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Shoreline Changes during the last 60 years in Arecibo, Puerto Rico

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Abstract

A previous study shows that Arecibo is undergoing coastal erosion. However, the study does not display a detailed analysis of Barrio Islote area in that town. That zone is very important because of its proximity to Cueva del Indio Natural Reserve and its potential for dune preservation. The USGS extension tool known as Digital Shoreline Analysis System (DSAS) was used in ArcGIS to create transects and statistical analyses of the coastline and the dune foot. Coastline analyses revealed a dominant erosion rate of -0.10 m/yr while the eolian deposit was also eroding at a rate of -0.21 m/yr. The DSAS tool displayed great performance while calculating the statistics of End Point Rate, Net Shoreline Movement and Shoreline Change Envelope, but revealed difficulties at creating transects in cliff areas increasing the error in the analysis.

Keywords: Coastlines, Shorelines, GIS, Eolian Deposits, DSAS, Aerial Photographs, Coastal Erosion

1. Introduction

Shoreline changes have large importance for coastal communities and people living from the resources of the coastal environment (Rodríguez *et al.*, 2009). Coastlines changes in Puerto Rico due to erosion and deposition are occurring nowadays and have been documented in the past (e.g. Thieler *et al.*, 2007). This affects the resources available in the area and quantifying the evolution of these systems through transects enhances the probabilities of a better understanding of coastal dynamics (Jackson *et al.*, 2012). Transects are small segment areas that quantify the change of the shoreline at the same spatial interval (Thieler *et al*., 2007). The study of these changes can be done by different tools, but a remote sensing approach can be more efficient and cost effective (Jackson *et al.,* 2012; Avinash *et al.*, 2010).

Also recent improvements in Geographical Information Systems (GIS) and hardware capabilities have led to more and better analyses of coastal areas leading to a widely use and recommended by coastal researchers (Andrews *et al.,* 2002; Rodríguez *et al.,* 2009). GIS software has a variety of capabilities and its importance is based on the amount of layers or information that can be stacked-up to create further analyses (Rodríguez *et al.* 2009). The possibility of reconstructing historical shorelines of the study area into a single map is one of the strongest tools that GIS allows for analysis and interpretation (Rodríguez *et al.,* 2009). The stack of informational layers is one of the best methods in our project to identify if the shoreline has any direct relation with the dunes.

Shoreline change is mostly associated with the change of the high and low water levels (Stive *et al*., 2002). But the dune foot is also used as a proxy of shoreline evolution (Stive *et al.,* 2002). The dune foot is considered as the end of the backshore in a beach environment, a place where the ocean water does not reach (Del Rio *et al*., 2013; Stive *et al*., 2002). Stive et al. (2002) shows a relationship between the dune baseline and the high and low water levels. The shoreline changed at a faster rate than the eolian deposits, but a clear association between both systems remained (Stive *et al*., 2002).

Thieler et al. (2007) used GPS data and ArcGIS software to produce a shoreline analysis on the coast of Rincón. The analysis was done through the USGS extension tool called Digital Shoreline Analysis System better known as DSAS for its acronym (Thieler *et al*., 2007). DSAS is free software used to calculate shoreline change statistics through vector data (Thieler *et al*., 2009). This software is intended for use on coastal environments but it is useful in other environments that display boundaries like snowlines, land cover and vegetation lines (Thieler *et al*., 2009).

In Rincón the shorelines mostly appeared to be eroding due to a certain number of natural and anthropogenic factors (Thieler *et al*., 2007). In the coasts of Arecibo a similar trend was recorded by Morelock (1984). Although in Arecibo the erosion has been severe due to the constructions of jetties and ports in the shoreline, leading to stop the longshore transport (Morelock, 1984). Also, a dam on the Río Grande de Arecibo upstream stops the supply of sediments from the river affecting the dynamics of the coast (Morelock, 1984). Still Morelock (1984) does not explain what happens in all the coast of Arecibo and he was mainly focused in the area close to the Río Grande de Arecibo and to Caño Tiburones. There is no quantitative data by Morelock (1984) explaining the trends of erosion or deposition to the east of the port indicating if there is a lack of longshore drift due to the jetty construction. This leads to the question of what changes have occurred to the coastline and eolian deposits in the last 60 years over that area.

This study conducted a remote sensing survey of the coastline changes of Barrio Islote, Arecibo, Puerto Rico (Figure 1). Aerial photographs of the last 60 years (from 1950 to 2010) were analyzed with the ESRI ArcGIS 10.1 software and DSAS. Also ArcGIS was used to analyze eolian deposits to determine a relationship between the presence of dunes and shoreline changes.

Similar projects have been done in other coastlines of Puerto Rico to determine shoreline changes and in other parts of the world like India and Spain (e.g. Avinash *et al*., 2010; Del Rio *et al*., 2013; Thieler *et al*., 2007). However it has never been done in the selected study area. Therefore, the specific objectives of this study were:

1. Use DSAS to determine shoreline changes in two beaches of Barrio Islote, Arecibo during the last 6 decades.
2. Evaluate the erosion or deposition in the coastline along the same period of time.
3. Test methods in ArcGIS to observe the eolian deposits baseline and determine its accretion or erosion.
4. And lastly, compare the coastline changes with the evolution of the eolian deposits observed in the area to find possible trends.

2. Study area

The study area is located in Barrio Islote in the northern coast of Puerto Rico at the municipality of Arecibo. The total area is enclosed in a polygon approximately in the latitude 18°29’40 N and longitude 66°38’30” W and, latitude 18°29’15” N and longitude 66°36’00” W (Figure 1). This town is bordered by the Atlantic Ocean and the shore is oriented mostly on an East-West direction. Geologically the area is formed of various Quaternary deposits including beach deposits, beach rock, sand dunes and eolianites (Briggs, 1965; Briggs, 1968). The beach deposits are mainly composed of carbonates by the presence of calcite and other fossiliferous fragments and small amounts of volcanic sediments and quartz (Briggs, 1965; Briggs 1968). The dunes are composed mainly of the materials in the near beach deposits (Briggs, 1965; Briggs, 1968).

3. Methodology

3.1 Sample Description

This study used 5 mosaics of vertical aerial photographs from 1950, 1963, 1971, 1977, 1998 provided by DRNA and an aerial photograph of 2010 provided by the GERS Lab with a spatial resolution of 1 foot. Photos from 1950 to 1977 (Figures 2-5) are in black and white and the last two photos from 1998 (Figure 6) and 2010 (Figure 7) are in true color. The area to be analyzed in the photo comprehends approximately 4.3 km of coastline in Barrio Islote, Arecibo, Puerto Rico. The datum used for the photographs and digitalized objects is NAD 1983 State Plane Puerto Rico Virgin Islands FIPS 5200 and the units used are meters.

3.2 Shoreline Changes

Shoreline changes in the study area were analyzed in ESRI ArcGIS v10.1 Software with six georeferenced aerial photographs of the coasts of Arecibo collected during 1950, 1963, 1971, 1977, 1998 and 2010. The oldest aerial photographs were received from the Departmento de Recursos Naturales y Ambientales (DRNA) in a tif format. The 2010 photo was provided by the Geological and Environmental Remote Sensing Laboratory of the Geology Department in the University of Puerto Rico at Mayaguez.

Each photograph was examined and the shorelines were digitized through shapefiles with the utmost accuracy. The shoreline proxy selected was the boundary between the land and water seen in the aerial photographs. The digitalization process was done for all six photos (Figure 8). Henceforth, all the different shapefiles (or shorelines) were stacked-up and compared with the latest photograph. This step allowed visualizing the shorelines in the sixty years period to determine their qualitative changes. But, quantitative analyses were required for more accurate conclusions. The statistics used were End Point Rate (EPR), Net Shoreline Movement (NMS) and Shoreline Change Envelope (SCE). For this step, analytical graphs depicting the rate of change of the coastline were produced. The graphs produced came from the same statistics mentioned above. The USGS tool called DSAS was used to create transects and to analyze the changes of the coastline at different points in the coasts with the rates of change in meters per year as in Thieler *et al*. (2007). In order to compare the shorelines in DSAS a new shapefile was created to include all six shorelines in the same file. A baseline was established considering the three available methods in DSAS. The buffer method of an existing shoreline was selected because it is the easiest one. A buffer of 50 meters was made from the 2010 shoreline because it is the most recent. The buffer was created as a polygon file by the GIS software and therefore it was changed to a polyline using the Polygon to Line tool in Arctoolbox. Transects spacing was selected to be 40 m and the transect length was set to 100 m. The spacing was determined after observing different options 10 m, 20 m, 30 m, 40 m and 50 m. The first three options analyzed more coastlines and/or crossed other transects in the cliffs, while the 50 m spacing started to leave out areas. Transects length was determined to assure that all the shorelines were collected inside them. Then, the development of a map and table identifying the areas with erosion or accretion was produced. Finally, the area was divided according to the observed changes in smaller areas and for a general result of the site.

3.3 Eolian Deposits Change

In a second phase of this study a new set of boundaries were digitized with ArcGIS establishing the change of the eolian deposits between 1950 and 2010 (Figure 9). The new boundaries used where the vegetation line as a representation of the dune baseline toward the sea indicated by the backshore line (Moore and Griggs, 2002; Del Río *et al*., 2013). Transects displaying the rates of change were also done for the eolian boundaries, because DSAS can function with different kinds of boundaries (Thieler *et al*., 2009). Graphs presenting where erosion and deposition areas are located in relation with these eolian boundaries were created to help describe the evolution of this system. The setting up of DSAS with the dune foots was similar to the shoreline, but the transect length was of 160 meters to cover all the eolian boundaries.

The shoreline and eolian deposits boundaries were compared looking for similarities and differences. The assessment of DSAS produced data and graphs and were carried out for both scenarios in order to analyze its applicability in the study area.

4. Results and Discussion

4.1 Coastline Changes

The coastline change in the study area from 1950 to 2010 at first glance, looks like the coast did not change much (Figure 8). Exceptions found at certain areas like the small bay between the rocks in the central area and at the Eastern end of the rocky area. EPR shoreline analysis for the area gave a mean of -0.10 m/year with a standard deviation of 0.28 m/year. This analysis measures the distance of the oldest and youngest coast and divides it by the years. The NSM another analysis used by DSAS that determines the distance of the first and last shoreline. The mean shoreline movement using this analysis for the selected time period was -6.2 meters with a standard deviation of 15.6 meters. The last analysis used to observe the coastal changes in Islote was the SCE. This method gave a mean value of 27.2 meters of shoreline movement in through the whole period and a standard deviation of 13.4 meters.

4.2 Shoreline Rate of Change

The digitized shorelines displayed similar trends as expected after creating the six shorelines (Figure 8). Variations between each shoreline were observed that could be called either accretion or erosion. Although at cliffs almost no change or erosion were expected, those areas had unusual changes from the results found by Moore and Griggs (2002) where he found a constant erosion rate at cliffs the results of the coast in Arecibo indicated deposition (Figure 8). The reason for this may be related to how the transects were positioned by DSAS with respect to the shorelines (Figure 12). At certain points it is observed that transects are crossing the same line a second or third time, or the transect crosses another one and takes the input from a farther boundary.

The mean EPR for the coast of Arecibo presented mostly a trend of constant erosion. The value obtained of -0.10 m/yr is lower than Morelock (2003) result of -0.21 m/yr. However, the -0.10 m/yr had a standard deviation of 0.27 m/yr, meaning that this value is how much the given result can spread from the given data and still be correct. Also the deposition found could be the factor that is lowering the EPR and increasing the standard deviation. The high standard deviation is obtained from measuring small and large changes in the transects. Thieler et al. (2007) obtained different standard deviations and in areas of large differences the standard deviation was higher than in the other regions. The EPR, as well as the NSM analysis display an accretion for the first five transects from West to East. These results could be misleading, because those transects are located in a rocky cliff where erosion is more likely to occur.

Observations of transects trend for the EPR reveal small sections of accretion and erosion (Figure 10) (Table 1). The Western corner starts with accretion area for the first 10 transects, then up to the 50 transect there is erosion with a few exceptions. The next section encloses transects 51 to 60 with accretion, followed by erosion from up to the 65 transect. Afterwards, transects 66 to 77 have no obvious trend; although most transects appear to display erosion. The next section from transect 78 to 90 shows the maximum erosion in the coast. This section is followed by an accretion section from transects 91 to 120 and towards the Eastern limit, transects 121 to 170 display erosion. Similarly the NSM statistic had almost the same result. The main difference is seen in the unit and values, because one is in meters per year and the other in meters. This trend was expected because of the formulas to compute the EPR and NSM, where EPR = distance between the oldest and youngest shoreline/years and NSM = distance between the oldest and youngest shoreline. SCE only described the greatest distance of shoreline movement.

4.3 Eolian Deposit Changes

In the case of the dune foot changes, they were mainly horizontal, except at the rocky central region of the study area where the lines indicating the eolian deposit limit became more hectic (Figure 9). Similar to the coastlines in that sense. The mean value of the time period for the EPR analysis was -0.21 m/year with a standard deviation of 0.29 m/year. Mean NSM statistic gave a value of -12.6 meters and the SCE statistic gave a mean of 27.2 meters. The standard deviations for these statistics were 17.3 meters and 21.1 meters, respectively.

4.4 Eolian Deposits Rate of Change

Dune foots displayed fewer divisions of erosion and accretion. Transects 1 to 5 and 115 to 118 showed accretion while the other transects showed eroding areas (Figure 11) (Table 2). Even when the same number of transect space was used for the shoreline and dune foot the amount of transects for the dune were less, but here the baseline was completely onshore differently from the coastline baseline that was onshore and offshore. The NSM also followed the same trend of the EPR, but the SCE was different. Furthermore, SCE values mostly remained below the mean of 27 meters. The exceptions were transects 35-40, 50-78 and 100-118, and transects 53 to 65 displayed the biggest change during the time period. In the aerial photograph this zone is located in the bay area. In contrast from the shoreline it remained fairly constant and the greatest changes were seen at the end of the rocky cliffs. While comparing the aerial photographs the trees in that area were cut, which increased the distance between the shorelines.

6. Conclusion

The coast of Arecibo is certainly being eroded at a rate of -0.10 m/yr as well as the dune foot is eroding at a faster rate of -0.21 m/yr. Even though, shoreline evolution varies differently at the short and long range. Therefore, both boundaries have a relationship that could be observed from the EPR and NSM statistics. However, the individual shorelines and dune foots present different variations than the overall trend. The erosion of the coastline seem to be from natural causes like storms, swells because there are no structures close, but for the dune base a human factor may be present due to structures and deforestation. The use of GIS system proved to be cost-efficient, accessible and easy to operate for the creation of the project. Therefore it proved to be the ideal instrument to generate coastlines, dune foots and others. The DSAS extension tool demonstrated its use on horizontal coasts, but it had problems with land spits and concave areas. However, the statistics and shoreline change envelope clip tools were efficient in displaying the information. In the future it would be helpful to use another program like AMBUR for the generation of transects and statistics. This would help compare the functionality of both software and to determine which is better. Also a more detailed analysis of the shoreline changes in a smaller temporal resolution and the creation of a new baseline based on the most recent shoreline.

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Figures and Graphs

Figure 1: Aerial photograph of the location where the shoreline and dune foot analysis were held in Arecibo, Puerto Rico. The photo was taken in 2010 by the US Army Corps of Engineering and provided by the GERS Lab. Yellow pin on the island image indicates the study site. Puerto Rico image taken from Google Earth (2013).

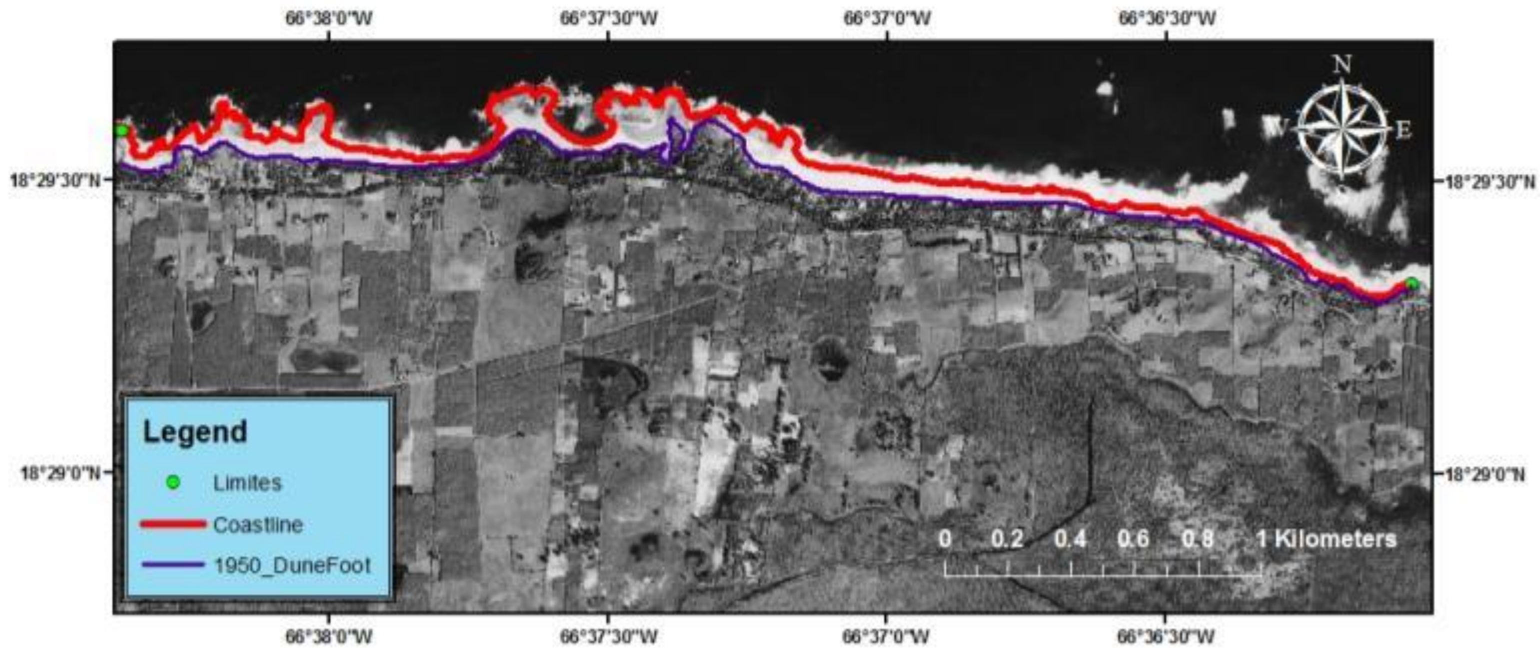


Figure 2: Black and white aerial photograph of Barrio Islote, Arecibo, Puerto Rico in 1950. Image provide by DRNA (1950).

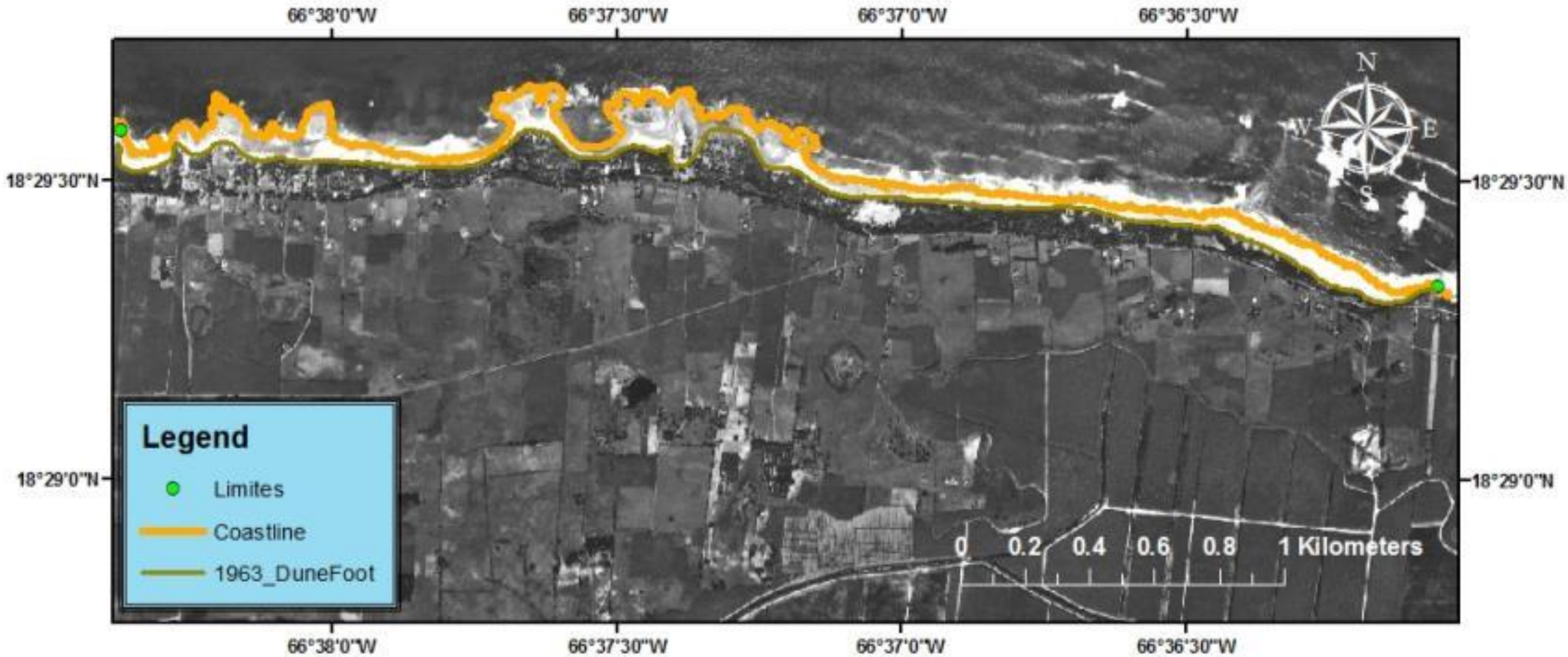


Figure 3: Black and white aerial photograph of Barrio Islote, Arecibo, Puerto Rico in 1963. Photo provided by DRNA (1963).

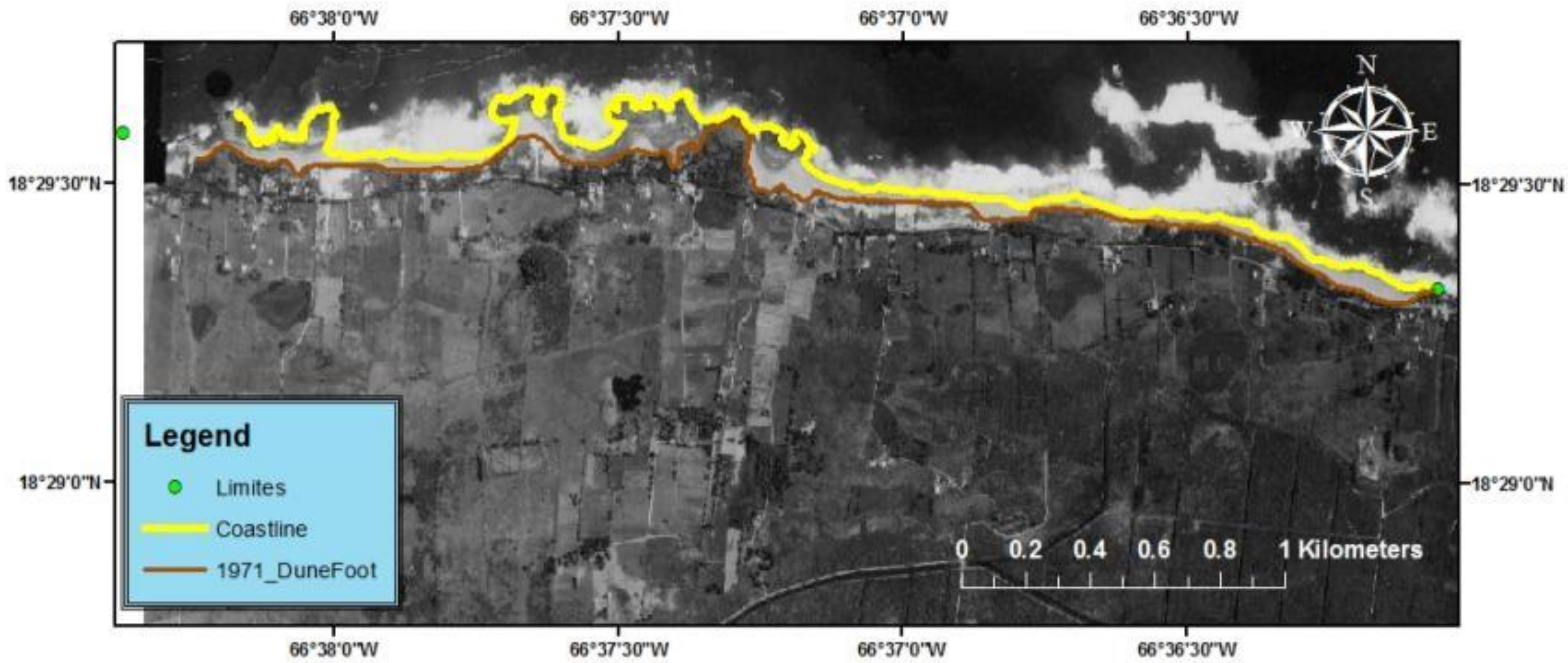


Figure 4: Black and white aerial photograph of Barrio Islote, Arecibo, Puerto Rico in 1971. The photo is damaged in the Northwest corner which impede the digitizing of the coastline and dune foot in that end. Aerial photograph provided by the DRNA.

Figure 5: Black and white aerial photograph of Barrio Islote, Arecibo, Puerto Rico in 1977. A small section of the photo was missing and attempts to find the missing section were in vain. Image provided by DRNA.

Figure 6: True color aerial photograph of Barrio Islote, Arecibo, Puerto Rico. Image provided by DRNA.

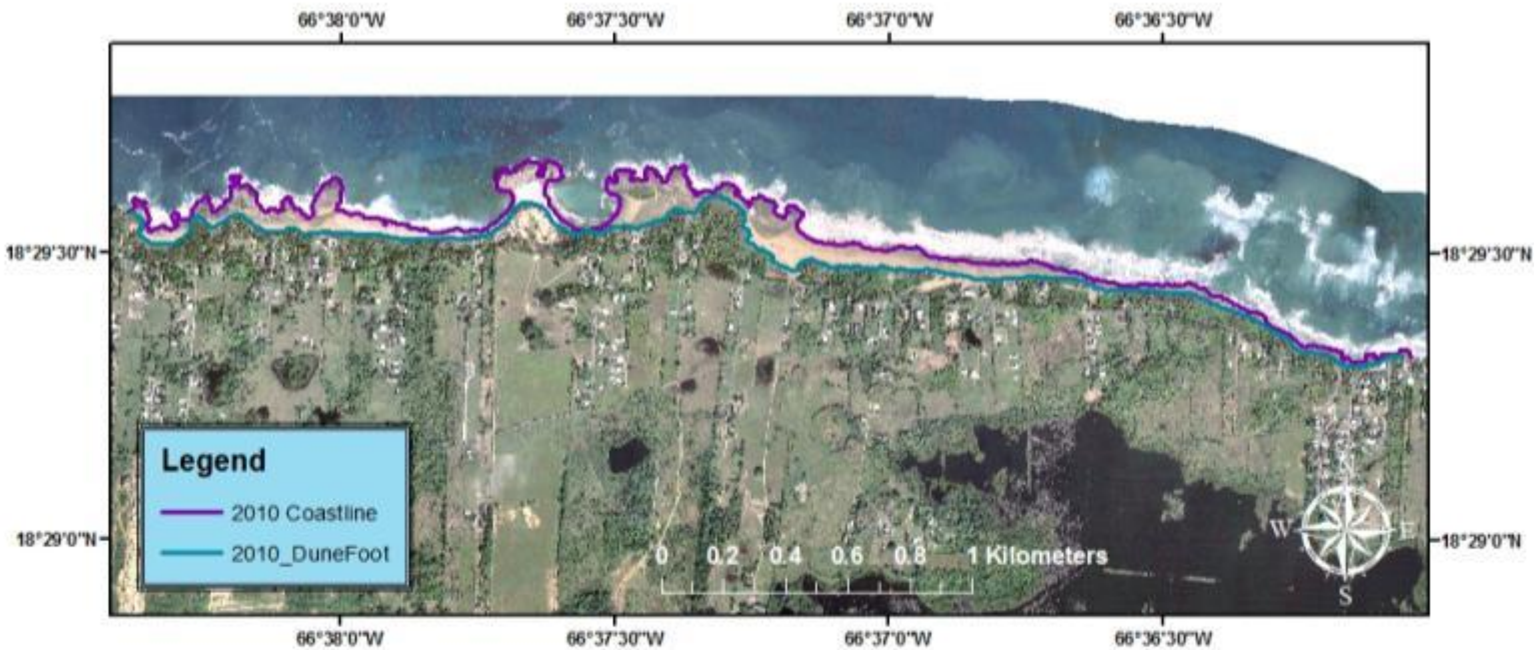


Figure 7: True color aerial photograph from Barrio Islote, Arecibo, Puerto Rico. This photo contains the latest coastline and dune baseline. This photo was provided by the GERS Lab.

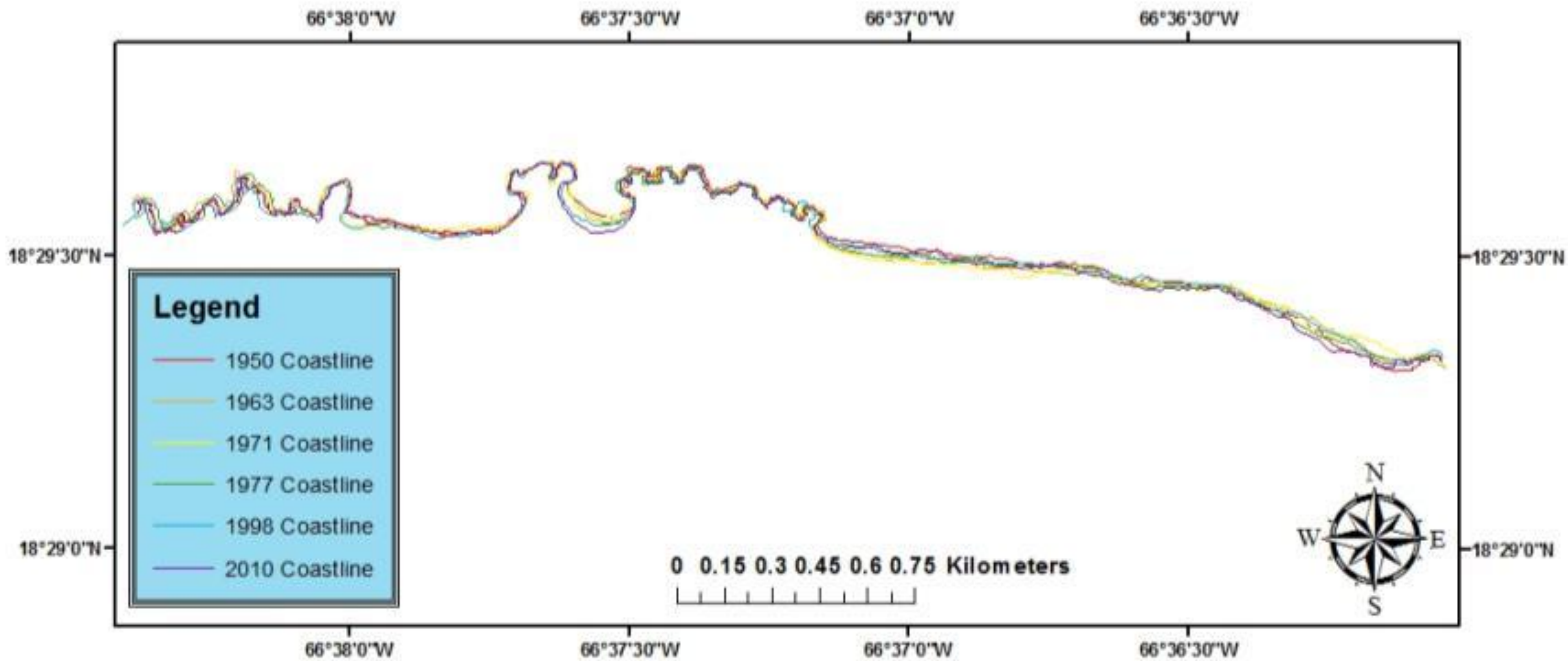


Figure 8: Image displaying the coastlines between 1950 and 2010. This stacking is presented on a white background to allow a better understanding of the coastline changes.

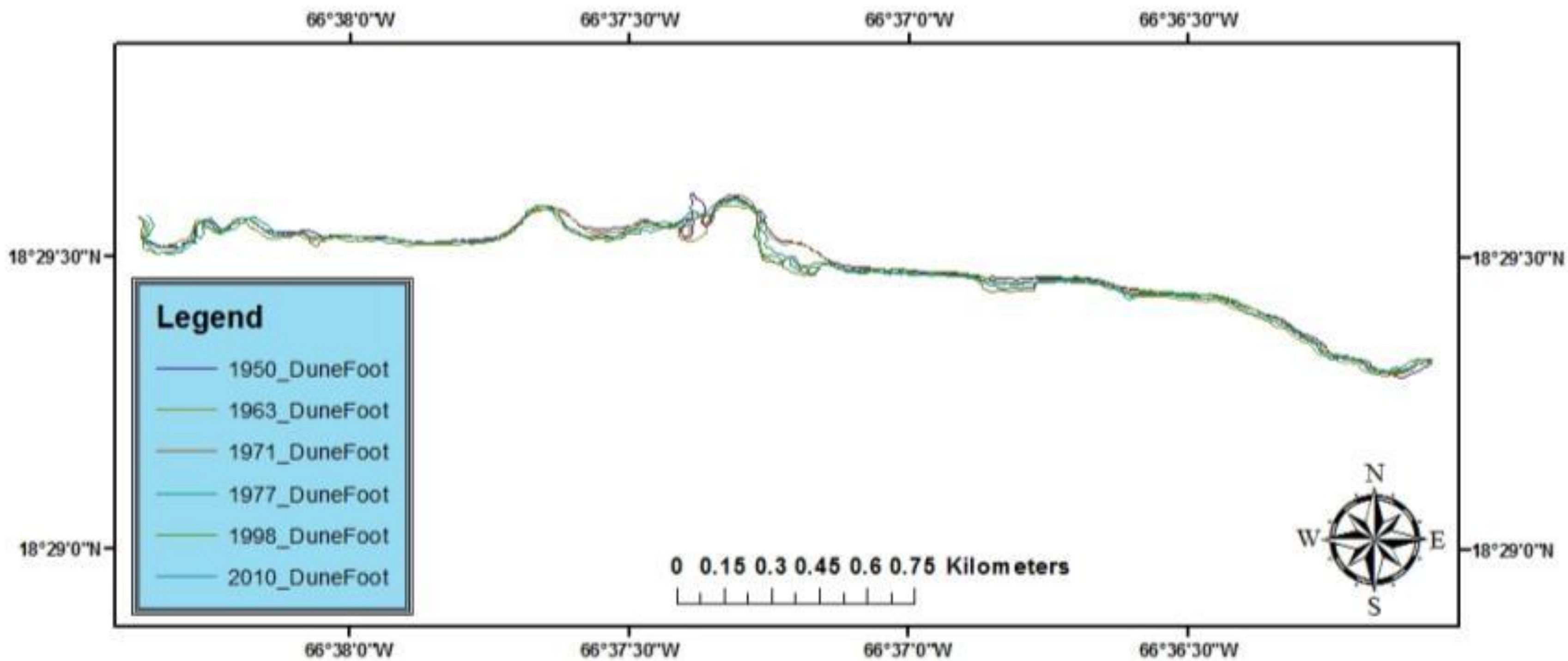
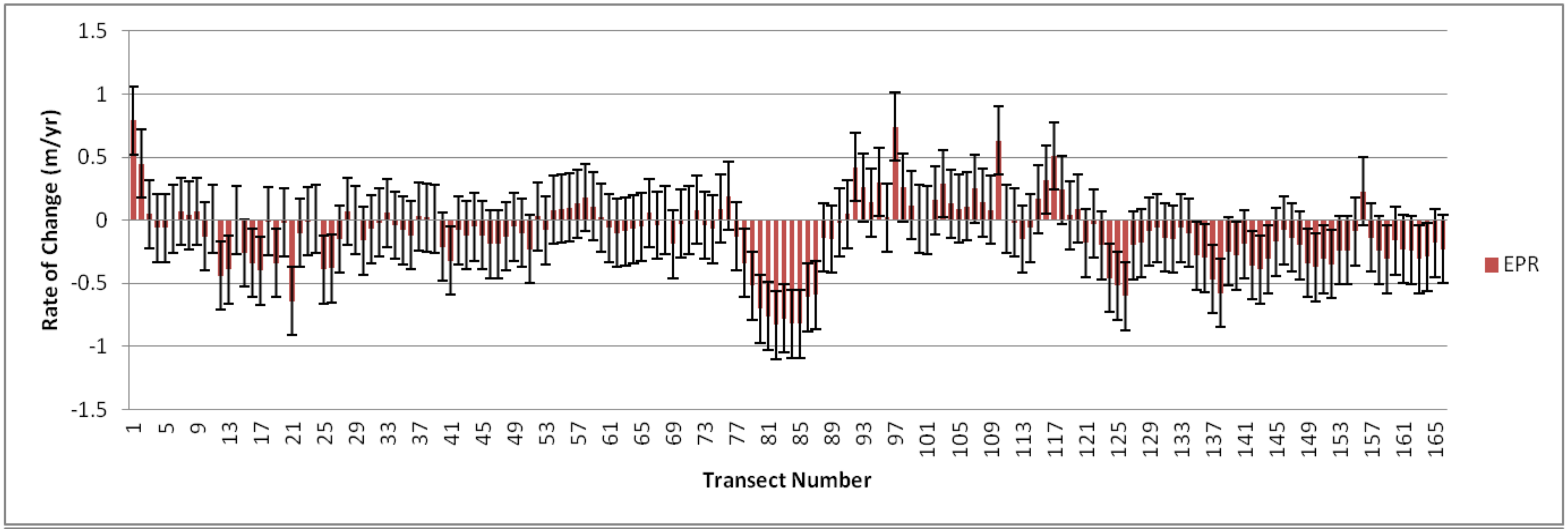
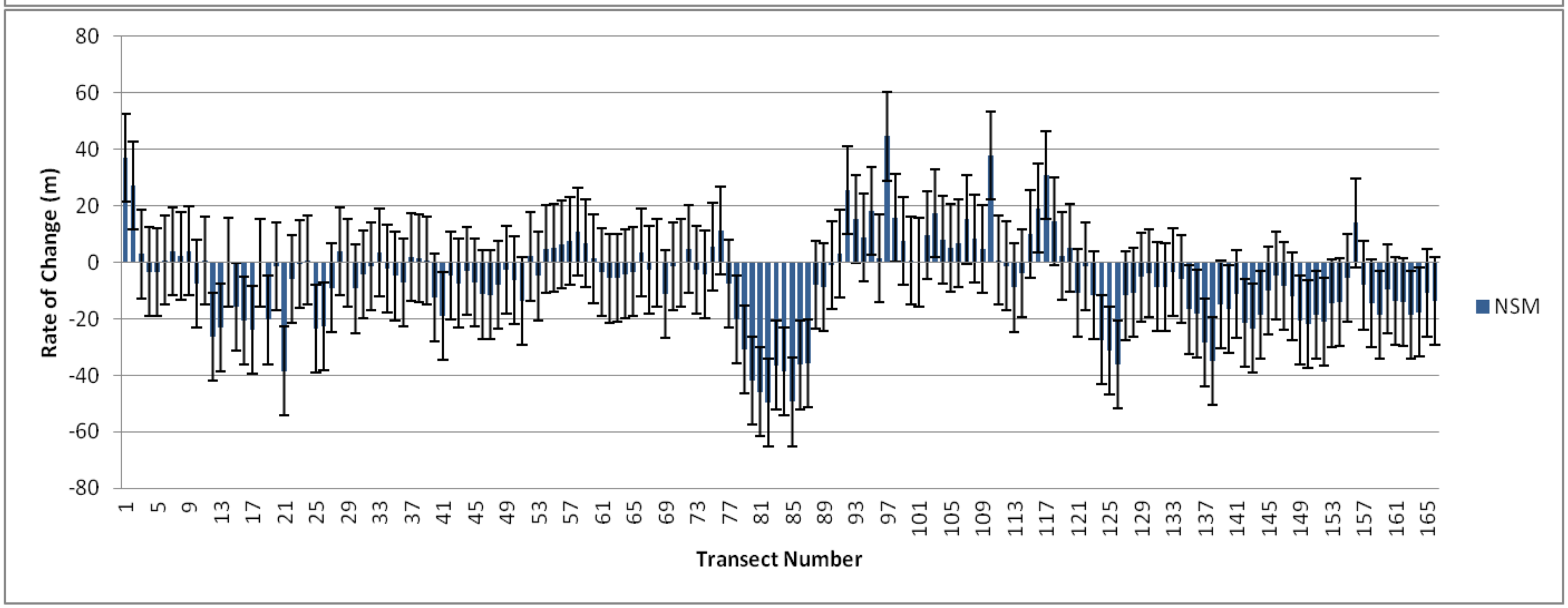


Figure 9: Image displaying the sequential dune foots in barrio Islote, Arecibo, Puerto Rico.


Rate of Change (m/yr)
1.5
1
0.5
0
-0.5
-1
-1.5
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133 137 141 145 149 153 157 161 165
Transect Number
EPR


Rate of Change (m)
80
60
40
20
0
-20
-40
-60
-80
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133 137 141 145 149 153 157 161 165
Transect Number
NSM

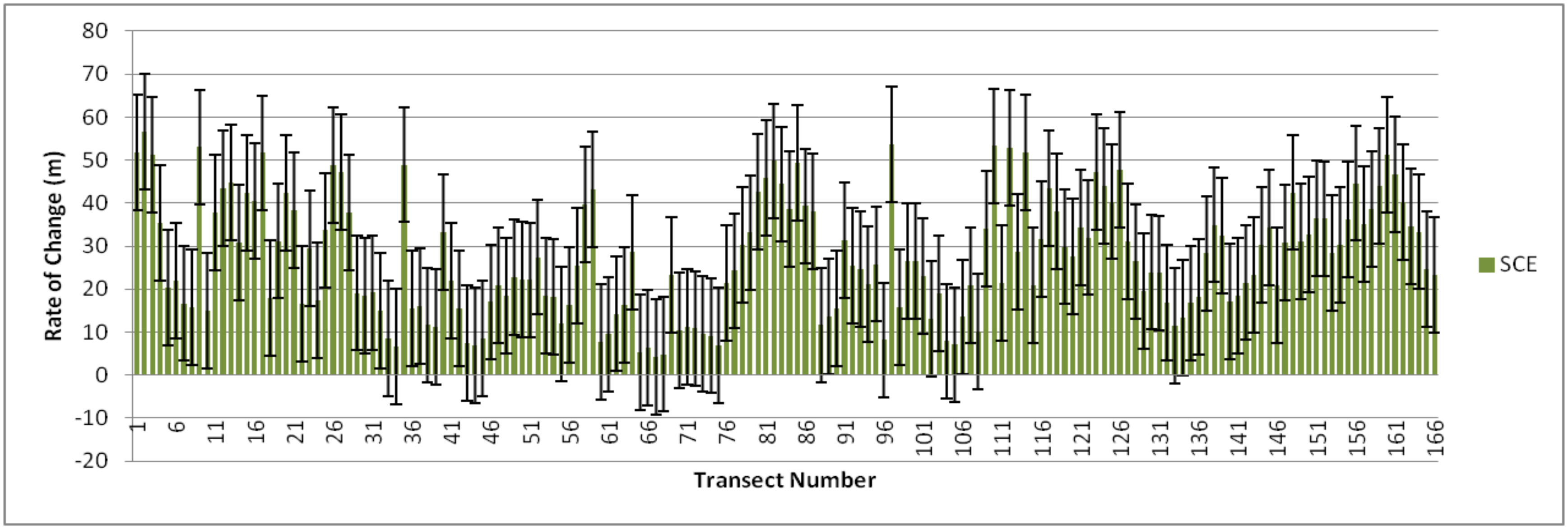
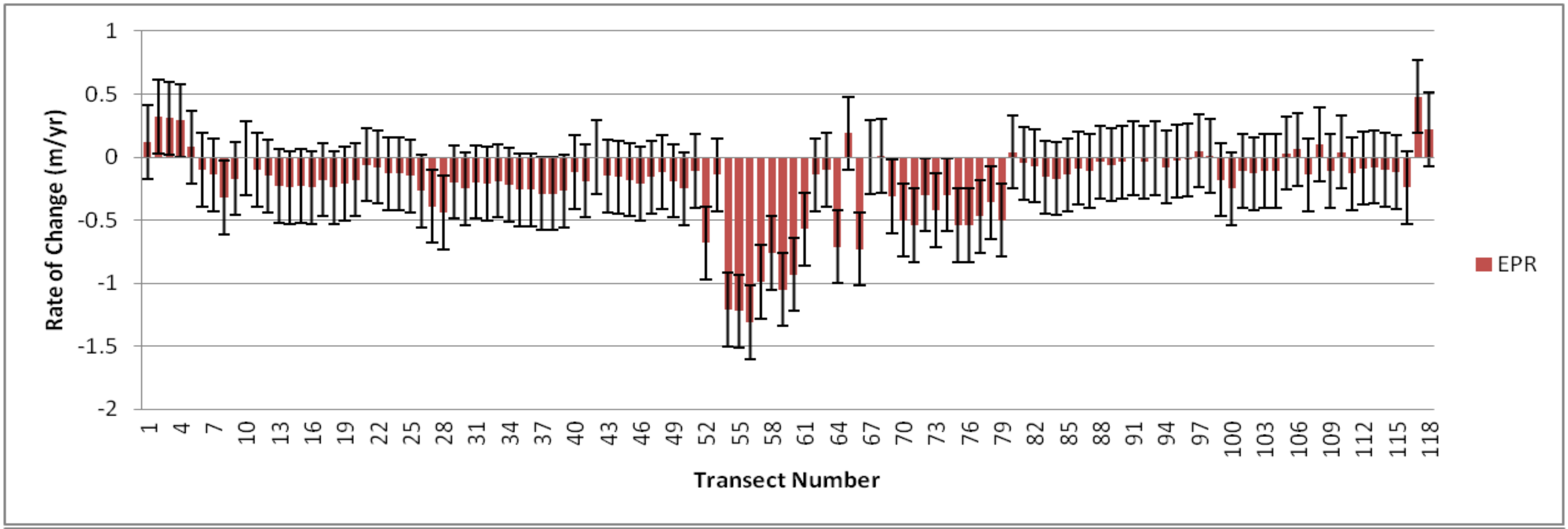
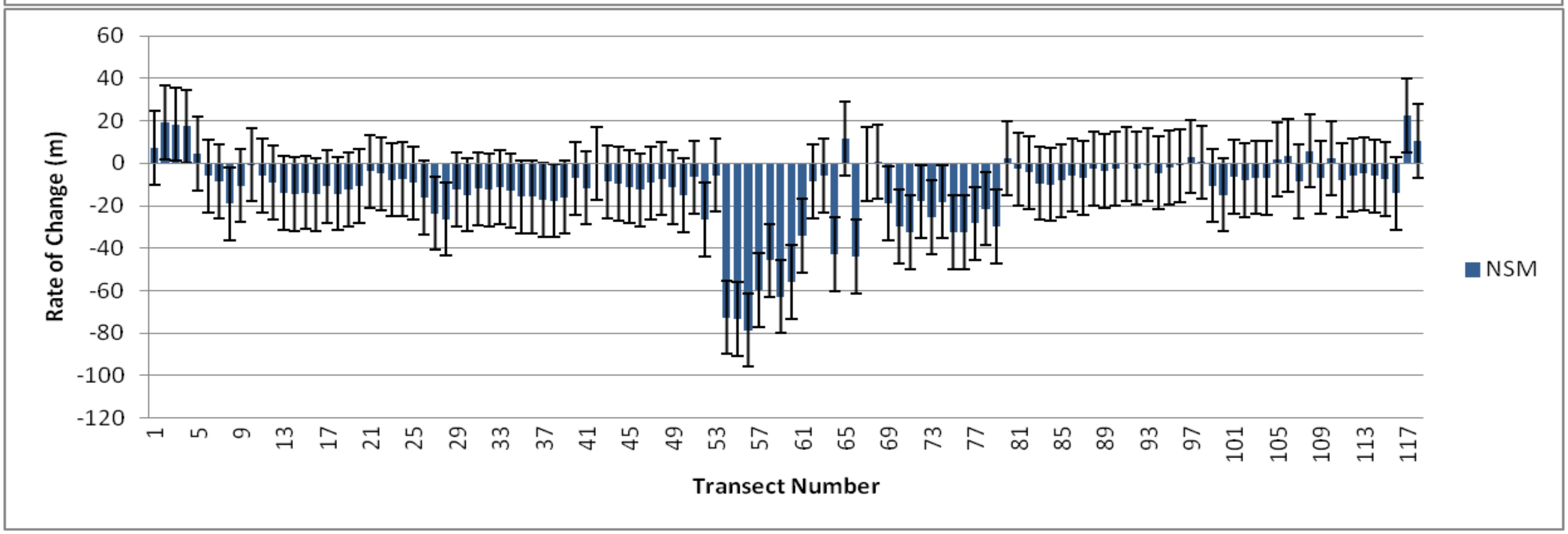


Figure 10: Graphs of the coastline End Point Rate (EPR), Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE). The EPR units are in m/yr and the transect number is merely recognizing the transects. Notice that most of the graph is in the negative area which indicates erosion. The NSM units are meters and the transect number is recognizing the transects. Observe the similarities between the EPR and the NSM. It is almost the same graph, but with a few differences in scale and values. The SCE units are in meters and the object identifier is recognizing the transects.


1
0.5
0
-0.5
-1
-1.5
-2
Rate of Change (m/yr)
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118
Transect Number
EPR


60
40
20
0
-20
-40
-60
-80
-100
-120
Rate of Change (m)
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117
Transect Number
NSM

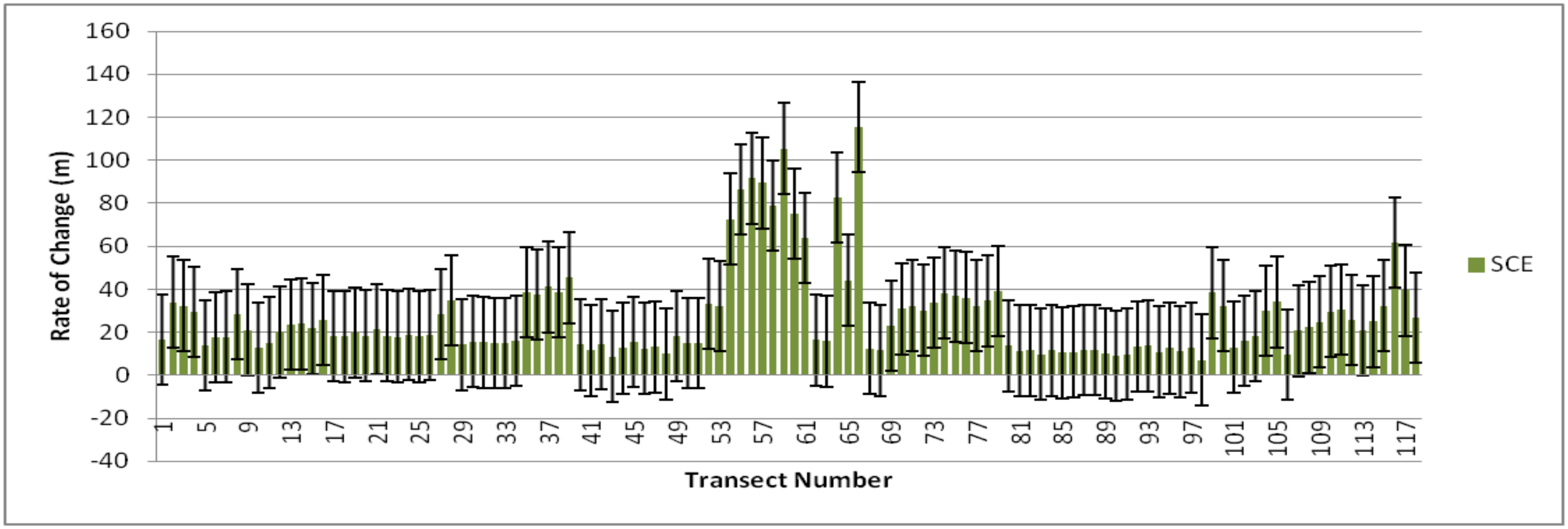


Figure 11: Graphs of the End Point Rate (EPR), Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE) for the eolian deposit boundary. The EPR units are in m/yr and the transect number is merely recognizing the transects. Notice that most of the graph is in the negative area which indicates erosion. The NSM units are in meters and the transect number is recognizing the transects. The SCE units are in meters and the transect number is recognizing the transects.

Figure 122: Map displaying the Shoreline Change Envelope Clip of the shorelines.

Figure 13: Map displaying the Shoreline Change Envelope Clip of the dune foot. This image allows the comparison between the data and the shorelines. Notice the extensive erosion in the central area due to deforestation, seen from Figures 3 & 4.

Tables

Table of statistics for Coastline Changes in Barrio Islote, Arecibo, Puerto Rico				
Object Identifier *	TransectId	EPR	SCE	NSM
1	1	0.79	51.73	37.03
2	2	0.45	56.52	27.24
3	3	0.05	51.3	2.9
4	4	-0.06	35.34	-3.31
5	5	-0.06	20.45	-3.51
6	6	0.01	21.91	0.81
7	7	0.07	16.72	3.96
8	8	0.04	15.81	2.16
9	9	0.07	52.99	4.04
10	10	-0.13	15.04	-7.58
11	11	0.01	37.73	0.53
12	12	-0.44	43.51	-26.48
13	13	-0.39	44.88	-23.16
14	14	0	30.8	-0.03
15	15	-0.26	42.45	-15.62
16	16	-0.34	40.55	-20.57
17	17	-0.4	51.66	-24
18	18	-0.01	17.88	-0.33
19	19	-0.34	31.2	-20.43
20	20	-0.02	42.47	-1.37
21	21	-0.64	38.42	-38.42
22	22	-0.1	16.59	-5.98
23	23	-0.01	29.45	-0.53
24	24	0.01	17.47	0.78
25	25	-0.39	33.67	-23.6
26	26	-0.38	48.76	-22.61
27	27	-0.15	47.16	-9.06
28	28	0.07	37.76	4
29	29	0	19.12	-0.3
30	30	-0.16	18.51	-9.39
31	31	-0.07	19.17	-4.36
32	32	-0.02	15.07	-1.37
33	33	0.06	8.53	3.43
34	34	-0.04	6.68	-2.36
35	35	-0.08	48.95	-4.87
36	36	-0.12	15.59	-7.23
37	37	0.03	16.1	1.84
38	38	0.02	11.63	1.39

39	39	0.01	11.13	0.57
40	40	-0.21	33.19	-12.35
41	41	-0.32	21.86	-18.94
42	42	-0.08	15.56	-4.78
43	43	-0.12	7.39	-7.39
44	44	-0.05	7.01	-3.1
45	45	-0.12	8.54	-7.18
46	46	-0.19	17	-11.44
47	47	-0.19	20.81	-11.48
48	48	-0.13	18.48	-8
49	49	-0.05	22.81	-2.78
50	50	-0.1	22.13	-6.28
51	51	-0.23	22.12	-13.63
52	52	0.03	27.46	2.05
53	53	-0.08	18.46	-4.9
54	54	0.08	18.12	4.58
55	55	0.09	11.91	5.16
56	56	0.1	16.37	6.28
57	57	0.13	25.44	7.69
58	58	0.18	39.68	10.71
59	59	0.11	43.11	6.62
60	60	0.02	7.76	1.27
61	61	-0.06	9.48	-3.57
62	62	-0.1	14.28	-5.71
63	63	-0.09	16.33	-5.52
64	64	-0.07	28.56	-4.09
65	65	-0.05	5.3	-3.29
66	66	0.06	6.36	3.44
67	67	-0.04	4.14	-2.67
68	68	0	4.89	-0.15
69	69	-0.19	23.37	-11.23
70	70	-0.03	10.38	-1.55
71	71	0	11.31	-0.22
72	72	0.08	10.82	4.8
73	73	-0.04	9.67	-2.6
74	74	-0.07	9.19	-4.23
75	75	0.09	6.91	5.44
76	76	0.19	21.46	11.16
77	77	-0.13	24.26	-7.59
78	78	-0.34	30.2	-20.23
79	79	-0.52	33.12	-30.92
80	80	-0.7	42.67	-41.97
81	81	-0.76	45.78	-45.78

82	82	-0.83	49.78	-49.78
83	85	-0.78	44.42	-36.44
84	86	-0.82	38.66	-38.66
85	87	-0.82	49.45	-49.45
86	88	-0.61	39.31	-36.32
87	89	-0.59	38.01	-35.64
88	90	-0.14	11.63	-8.1
89	91	-0.15	13.67	-8.79
90	92	-0.02	15.49	-1.02
91	93	0.05	31.29	3.16
92	94	0.42	25.41	25.41
93	95	0.26	24.62	15.33
94	96	0.14	21.17	8.67
95	97	0.3	25.85	18.12
96	98	0.02	8.15	1.44
97	99	0.74	53.69	44.58
98	100	0.26	15.76	15.76
99	101	0.12	26.45	7.47
100	102	0.01	26.55	0.7
101	103	0	23.14	-0.05
102	104	0.16	13.07	9.7
103	105	0.29	19	17.3
104	106	0.13	7.87	7.87
105	107	0.09	7.06	5.16
106	108	0.11	13.51	6.73
107	109	0.25	20.92	15.15
108	110	0.14	10.08	8.43
109	111	0.08	33.96	4.82
110	112	0.63	53.28	37.89
111	113	0.01	21.39	0.8
112	114	-0.02	52.94	-1.24
113	115	-0.15	28.77	-8.94
114	116	-0.06	51.69	-3.88
115	117	0.17	20.93	10.08
116	118	0.32	31.61	19.17
117	119	0.51	43.48	30.73
118	120	0.24	38.17	14.38
119	121	0.04	29.86	2.24
120	122	0.09	27.56	5.24
121	123	-0.18	34.35	-10.7
122	124	-0.03	32.02	-1.54
123	125	-0.2	47.17	-11.74
124	128	-0.46	44.09	-27.4

125	129	-0.52	40.36	-31.37
126	130	-0.6	47.69	-36.29
127	131	-0.2	31.11	-11.81
128	132	-0.18	26.4	-10.65
129	133	-0.09	19.63	-5.25
130	134	-0.06	23.95	-3.85
131	135	-0.14	23.74	-8.65
132	136	-0.15	16.76	-8.71
133	137	-0.06	11.43	-3.53
134	138	-0.1	13.35	-5.89
135	139	-0.28	16.75	-16.75
136	140	-0.3	18.22	-18.22
137	141	-0.47	28.28	-28.28
138	142	-0.58	34.99	-34.99
139	143	-0.25	32.36	-14.87
140	144	-0.28	17.14	-16.58
141	145	-0.19	18.56	-11.36
142	146	-0.36	21.55	-21.55
143	147	-0.39	23.32	-23.32
144	148	-0.31	30.27	-18.7
145	149	-0.17	34.23	-10.13
146	150	-0.08	20.8	-4.72
147	151	-0.14	30.84	-8.48
148	152	-0.2	42.5	-12.1
149	153	-0.34	31.04	-20.5
150	154	-0.37	32.67	-22
151	155	-0.31	36.52	-18.67
152	156	-0.35	36.36	-21.17
153	157	-0.24	28.48	-14.52
154	158	-0.24	30.32	-14.22
155	159	-0.09	36.11	-5.56
156	160	0.23	44.65	13.92
157	161	-0.14	35.12	-8.13
158	162	-0.24	38.58	-14.59
159	163	-0.31	43.95	-18.71
160	164	-0.16	51.18	-9.41
161	165	-0.23	46.72	-13.67
162	166	-0.24	40.22	-14.15
163	167	-0.31	34.58	-18.56
164	168	-0.29	33.35	-17.59
165	169	-0.18	24.75	-10.83
166	170	-0.23	23.28	-13.75

Table 1: The table contains the statistics for each transect created by DSAS for the coastline.

Table of Statistics for Dune Foot Changes in Barrio Islote, Arecibo, Puerto Rico				
object identifier *	TransectId *	EPR	SCE	NSM
1	1	0.12	16.59	7.29
2	2	0.32	34.04	19.28
3	3	0.31	32.38	18.33
4	4	0.29	29.54	17.38
5	5	0.08	13.8	4.64
6	6	-0.1	17.73	-5.98
7	7	-0.14	17.79	-8.51
8	8	-0.32	28.47	-19.12
9	9	-0.17	21.08	-10.45
10	10	-0.01	12.76	-0.72
11	11	-0.1	15.18	-5.87
12	12	-0.15	20.13	-9.1
13	13	-0.23	23.56	-14.02
14	14	-0.24	23.99	-14.6
15	15	-0.23	21.73	-13.74
16	16	-0.24	25.62	-14.69
17	17	-0.18	18.21	-10.96
18	18	-0.24	18.06	-14.37
19	19	-0.21	19.93	-12.36
20	20	-0.18	18.39	-10.58
21	21	-0.06	21.42	-3.81
22	22	-0.08	18.42	-4.9
23	23	-0.13	17.84	-7.73
24	24	-0.13	18.88	-7.54
25	25	-0.15	18.04	-9.27
26	26	-0.27	18.76	-16.01
27	27	-0.39	28.39	-23.51
28	28	-0.44	34.94	-26.33
29	29	-0.2	14.19	-12.25
30	30	-0.25	15.71	-14.81
31	31	-0.2	15.26	-11.95
32	32	-0.21	15.05	-12.57
33	33	-0.19	15.08	-11.39
34	34	-0.22	16.17	-12.97
35	35	-0.26	38.56	-15.83
36	36	-0.26	37.59	-15.86
37	37	-0.29	41.12	-17.39
38	38	-0.29	38.67	-17.57
39	39	-0.27	45.48	-15.91
40	40	-0.12	14.3	-7.11

41	41	-0.19	11.61	-11.61
42	42	0	14.45	-0.18
43	43	-0.15	8.75	-8.75
44	44	-0.16	12.58	-9.55
45	45	-0.18	15.49	-11.05
46	46	-0.21	12.51	-12.51
47	47	-0.16	13.15	-9.32
48	48	-0.12	9.99	-7.24
49	49	-0.19	18.18	-11.16
50	50	-0.25	14.92	-14.92
51	51	-0.11	15.05	-6.54
52	52	-0.68	33.15	-26.51
53	53	-0.14	32.08	-5.56
54	54	-1.21	72.61	-72.61
55	55	-1.22	86.41	-73.18
56	56	-1.31	91.67	-78.53
57	57	-0.99	89.43	-59.68
58	58	-0.76	78.93	-45.78
59	59	-1.05	105.39	-62.75
60	60	-0.93	75.16	-55.87
61	61	-0.57	63.88	-34.09
62	62	-0.14	16.42	-8.49
63	63	-0.1	15.88	-5.8
64	64	-0.71	82.77	-42.86
65	65	0.19	44.19	11.66
66	66	-0.73	115.49	-43.92
67	67	0	12.54	-0.3
68	68	0.01	11.61	0.73
69	69	-0.31	23.08	-18.76
70	70	-0.5	30.97	-29.89
71	71	-0.54	32.34	-32.34
72	72	-0.3	30.29	-17.98
73	73	-0.42	33.8	-25.37
74	74	-0.3	38.3	-18.14
75	75	-0.54	36.79	-32.42
76	76	-0.54	36.13	-32.49
77	77	-0.47	32.31	-28.32
78	78	-0.36	34.61	-21.43
79	79	-0.5	39.11	-29.82
80	80	0.04	13.65	2.5
81	81	-0.05	11.48	-2.77
82	82	-0.07	11.54	-4.39
83	83	-0.16	9.81	-9.37

84	84	-0.17	11.6	-9.94
85	85	-0.14	10.52	-8.15
86	86	-0.09	10.87	-5.54
87	87	-0.11	11.64	-6.89
88	88	-0.04	11.85	-2.67
89	89	-0.06	10.04	-3.76
90	90	-0.04	9.18	-2.52
91	91	-0.01	9.78	-0.4
92	92	-0.04	13.45	-2.36
93	93	-0.01	13.65	-0.7
94	94	-0.08	10.83	-4.54
95	95	-0.03	12.63	-2
96	96	-0.02	11.05	-1.07
97	97	0.05	12.92	3.08
98	98	0.01	7.08	0.57
99	99	-0.18	38.42	-10.55
100	100	-0.25	32.39	-14.86
101	101	-0.11	13.01	-6.43
102	102	-0.13	15.96	-7.98
103	103	-0.11	18.26	-6.73
104	104	-0.11	30.11	-6.87
105	105	0.03	34.17	1.96
106	106	0.06	9.55	3.69
107	107	-0.14	20.68	-8.64
108	108	0.1	22.24	5.86
109	109	-0.11	24.88	-6.7
110	110	0.04	29.71	2.25
111	111	-0.13	30.62	-7.98
112	112	-0.09	25.7	-5.65
113	113	-0.08	20.93	-4.92
114	114	-0.1	25.02	-6.07
115	115	-0.12	32.3	-7.49
116	116	-0.24	61.65	-14.22
117	117	0.48	39.54	22.64
118	118	0.22	26.88	10.52

Table 2: The table contains all the statistics created by DSAS for each transect of the eolian deposits.