Shoreline Changes in the West Coast of Puerto Rico as Determined by Remote Sensing Techniques and their Correlation to Changes in the Diversity of Shell-Mollusks

Dimaris Colón Molina

Department of Biology, University of Puerto Rico – Mayaguez, P.R 00683 e-mail: dimaris.colon@upr.edu

Abstract –Remote sensing is a valuable tool for comparing aerial photographs of coastal systems. We assessed shoreline changes in the west coast of Puerto Rico using images of six beaches from the years 1930, 1950 and 2010. The beaches selected were El Maní (Mayagüez), Punta Arenas (Cabo Rojo), Playa Joyuda (Cabo Rojo), Combate (Cabo Rojo), Playa Sucia (Cabo Rojo) and Playa Córcega (Rincón). The main objective were to compare shoreline changes along the west coast over different years and explore the different causative factors (erosion, deposition, human impact, etc.). We used QGIS to Georeference the image and ENVI 5.2 to conduct supervised and unsupervised classification and for the calculation of erosion and deposition. Shoreline changes were correlated to diversity changes within marine mollusk communities. Playa Sucia, Punta Arenas, Joyuda (all at Cabo Rojo) and Córcega (Rincón) presented erosion. El Combate showed highest erosion in its shoreline. El Maní was the only beach that presented deposition in its shoreline and it also was the only place that lacked snails, suggesting that deposition affects negatively this particular component of the mollusk fauna.

Key words: beaches, biodiversity, deposition, erosion, remote sensing, shell-mollusk, shoreline

INTRODUCTION

The shoreline zone is an area where the sea and land join and plays a very important role in integrating a sea and its watershed in a whole system (Cepeda et al., 2003). Among the main environmental problems of the coastal zones, two critical ones are coastal erosion and a biodiversity loss. The problem of coastal erosion is recognized worldwide (Laborde, 2010). Most marine sediments are derived from terrestrial erosion and transport to the sea, and the disintegration of marine organisms within the environment of deposition (Morelock et al., 1997). The erosion is mainly the loss or displacement of sand beaches as a result of the effects of wind, waves and currents. It also responds to both natural (climate change and increase of sea level) and anthropogenic factors. In general, waves and currents have more marked effects in the transport of sediments and these effects are exacerbated as beach sand does not always returns to the shore. In consequence, there is a loss in habitat and a change in the content of organic matter and other source of food for many species. Remote sensing techniques to study shoreline changes may prove useful, especially in the comparison of images from different years in order to detect shoreline changes. Applied correctly, it may aid in protecting such areas when it comes to decision making (Cepeda et al., 2003). The main purpose of this study was to compare shoreline changes of the west coast over different years and explore the different causative factors (human impact and natural phenomena) and distinguish the biodiversity of shell mollusks. The hypothesis is that there are correlations in shoreline changes (erosion and deposition) with the biodiversity of shell-mollusks. Many snails scrape their food over hard surfaces, while bivalves are mostly filter-feeders. We predict that snails will be negatively affected by deposition along the shorelines, while bivalves should benefit from high rates of sediment re-suspension, especially under deposition scenarios.

MATERIALS AND METHODS

A. Study Area

In this study, six beaches of the west coast of Puerto Rico were selected. Their coordinates, for the beginning and ending of each beach and their sand composition are shown in Table 1. I used images of aerial photography from the selected beaches from 1930 and 1950 provided by the 1930 Porto Rico Aerial Image Database and EarthExplorer® Website. Dr. Fernando Gilbes from Department of Geology at University of Puerto Rio, Mayagüez, provided images of aerial photography from the selected beaches from 2010. Images from 1930 to 1950 (Appendix A) are in black and white. The other six images from 2010 (Appendix B) are in true color. The beaches were: El Maní (Mayagüez), Punta Arenas (Cabo Rojo), Playa Joyuda, Combate, Playa Sucia (all at Cabo Rojo) and Córcega (Rincón).

Table 1. Coordinates (Latitude and Longitude) and Sand Composition of the selected beaches. Larger Table can be found in Appendix E.

Beach	Coordinates of beginning of the beach		Coordinates of ending of the beach		Sand Composition
	Latitude	Longitude	Latitude	Longitude	
El Maní, Mayagüez	18° 14' 42"N	-067° 10' 29"W	18° 13' 50"N	-067° 10' 23" W	volcanic debris, serpentine, quartz and coral detritus
Playa Sucia, Cabo Rojo	17° 56' 06"N	-067° 11' 26"W	17° 56' 06"N	-067° 11' 13" W	calcareous sand and is composed of fragments of coral and shells
El Combate, Cabo Rojo	17° 58' 12"N	-067° 12' 44"W	17° 58' 31"N	-067° 12' 45" W	calcareous sand and is composed of fragments of coral and shells
Joyuda, Cabo Rojo	18° 08' 05"N	-067° 11' 11"W	18° 08' 11"N	-067° 11' 09" W	calcareous sand and is composed of fragments of coral and shells
Córcega, Rincón	18° 19' 32"N	-067° 14' 59"W	18° 19' 06"N	-067° 14' 45" W	limestone debris, quartz and fragments volcanic.
Punta Arenas, Cabo Rojo	18° 08' 12"N	-067° 11' 10"W	18° 08' 12"N	-067° 11' 09" W	calcareous sand and is composed of fragments of coral and shells

B. Image Processing

Images of Aerial Photography were found in the websites 1930 Porto Rico Aerial Image Database and EarthExplorer® for images 1930 and 1950. Images from 2010 were provided by Dr. Fernando Gilbes. The program used to process the images was ENVI (Environment for Visualizing Images) version 5.2 and QGIS. The images of the years 1930 and 1950 had to be georeferenced with images of 2010 (already georeferenced). QGIS is an Open Source Geographic Information System. QGIS aims to be a user-friendly GIS, providing common functions and features. The initial goal of the project was to provide a GIS data viewer. The first step of the method involved reading the coordinates from your scanned map and inputting it manually. In the Georeferencer window, I went to File ‣ Open raster Navigate to the downloaded image file and clicked Open. In the Coordinate Reference System Selector, I chose WGS 84 EPSG4326 (longitude and latitude) that is an useful tool for georeference. Then, clicked on the Add Point button on the toolbar and selected an easily identifiable location on the image. Corners, intersections, poles, etc., made good control points. Similarly, I chose at least 4 points on the image and add their coordinates from the reference layer in order to continue to georeferenced the images. Once the process was done, chose toolbox Transformation type Helmet and resampling method cubic spline. Back in the Georeferencer window; I went to File ‣ Start georeferencing. This started the process of warping the image using the GCPs and creating the target raster in order to have the image georeferenced in TIFF type. In addition, ENVI 5.2, was used to trace lines in the zone coast of the selected beaches; the toolbox supervised classification and unsupervised classification were helpful ways to determined shoreline changes. In the supervised classification, I included ROI files choosing different types of 5 classes (road, vegetation, ocean, city and shoreline) for the line of coast zone in the beaches. Next, select the toolbox Minimum Distance Classification to complete the process of the different types of classes (Figure1)

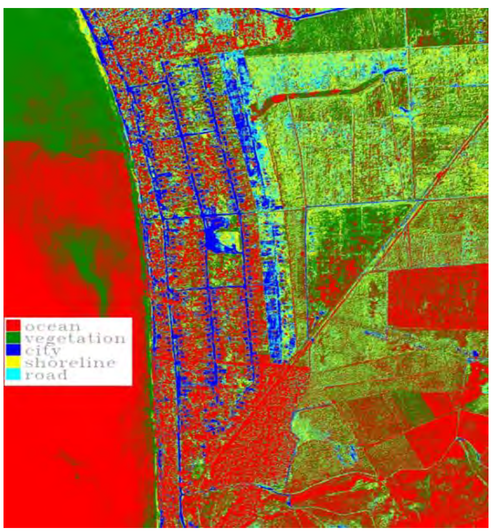

Figure1. Image of Supervised Classification (Minium Distance Classification) 1950 El Maní, Mayagüez

In the unsupervised classification, I used the toolbox of Isodata with 3 iterations and Kmeans with 3 iterations to complete the process. Then, chose ten classes and the program automatically did it (Figures 2 and 3).

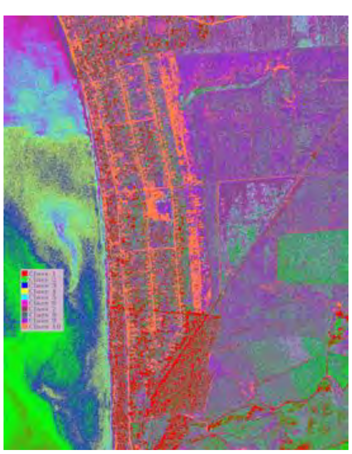

Figure 2. Image of Unsupervised Classification (Kmeans Classification) 1950 Playa El Maní, Mayagüez

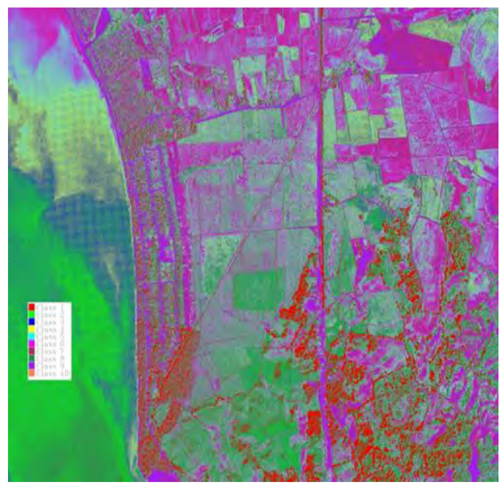

Figure 3. Image of Unsupervised Classification (Isodata) 1950 El Maní, Mayagüez

Later on, I calculated erosion in in all images from 1930 and 2010. By using ENVI 5.2 program, I opened the images from different years and selected resize data, to crop them to the same size. The shoreline was outlined on both aerial photographs and then put one on top of the other to quantify changes due to erosion or accretion (Cepeda et al., 2003). Then, selected the toolbox ROI File and chose the icon Polygon to trace the area. Polygons were used to calculate the area, which represents the change in shoreline. The area was reported square meters (m^2). I calculated erosion by subtracting the two areas of the beaches from different years (2010 with 1930 and 1950) in order to compare shoreline changes among them (Figure 4). Later on, used the toolbox ROI File, selected icon lines and traced shoreline transect zone to compare shoreline changes from the years 1930, 1950 and 2010.

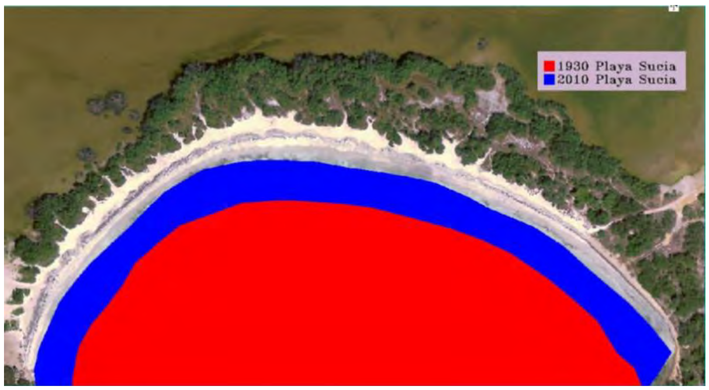

Figure 4. ROI File to calculate erosion at Playa Sucia. Shoreline changes in the years 1930 (red polygon) and 2010 (blue polygon). The other images of the beaches are in Appendix C.

C. Changes in shell mollusk biodiversity

The data from Dr. Carlos Aguayo's Shell Collection (UPR-RUM, Department of Biology) was used to assess changes of biodiversity of beach-dwelling shell-mollusks over the last 30-60 years. The Aguayo's Collection has specimens from the above-mentioned beaches collected since 1950's. A sampling campaign was done in the beaches El Maní (Mayagüez) Punta Arenas (Cabo Rojo) and Joyuda (Cabo Rojo) to assess the actual diversity of species and used the Collection's log-book as a proxy of the species composition of the beach-dwelling mollusk community at a particular time and place. I visited El Maní, Mayagüez in November 4th 2015 and the beaches Joyuda, Cabo Rojo and Punta Arenas, Mayagüez in November 18th 2015. Two helpers contributed to the sampling effort. In order to accomplish the sampling campaign we searched for the shell-mollusk habitats. These habitats of the shell-mollusk were: under rocks, sand, attached to other shells, intertidal zone (seashore), rocky shores and low tidal wave. In the future, I will make a capture effort analysis by number of observers and distance walked along the shores, and will determine the number of species within range, and collect a representative specimen of each species.

RESULTS

A. Image process

The program QGIS did an excellent job in georeferencing all the images. In ENVI, the toolbox of supervised classification (minimum distance) and unsupervised classification (Kmeans and Isodata) showed several errors in the images. The images that are black and white (panchromatic band) cannot show a precise shoreline in the beaches. Some errors in the shorelines changes in supervised classification toolbox occured; when I tried to determine the line of transect of shoreline, it was difficult to identify it with precision. Kmeans and Isodata unsupervised classification presented the shoreline in the same color (orange or purple) as the roads because in past years these were covered with soil or sand and were not paved. Nevertheless, unsupervised classification helped me to determine where the shoreline of the selected beaches began and ended. By using ROI File, we could observe the expected results by calculating erosion or deposition in shoreline changes in the six beaches of the study area. El Maní was the only that shows deposition in its shoreline (Table 2). Also, using ROI File helped to trace two lines from the shoreline transect zone to distinguish shoreline changes from the years 1930, 1950 and 2010 (Figures 5-9).

Table 2. Calculate Erosion and Deposition in the six beaches

Beach	2010 Area m^2	1950 Area m^2	1930 Area m^2	Difference m^2	Water more/less	Erosion or Deposition
Playa Sucia, Cabo Rojo	36,150.21 m^2		26,711.28 m^2	9438.93m^2	More water	Erosion
Playa Joyuda, Cabo Rojo	43,043.22m^2		34,440.70 m^2	8602.52m^2	More water	Erosion
Punta Arenas, Cabo Rojo	43,043.22 m^2		34,440.70m^2	8602.52m^2	More water	Erosion
Córcega, Rincón	625,120.47m^2	617,278.68 m^2		7841.79m^2	More water	Erosion
El Combate, Cabo Rojo	295,417.08m^2		280,731.18 m^2	14685.9m^2	More water	Erosion
El Mani, Mayagüez	3409974.18m^2	3481287.93m^2		-71313.75m^2	Less water	Deposition

Positive value shows erosion and negative values shows deposition. Most of the beaches shows erosion and more water in its shoreline. In addition, El Maní was the only that shows deposition and less water in its shoreline. Ecuation is A1-A2= Total area where A1(image 2010) and A2 (1930 or 1950 image). Larger Table can be found in Appendix E

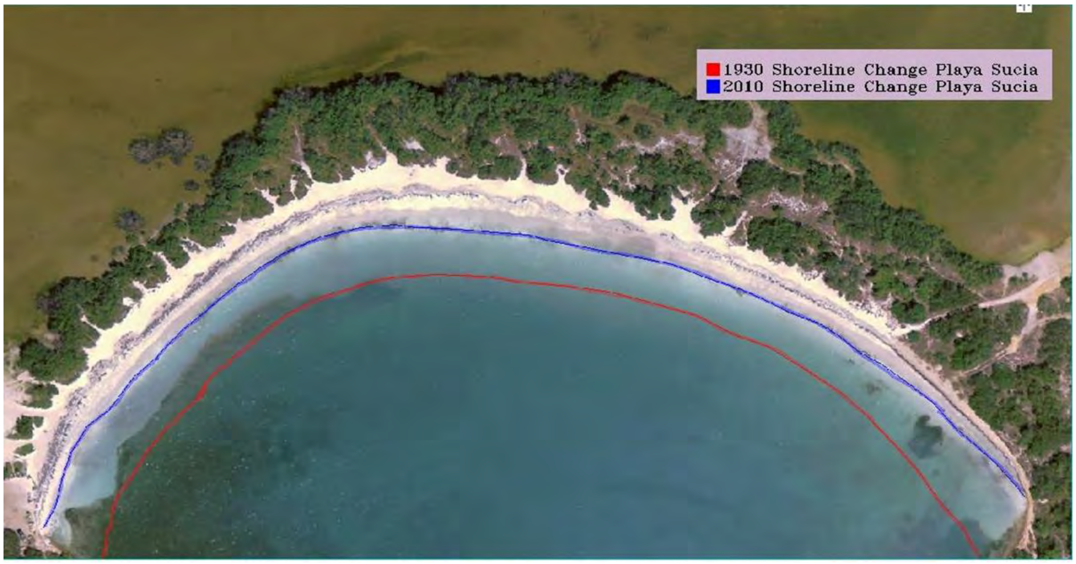

Figure 5. Shoreline zone transect line changes. Red line shows 1930 shoreline change in Playa Sucia. Blue line shows 2010 shoreline change in Playa Sucia. In conclusion, this beach had erosion.

Figure 6. Shoreline zone transect line changes. Red line shows 1930 shoreline change in El Combate. Blue line 2010 shows shoreline change in El Combate. In conclusion, this beach had erosion.

Figure 7. Shoreline zone transect line changes. Red line shows 1930 shoreline change in Punta Arenas and Joyuda .Blue line shows 2010 shoreline change in Punta Arenas and Joyuda. In conclusion, this beach showed erosion.

Figure 8. Shoreline zone transect line changes. Orange line shows 1950 shoreline change in Córcega. Blue line shows 2010 shoreline change in El Córcega. This beach showed erosion.

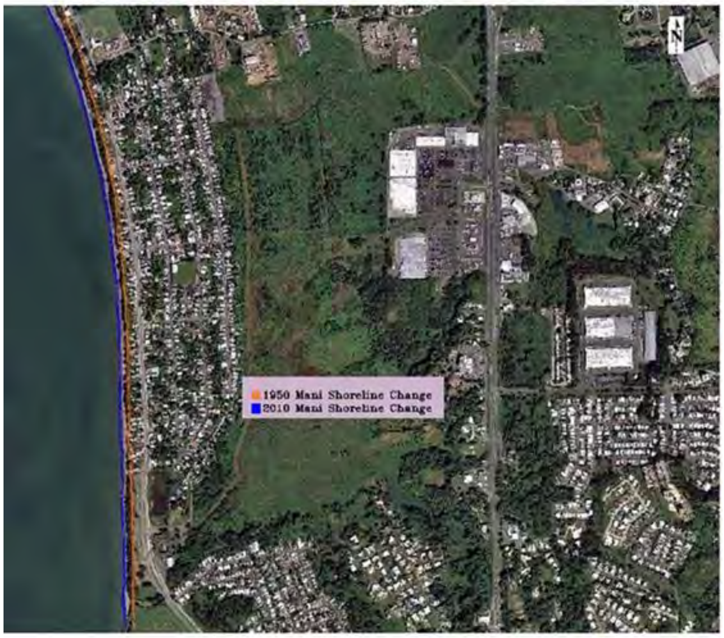

Figure 9.Shoreline zone transect line changes. Orange line shows 1950 shoreline change in Maní .Blue line shows 2010 shoreline change in Maní. In conclusion, this beach shows deposition effect.

B. Biodiversity change of shell mollusk

Among the beaches that we visited, El Maní at Mayagüez presented deposition of sand, presence of clams and absence of snail. The deposition of sand in the beach, with terrigenous material, may have caused the absence of snail mollusks. Punta Arenas and Joyuda, which presented all sort of shell mollusks (snails and clams), also showed erosion in their shorelines.

DISCUSSION

The rate of erosion or deposition of the coastline can be estimated by measuring the change of shoreline position in time from aerial photographs. In conclusion, there were changes in shoreline in selected beaches among years 1930, 1950 and 2010. Possible causative factors are human impacts, erosion, deposition and natural phenomena. Human activities may have caused shoreline changes on most of the beaches included in this study. Activities such as coastal modification related to sand extraction and construction of buildings occurred along the coasts. Natural phenomena such as hurricanes and tropical storms might have affected shorelines in the selected beaches through the years. Playa Sucia, Punta Arenas, Joyuda (all at Cabo Rojo) and Córcega (Rincón) showed erosion in their shoreline. El Comabte showed highest erosion in its shoreline.El Maní was the only beach that showed deposition in its shoreline (Appendix D). Also, it lacked snail mollusks.

This last result could be because the beach is surrounded by ponds and mangroves that presented terrigenous materials. In addition, the sand composition of El Maní consists of volcanic debris, serpentine, quartz and coral detritus. Both Punta Arenas and Joyuda (Cabo Rojo) beaches showed snail mollusks and clams. Their sand compositions are calcareous sand with fragments of coral and shells. I recommend future studies in biodiversity of shell mollusks, especially species richness (S-value) and biotic indexes, in the selected beaches.

ENVI can help calculate shoreline erosion and its effects on beaches using statistics and classification toolbox**.**

ACKNOWLEDGEMENTS

Special thanks to Dr. Carlos Santos for his patience and knowledge and for the sampling campaign in the three beaches selected for the biodiversity changes in marine mollusk; Dr. Carlos Aguayo (deceased) provided his data of collection of marine shell-mollusks, and to Dr. Fernando Gilbes for his advice and for providing the 2010 images of aerial photography.

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Appendix A

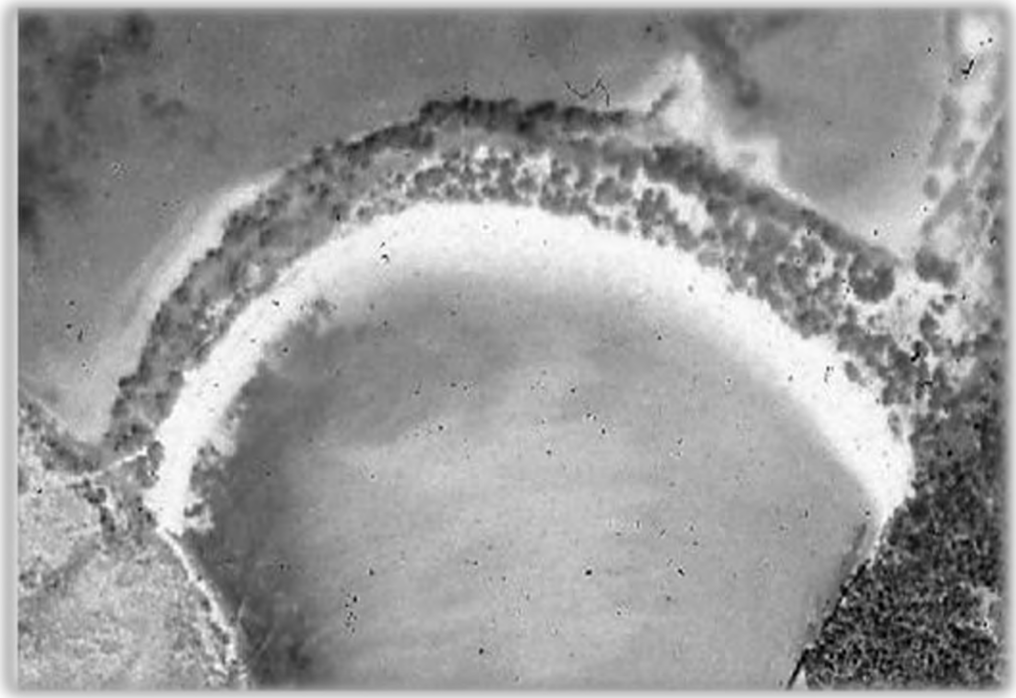

Figure 1. Aerial Image 1930 Playa Sucia, Cabo Rojo

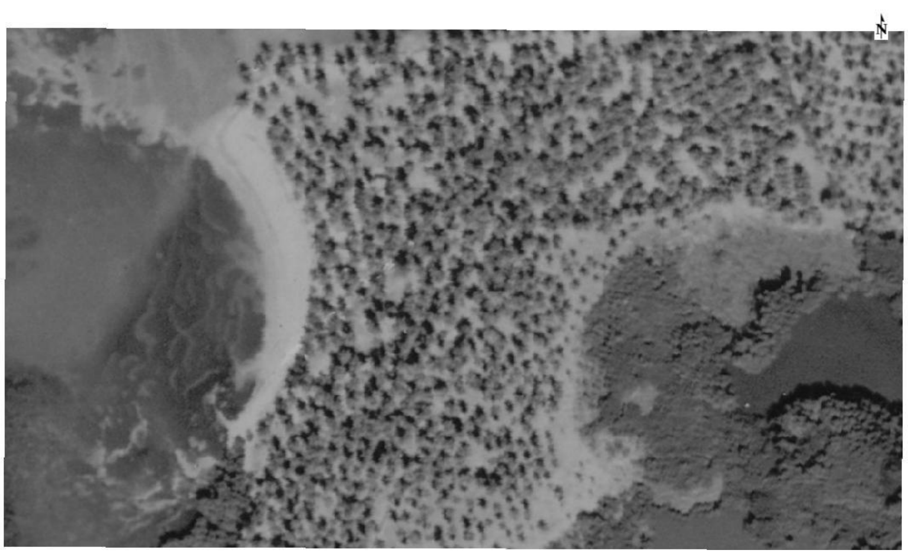

Figure 2. Aerial Image 1930 Playa Joyuda, Cabo Rojo and Punta Arenas, Mayagüez

Figure 3. Aerial Image 1930 Playa El Combate, Cabo Rojo

Figure 4. Aerial Image 1950 Playa Córcega, Rincón

Figure 5. Aerial Image 1950 Playa El Maní, Mayagüez

Appendix B

Figure 6. Aerial Image 2010 Playa El Maní, Mayagüez

Figure 7. Aerial Image 2010 Playa El Combate, Cabo Rojo

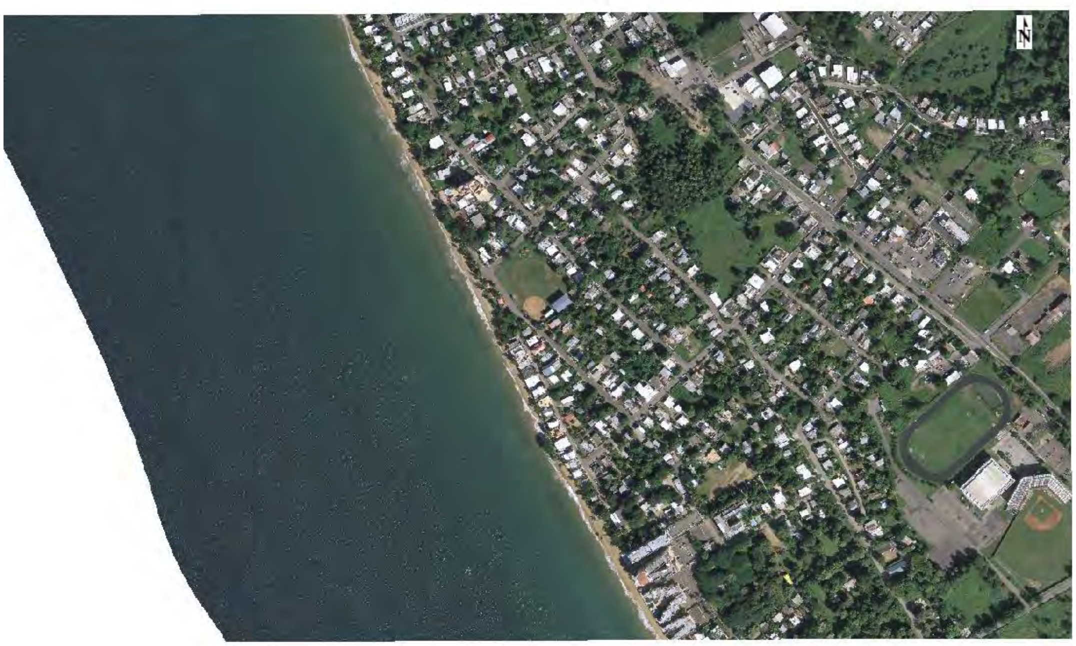

Figure 8. Aerial Image 2010 Playa Córcega, Rincón

Figure 9. Aerial Image 2010 Playa Sucia, Cabo Rojo

Figure 10. Aerial Image 2010 Playa Punta Arenas, Mayagüez and Playa Joyuda, Cabo Rojo

Appendix C

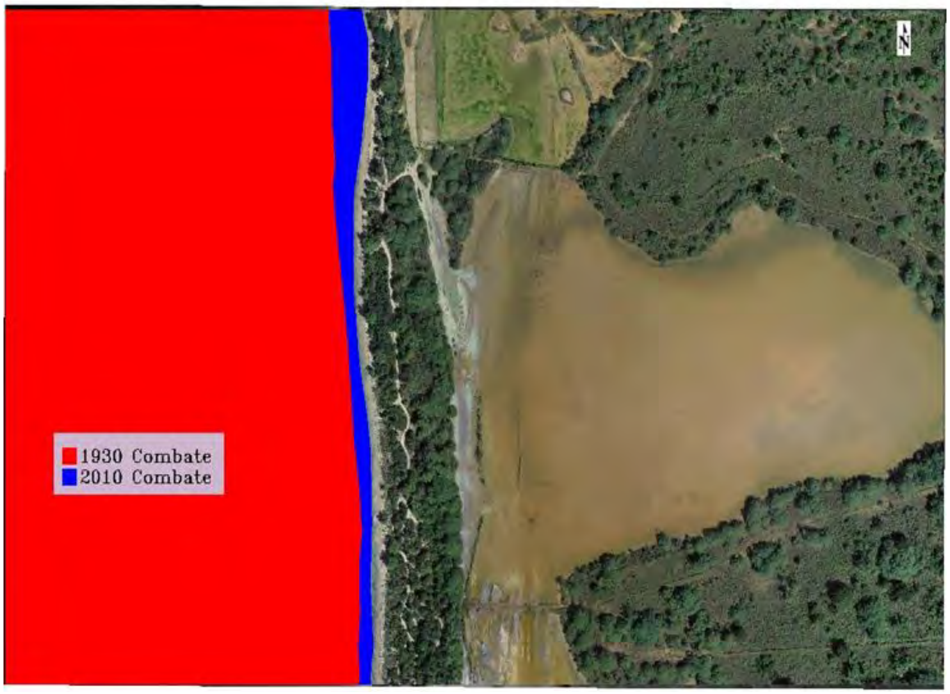

Figure 1. ROI File to calculate erosion in Combate, Cabo Rojo. Shoreline changes in 1930 (red polygon) and 2010 (blue polygon).

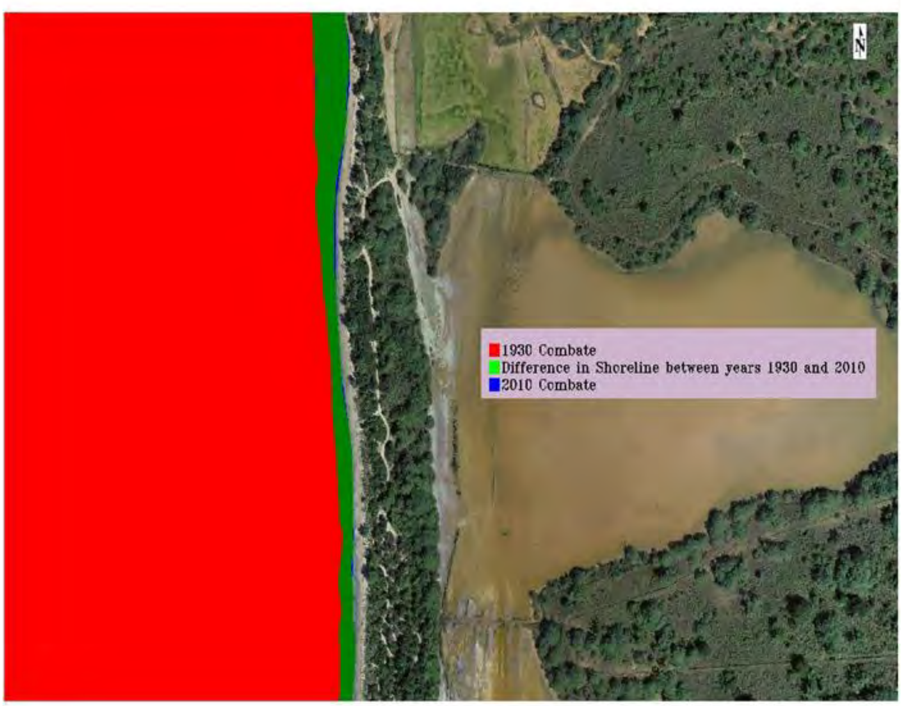

Figure 2. ROI File to calculate erosion in Combate, Cabo Rojo. Shoreline changes in 1930 (red polygon) and 2010 (blue polygon). Also, differences in shoreline changes showed El Combate between 1930 and 2010 (green polygon).

Figure 3. ROI File to calculate erosion in Punta Arenas and Joyuda, Cabo Rojo. Shoreline changes from 1930 (red polygon) and 2010 (blue polygon) in Punta Arenas and Joyuda.

Figure 4. ROI File to calculate erosion in Maní .Shoreline change in 1950 (orange polygon) and 2010 (blue polygon)

Figure 5. ROI File to calculate erosion in Córcega .Shoreline change in 1950 (orange polygon) and 2010 (blue polygon)

Appendix D

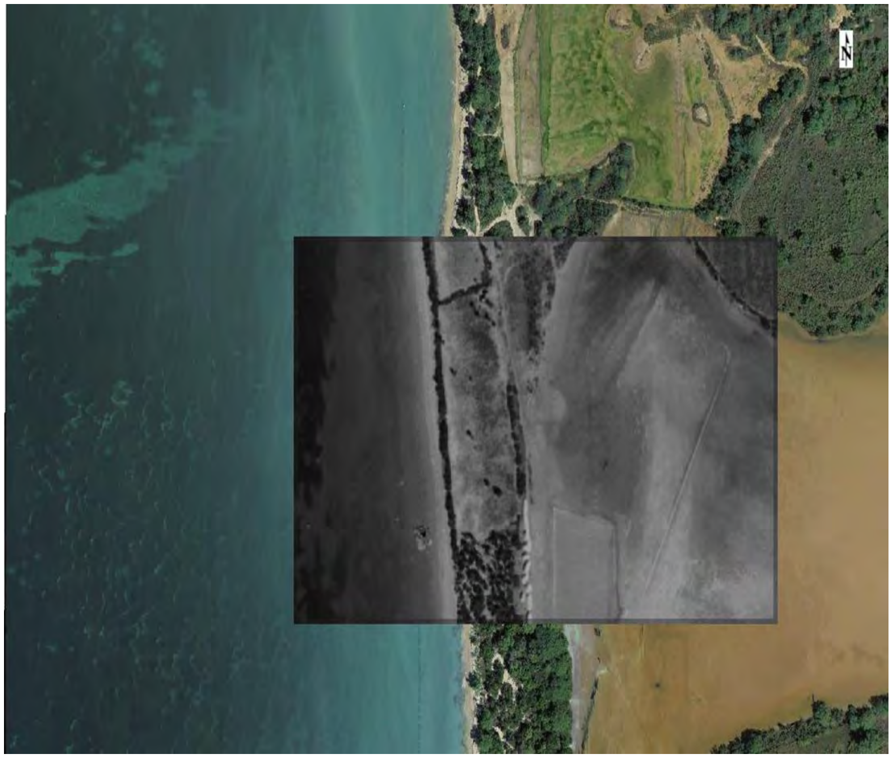

Figure 1. Shoreline Changes between the years 1930 with 2010 in El Combate, Cabo Rojo

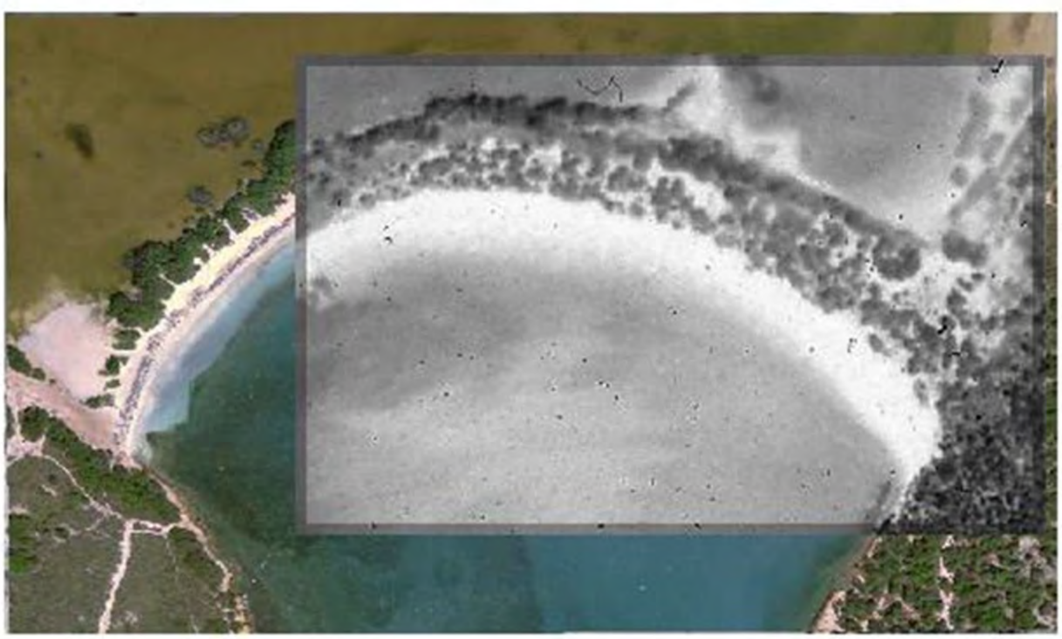

Figure 2. Shoreline Changes between the years 1930 with 2010 in Playa Sucia, Cabo Rojo

Figure 3. Shoreline Changes between the years 1930 with 2010 in Joyuda, Cabo Rojo

Figure 4. Shoreline Changes between the years 1930 with 2010 in Punta Arenas, Cabo Rojo

Figure 5. Shoreline Changes between the years 1950 with 2010 in Córcega, Rincón

Figure 6. Shoreline Changes between the years 1950 with 2010 in El Maní, Mayagüez

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