters such as cyclones and storms (Bush and Young, 2009).

Based on the new analyses the dominant shoreline change at the different sections of Playa Jayuya during the past 80 years has been erosion. This coastal “behavior” may be due to the presence of beachrocks and wave action. This because it forms a natural wall against deposition (Kaye, 1959). In this cases wave erosion takes over the un-cemented 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 generally of $CaCO_3$ (Kaye, 1959).

Playa Jayuya, at long term (1930- 2010) is eroding at an average rate of -0.120 meters per year with an average shoreline movement of -9.69 meters and an average linear regression of -0.11 meters per year with a mean standard error of 3.25 meters per year (Table 13) (Figure 26). The shoreline erosion rate is higher in section A (-0.198 meters per year), in the east part of Playa Jayuya followed by sections D (-0.143 meters per year) and

F (-0.13 meters per year). However, transect one in section A is positive because the most resent shoreline (2010) does not touch that transect and the statistics are calculated using the shoreline from 1962 as the youngest (Figure 27). It is also occurring in section F were transects 51 and 52 do not touch all of the shorelines (Figure 28). By dividing the beach in sections it is possible to note that Playa Jayuya is not eroding at the same rate and the erosion rate is more visible at long terms. Sections A, D and F are more susceptible to long term erosion and section D is more susceptible to short term erosion (Figures 29 and 30).

Playa Jayuya from 1930 to 1950 is eroding at an average rate of -0.292 meters per year (Figure 31) (Table 14) and an average net shoreline movement of -6.09 meters. Section A presents the higher value of erosion during these years and section F the lowest value. In figure 32 it is visible the difference between the two shorelines. From 1994 to 2010 the erosion rate is lower than the one presented during the 1930 to 1950 this may be due by the time between each period (20 and 15). Playa Jayuya was eroding at rate (Table 15) of -0.012 meters per year (Figure 33) during 1994 to 2010 and had average net shoreline movement of -0.189 meter. This time section D reported the highest erosion rate (Figure 34).

6. Conclusion

The Playa Jayuya is most likely eroding as a result of natural causes because there are no human modifications, such as jetty or sea walls. It may be the result of physical processes and the geologic setting. Playa Jayuya is eroding at a long term average rate of -0.120 meters per year were sections A, D, and F are more prone to erosion. Playa Jayuya from 1930 to 1950 erode at a rate of -0.292 meters per year, from 1994 to 2010 erode at an average rate of -0.012 meters per year. This results may suggest that during 1930 to 1950 an atmospheric event or other natural event occur. By dividing the beach in sections it is possible to note that Playa Jayuya is not eroding at the same rate and the erosion rate is more visible at long terms. Sections A, D and F are more susceptible to long term erosion and section D is more susceptible to short term erosion. This study was possible using remote sensing techniques that facilitate the process and provided a better understanding of how Playa Jayuya had change over the years. In addition, with the use of ArcGIS system and its extension, DSAS, shoreline change statistics were able to be obtained. In order to have a more accurate result it is possible to repeat and compare the study with another program, such as the Analyzing Moving Boundaries Using R, (AMBUR) software, adding a more recent shoreline to the study, developing beach profiles, and generating more shoreline combinations in order to obtain short term analyses between each shoreline.

7. Acknowledgements

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9. Figures

Figure 1: Las Cabezas de San Juan Nature Reserve. Image developed in ArcMap by Yanira Santiago.

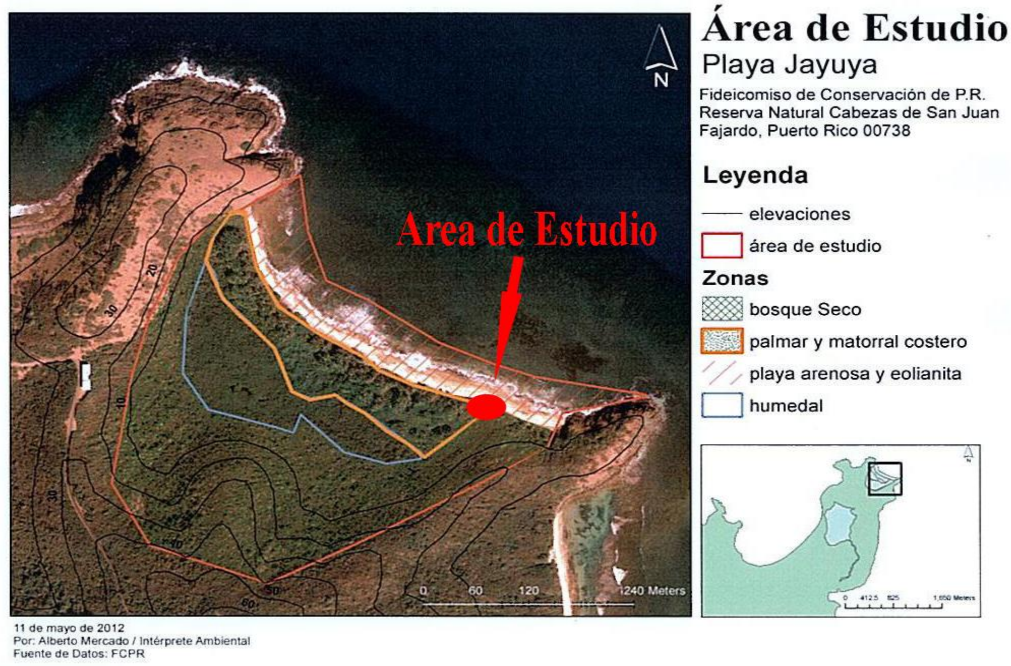


Figure 2: Shoreline analysis location, Playa Jayuya, situated in Fajardo Puerto Rico. The red dot is where an archeological site is located. The image was taken by the Conservation Trust of Puerto Rico in 2012. The image was provided by archeologist Carlos Perez.

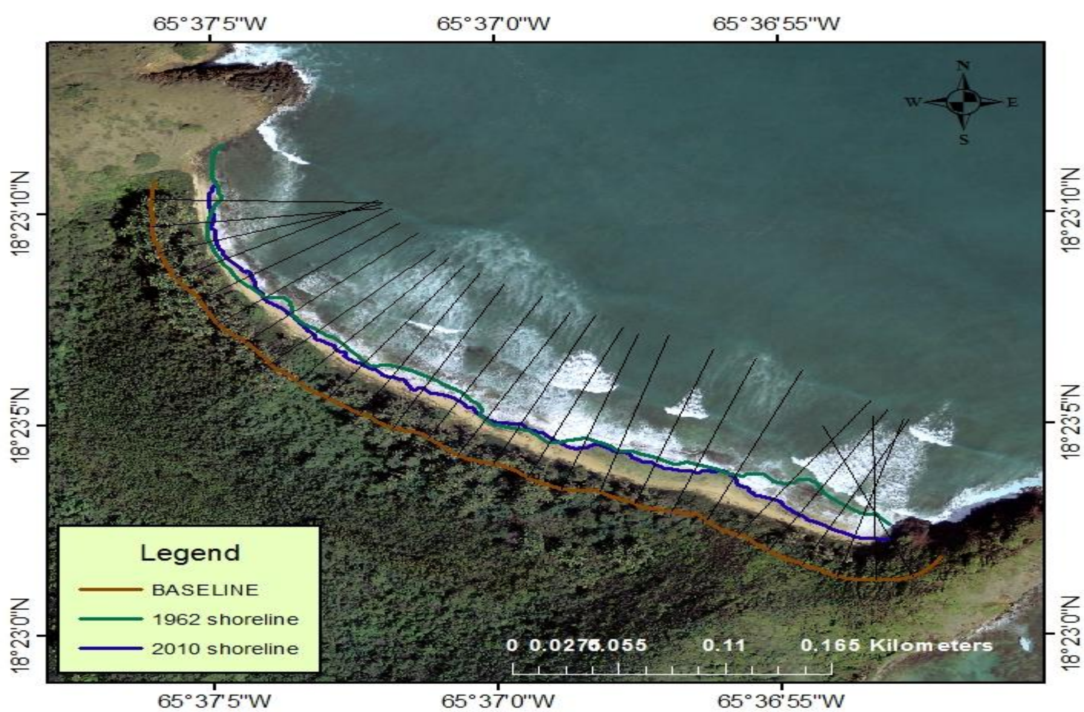


Figure 3: Shorelines of 1962 (green) and 2010 (blue), baseline, and transects from the previous study. Map developed in ArcMap by Yanira Santiago (Santiago, 2015).

Las Cabezas de San Juan Nature Reserve

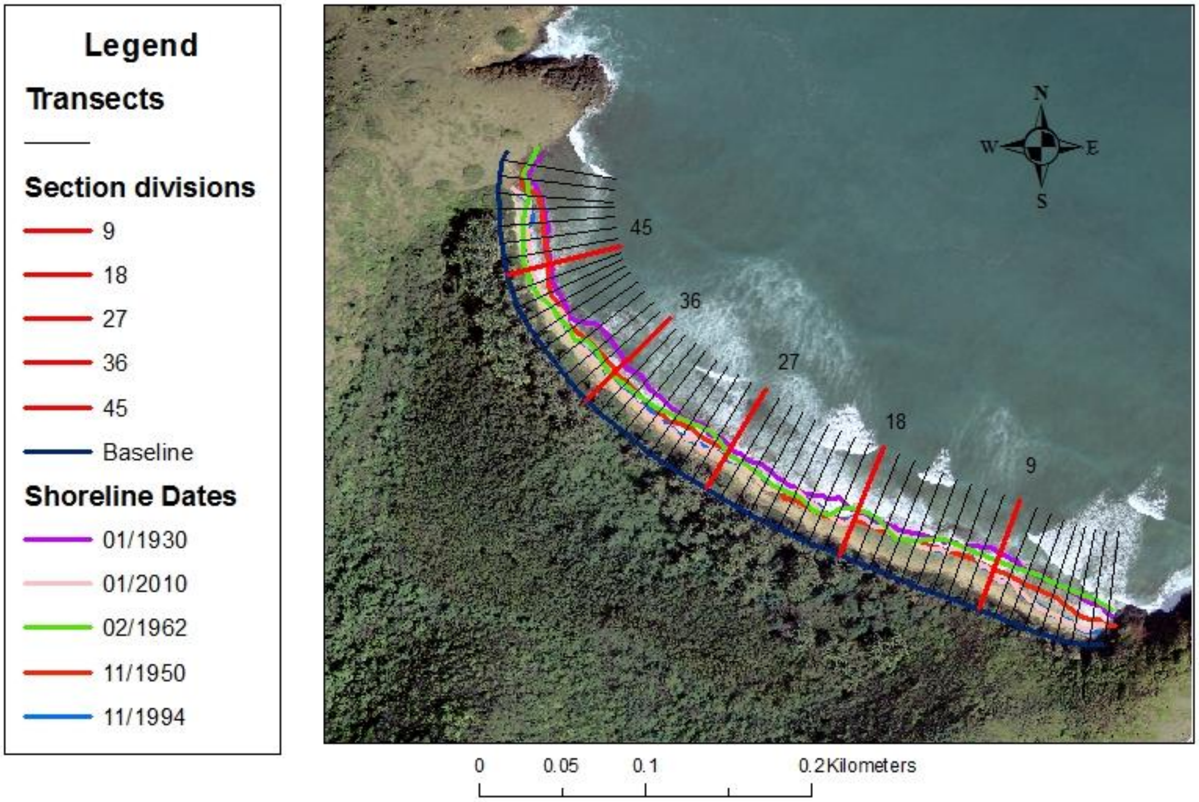


Figure 4: Study area with digitized shorelines. Red transects are the division of each section.

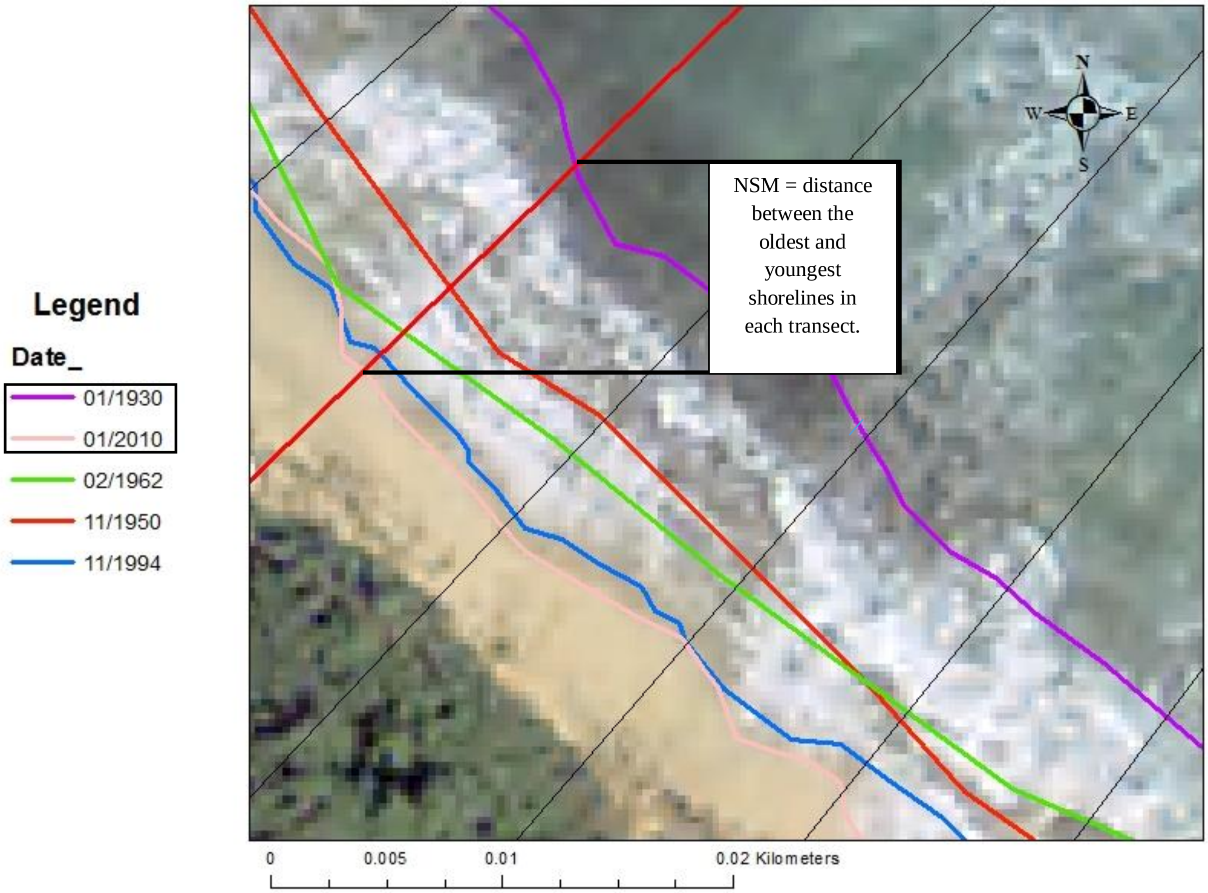


Figure 5: Example of the net shoreline movement showing the distance of -12.79 m between the oldest 1930 and youngest 2010 shorelines.

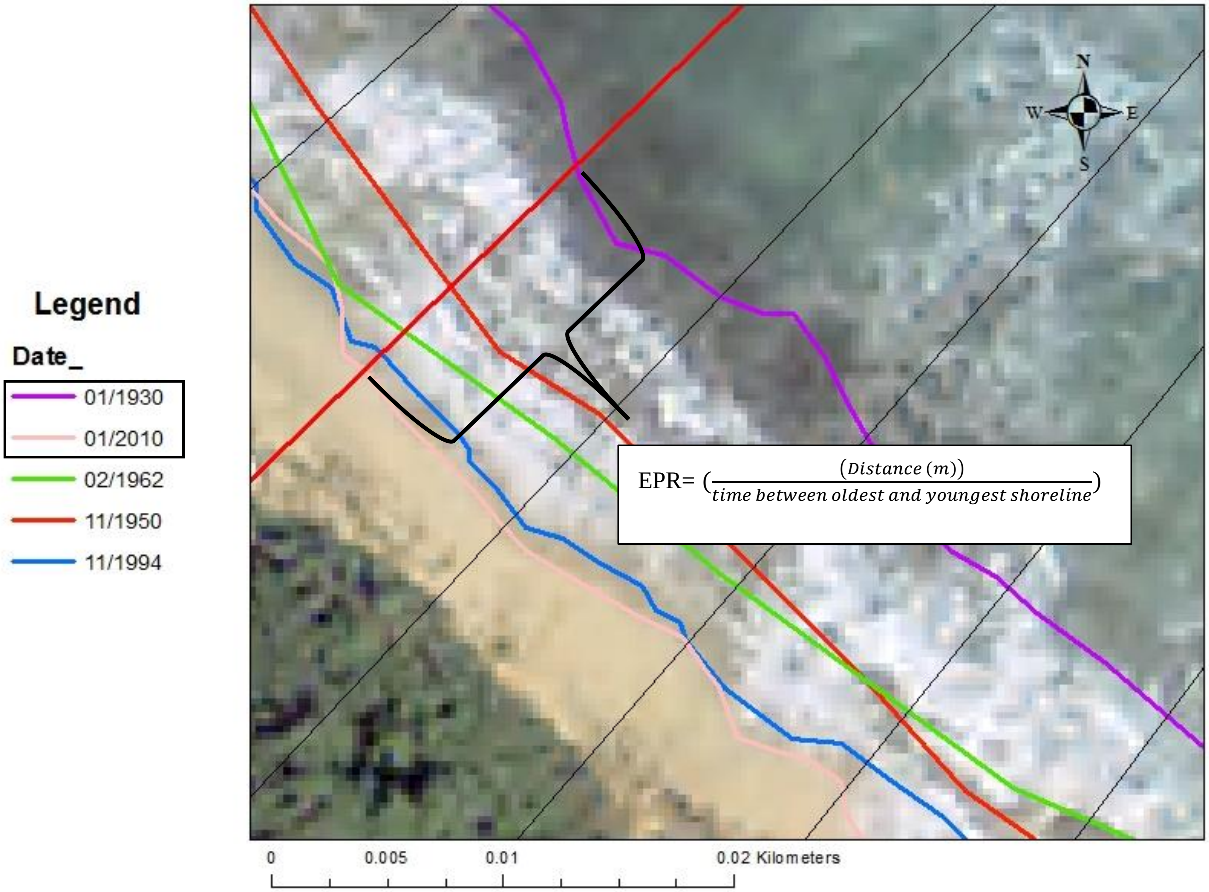
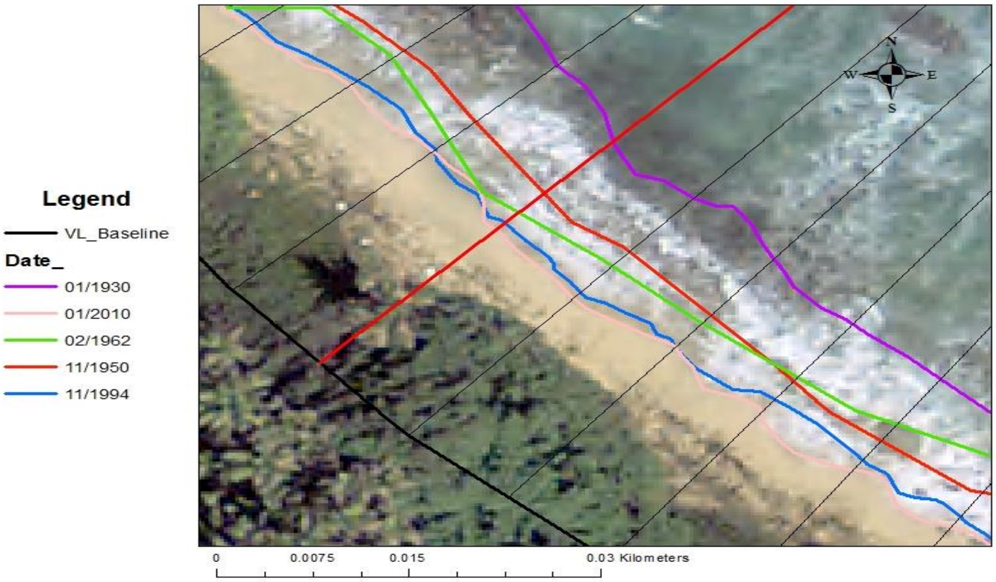


Figure 6: Example of the end point rate showing -0.16 meters per year as the distance between the 2010 and 1930 shorelines divided by the span of time elapsed between the two shoreline positions (80 years). All other shoreline data are ignored.



Year	distance
1930	31.95
1950	24.35
1962	21.58
1994	20.17
2010	19.16

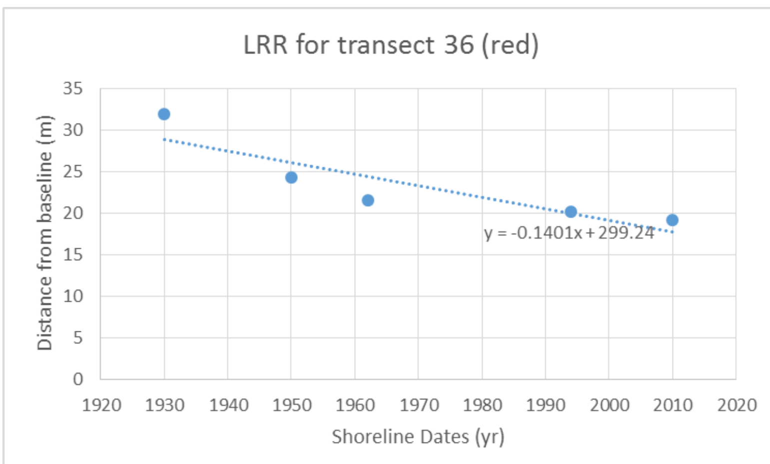


Figure 7: The simple linear regression is determined by fitting a least-squares regression line to all shoreline points for a particular transect (Transect 36). The linear regression rate is the slope of the line, in this case -0.14 m/yr.

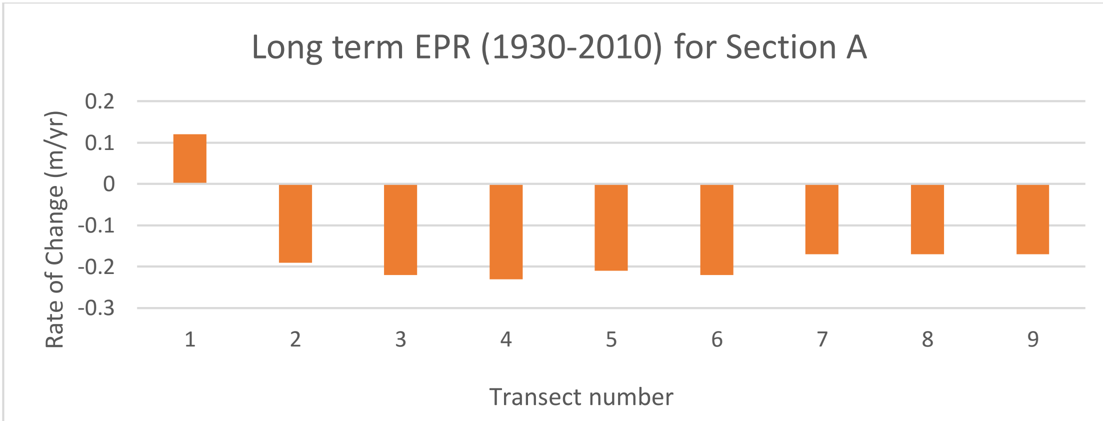


Figure 8: Section A alongshore spatial distribution of long-term (80 years from 1930-2010) rates of shoreline change.

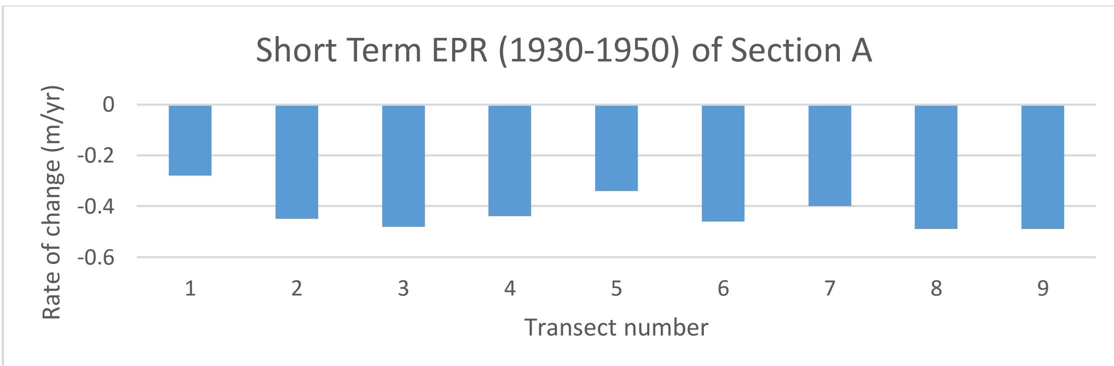


Figure 9: Section A alongshore spatial distribution of short term (1930-1950) rate of shoreline change.

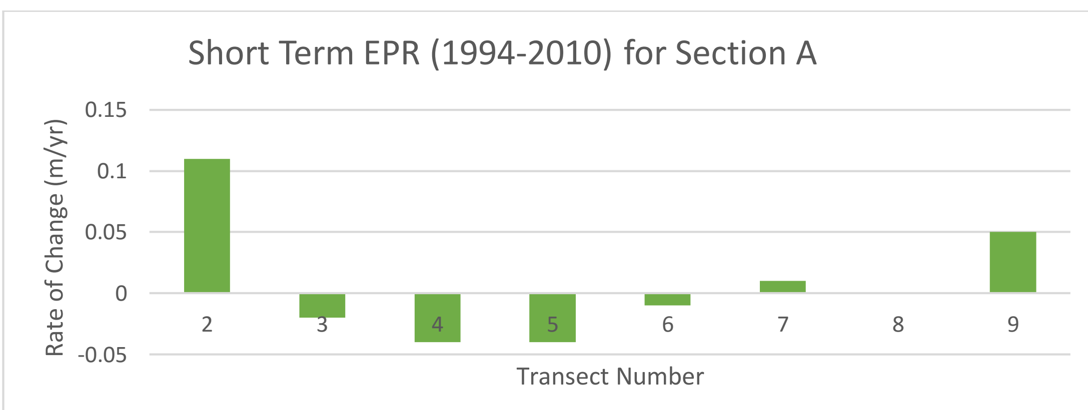


Figure 10: Section A alongshore spatial distribution of short term (1994-2010) rate of shoreline change.

Table 1: Long term (1930-2010) Statistics for section A including an average for each one. The numbers highlighted in yellow represents the numbers that can be consider outliers

Section A			
Object ID	**EPR (m/yr)**	**LRR (m/yr)**	**NMS (m)**
1	0.120	0.070	3.83
2	-0.190	-0.210	-15.47
3	-0.220	-0.220	-17.28
4	-0.230	-0.240	-18.17
5	-0.210	-0.230	-16.95
6	-0.220	-0.230	-17.52
7	-0.170	-0.170	-13.42
8	-0.170	-0.150	-13.21
9	-0.170	-0.160	-13.45
Average	-0.162	-0.171	-13.5156
Average without transect 1	-0.198	-0.201	-15.6838

Table 2: Short term EPR table statistics for section A including average.

	1930-1950	**1994-2010**
Object Id	EPR	EPR
1	-0.28	--
2	-0.45	0.11
3	-0.48	-0.02
4	-0.44	-0.04
5	-0.34	-0.04
6	-0.46	-0.01
7	-0.4	0.01
8	-0.49	0
9	-0.49	0.05
Average	-0.425	0.0075

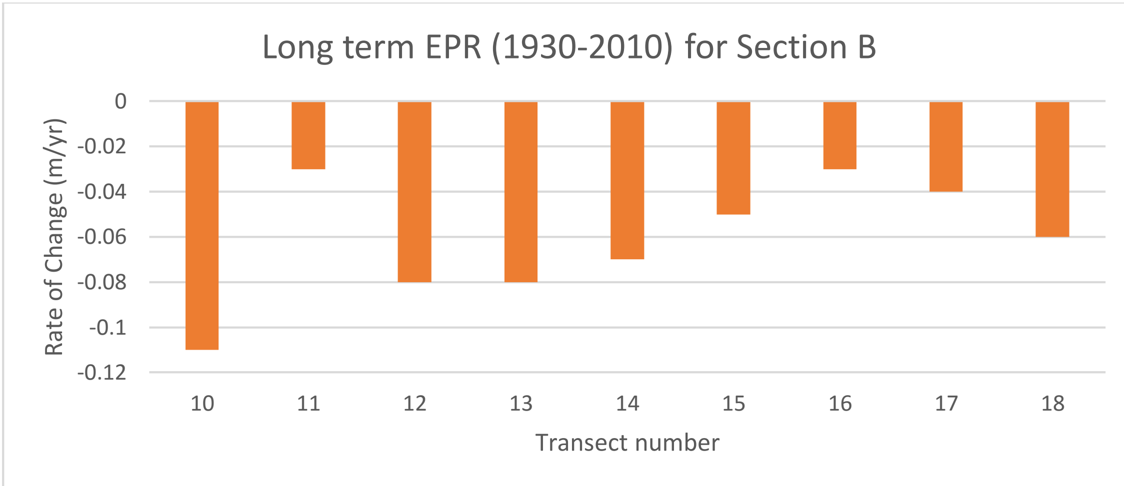


Figure 11: Section B alongshore spatial distribution of long-term (80 years from 1930-2010) rates of shoreline change

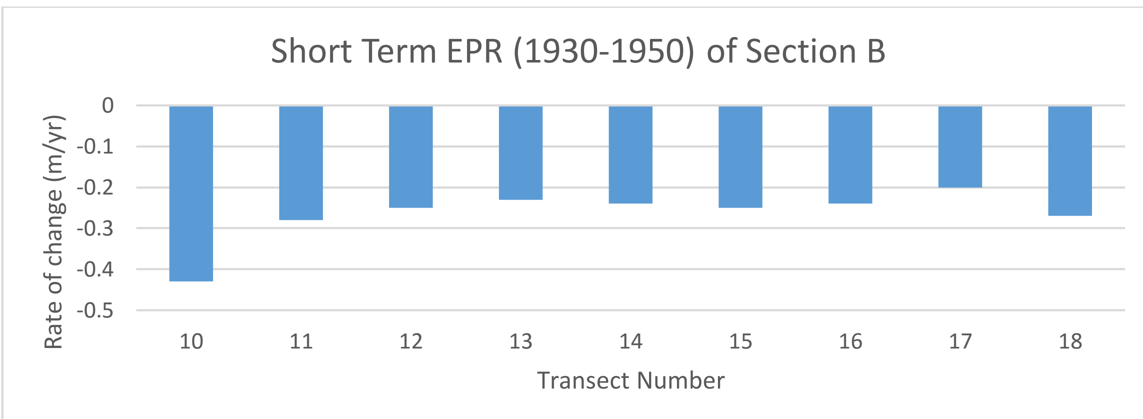


Figure 12: Section B alongshore spatial distribution of short term (1930-1950) rate of shoreline change.

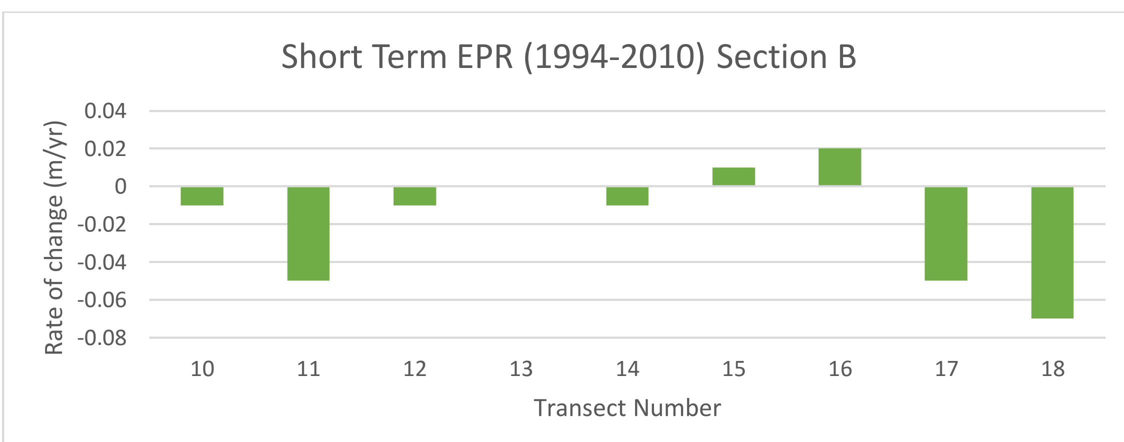


Figure 13: Section B alongshore spatial distribution of short term (1994-2010) rate of shoreline change.

Table 3: Long term (1930-2010) Statistics for section B including an average for each one.

Section B			
Object ID	**EPR (m/yr)**	**LRR (m/yr)**	**NMS (m)**
10	-0.11	-0.09	-8.7
11	-0.03	0	-2.39
12	-0.08	-0.07	-6.41
13	-0.08	-0.08	-6.77
14	-0.07	-0.06	-5.96
15	-0.05	-0.03	-4.3
16	-0.03	-0.01	-2.29
17	-0.04	-0.03	-3.1
18	-0.06	-0.05	-5.08
Average	-0.06111	-0.04667	-5

Table 4: Short term EPR table of statistics for section B including an average for each one.

	1930-1950	**1994-2010**
Object Id	EPR	EPR
10	-0.43	-0.01
11	-0.28	-0.05
12	-0.25	-0.01
13	-0.23	0
14	-0.24	-0.01
15	-0.25	0.01
16	-0.24	0.02
17	-0.2	-0.05
18	-0.27	-0.07
Average	-0.265	-0.01889

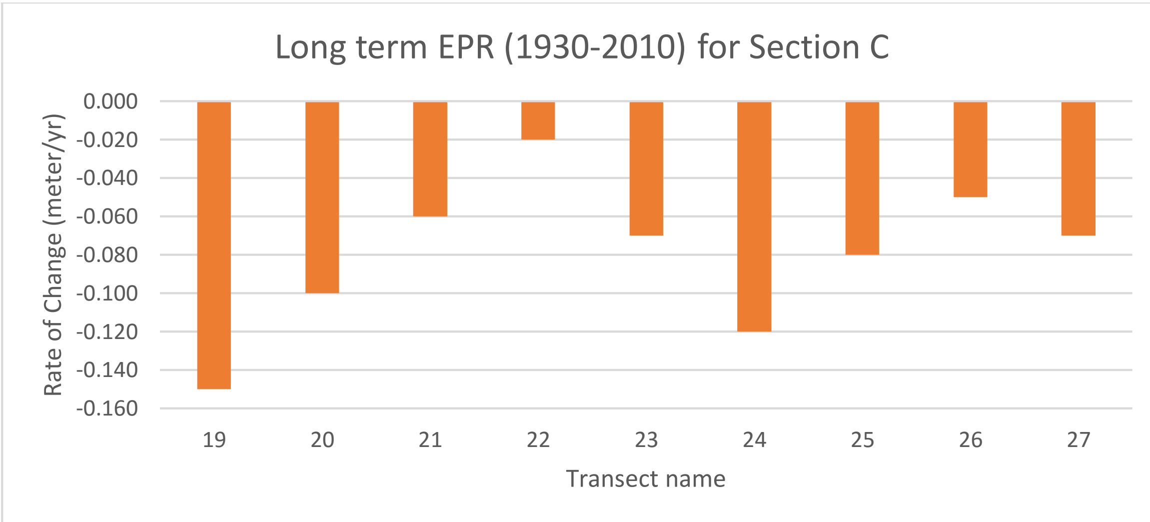


Figure 14: Section C alongshore spatial distribution of long-term (80 years from 1930-2010) rates of shoreline change

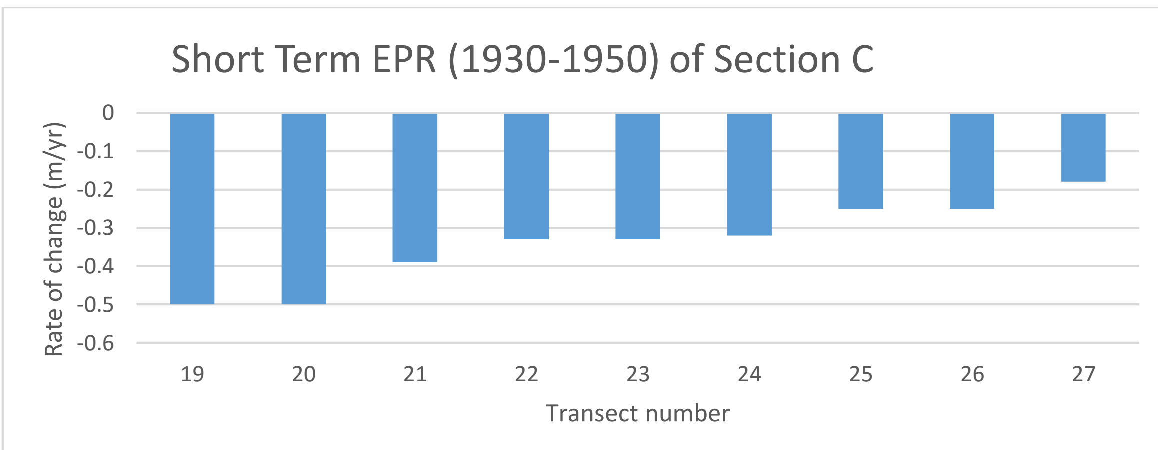


Figure 15: Section C alongshore spatial distribution of short term (1930-1950) rates of shoreline change.

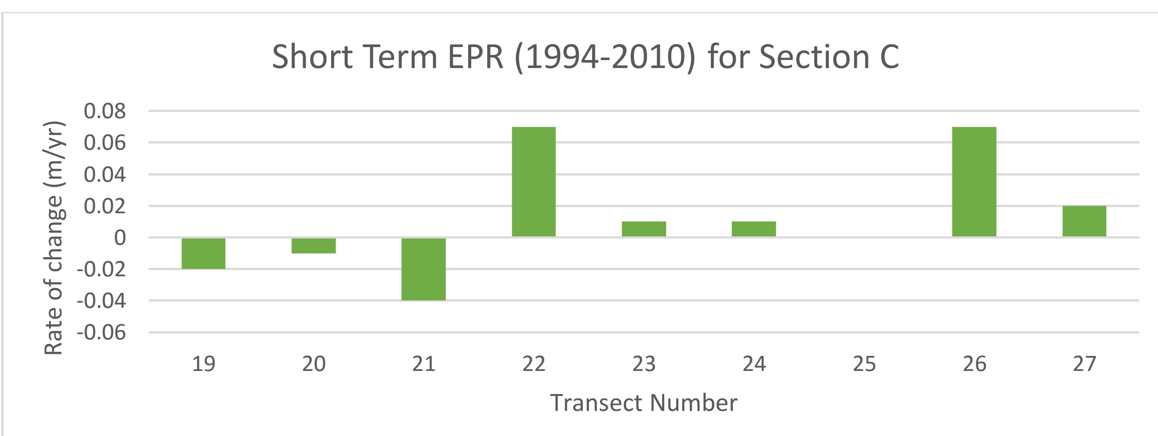


Figure 16: Section C alongshore spatial distribution of short-term (1994-2010) rates of shoreline change

Tabla 5: Long term (1930-2010) Statistics for section C including an average for each one.

Section C			
Object ID	**EPR (m/yr)**	**LRR (m/yr)**	**NMS (m)**
19	-0.150	-0.130	-11.810
20	-0.100	-0.060	-8.280
21	-0.060	-0.020	-4.530
22	-0.020	0.010	-1.310
23	-0.070	-0.050	-5.720
24	-0.120	-0.100	-9.260
25	-0.080	-0.070	-6.630
26	-0.050	-0.040	-4.260
27	-0.070	-0.070	-5.780
Average	-0.080	-0.059	-6.398

Table 6: Short term EPR table of statistics for section C including an average for each one

	1930-1950	**1994-2010**
Object id	EPR	EPR
19	-0.5	-0.02
20	-0.5	-0.01
21	-0.39	-0.04
22	-0.33	0.07
23	-0.33	0.01
24	-0.32	0.01
25	-0.25	0
26	-0.25	0.07
27	-0.18	0.02
Average	-0.338	0.012222

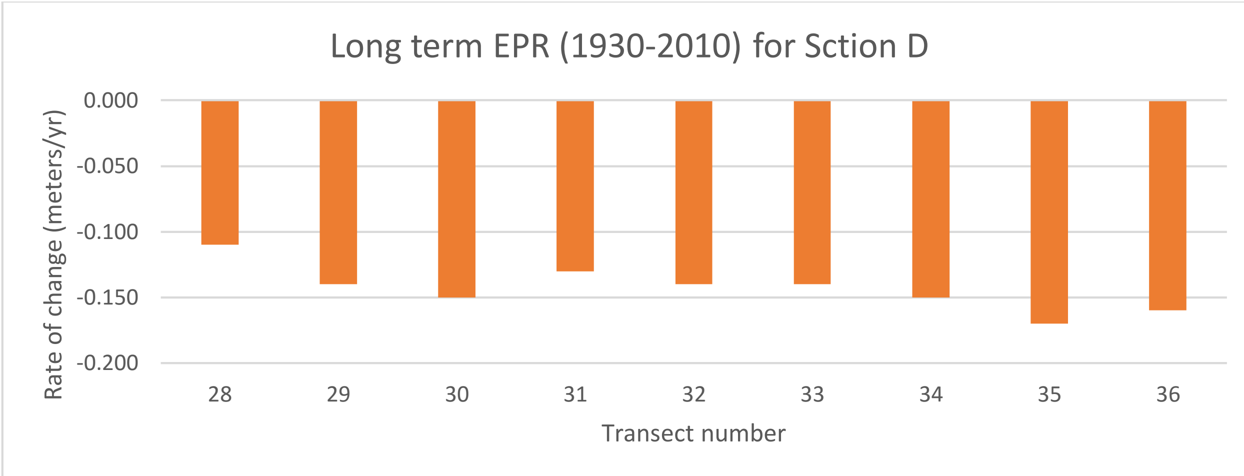


Figure 17: Section D alongshore spatial distribution of long-term (80 years from 1930-2010) rates of shoreline change

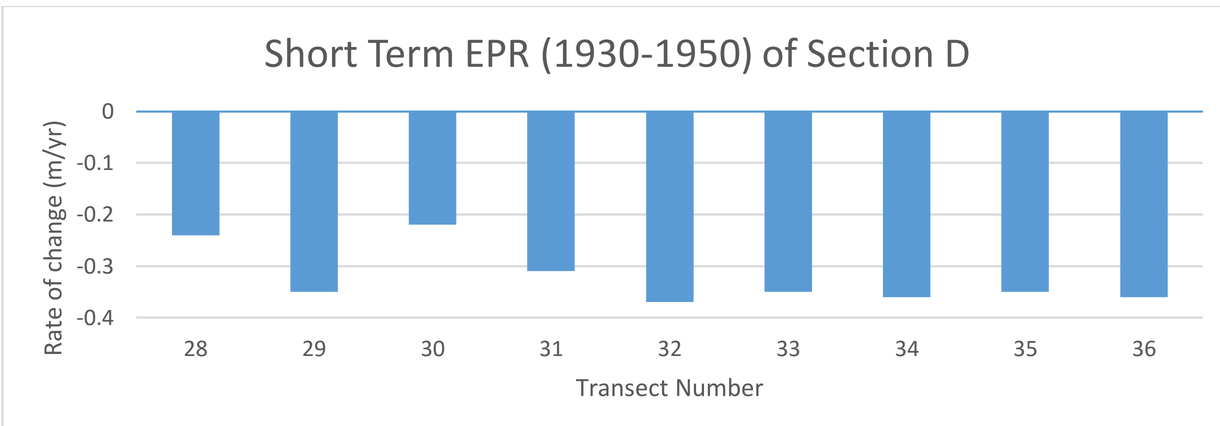


Figure 18: Section C alongshore spatial distribution of short term (1930-1950) rates of shoreline change.

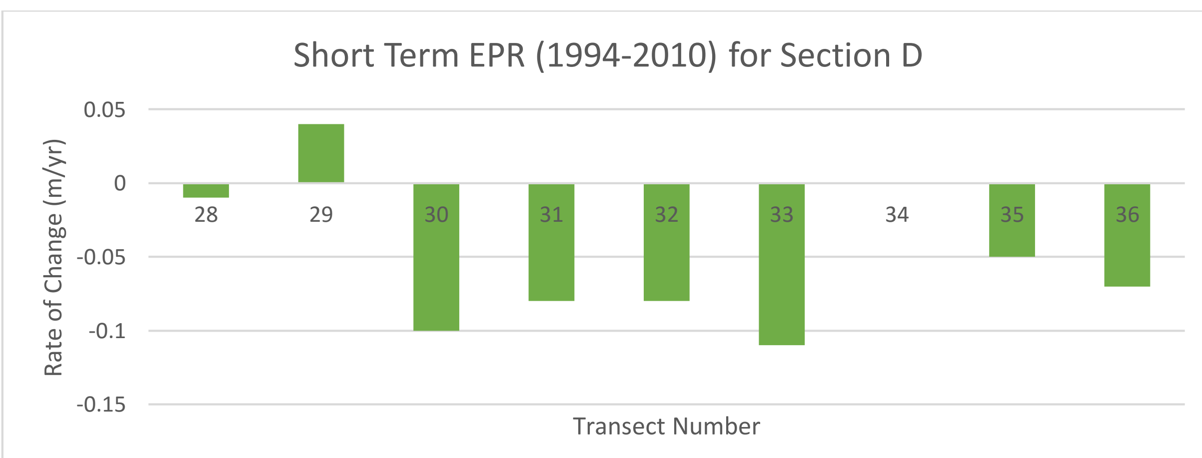


Figure 19: Section D alongshore spatial distribution of short-term (1994-2010) rates of shoreline change.

Table 7: Long term (1930-2010) Statistics for section D and an average for each one.

Section D			
Object ID	**EPR (m/yr)**	**LRR (m/yr)**	**NMS (m)**
28	-0.110	-0.110	-8.620
29	-0.140	-0.150	-11.460
30	-0.150	-0.150	-12.000
31	-0.130	-0.120	-10.570
32	-0.140	-0.120	-11.340
33	-0.140	-0.130	-11.410
34	-0.150	-0.160	-11.790
35	-0.170	-0.140	-13.660
36	-0.160	-0.140	-12.790
Average	-0.143	-0.136	-11.516

Table 8: Short term EPR table of statistics for section D including an average for each one

	1930-1950	**1994-2010**
Object ID	EPR	EPR
28	-0.24	-0.01
29	-0.35	0.04
30	-0.22	-0.1
31	-0.31	-0.08
32	-0.37	-0.08
33	-0.35	-0.11
34	-0.36	0
35	-0.35	-0.05
36	-0.36	-0.07
Average	-0.323	-0.051

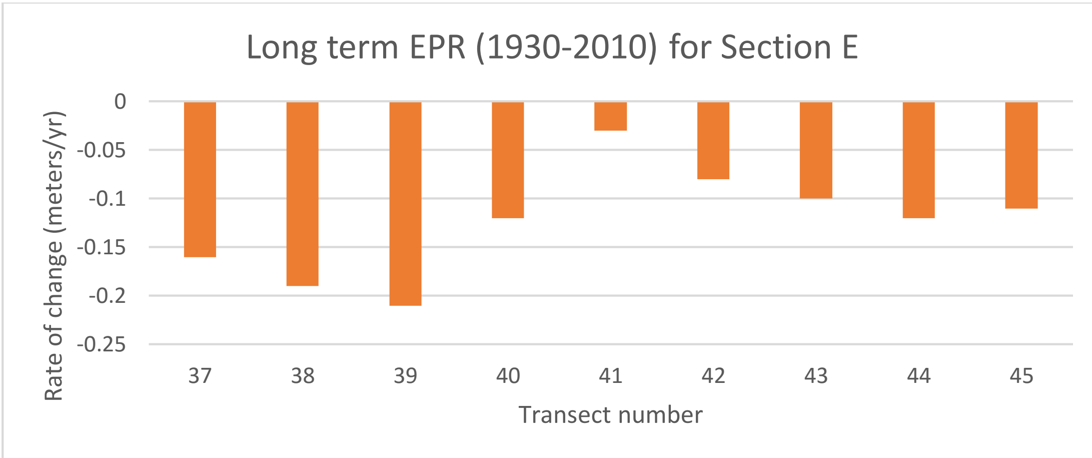


Figure 20: Section E alongshore spatial distribution of long-term (80 years from 1930-2010) rates of shoreline change

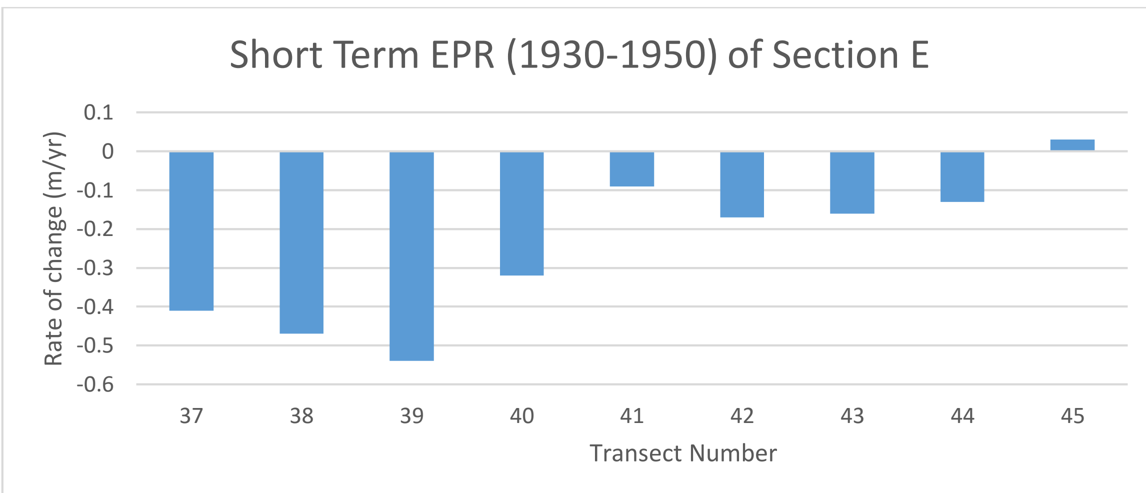


Figure 21*:* Section E alongshore spatial distribution of short term (1930-1950) rates of shoreline change.

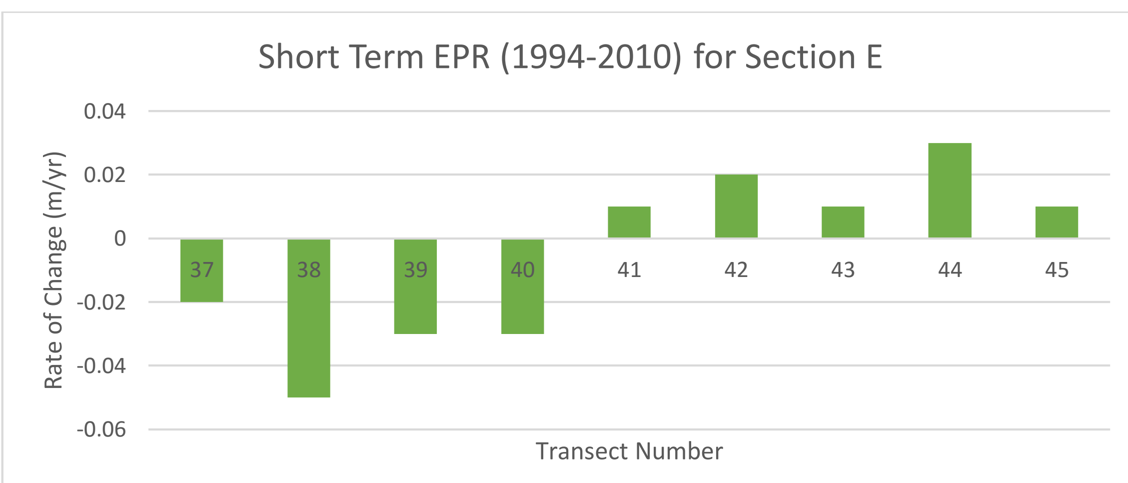


Figure 22: Section E alongshore spatial distribution of short term (1994-2010) rates of shoreline change.

Table 9: Long term (1930-2010) Statistics for section E and an average for each one.

Section E			
Object ID	**EPR (m/yr)**	**LRR (m/yr)**	**NMS (m)**
37	-0.16	-0.17	-12.94
38	-0.19	-0.19	-15.14
39	-0.21	-0.1	-17.19
40	-0.12	-0.02	-9.84
41	-0.03	-0.07	-2.24
42	-0.08	-0.1	-6.13
43	-0.1	-0.12	-8.28
44	-0.12	-0.12	-9.95
45	-0.11	-0.14	-9.18
Average	-0.124	-0.114	-10.09

Table 10: Short term EPR table of statistics for section D including an average for each one

	1930-1950	**1994-2010**
Object Id	EPR	EPR
37	-0.41	-0.02
38	-0.47	-0.05
39	-0.54	-0.03
40	-0.32	-0.03
41	-0.09	0.01
42	-0.17	0.02
43	-0.16	0.01
44	-0.13	0.03
45	0.03	0.01
Average	-0.251	-0.005

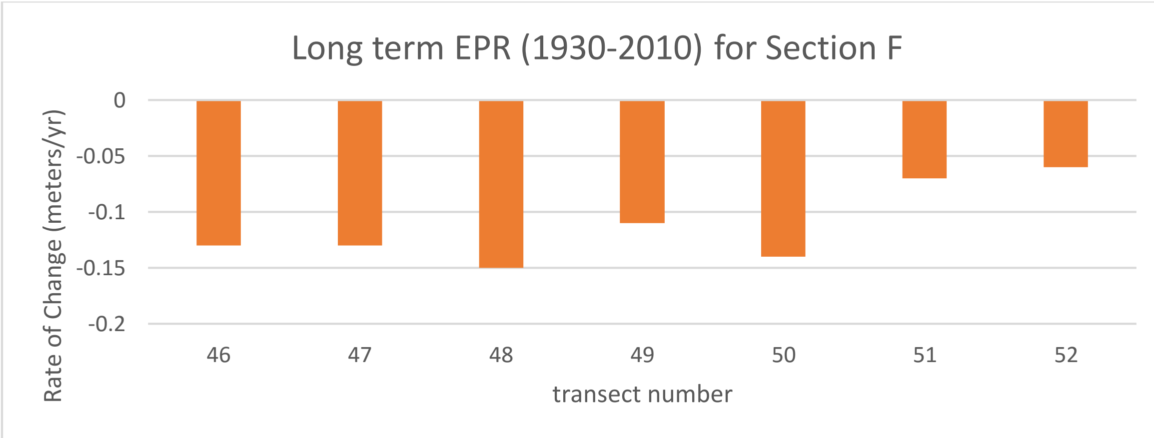


Figure 23: Section F alongshore spatial distribution of long-term (80 years from 1930-2010) rates of shoreline change

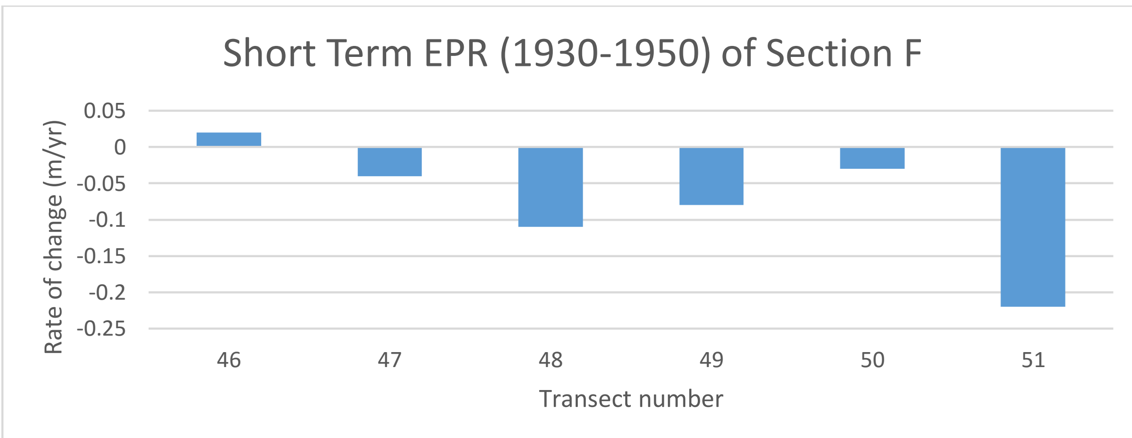


Figure 24: Section F alongshore spatial distribution of short term (1930-1950) rates of shoreline change.

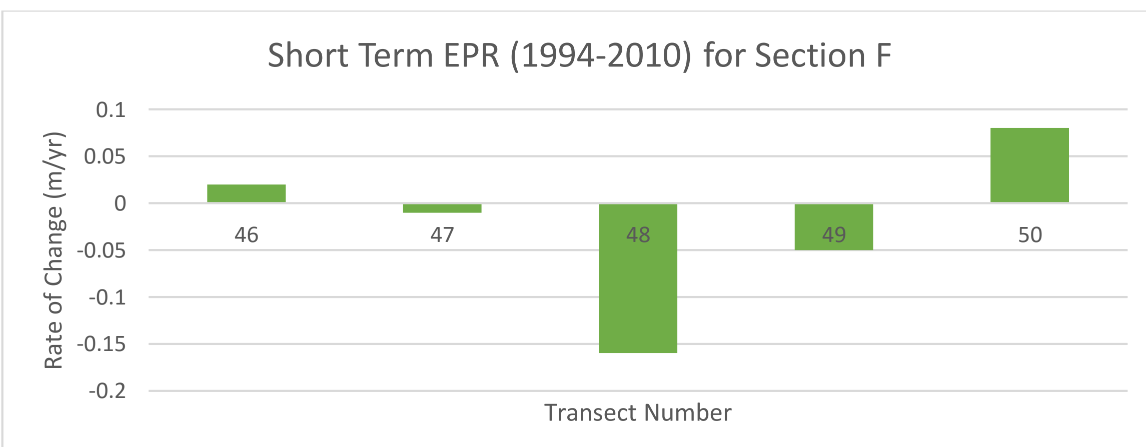


Figure 25: Section F alongshore spatial distribution of short term (1994-2010) rates of shoreline change.

Table 11: Long term (1930-2010) Statistics for section F and an average for each one. The numbers highlighted in yellow represents the numbers that can be consider outliers.

Section F			
Object ID	**EPR (m/yr)**	**LRR (m/yr)**	**NMS (m)**
46	-0.13	-0.13	-10.56
47	-0.13	-0.14	-10.09
48	-0.15	-0.1	-11.88
49	-0.11	-0.17	-8.43
50	-0.14	-0.09	-11.35
51	-0.07	-0.09	-2.31
52	-0.06		-1.95
Average	-0.112	-0.12	-8.08
Average without 51 and 52	-0.132	-0.126	-10.462

Table 12: Short term EPR table of statistics for section F including an average for each one

	1930-1950	**1994-2010**
Object Id	EPR	EPR
46	0.02	0.02
47	-0.04	-0.01
48	-0.11	-0.16
49	-0.08	-0.05
50	-0.03	0.08
51	-0.22	--
Average	-0.076	-0.024

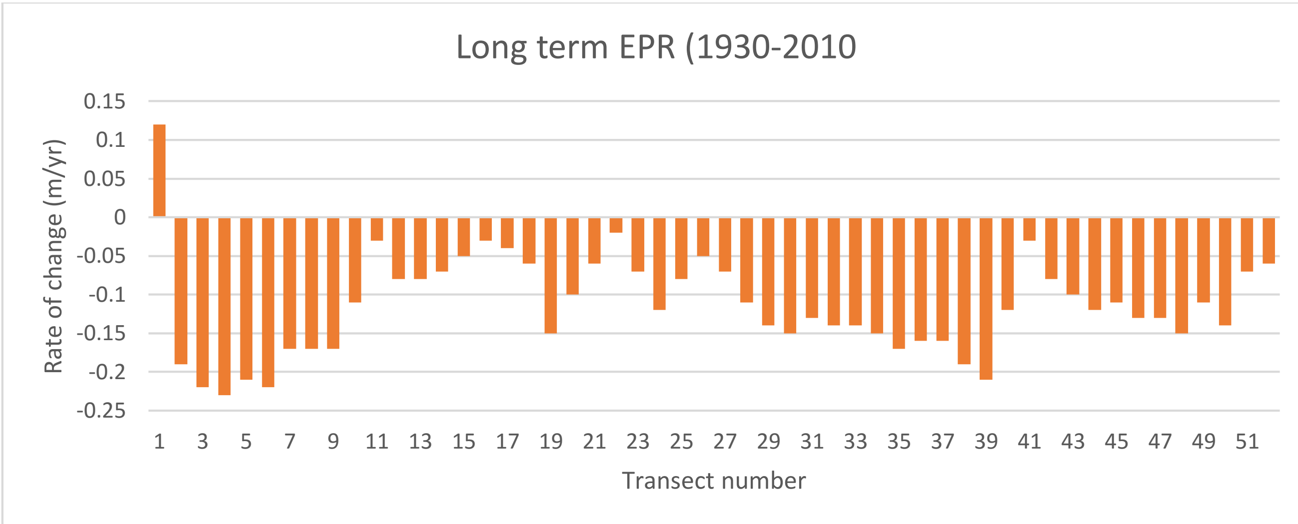


Figure 26: Long term (1930-2010) End Point Rate of Change (EPR) analysis with units in m/year. It represents the rate of change movement of shorelines. Graph created in excel.

Table 13: Long term (1930-2010) Statistics for each transect and the average for each one. The numbers highlighted in yellow represents the numbers that can be consider outliers. Graph values generated using DSAS.

Object ID	EPR	LRR	NMS
1	0.12	0.07	3.83
2	-0.19	-0.21	-15.47
3	-0.22	-0.22	-17.28
4	-0.23	-0.24	-18.17
5	-0.21	-0.23	-16.95
6	-0.22	-0.23	-17.52
7	-0.17	-0.17	-13.42
8	-0.17	-0.15	-13.21
9	-0.17	-0.16	-13.45
10	-0.11	-0.09	-8.7
11	-0.03	0	-2.39
12	-0.08	-0.07	-6.41
13	-0.08	-0.08	-6.77
14	-0.07	-0.06	-5.96
15	-0.05	-0.03	-4.3
16	-0.03	-0.01	-2.29
17	-0.04	-0.03	-3.1
18	-0.06	-0.05	-5.08
19	-0.15	-0.13	-11.81
20	-0.1	-0.06	-8.28
21	-0.06	-0.02	-4.53
22	-0.02	0.01	-1.31
23	-0.07	-0.05	-5.72

24	-0.12	-0.1	-9.26
25	-0.08	-0.07	-6.63
26	-0.05	-0.04	-4.26
27	-0.07	-0.07	-5.78
28	-0.11	-0.11	-8.62
29	-0.14	-0.15	-11.46
30	-0.15	-0.15	-12
31	-0.13	-0.12	-10.57
32	-0.14	-0.12	-11.34
33	-0.14	-0.13	-11.41
34	-0.15	-0.16	-11.79
35	-0.17	-0.14	-13.66
36	-0.16	-0.14	-12.79
37	-0.16	-0.17	-12.94
38	-0.19	-0.19	-15.14
39	-0.21	-0.1	-17.19
40	-0.12	-0.02	-9.84
41	-0.03	-0.07	-2.24
42	-0.08	-0.1	-6.13
43	-0.1	-0.12	-8.28
44	-0.12	-0.12	-9.95
45	-0.11	-0.14	-9.18
46	-0.13	-0.13	-10.56
47	-0.13	-0.14	-10.09
48	-0.15	-0.1	-11.88
49	-0.11	-0.17	-8.43
50	-0.14	-0.09	-11.35
51	-0.07	-0.09	-2.31
52	-0.06	---	-1.95
Average	-0.114	-0.107	-9.14
Average without #	-0.120816327	-0.1110204	-9.691632653

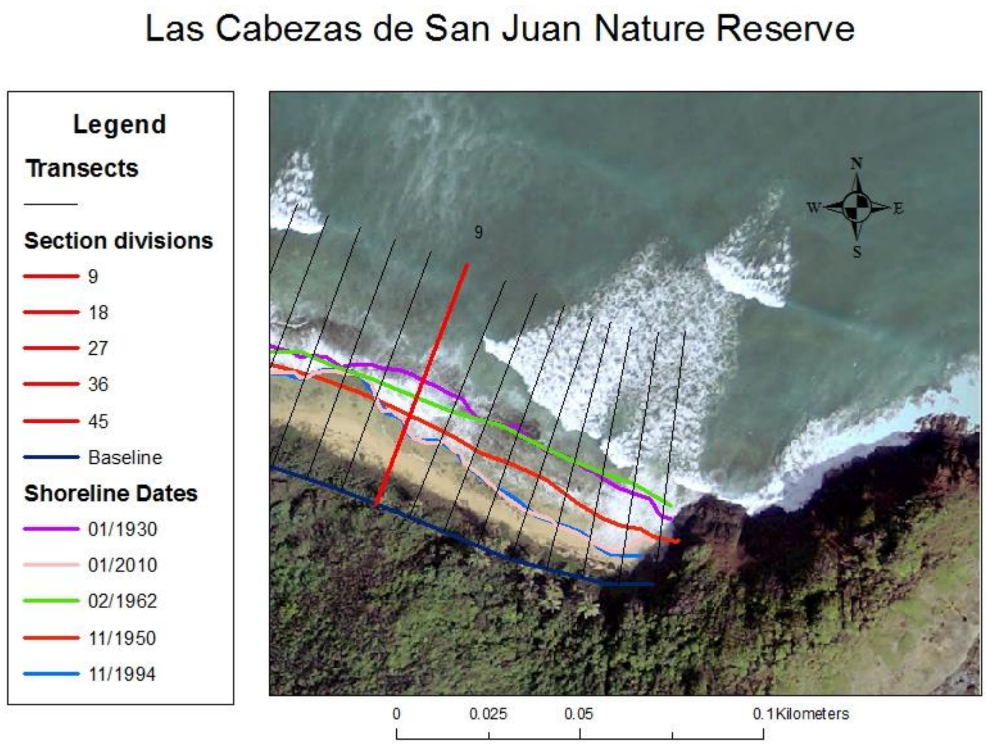


Figure 27: Location of section A and the shorelines in contact with transect one.

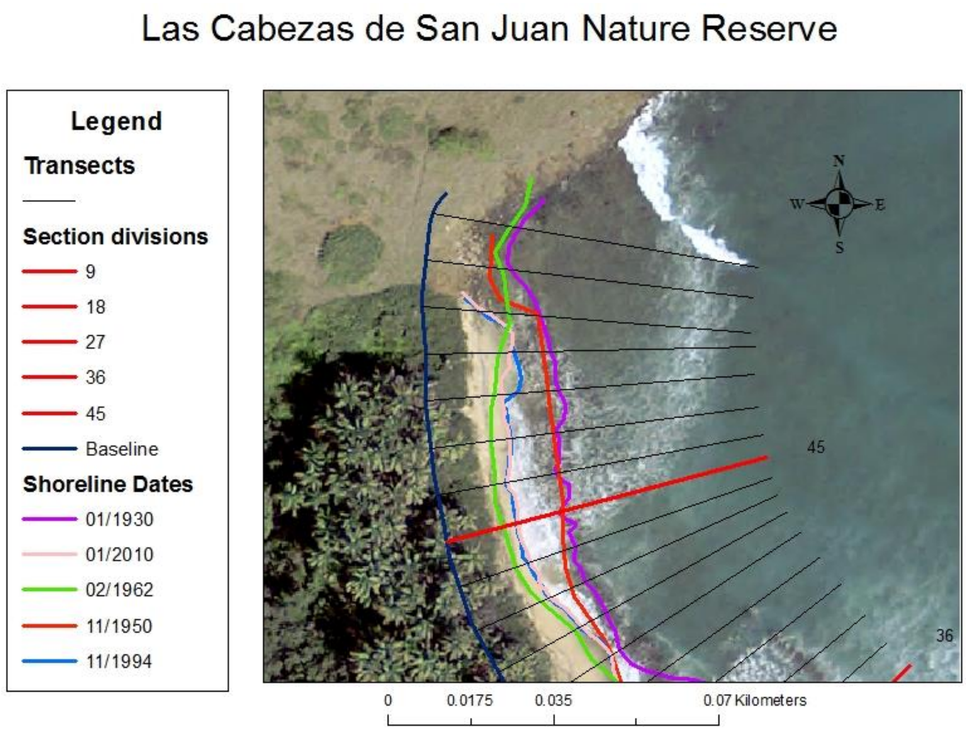


Figure 28: Location of section B and how transects 51 and 52 are not touched by all shorelines.

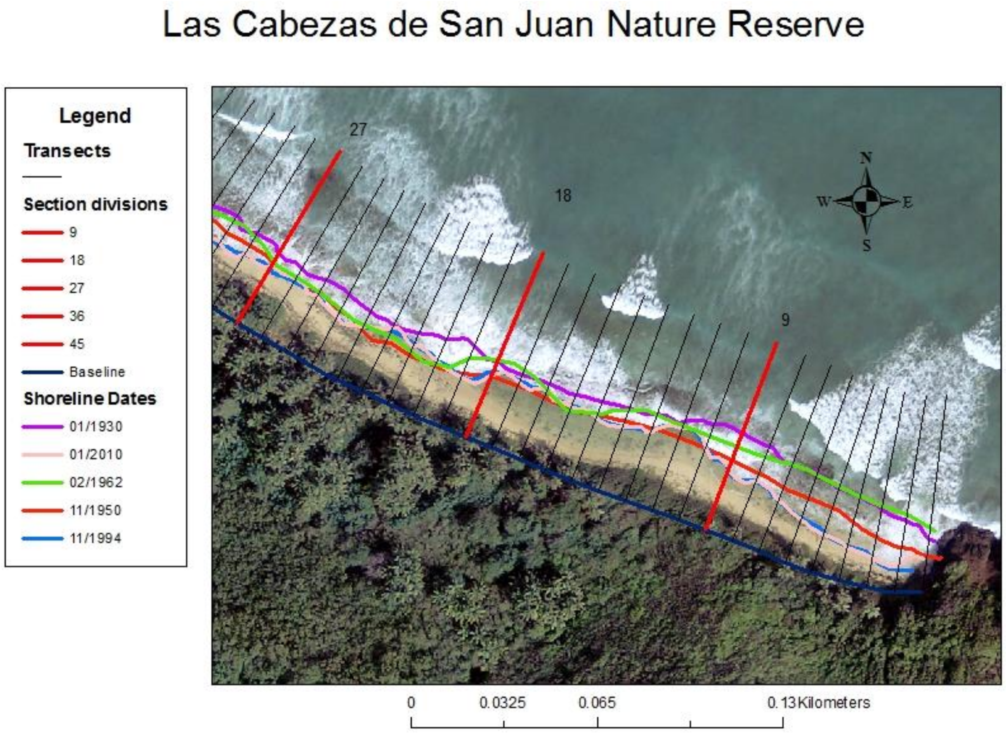


Figure 29: Location of Sections A, B, and C.

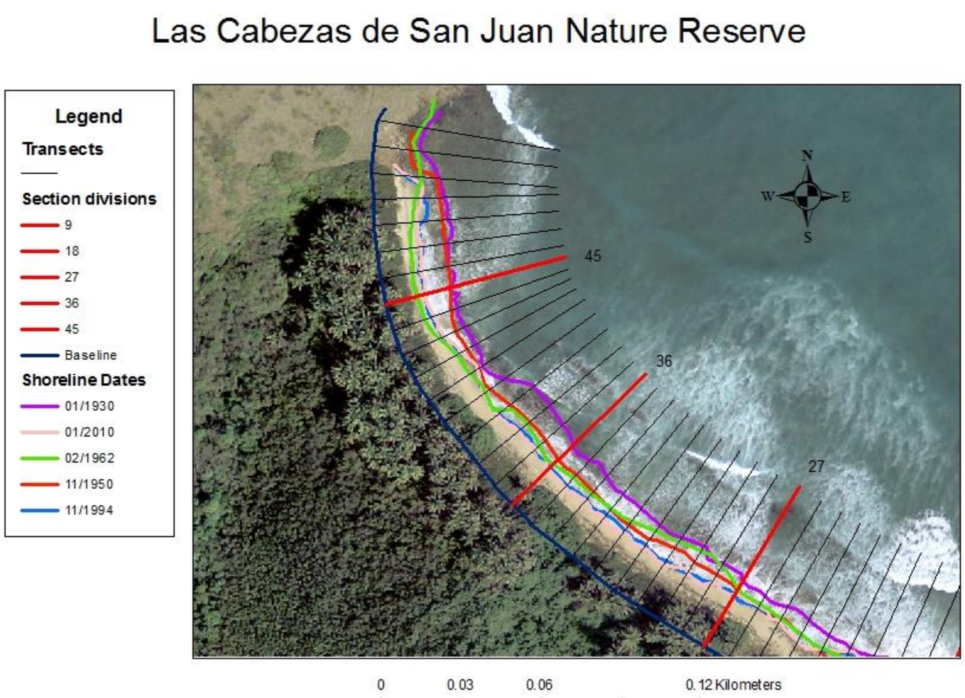


Figure 30: Location of Sections D, E, and F

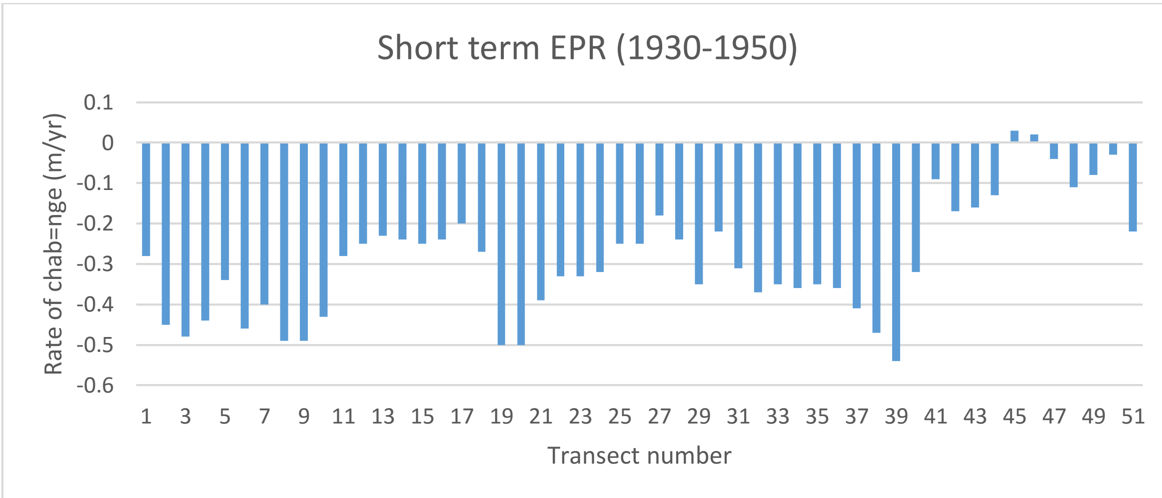


Figure 31*:* Short term (1930-1950) End Point Rate of Change (EPR) analysis with units in m/year. It represents the rate of change movement of shorelines. Graph created in excel

Table 14*:* Short term (1930-1950) Statistics for each transect and the average for each one. Graph values generated using DSAS

1930-1950	
Object Id	EPR
1	-0.28
2	-0.45
3	-0.48
4	-0.44
5	-0.34
6	-0.46
7	-0.4
8	-0.49
9	-0.49
10	-0.43
11	-0.28
12	-0.25
13	-0.23
14	-0.24
15	-0.25
16	-0.24
17	-0.2
18	-0.27
19	-0.5
20	-0.5

21	-0.39
22	-0.33
23	-0.33
24	-0.32
25	-0.25
26	-0.25
27	-0.18
28	-0.24
29	-0.35
30	-0.22
31	-0.31
32	-0.37
33	-0.35
34	-0.36
35	-0.35
36	-0.36
37	-0.41
38	-0.47
39	-0.54
40	-0.32
41	-0.09
42	-0.17
43	-0.16
44	-0.13
45	0.03
46	0.02
47	-0.04
48	-0.11
49	-0.08
50	-0.03
51	-0.22
Average	-0.292

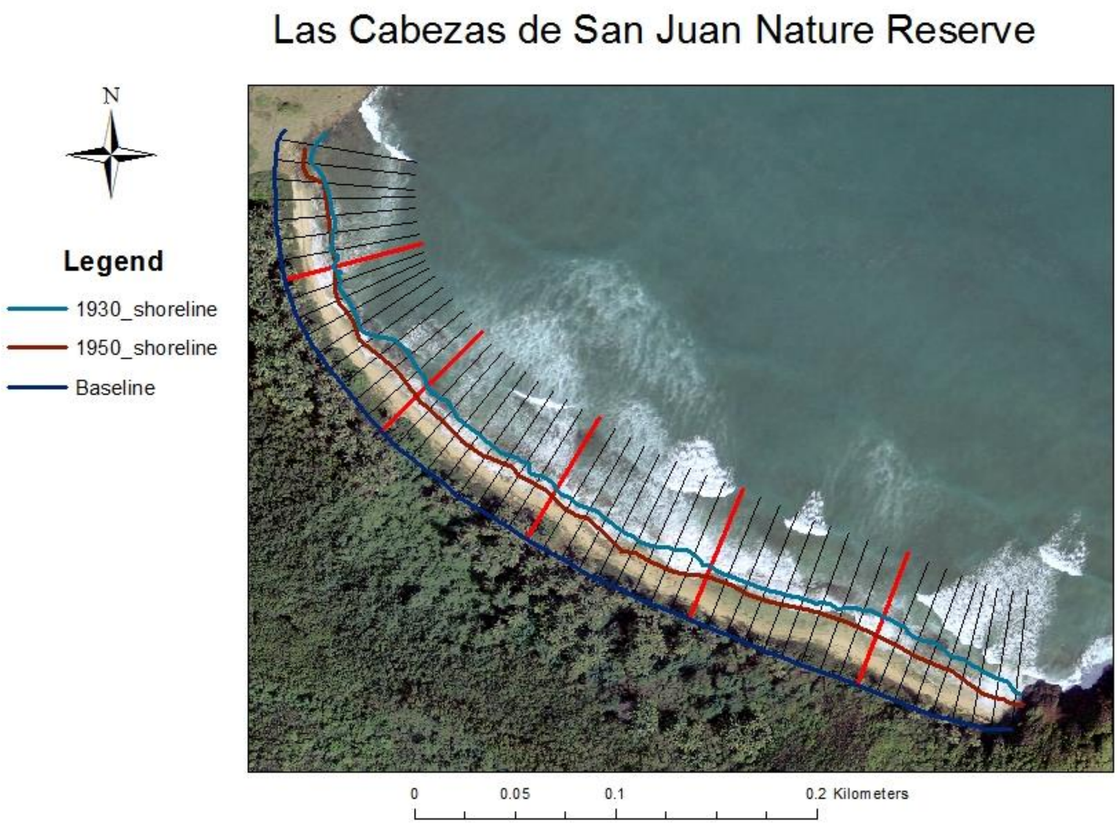


Figure 32: 1930 and 1950 shorelines divided in section. It expose how section A has the most loss of sediments and section F the lest.

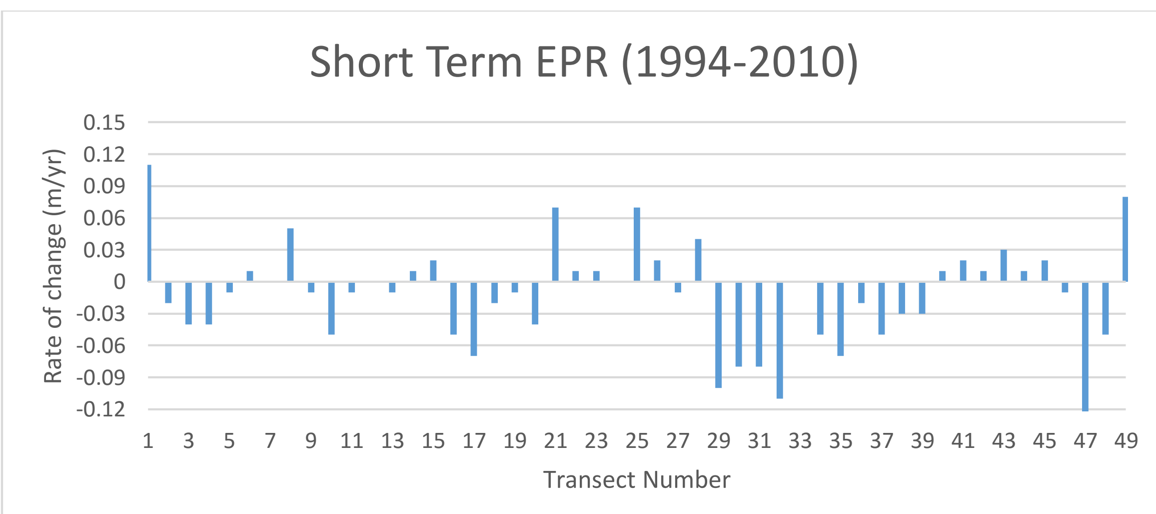


Figure 33: Short term (1994-2010) End Point Rate of Change (EPR) analysis with units in m/year. It represents the rate of change movement of shorelines. Graph created in excel.

1994-2010	
Object id	EPR

1	--
2	0.11
3	-0.02
4	-0.04
5	-0.04
6	-0.01
7	0.01
8	0
9	0.05
10	-0.01
11	-0.05
12	-0.01
13	0
14	-0.01
15	0.01
16	0.02
17	-0.05
18	-0.07
19	-0.02
20	-0.01
21	-0.04
22	0.07
23	0.01
24	0.01
25	0
26	0.07
27	0.02
28	-0.01
29	0.04
30	-0.1
31	-0.08
32	-0.08
33	-0.11
34	0
35	-0.05
36	-0.07
37	-0.02
38	-0.05
39	-0.03
40	-0.03
41	0.01

42	0.02
43	0.01
44	0.03
45	0.01
46	0.02
47	-0.01
48	-0.16
49	-0.05
50	0.08
51	--
52	--
Average	-0.012

Figure 34: 1994 and 2010 shorelines divided in section. Section D reported the highest erosion rate.