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Morphodynamic Variability of the Galinhos Spit, Northeastern Brazil

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ABSTRACT

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Morphodynamic studies were carried on the Galinhos spit, located on the setentrional coast of the Rio Grande do Norte State (NE Brazil). The surveys have been conducted to monitor morphological variations of the beaches through time: annual, monthly and diurnal, along the Galinhos spit. Beach profiling was performed on three key areas along this spit: Galos Beach (profile A), Galinhos Beach (profile B) and Farol Beach (profile C). The field works were carried from December 1999 to August 2001. The analysis of the annual dataset shows that areas with beach rock lines parallel to the coast prevents morphology modifications. On the other hand, the other areas presents a tendency to erosion (until 2,16 m3/m/year). A ciclicity was also detected on the beach morphology, with the presence of longitudinal bars versus pronounced berms. The data set collected during a lunar cycle shows that deposition was most expressive during the full moon. The changes observed during the tide cycle show that modifications on the beach profile begins soon after the slack tide, when the tide begin to flood. The integration of the complete dataset is important to understand coastal erosion, as well coastal evolution on the area.

ADDITIONAL INDEX WORDS: *Coastal erosion, beach profiles, environmental monitoring.*

INTRODUCTION

Morphodynamic changes on the coastal zone are related to different processes such as winds, waves, currents, and from the interaction between them results the environment's morphology. It is important to mention that the monitoring of beaches with low degree impact, through the understanding of the morphologic and hydrodynamic answers of them, are considered as one of the best way to the understanding of the beach environment, making possible predictions for coastal management tasks.

In this research line, giving emphasis to the interpretation of the erosional and depositional processes ongoing the shoreline, we can mention some works presented by ALVAREZ *et al*. (1981); WRIGHT and SHORT (1984); AUBREY and ROSS (1985); BITTENCOUT *et al*. (1987); MUEHE and CORREA (1989); AAGAARD, (1991); SHORT (1991); DEAN (1991); MUEHE and ALBINO (1992); CALLIARI and KLEIN (1993); MASSELINK and SHORT (1993); SHORT and AAGAARD (1993); PILKEY *et al*. (1993); TOMAZELLI *et al*. (1996); ANTHONY (1998); GORMAN *et al*. (1998); FINKL JR. (1994) among others. Most of these works were performed taking in account different tidal-range, grain-size variations and wave energy. However, most of them were carried on high latitude areas and data from tropical areas are lacking.

This way, this work consists of the morphodynamic monitoring of beaches in the spit of Galinhos, along 21 months of observation (12/1999 to 08/2001). This sandy spit has an east-west direction, with approximately 10 km length and medium width of 550 m. The aim of this research is focused on the understanding of beaches profile variability in different temporal scales: annual, monthly and daily, along a tropical spit. Moreover all data were stored on a Geographical Database for generation of Oil-Spill Environmental Sensitivity Maps, and for integrated costal zone management.

The profile of a beach changes with the acquisition or loss of sand, according to the energy of the waves, in other words, according to alternations between good time (sedimentation) and storm (erosion) MUEHE (1994). Thus, response to energy variations may be traced through changes in morphology and sediments.

The study site is inserted in a tropical recent coastal landscape, located in the septentrional coast of the Rio Grande do Norte State northeast of Brazil (Figure 01). It can be classified as a high-energy, current-dominated environment, exposed to a meso-tidal range, and characterized by the complexity of their geomorphologic features, represented by beaches, reefs, estuaries, swamps, ponds and dunes.

The modelling of those features is directly correlated to the united performance of waves, coastal currents, tides, and winds, related with the variations of the sea level occured during the Quaternary Period (LIMA *et al*., 2001).. The scenic potential of this landscape, associated with the of the existent natural resources, has motivated an accelerated soil occupation, mainly in the last years. Reference should be given to competing interests between different user-groups of the coastal zone e.g. tourism, fisheries, shrimp farming, exploitation of mineral resources (mainly Oil and Gas), petrochemical and salty industries etc. This development process, not preceded by diagnosis of the support capacity of this space, together with the lack of basic services infrastructure, can generate big environmental problems in this area once it is an extremely fragile environment.

METHODS

Three beach stations were surveyed on the Galinhos spit shore. The stations, from east to west, are located at Galos Beach (profile A), Galinhos Beach (profile B) and Farol Beach (profile C) (Figure 1). These stations were positioned in strategic places, according to the general characteristics of the beach, standing out among other, erosion or sedimentation areas and occurrences of reefs.

Field data were gathered during spring tide (full moon). Topographic profiles of the beach normal to the coast line were measured one time monthly from December 1999 to August 2001; in November 2000 the profiles were measured in all stations four times according to the phases of the moon. Moreover in the Galinhos Beach (Profile B) topographical profiles were measured five times in the full moon phase of November 2000, with intervals of one hour among each profile and beginning 2 hours before the low tide.

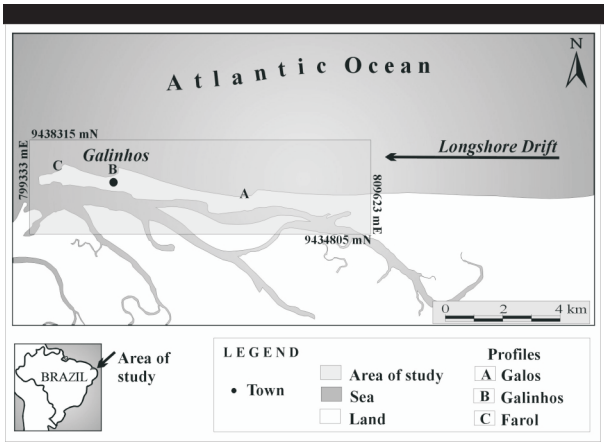

Figure 1. Location of the study site and the beach stations A (Galos), B (Galinhos), and C (Farol).

The beach profiles were obtained by a three-person team using a precision level, measuring tape and graduate sight; from the backshore to the breaking zone, according to SWIFT *et al*. (1985). All elevation profiling is referenced to a datum satake, which is at a known elevation above mean spring low water (MSLW).

It was used the method of "Stádia" improved by BIRKEMEIER (1981); this study presents a decimetric precision, with estimated error among 10 to 20 cm and, in addition, it makes possible to monitor the underwater profile until approximately 1,5 meter depth (TOZZI and CALLIARI, 1999).

Using the program Surfer for Windows (version 7.0), the transit data were plotted as elevation profiles and profile volumes were determined. The month of smaller profile was adopted as standard length, in way to turn the calculated volumes comparable with each other. Once established the limits of each group of profiles was possible to determine the volume of each profile and the area of each one of them as well. It was considered, for each profile, a width equal to 1 m, obtaining, in this way, the sand volume for linear meter of beach, expressed in cubic meters for meter (m^3/m).

RESULTS AND DISCUSSION

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The beach profile is important in that it can be viewed as a natural mechanism that causes waves to break and dissipate their energy, and in this way shifts the sand from the dry beach to the offshore and back again.

In this section we present our results and discuss the changes in the beach profile-volume time-series for each station.

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Profile A Galos

The beach profile A - is located on Galos Beach (Fig. 1). Their morphologic units are preserved, and in the 21 monitored months the shoreface presents 75 m, the foreshore 50 m, and the backshore 45m of length, on average. During the monitored period, this station showed almost any change in its morphology. However, it was observed that it presents an increment in the sediment volume in all months when compared with the month of reference (December 1999) (Figure. 2.A). In the months of June and December 2000, in which the variation in the beach profile was observed also in the backshore, the sediment volumes were of 3,5 m^3/m and 2,2 m^3/m respectively; on the other hand April 2001 was the month that presented the largest similarity in the morphology of the beach profile with the month of reference (December of 1999) being observed an increment in the volume of 0,8 m^3/m.

Comparing the volumes of the beach profiles of the periods from December 1999 to August 2000 with that from December 2000 to August 2001, we observed that there was a tendency to erosion from one year to the other; in the months of January and July the beach profile presented big similarity among them, but in the month of December occurred an increment in the sediment volume of 2,2 m^3/m. In the other months a volume decrease was observed (erosion) in the order of -0,5 m^3/m to -2,1 m^3/m. As explanation for such occurrence we can suggest that the sediment transport was improved because the month of December was a dry month (without rains) and of strong winds, favoring the transport of sediments.

Another important observation was the presence of beach cusps with 25 m length, observed only in this profile; this process is explained by the alterations imposed by the wave front. When reach the beachrocks they suffer diffraction and generate rip currents thus making possible the beach cusps formation In a general way it was observed that the morphology of the beach profile remained constant regarding the month of reference (December of 1999); although erosion as well deposition were present during the monitored months. We attributed this fact to the presence of a beachrock line in the foreshore area. For the calculations of the volumes for this station, the standard length of 140 m was adopted starting from the reference datum, common to all the measures. The studies accomplished in this profile presented a positive sedimentary balance, presenting a mean deposition by month of the order of 0,1 m^3/m/month and 0,8m^3/m/year. In this way, along the monitored period, the volume of accumulated material was of the order of 1,49 m^3/m.

Profile B Galinhos

This beach profile is located on the Galinhos beach (profile B) (Figure 1). Their morphologic units are constituted by the backshore with 40 m, the foreshore with 135 m, and the shoreface with 60 m of length, on average.

Cyclic changes were observed in its morphology during the 21 months of monitoring. Longitudinal sandy bars were observed in the foreshore from December 1999 to February 2000. While in the months from March to September 2000 occurred a beach with very pronounced berm. From October 2000 to January 2001 the longitudinal bars return, followed by the berm formation between February and August of 2001. Such feature allow us to affirm that it is a cyclical event where in the months of drought period and strong winds occur the formation of longitudinal bars in the foreshore, while in the rainy months occur the berm formation.

If we take the month of December 1999 as reference we observed a tendency to erosion in all of the monitored months (Figure. 2.B), meantime when we make the comparison among different years (1999 to 2001) it was observed that exists small differences; being the largest difference among the months of December 1999 and 2000 when the erosion was in the order of -1,7 m^3/m, and in the months of February to April when deposition occurred. The largest deposition was in the month of April 2001 of the order of 1,60 m^3/m. It coincides with the month of smaller wave height (6 cm). Better correlations were showed by the months of May (2000 and 2001) and July (2000 and 2001).

For the calculations of the volumes in this profile, it was adopted the standard length of 190 m from the reference datum, common to all the measures. The studies accomplished in this profile presented a negative sedimentary balance, presenting a medium erosion by month in the order of -0,2 m^3/m/month and -2,2 m3/m/year. In this way, along the monitored period, the volume of material eroded was approximately of -3,8 m^3/m.

Profile C Farol

This beach profile is located on the Farol beach (profile C) (Figure. 1). Their morphology is characterized by a 20 m length backshore, a foreshore with 135 m and a shoreface with 45 m length.

It was observed the same behavior of the profile B Galinhos regarding the bars/berm alternation. The formation of longitudinal sandy bars occur in the months of December 1999 to March 2000, while berm formation started in April going to October 2000. Already in the months of November 2000 until to June of 2000 the longitudinal bars turn to appear, evidencing the cyclic way in the implantation of these forms. Taking in account the reference month of December 1999 we observed a tendency to the erosion in the whole monitoring period (Fig. 2.C).

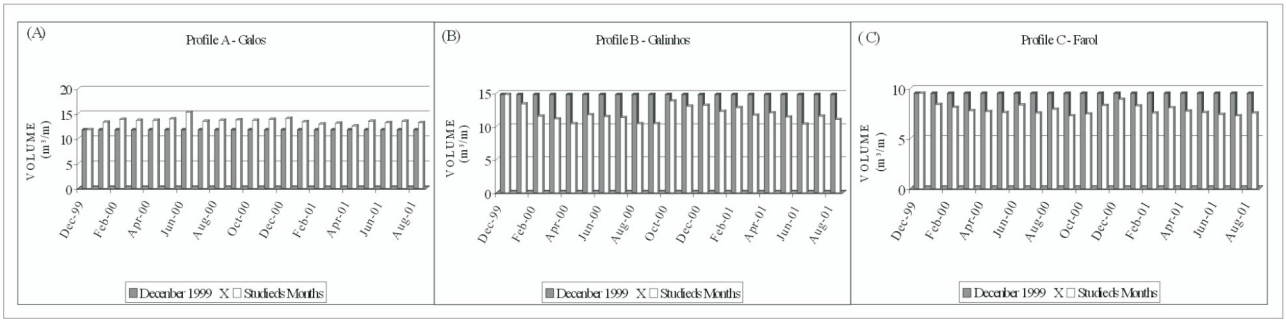

Figure 2. Beach profile volume records for the three beach profile stations shown in Figure 1. The black columns represent the month of reference (December of 1999) for comparison.

When comparing the volumes of the beach profiles during the periods from December 1999 to August 2000 with the one from December 2000 to August 2001, we observed that the tendency to the erosion is confirmed of one year for the other. However, when comparing the topographical profiles from one year to the other, we observed that the formation of the longitudinal sandy bar occurred from December 1999 to February 2000, while in the following year their formation begun in December 2000, but extended until May 2001; and only in the month of June was observed the formation of a pronounced berm.

The strongest erosion occurred in September 2000 with -2,2 m^3/m erosion, on this same month it was registered the largest period of waves (109 seg.) for the monitored months. For the calculations of the volumes made for the studies executed in this profile, the standard length of 160 m was adopted starting from the reference datum, common to all the measures. The studies accomplished in this profile presented a negative sedimentary balance, presenting a medium erosion by month in the order of -0,1 m^3/m/month and -1 m^3/m/year. this way, along the monitored period, the volume of material eroded was approximately of -2 m^3/m.

Profiles Executed Accorded to the Moon Phase (November 2000).

In the profile A (Galos) - there was not significant change in the morphology of the profiles monitored during the moon phases, except in the foreshore, where occurs a small enlargement; observing the beach profile volume record for this station, was verified that there are small volume difference between the different phases of the moon. A sediment increment of around 0,5 m^3/m, characterize a positive balance in the full moon period, while erosion in the order of -0,3 m^3/m occurred in the new moon phase.

In the Profile B (Galinhos) occurred significant variations among the monitored dates. The incipient formation of a longitudinal sandy bar was observed in the beach profile measured during waxing moon,between the distances of 75 m and 130 m starting from the reference datum, while in the full moon profile it was noticed the displacement of this longitudinal sandy bar in the backshorewards. In the moon of wane quadrature it was observed the bar move back shorefacewards and finally in the new moon the sediment that formed the sandy bar was transported to backshore forming a very pronounced berm. Beach profile volume records for this period showed that the largest volume of sediment occurred in the full moon phase, and it was in the order of 13 m^3/m . The largest erosion take place in the wane phase with approximately 1,6 m^3/m.

In the Profile C (Farol) significant variations were also observed. The formation of a longitudinal sandy bar less than a meter of height was observed in the profile of the waxing moon. This sandy bar reached more than 1 meter height in the full moon phase, and in the phase of waning moon assumes its largest height with around 2 m. Finally in the new moon a small displacement of the bar is observed in the sense of the backshore as well as an thinning in its morphology. The beach profile volume records reveals clearly the volume difference between the wane phase and the other phases. In the wane phase was registered a positive volume of 10 m^3/m, while in the new moon phase occurs erosion in the order of 2 m^3/m.

Profiles measured in the full moon period in the profile B - Galinhos (November 2000).

The analysis of these profiles showed us that there were no significant morphologic modifications along the profile; however, a volume variation occur between the low tide and the two hours measured after the low tide, mainly in the shoreface.

CONCLUSIONS

The studied area is a very fragile area and susceptible to significant modifications in its morphology in the annual period and in short period (phases of the moon). Inside of this vision, it is important to take knowledge that the natural environments should be understood in an appropriate way so that they can be managed and protected in an appropriate way. The researches accomplished in the spit of Galinhos in the period of December of 1999 to August of 2001, favored the understanding of the current situation of the beach morphology of this area. Through the monitoring work of the three profiles (profile - A Galos; profile B - GAlihnos and profile C - Galos) it can be concluded that:

In the profile A Galos it was observed that although it has occurred as much erosion as deposition during the monitored months, the morphology of the beach profile stayed constant regarding the month of reference (December of 1999). This fact was attributed to the existence of a beachrock line in the foreshore area, that acts as natural protection, reducing the energy dissipated by the waves on the continent. The studies accomplished in this profile presented a positive sedimentary balance presenting a medium deposition by month in the order of 0,1 m^3/m/month and 0,8 m^3/m/year. This way, along the monitored period, the volume of accumulated material was of the order of 1,4 m^3/m.

In the Profile B Galinhos, it were observed abrupt changes in its morphology, during the 21 months of monitoring. The formation of longitudinal sandy bars were observed in the foreshore, followed by the occurrence of a beach with very pronounced berm; After the berm formation turn to appear the longitudinal sandy bars again. Such feature allow us to affirm that it is a cyclical event where in the months of drought period and strong winds occurs the formation of longitudinal bars in the foreshore, and during the rainy months occurs the berm formation. The studies accomplished in this profile presented a negative sedimentary balance, presenting an average erosion by month in the order of -0,2 m^3/m/month and of -2,7 m^3/m/year. This way, along the period of 21 monitored months, the volume of material eroded was approximately of 3,8 m^3/m.

In the Profile C (Farol), it was observed the same behavior of the profile B (Galinhos), formation of longitudinal sandy bars and the berm implantation, evidencing the cyclic way in the formation these forms. When we compared the volume of sediments with the month of reference (December 1999) a tendency was observed to the erosion in the whole monitoring

period. The sedimentary balance was negative, presenting mean erosion by month in the order of -0,1 m^3/m/month and -1,0 m^3/m/year. During the monitored period, the volume of material eroded was approximately of 2 m^3/m.

The analysis of profiles measured during the different moon phases during the month of November 2000, show that in the profile A (Galos) there was not significant change in the morphology of the profiles, however, in the full moon was observed the largest deposition of sediments; in the profile B (Galinhos) occurred significant variations in the morphology of the profiles, but again the largest deposition of sediments in this profile occurred in the full moon phase. On the other hand, in the profile C (Farol) it was also observed changes in the morphology of the profile, however different from the profiles A and B, in this profile the phase that more accumulated sediments was in the moon last quarter.

The analysis of the profiles measured of hour by hour in the full moon period (profile B Galinhos) of the month of November 2000, showed that there were no significant morphologic modifications along the profile; however, occurred a small volume variation just after de low tide, mainly in the shoreface.

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