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Mapping of Coastal Changes Applying Maps, Satellite Images and GIS in Samborombón Bay, Argentina.

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Abstract

The study area is the Samborombón Bay in the Atlantic Ocean in Buenos Aires Province, Argentina. Its coastline experiences important stressors by natural and/or anthropogenic influences. The main goal of this study was to develop a methodology to estimate and identify the changes in the coastal line in Samborombón Bay by mean of the integration of historic topographic maps (years 1936-41/68/71), satellite charts (years: 1994-96) and multitemporal satellite images of Spot (year 1998), Landsat 5 TM (year 2004) and SAC-C (year 2005), the first Argentinean satellite for land observation.

An extensive progradation process was registered in the centre and in the south (Punta Rasa) of the bay. New island formation was also observed in the centre of the bay. On the contrary, slight erosion of the coast line was observed in the north of the bay (Punta Piedras).

The applied methods and the obtained results were very useful to detect the coastal changes and to update the cartographic information in this wetland.

Keywords: Coastal changes, Wetland, Ramsar site, Samborombón Bay, Topographic maps, Remote sensing, GIS.

Mathematics Subject Classification: 00-02.

JEL classification: Q30

1 Introduction

Coastline movement due to erosion and deposition is a major concern for coastal zone management (Barragán *et al.*, 2003). This is the most dynamic part of wetland since its shape is affected by different factors, such as hydrology, geology, altimetry, climate and vegetation. All these factors contribute to change the coastline shape in a dynamic equilibrium. In addition, anthropogenic activities have a crucial role in modifying such equilibrium (Guariglia *et al.*, 2006; Conzonno *et al*, 2001).

In some littoral sites the processes of erosion and progradation for natural or human causes modify permanently the shoreline and yield a sedimentary imbalance (Marcomini & López, 1997; Marcomini 2006).

Since the coastline is the line of contact between water, atmosphere and land, as the sea level varies, it is difficult to exactly identify its position. Variations in coastline position can be long-term (sand storing processes or due to relative sea level rising), cyclical (coastal width and shape changes related to the seasonality or tidal conditions) or random (variations mainly with local character - wave conditions, storms or floods-). One of the major requirements for planning coastal protection work is to understand all these changes including the main governing processes of erosion, deposition, sediment transport and flooding (Nayak, 2000).

In the study area, Samborombón Bay, the geomorphology and sedimentology were studied by Bértola (1994) and Bértola & Morosi (1997).

Bértola (1994) suggested that, in the centre of the bay, there was a progradation of 1 m/year while the area between the north of Salado River and Punta Piedras was considered a transition zone. In the north of the bay (Punta Piedras), he observed an erosion of 0.8 m/year. He confirmed his results, obtained by field works, by the observation of SPOT HRV images and early topographic maps. In the NNE sector of Punta Rasa (south of the bay) Bértola (1994) and Bértola & Morosi (1997) observed a progradation of 10 m/year. Dalmau (1996) confirmed the observations of Bértola (1994) comparing nautical charts and aerial photographs. Bértola *et al.* (1993) studied the area of San Antonio Cape (Punta Rasa) near the lighthouse (Faro San Antonio) comparing aerial photographs and data of field works. They inferred an erosion of 2 m/year.

Traditional methods for mapping coastline change are based on conventional field surveys or on the interpretation of aerial photographs. Those methods imply a high cost for updating coastlines (Guariglia *et al*., 2006). So, the integration of historic topographic maps, satellite charts and multitemporal satellite images can provide a suitable tool for updating coastal maps over large areas at relatively low costs (Cracknell, 1999; Yang *et al*., 2006). Remote sensing data, because of their repetitive, multispectral and synoptic nature, seems to be extremely useful in providing information on various components of the coastal environment.

Remote sensing techniques were applied in Samborombón Bay coastal area in several works: Rosenthal & Ulibarrena (1966) have applied aerial photographs to describe the geology of this zone, Milovich *et al.* (1992), using Landsat MSS, SPOT-HRV data and field observation, studied the structure of the salt marsh. Lasta *et al.* (1996) used NOAA-AVHRR and hydrological data to observe seasonal variations in surface water temperature, while Dogliotti *et al.* (2002) used satellite data to determine the main environmental characteristics of the bay.

This is the first attempt of mapping coastal changes in the whole bay using multitemporal satellite images and charts and early topographic maps.

Remote sensing techniques and historic topographic maps have been used to detect coastline changes in several places around the world; for example: in Sunderban delta, India (Rao *et al*., 1999); Nilo river, Egypt (Frihy *et al*., 1998), Guapo river delta, Venezuela (Calzadilla Pérez *et al*., 2002); Grado island, Italy (Favretto *et al*., 2003), Peninsula of Istambul, Turkey (Bayram *et al*., 2004), Saunders Coast area, Antarctica (Swithinbank *et al*., 2003), Ionian area in Basilicata Region, Italy (Guariglia *et al*., 2006), Haeundae Beach, South Korea (Yang *et al*., 2006), among others. In Argentina, Apostolu & Peluso (2006) updated the coast line of Anegada Bay in Buenos Aires province.

The main goal of this study was to develop a methodology to identify and quantity the recent changes in the coastal line of Samborombón Bay, based on a multisource and multitemporal approach, by means of the integration of historic topographic maps, satellite charts and multitemporal satellite images.

1.2 Study Area

The study area is the Samborombón Bay, in the Atlantic Ocean, at the outlet of the Río de la Plata (west coast) in Buenos Aires Province, Argentina. The bay is 140 km long and stretches from Punta Piedras (35°27′S - 56°45′W) to Punta Rasa (36°22′S - 56°35′W) (Figures 1 and 2). This last place is the southern extreme of the Río de la Plata Estuary. The bay receives the Salado and Samborombón rivers, as well as other minor streams and artificial channels.

The bay is one of the most extensive, rich and important wetlands of Argentina and was declared Ramsar Site in 1997 (according to Ramsar Convention on Wetlands held in Iran in 1971). They are ecosystems which play varied and important roles in the landscape; depending on their type and location, they can moderate and influence the timing of flows in streams and rivers and they play important roles in helping to maintain streams flow and groundwater supplies. They are sensitive to several vast environmental conditions, sediment load and vegetation (IUCN, 1990; Bértola *et al.* 1993, Bértola 1994, Villar *et al.,* 1999). This Ramsar site comprises two natural reserves, some land belonging to the Argentine Army and some privately owned land. It covers a total of 243.965 hectares of which 147.245 hectares are land and the rest correspond to the open water to 3 meters average depth. It has very extensive intertidal mudflats locally called ("cangrejales") and creeks, tidal salt marshes, sand dunes and permanent and seasonally flooded freshwater lagoons and marshes, slow-flowing streams and grassland. Its vegetation is mainly herbaceous, with a rich variety of communities as a result of the diverse types of soil and water. It is a very sensitive site, where many migratory birds stop-over on their annual migration between southern wintering and northern breeding grounds (Perillo *et al.*, 2005).

2 Materials and methods

The variations in the line contact between land and water, associated with the effects of tides, differences in daily mean sea level and long term changes in sea level, are minimal. These factors are not thought to constitute a significant source of error.

In this study, the sea level elevation in Buenos Aires was estimated by Lanfredi *et al.* (1988) to be 1.6 mm/year. The astronomical tides registered at the Río de la Plata Estuary, ranged 0.3-1 meters (Guarga *et al.,* 1991). The basin downfall was estimated by Introcaso & Gerster (1985) in 0.04 mm/year. Regarding tidal variations, it is clear that satellite images are affected by depending on their spatial resolution. The images used to extract coastline have spatial resolution between 10-175 meters. Guariglia *et al*. (2006) recommended that tidal effects only must be considered when the coastline is identified from images having higher spatial resolution than the errors induced by tide.

Table 1 shows all the topographic and satellite charts (period, chart type, name, code, date and scale), Table 2 shows all the satellite images (period, sensor, date and path/row) and Table 3 shows the technical specifications of each satellite used in the study.

The data in analog format (historic topographic maps - years: 1936/37/38/39/41/68/71- and satellite charts -years: 1994/95/96-) were digitized as the multitemporal satellite images: (SPOT 1 PAN (year 1998), Landsat 5 TM (year 2004) and SAC-C (year 2005).

Only images with less than 10% cloud cover were used for the analysis. All material (maps and images) were registered to Transverse Mercator Gauss Kruger Zone 6 (cartographic projection), Campo Inchauspe 1969 (datum) and International 1909 (ellipsoid). The registration process used approximately 20-25 selected ground control points. The root mean square error (RMSE) for positional accuracy was less than 0.75 pixels for all images. A nearest-neighbor resampling method was conducted using ERDAS 8.7 Imagine software. The study area (coastal sector only) was clipped from the original maps and images. Then, the topographic maps and satellite charts were mosaicked. These sources were integrated and analyzed in a Geographical Information System (GIS) using Arc View 3.3 software, where the coastal line was digitized for the three sets of data: 1936-71, 1994-96 and 1998-2005. The changes were estimated by measuring the distances between lines.

Also a preliminary analysis of Seawifs images was carried out to evaluate the source of sediments responsible of the progradation in the central and south sectors of the Samborombón Bay. A specific algorithm (K-490), with SEADAS software, was applied to visualize the suspended sediments in the study area. This algorithm is defined as the "diffuse attenuation coefficient at 490 nanometers" (corresponding to Seawifs band 3). This algorithm provides a way to determine how rapidly light is "attenuated" by material in the water column (Mueller; 2000). Higher values of K-490 indicate higher suspended matter concentrations. It is important to highlight that the detected materials can be either inorganic sediments or living or dead organic matter.

3 Results and discussion

Figure 3 shows the overlay of the topographic chart (a) and satellite charts (b) on the Landsat 5 TM image (2004). The sector of the bay where the change in shoreline is most conspicuous is showed in the Figure 4a (centre of the bay). Shoreline in 1968 is represented in blue, and in red the corresponding of 1994, all overlaid on the Landsat 5 TM image. It is possible to observe the shoreline progradation and the formation of new islands along the last 37 years (Figure 4b).

Progradation along the central coast of the bay (difference between present shoreline and that of 1968) ranged between a minimum value of 456 meters, and a maximum of 761 meters, attaining a mean value of 597 meters. Progradation presently occurs along 89 km, of the shoreline representing roughly 64% of the whole Samborombón Bay coastline. The appearance of several newly formed islands displayed parallel to the shoreline is also evident. These islands are thin, (290-800 meters) and elongated (730- 2850 meters) representing 3.5 km^2 of newly emerged wetland surface.

In the northern extreme of the bay no significant changes were detected, only a few small sectors were affected by erosion processes.

Figure 5 shows the changes in the south extreme of the bay (Punta Rasa). The blue line represents the shoreline in 1938-1941 and the red one the shoreline of the year 1994, overlaid on the Landsat 5 TM image, 2004.

At Punta Rasa the shoreline changes between the two temporal series (present and 1938-41) was also measured. Progradation ranged between a minimum of 253 meters and a maximum of 640 attaining a mean value of 456 meters. Small erosion processes were observed in restricted areas at the north of the lighthouse (Faro San Antonio) (Figure 5a).

Punta Rasa shows an on going sand bar formation that increased its length throughout the studied period. This site represents the southern extreme of the Río de la Plata Estuary and is at the confluence of two coastal currents. The most important one runs from south to north and borders the continental shoreline of the Atlantic Ocean and the other one, originated from the Río de la Plata, borders the Samborombón Bay in the opposite direction. This confluence reduces the currents capacity and enhances sedimentation enlarging Punta Rasa progradation. The eastern side of the bar is sandy, looks white in Figure 5 and is mainly formed by sand contributed by the marine coastal current. The western side is muddy, extensive mudflats emerge from the water at low tide as observed in brown in Figure 5. This sediment material is mainly contributed by the Río de la Plata suspended matter as seen in Figure 6; where the result of K-490 application to Seawifs images can be observed. In yellow tones appear the sediments transported by Río de la Plata flowing into the Argentine Sea (blue tones).

Our results are consistent with previous observations reported by Bértola (1994) based mainly on field work. He observed the erosion processes in the north sector of the bay (Punta Piedras) and the progradation in the middle and in the south (Punta Rasa) of the bay (also observed by Dalmau, 1996). In this place the exception is a small area in the north of the lighthouse where an erosion process is predominant confirming the field observations made by Bértola *et al.* (1993).

Conzonno *et al.* (2001) concluded that most of the Salado River discharge water goes into artificial Channel 15 and reaches the Samborombón Bay. This situation leads to the decrease in Salado river discharge between the beginning of Channel 15 and the river's mouth at Samborombón Bay and leads to the increase in Channel 15 discharge at the bay. This situation might have contributed to the formation of new islands observed at the south of the Channel 15 mouth.

Bértola (1994) recognizes four sediments sources responsible of the land increase in the bay (centre and south): 1) sediments transported from the north by Río de la Plata, as we can observed in the Seawifs images, 2) from the south, littoral current transports the sand presents in Punta Rasa, the Seawifs images corroborate this issue (this source is consistent with Dalmau, 1996), 3) “pampeanos” sediments come from rivers and channels in flooding periods and (4) by eolic actions.

4 Conclusions

Our results are consistent with Bértola (1994), Bértola *et al.* (1993) and Dalmau (1996) and show an ongoing progradation process along the Samborombón coastal marshes.

We conclude that the remote sensing tools and the methodology applied in our study were adequate to evaluate recent shoreline changes and to update the cartographic information in the Samborombón Bay coastal marshes, an important region from environmental point of view.

It seems important to mention that although the region is very dynamic, the available topographic maps have more than 60 years old in the south and more than 30 years old in the centre of the bay, being completely outdated.

The Samborombón Bay coastal marshes have been prograding in the last 4 decades in spite of the estimated sea level rise. The recent development of these environments was sustained by the large sediment load contributed by the Río de la Plata and, to a lesser extent, by the coastal marine current and the Salado and Samborombón rivers. The situation could probably be maintained for a long time if the sedimentary loads remain at its present levels. The Río de la Plata affluents must not be dammed because it will cause a decrease in the sediment load.

Finally, the use of Seawifs data must be further improved because the information of this type of data is very important to know the distribution of sediments and currents actions along the coast. Nevertheless, our first approach, confirming the results of Dalmau (1996) is very positive.

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Table 1. Topographic and satellite charts used in the study.

Period	Chart Type	Name	Code	Date	Scale
1936-1971	Topographic	Desembocadura Canal Nº 1	3557-3-4 Y 3-2	1937/36/65	1: 50.000
		General Lavalle	3557-10 Y 4	1938/39/41	1: 100.000
		General Lavalle	3557-10-1 y 4-3	1938/39/41	1: 50.000
		Cerro de la Gloria	3557-33	1968	1: 100.000
		Estancia Santa Lucía	3557-3	1968	1: 100.000
		Estancia Juan Gerónimo	3557-27-4	1971	1: 50.000
		Punta Piedras	3557-27-2	1971	1: 50.000
		Pipinas	3557-27-3	1971	1: 50.000
1994-1996	Satellite	Santa Teresita	3557-10 y 4	28/01/1994	1: 100.000
		Estancia Santa Lucía	3557-3	20/02/1994	1: 100.000
		Cerro de la Gloria	3557-33	20/02/1994	1: 100.000
		Estancia Juan Gerónimo	3557-27-4	20/02/1994 30/03/1991	1: 50.000
		Estancia Rincón de Noario	3557-27-2	20/02/1994 30/03/1991	1: 50.000
		Pipinas	3557-27-3	20/02/1994 30/03/1991	1: 50.000

Table 2. Satellite images used in the study.

Period	Sensor	Date	Path/Row
1998-2005	Landsat 5 TM	03/March/2004	224/85
	SPOT	03/May/1998	702/423
	SAC-C	26/Feb/2005	224
	Seawifs	2004-2005 (8 images)	224

Table 3. Technical specifications of the satellites used in this study.

SATELLITE	SENSOR	RESOLUTION				SCENE		SOURCE
		TEMPO-RAL	SPATIAL	SPECTRAL (μm)	RADIO-METRIC (bits)	WIDTH	LENGTH	
Landsat 5	Thematic Mapper (TM)	16 days	B1-5 and 7: 30 m B6: 120 m	B1 :0.45-0.52 / B2: 0.52-0.60 / B3: 0.63-0.69 / B4: 0.76-0.90 / B5: 1.55-1.75 / B6 (thermal): 10.40-12.50 / B7: 2.08-2.35	8	170 km	183 km	http://eros.usgs.gov/products/satellite/landsat7.html
Spot 1	HRV	2 or 3 days (depending on latitude)	B1-3: 20 m P: 10 m	B1: 0.50-0.59 / B2: 0.61-0.68 / B3: 0.78-0.89 / P: 0.50-0.73	8	60 km	60 to 80 km.	http://www.spotimage.fr/automne_modules_files/standard/public/p445_3a1cd2cb59b76fc75e20286a6abb7efegeneral-features.pdf
SAC-C	MMRS - HRTC	9 days	B1-5: 175 m P: 35 m	B1: 0.48-0.5 / B2: 0.54-0.56 / B3:0.63-0.69 / B4: 0.795-0.835 / B5: 1.55 – 1.7 / P: 0.40-0.90	8	350 km	--------	http://www.conae.gov.ar/sac-c/desc_const/
SeaStar	SeaWifs	1 day	LAC: 1.1 km GAC: 4.5 km	B1: 0.402-0.422 / B2: 0.433-0.453 / B3: 0.480-0.50 / B4: 0.50-0.520 / B5: 0.545-0.565 / B6: 0.66-0.68 / B7: 0.745-0.785 / B8: 0.845-0.885	10	2801km LAC/HRPT 1502 km GAC	----------	http://oceancolor.gsfc.nasa.gov/SeaWiFS/SEASTAR/SPACECRAFT.html

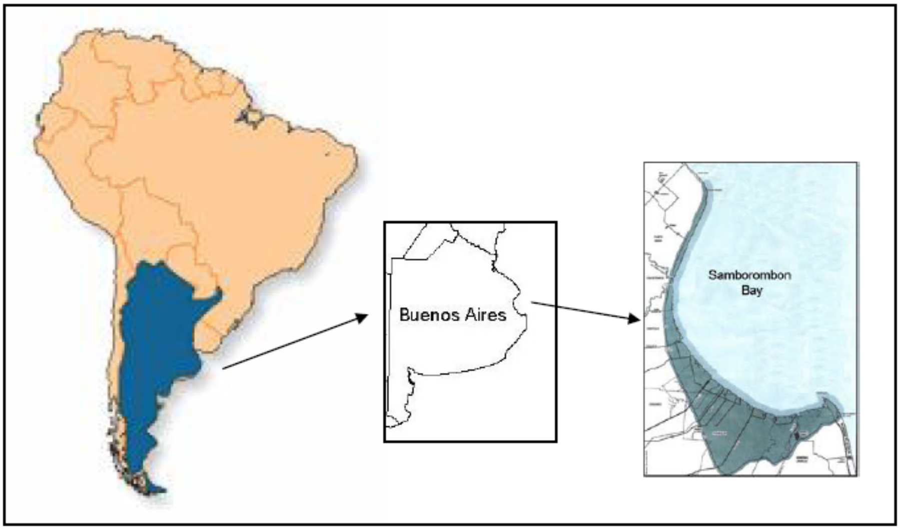

Figure 1: Location of the study area.

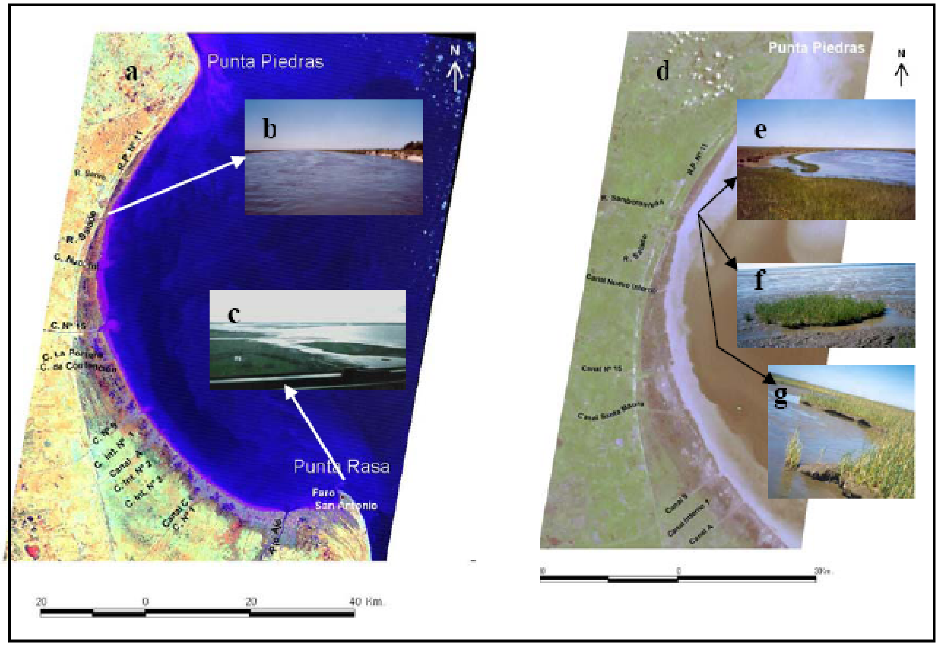

Figure 2: Samborombón Bay. **a)** Landsat 5 TM. Bands 453-RGB (2004). **b)** Picture of Salado river. **c)** View of the bay from San Antonio lighthouse. **d)** SAC-C. Bands 321-RGB (2005) **e), f)** and **g)** Pictures of Samborombón river's mouth.

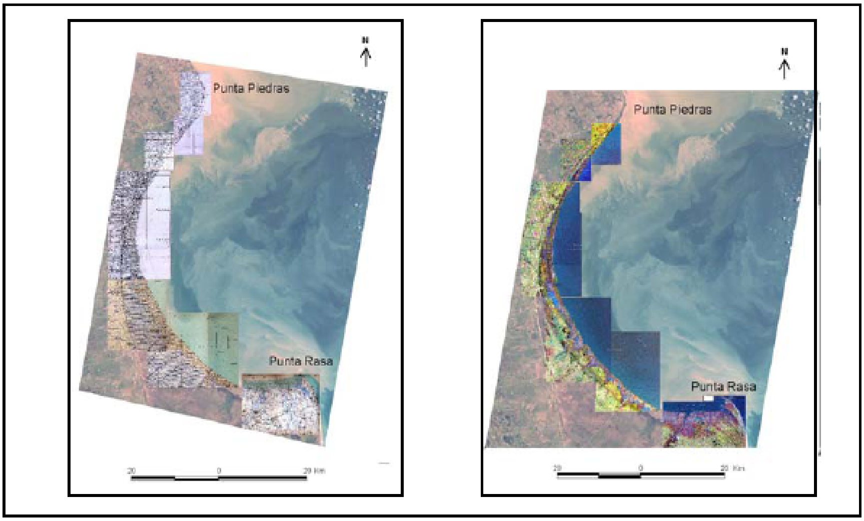

Figure 3: Landsat 5 TM image (2004). Bands: 321-RGB. **a)** Overlay of topographic charts. **b)** Overlay of satellite charts.

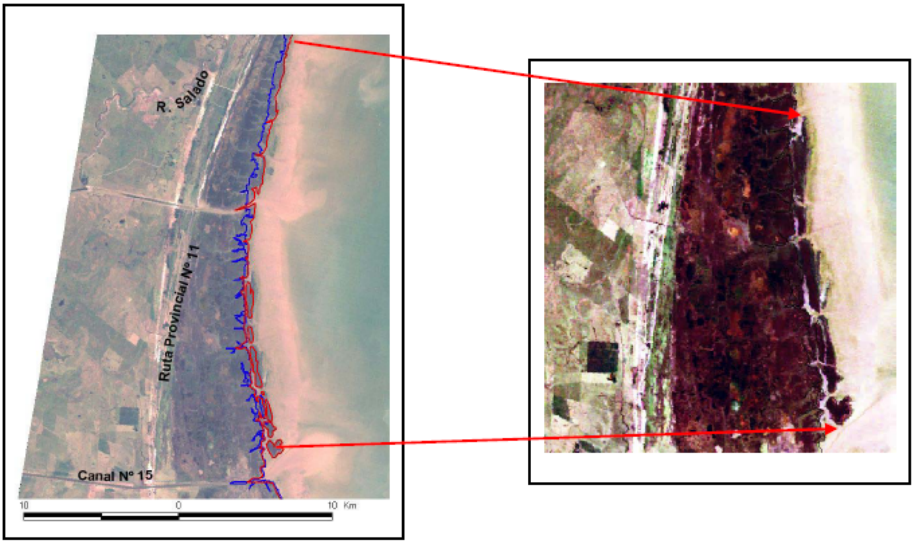

Figure 4: Progradation in the central sector of the bay. **a)** Shorelines in 1968 (blue) and in 1994 (red) overlaid on Landsat image (2004). **b)** Detail of formation of new small islands.

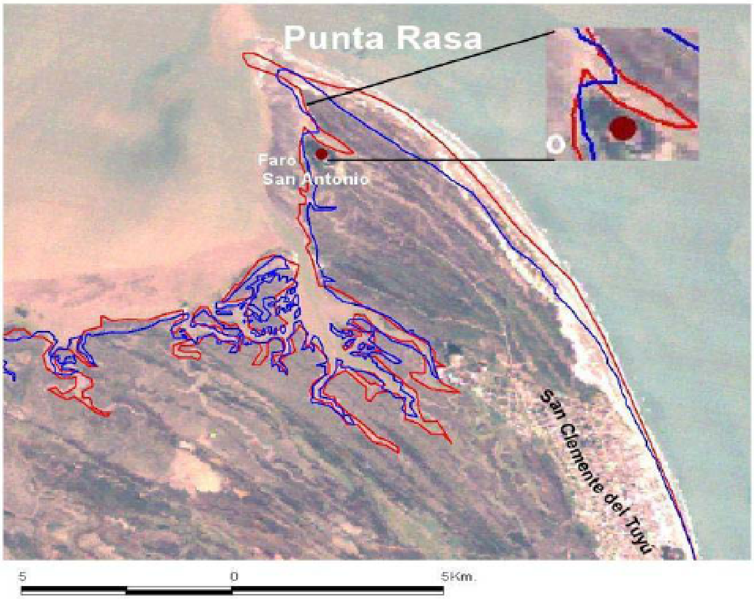

Figure 5: Progradation in the south extreme of Samborombón bay (Punta Rasa). Shoreline in 1938-41(blue) and in 1994 (red) overlaid on Landsat images of 2004.
a. Detail of the erosion process at the north of Faro San Antonio.

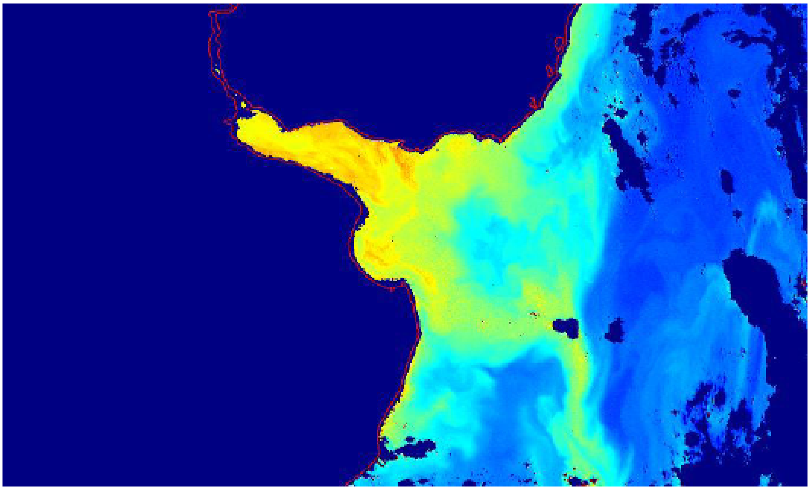

Figure 6: Result of the K-490 algorithm on a Seawifs Image.

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