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Historical Shoreline Changes Near Lagoonal and River Stabilized Inlets in Rio Grande do Sul State, Southern Brazil

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ABSTRACT

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Aerial photography time series of six ocean beaches (Cassino, Mar Grosso, Tramandaí, Imbé, Praia Grande and Passo de Torres beaches) adjacent to lagoonal and river inlets of southern Brazil were analyzed in order to verify the influence of jetties on its shoreline evolution and configuration. Digital processing and data standardization were performed in order to eliminate distortions. In a GIS database the changeable positions of the coastline were vectorized and its differences calculated. Two beach features: the High Water Line (HWL) and the Base of the Foredunes were used in order to represent the shoreline. Cassino beach displayed the higher accretion rates (4.10m/y) showing highly distinct accretion rates for two different time frames. For Mar Grosso beach, shoreline recession rate was -1.44m/year starting in a sector distant 3km from the inlet. The beaches of Tramandaí and Imbé displayed a homogeneous recession rate along the coastline, due to human impacts associated to urbanization and sand exploitation. For Praia Grande beach an intense accretion rate followed by a stabilization period was observed. At the same time Passo de Torres beach displayed an accretion rate adjacent to the jetty which was followed by a stabilization period. At a greater distance of the inlet coastline recession was noticed. Highly accretion versus low erosion rates respectively to the south and north of the two main inlets suggest a bi-directional littoral sediment transport process. The coastline suffered a reorientation process due to the bathymetric changes of the adjacent shoreface, reduction of beach exposure and interference on the littoral drift impinged by the jetties construction. The anthropogenic influence on these beaches and on its morphological evolution process emphasizes the urgent needs of setback lines, which represents a logical and rational urban development.

ADDITIONAL INDEX WORDS: *Coastal changes, aerial photographys, ocean beaches.*

INTRODUCTION

Except for the rocky formations at its extreme northern portion which offer a certain degree of shelter, the approximately 640km of coastline of the Rio Grande do Sul (RS) state is a long barrier island characterized by well developed beach, dunes and aeolian flats. The coast exhibit a low relief, is basically straight and totally exposed. This configuration makes it very difficult to locate fixed reference points which can be used to study shoreline changes based on repeated aerial photography surveys in scale of decades.

Comparisons of the different beaches located along the coast regarding their morphological variability, indicate that the most dynamic ones are situated around the fluvial and lagoonal inlets. Causes of this variability are mainly related to inlet stabilization, urbanization processes and for each particular inlet the permanent changes in the morphology of the ebb tide delta and supply of sediments from the drainage basin (in the case of Patos Lagoon estuary).

The presence of hard structures which were built several decades ago allow us to get reliable and permanent reference points that can be used to evaluate shoreline changes.

The objective of this work is to analyze shoreline changes of six ocean beaches adjacent to the major fluvial and lagoon inlets of the RS state in southern Brazil. Based on digital cartographic techniques and remote sensing, rates of shoreline change are determined and quantified.

STUDY AREA

Three places were selected along the RS coastline: the inlets of Patos and Tramandaí Lagoons and the mouth of the Mampituba river located at the border of Rio Grande do Sul and Santa Catarina states (Figure 1).

The most coastal urban cities of the RS state are related to these places, which combine both a significant amount of fresh water from the drainage basin and harbors for cargo ships and fishermen's boats. The three inlets are actually stabilized by jetties.

DATA PROCESSING

Several methods can be utilized in order to determine shoreline changes. The choice of a specific method depends on the data availability and the spatial and temporal scale of the analysis.

The existence of several aerial photographs dating back to 1947 for the RS coastline made these series the main data source of our study. Such data integrated to field monitoring done previously allowed us to establish the evolution pattern for these sectors of the coastline with good confidence. The methodology was based on the studies of DOLAN *et al.* (1978), DOLAN *et al.* (1980), LEATHERMAM (1983), CROWELL *et al.* (1993), THIELER and DANFORTH (1994) and MORTON (1997). It basically consists on the superposition of a temporal series of aerial photographs under the same cartographic projection, on the definition of normal profiles taken at regular intervals and on the calculation of the differences between each shoreline over each profile.

Initially it was necessary the establishment of certain common parameters for mapping each aerial photo of the temporal series. Some of them consist of: a) a limit on the difference in scale between the aerial photos; b) the choice of beach features which should represent the shoreline. We restricted the use of maximum scale of 1:40.000. The sequence of aerial photos utilized are shown on table 1.

Due mainly to the fact that both, the higher water line (HWL) and the base of the foredunes (also called the vegetation line),

Table 1. *Aerial surveys utilized in this study.*

SITE	DATE	SCALE	SPACIAL RESOLUTION
Patos Lagoon	1947	1:40000	1.7m
	1975	1:20000	1.4m
	2000	-	1.0m
Tramandaí Lagoon	1975	1:20000	1.4m
	2000	-	1.0m
Mampituba River	1974	1:20000	1.4m
	1989	1:20000	1.4m
	2000	-	1.0m

were more visible at the aerial photos, they were used as main features for our study. The HWL is defined by a line that differentiate the dry sand from the backshore from the wet sand from the foreshore. Studies done in other beaches also consider these features as being stable and reliable specially when the time interval between the surveys is higher than a decade (CROWELL *et al.*,1993).

Distortions from the time of acquisition of the aerial photos were corrected. A network of coordinates obtained on the field by a GPS and referred to fixed objects (notable points) in all the surveys was also established.

After being georeferenced, the data were inserted in a GIS (SPRING 3.6.03 CÂMARA *et al.*, 1996) where four main steps were done: 1- digitalization of the shoreline position; 2- determination of the normal profiles; 3- calculations of the changes in each profile, and 4- construction of evolution charts for each period (figure 2).

Sampling Error

The error introduced in this study has basically two sources:

1) Methodological: low quality of the original data (excess of distortion on the aerial photos); problems during the mosaic confection and in the scale correction of the aerial photos; field positioning errors introduced by the Global Position System (GPS); bad allocation of the control points used in the georeferencing and errors in the digitalization process.

2) Dynamic of the natural features: The analyzed features experiment short period changes which may interfere in the interpretation process.

In synthesis the total error can be represented by the following function:

$$\epsilon = f(\epsilon_1 + \epsilon_2 + ... + \epsilon_n) \quad (1)$$

Where ϵ_n represents the error of each step in the data processing. Practically it is almost impossible to determine the exact value of the error in each step. However, the results obtained should represent all the errors accumulated (ϵ).

In order to determine this value several measurements (using a NIKON Total Station surveing) were performed on the field between points which appear in all the aerial photographs. This distance was called L. After, this same distance was measured over the already processed aerial photos, being each value designated $L_1, L_2,..., L_n$. The difference obtained represents the errors. The maximum difference was considered a band of uncertainness (table 2).

However the error due to the environmental dynamic is impossible to calculate without field data at the moment of the aerial photos acquisition, or without knowing the variability of each feature along the year (DOLAN *et al.*, 1980). Because of this source of errors we stipulated an increase of 20m and 10m on the band of uncertainness respectively for the high water mark and for the charts of the foredunes line.

RESULTS AND DISCUSSION

Fifteen (15) aerial photographic mosaics and twenty four (24) charts representing the changes of each beach were created. Table 3 displays a synthesis of the measured changeable

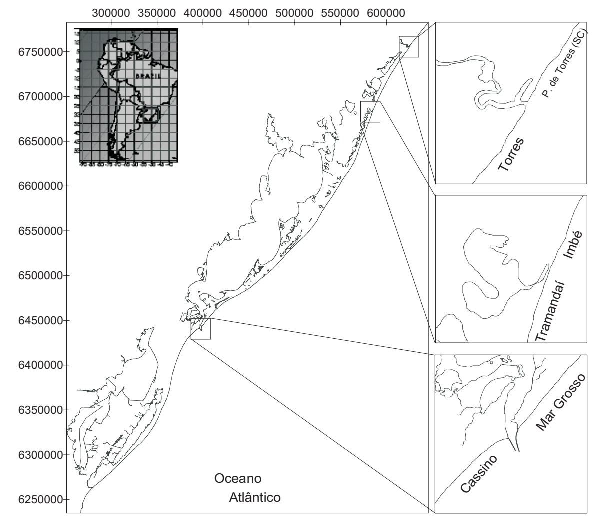

Figure 1. The three major inlets of RS coastline and the studied beaches.

values; figure 3 represents the variations charts. Although different rates are measured when using the HWL or the foredunes line, in most of the cases the tendencies of erosion or accretion are corroborated by the two methodologies.

Cassino beach located to the south of the Patos Lagoon inlet displayed high accretion rates (4.10 m/year), although showing distinct rates at two different periods. An interesting detail is the existence of a relatively stable sector located between 650m and 1800m to the south of the west jetty. From this sector towards both the north and south there is a progressive increase in the accretion rate impinging to the coastline an arcuate form similar to a spiral shape.

Historical data compiled by CALLIARI (1980) show that before the inlet stabilization and fixation, alternated phases of shoreline accretion/erosion occurred in conjunction with the changeable morphology of the ebb tide located at the lagoon mouth. After the end of the jetties construction, which begun in 1911 and ended in 1915, the shoreline started to accrete at higher rate. The shoreline accretion to the south of the inlet can be explained by the fact that the net littoral drift along the RS coastline is towards the northeast. An additional factor which

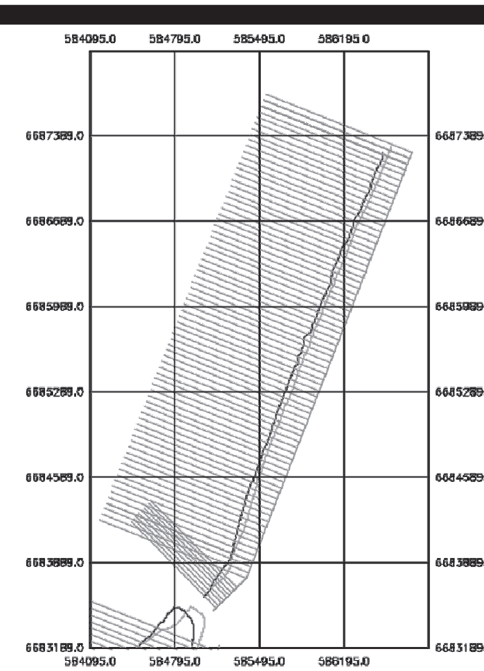

Figure 2. An example of transects utilized to calculate the position of the shoreline at each period.

Table 2. *Calculating the Uncertainness range* .

Measure	Value (m)
L	51.5
L1	47.3
L2	46.9
L3	47.6
Uncertainness g range	4.6
High water line error	***25***
Foredune error	***15***

could contribute for higher rates of accretion at 10km from the inlet is the presence of fluid mud deposits on the local shoreface (CALLIARI and FACHIN, 1993). Such deposits are responsible for high rates of wave energy attenuation causing a sink for sediments which arrive by littoral drift to this area. For Mar Grosso beach, located to the north of the inlet, erosion rates of the order of -1.44 m/year distant 3km to the north of east jetty were detected. Beach profiles monitored by SILVA and CALLIARI (2001) achieved the same pattern in this sector of the beach. Due to the length of both jetties and since the net transport is towards the northeast one should expect higher rates of recession for Mar Grosso beach. However, there is also an important process of littoral drift towards the south which is caused by sea waves generated by the predominant year around northeast winds.

Beaches of Tramandaí and Imbé, respectively located to the south and north of the inlet display a homogeneous erosion tendency along all the analyzed sectors.

This tendency is contrary to the patterns predicted by stratigraphic studies (DILLENBURG *et al.*, 2002) and refraction diagrams (CALLIARI *et al.*, 1998). The configuration of the coastline and the morphology of the inner continental shelf indicate that this area should be stable. The erosive tendency detected in the last 25 years may reflect the removal of sand from the frontal dunes and the backshore during the urbanization process as already discussed by ESTEVES *et al.* (2001) and DILLENBURG *et al.* (2002). Additionally, the jetties of Tramandaí inlet are not effective in trapping sand due to its reduced length. In fact they are restricted to the channel borders and do not cross the wide breaker zone, consequently its influence in changing the degree of exposure and width for Tramandaí beach is negligible.

Shoreline changes for Praia Grande Beach located to the south of Mampituba river, temporally display two different behaviors (table 3): intensive accretion between 1974 and 1989 followed by a stabilization period between 1989 and 2000.

Differently from the other sites this beach displays a certain degree of shelter since it has its southern and northern side respectively anchored by a rocky promontory and by the west jetty of the Mampituba river. The construction of jetties in 1970 is the main cause of the intense accretion rate occurred between 1974 and 1989. The stabilization period after 1989, probably represents a morphologic adjustment of the shoreline to the inlet stabilization process.

To the north of the Mampituba river, Passo de Torres beach displays a unique behavior. Accreting sectors close to the east jetty show a sharp contrast with erosion sectors further north. Unfortunately the inexistence of field data such as beach profiles make difficult to explain such pattern. However, the alterations observed close to the jetty can be attributed to anthropogenic influence since the aerial photographs demonstrate the closure of a big washout during the urbanization process. The presence of this active washout at that time was responsible for the discontinuity of the frontal dunes and removal of sand from the beach to the surf zone. The recovery of the sand deposits close to the jetty can also be attributed to the shadow zone impinged by the east jetty from the storms of the southern quadrant. Moreover, sands from the ebb tide delta of the Mampituba river can be transported and deposited just north of the east jetty since this structure is short and allows the bypassing of certain amount of sand across the inlet. The erosion pattern displayed further north may be due to the partial retention of the littoral drift by the jetties. Field evidences represented by scarped dunes can be observed nowadays.

CONCLUSIONS

The utilization of two reference features at significant time intervals between the aerial photography surveys allowed the identification of evolution patterns for the study sectors even with the limited field data regarding beach dynamics. Although the rates represent an approximation of the reality, both the HWL and the base of the foredunes display similar trends. The accreted sectors identified in the present study reveal the interruption of the littoral drift by man made structures (Cassino and Praia Grande). The erosive sectors reflect a sediment deficit by the impingement of these structures. The higher rate of accretion found 10km south of the Patos Lagoon inlet can also be attributed to the presence of muddy bottoms which can function as a trap for the sandy sediments by lowering the wave energy and retaining the fine sediments. The area of maximum accretion coincide with de depocenter of the muddy facies mapped by CALLIARI and FACHIN (1993). It is believed that in a

Table 3. *Variations in the position of features calculated for each period.*

BEACH	*PERIOD*	*HIGH WATER LINE*			*BASE OF FOREDUNE*		
		MEAN (m)	MAXIMUM VARIATION/ DISTANCE FROM INLET (m/m)	RATE (m/year)	MEAN (m)	MAXIMUM VARIATION/ DISTANCE FROM INLET (m/m)	RATE (m/year)
CASSINO	1947 – 1975	114.83	462/11500	4.10			
	1975 – 2000	36.67	78/8000	1.46	-	-	-
	1947 - 2000	171.0	-	3.22			
MAR GROSSO	1975 - 2000	-37.60	-118.6/3350	-1.44	-	-	-
TRAMANDAÍ	1974 - 2000	-22.45	-44.8/825	-0.86	-35.75	-44.2/30	-1.37
IMBÉ	1974 - 2000	-20.38	-39.7/630	-0.74	-35.5	-41.7/648	-1.28
PRAIA GRANDE	1974 – 1989	71.67	112/480	4.77	47.17	89/485	3.14
	1989 – 2000	21.89	805/553	1.99	-4.77	-51/12	-0.43
	1974 - 2000	93.57	138.5/489	3.59	50.66	89/251	1.94
PASSO DE TORRES	1974 – 1989	26.20	62/15	1.74	-4.12	122/477	-0.27
	1989 – 2000	-4.77	-22/988	-0.43	23.51	53.5/352	2.13
	1974 - 2000	12.97	75/52	0.49	48.2	153/700	1.0

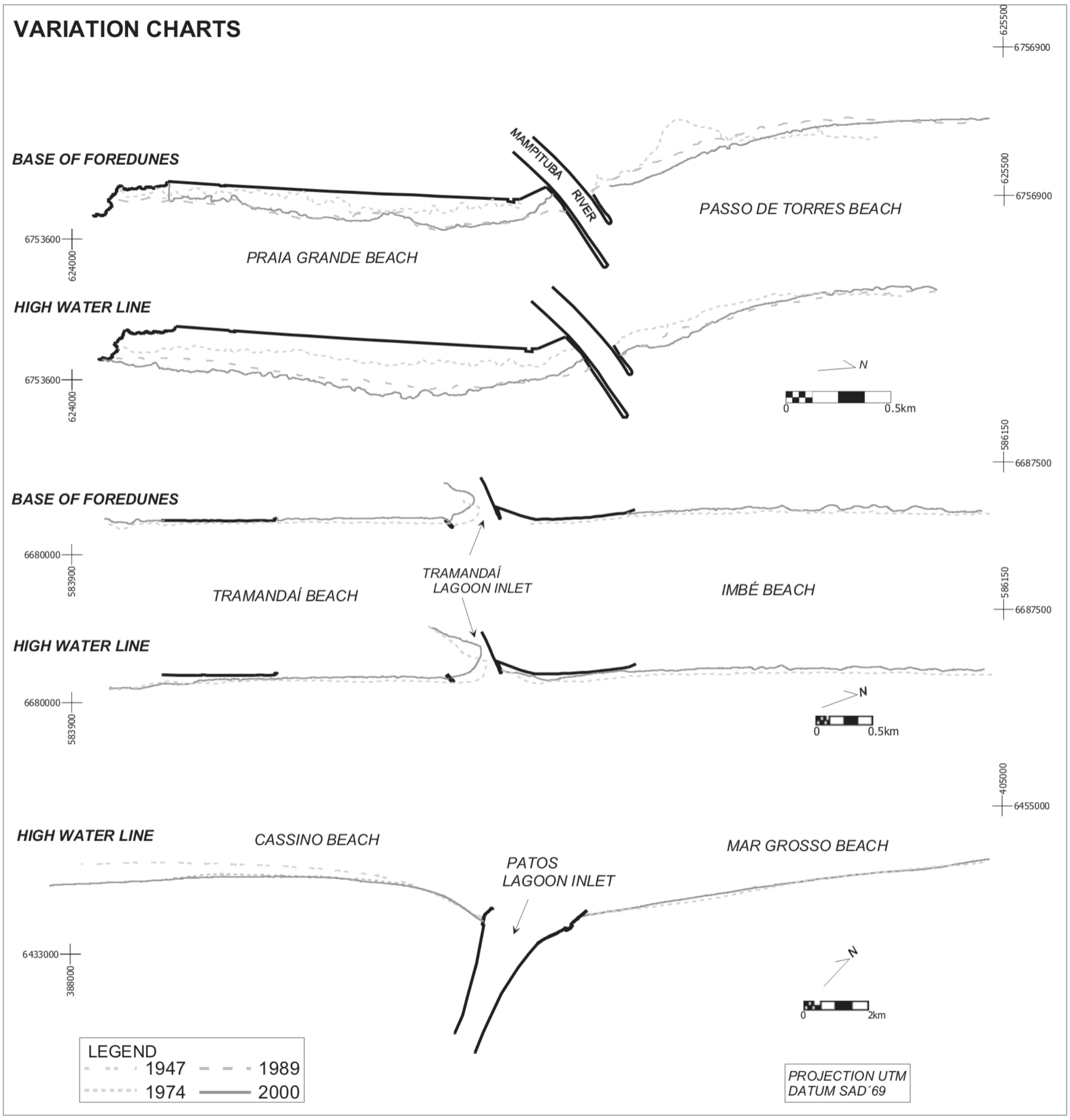

Figure 3. Variation Charts from each site.

scale of decades this mechanism can effectively contribute to shoreline accretion southward of the inlet.

The high rates of accretion versus the low rates of erosion detected respectively to the south and to the north of the two main inlets (Patos Lagoon and Mampituba River) is a strong evidence that the littoral drift along the coast is bidirectional. However, rates of accretion at the south of the two main structures (jetties of Cassino and Mampituba) corroborate the net transport to the northeast already described by early researchers (MOTTA, 1969; TOMAZELLI and VILLWOCK, 1992; CALLIARI *et al.*, 1998).

A series of geomorphologic evidences such as migration to northeast of the main channel of Patos Lagoon inlet before its fixation and the considerable increase of the dune fields and beach width at the south of the inlets (Patos and Mampituba) after the placement of jetties, are also evidences of this net transport. Constructions represented by old life guard stations that were placed at Cassino beach in the 1970´s are nowadays located in the middle of a dune field distant 175 m from the shoreline.

Even the channel of Tramandaí inlet displays a northern migration trend although a considerable portion is outside the range of the structure. The homogenous erosive tendency observed at both sides of the Tramandaí inlet shows evidences that the length of the structure is not important for the retention of the littoral drift. In fact, the jetties are located inshore of the breaker zone. The urbanization process which took place in most cases over the foredunes can be the cause of the erosive pattern.

Despite the hydrodynamic control over the RS coastline, beaches adjacent to inlets are subject to additional control factors. The presence of anthropogenic structures impose on them a dynamic-structural control which give rise to a morphodynamic adjustment. Bathymetric changes, reduction on the degree of exposure and interference on the littoral drift are the three main factors which induce a reorientation process of the shoreline.

Thus, human alterations on the coastline of RS by both the urbanization process and fixation of inlets can lead to considerable changes. The results here presented show that in a long term basis, setback lines should be planned for coastal areas under urbanization and specially for the areas located down drift of the inlets. In this regard, special care should be taken for places still undeveloped such as the beaches of Mar Grosso and Passo de Torres.

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