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The Fortaleza (NE Brazil) Waterfront: Port *Versus* Coastal Management

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ABSTRACT

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The coastal conflicts originated by the succesive implementations of a harbour along the Fortaleza coast (NE Brazil) during the last century are illustrated in this paper. Because all the designed layouts and the different locations selected for the harbour were done without considering the local coastal dynamics, the use itself was affected (port shoaling) and the system was rapidly degraded (coastal erosion). Since the economical benefits generated with the port was a priority for planners, solutions were mainly designed to optimize port exploitation without paying attention to the coastal response. The interest in mitigating the resource degradation appeared with the occurrence of extensive coastal damages and the nearly full disappearance of the beach in some stretches. Moreover, the appearance of a new coastal use, *i.e.* tourism, with a potential economic importance higher than the previous one, *i.e.* port, has originated a growing awareness in coastal zone management in the Fortaleza's "coastal" way of thinking.

ADDITIONAL INDEX WORDS: *Coastal zone management, port siltation, coastal erosion, coastal use conflicts, Fortaleza, Brazil.*

INTRODUCTION

The implementation of an effective coastal zone management policy involves the search for an equilibrium/accommodation between coastal uses and resources. This is because, in general, any such policy entails the use of a resource that may be non-renewable (see *e.g.* SORENSEN and MCCREARY, 1990). However, in many cases coastal management is not the product of a pre-determined policy but the result of a chain of actions in the coastal zone without consideration of the total system (*e.g.* VALLEGA, 1996; GARCIA, 1996). In such cases, we cannot properly speak of coastal management, but of coastal use or, in the best case, of coastal sectoral management, *i.e.* management of a single use of resource. Under this scenario, the interest in achieving an appropriate balance between the use and the resource will only appear when the latter begins to be consumed in such a way that other uses or even, other resources, are influenced.

According to the Coastal Area Management and Planning Network, CAMPN (1989), the most proper name for coastal management practice should be *integrated coastal zone management* (ICZM), which is defined as "a dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable use of the coastal zone".

SORENSEN and MCCREARY (1990) after an analysis of different ICZM efforts at national and sub-national levels, identified several steps in ICZM implementation. The initial step is an *incipient awareness* where the recognition of the need for an ICZM program requires the occurrence of intense conflicts among different coastal uses or coastal resources damage. The "ideal" final step should be the *program implementation* and *evaluation*, which implies the practical application of a specific coastal zone management program. Between both, there exist several steps in which coastal resources, uses, institutional arrangements and management options are analysed in order to develop a specific coastal program.

In many cases, the degradation of the resource (*e.g.* beaches) is not due to the absence of a management policy but due to mismanagement of the coastal zone or to its inefficient implementation (*e.g.* JIMENEZ, 1995). However, in some cases, they are the result of the initiation of a use during a period in which the concept of coastal management was uncommon and that use was essential for the development of that coastal zone.

This pessimistic view is not a rare case because many examples can be easily identified around the world. Thus, considering the specific case to be analysed here, *i.e.* influence of portuary use on adjacent beaches, some "classical" examples are the Port of Madras, India (CORNICK, 1959), Port Hueneme and Santa Barbara Harbour in California (SAVAGE, 1957; WIEGEL, 1959) among others.

In what follows we illustrate how one coastal use imple-

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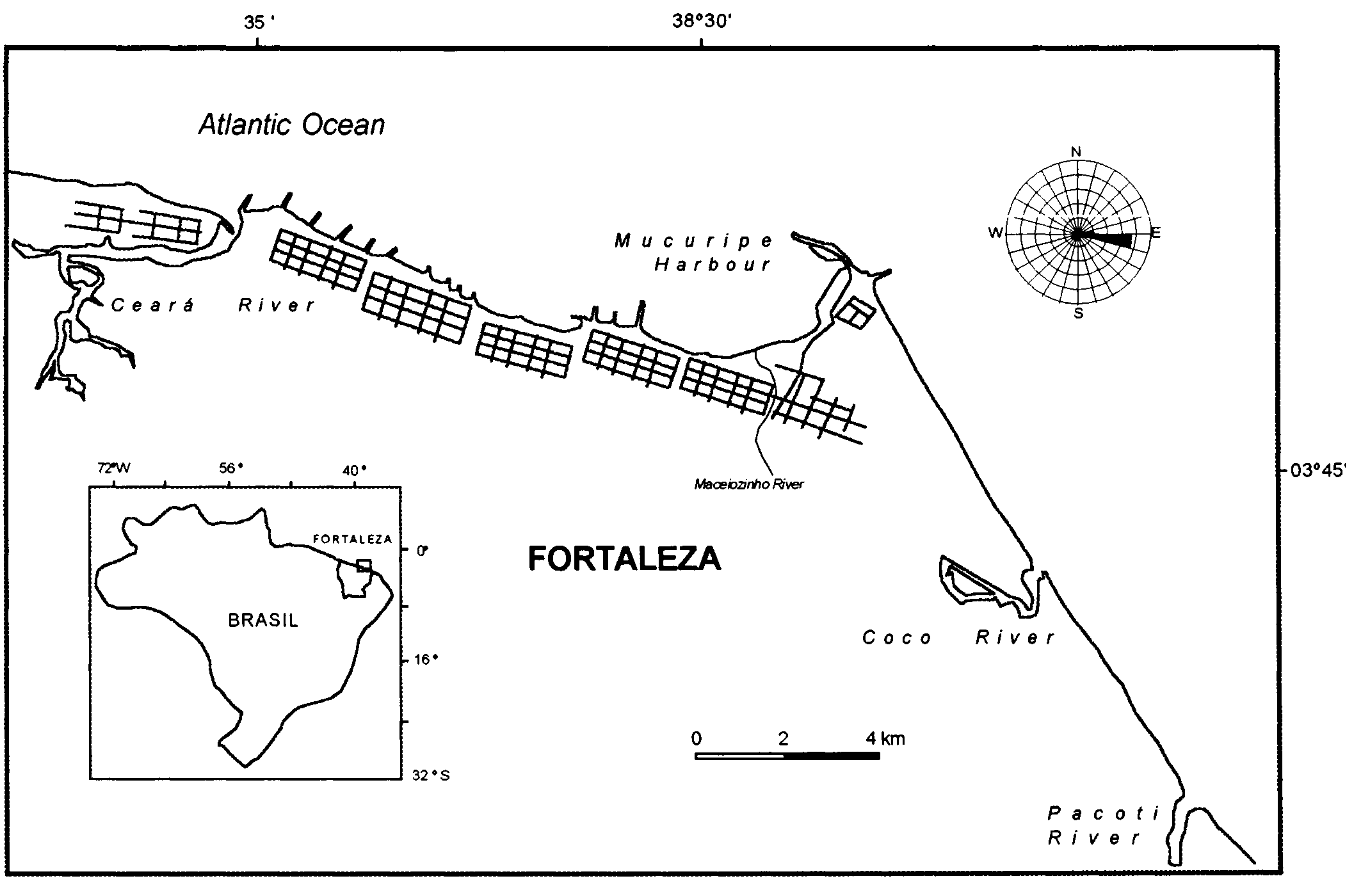

Figure 1. Map of the Fortaleza study area and wave directional distribution.

mented more than one century ago has determined the evolution of a specific resource, restricting the appearance of new uses, until the original resource is artificially restored. The case selected corresponds to the effects of a port development in Fortaleza (northeastern Brazil). The development of the port resulted in a continuous alteration of the resource (coastal fringe) as expected, but due to the local characteristics, also a continuous alteration of the use itself. Thus, the port had to be moved several times during its life because the dominant coastal dynamics along Fortaleza induced its siltation, making it non-operational. In all cases, the successive attempts to solve the problem were fixed only on the port and the attempts addressed the effects of the problem rather than its origin.

STUDY AREA

Fortaleza is on the northeastern Brazilian coast, in the Ceará state (Figure 1). The coastal zone of Ceará is about 572 km long, and it mainly consists of long sandy beaches, interrupted only by small river mouths and rocky headlands determining changes in the coastal orientation.

The main geomorphological feature is the former "Punta del Mucuripe" (presently Port of Mucuripe), a rocky headland splitting the coastline in two stretches with different orientations. Moreover, in the southeast part of Fortaleza large dune fields reach heights of up to 50 m.

The rivers have been classified as well mixed estuaries during times of high discharge, and salt wedges estuaries during the dry season. They presently are without any significant sediment supply (FREIRE and MAIA, 1991; MAIA *et al.* 1994). This area is a mesotidal environment, with a diurnal tide with a maximum astronomical range of 3 m. The local wave climate can be roughly described by a yearly averaged significant wave height, Hs, of 1 m, a mean period, Tz, of 5 sec and a full dominance of the eastern waves (see wave directional distribution in Figure 1). The wave characteristics and the coastal orientation determine a large angle between waves and coastline, which potentially induces very large longshore transport rates.

HISTORICAL ANTECEDENTS

The first attempt to create a port at Fortaleza was around the beginning of the nineteenth century. It was due to the interest of local authorities to promote and to improve the commercial activities in the zone. The first port facilities were built in 1807, consisting of a wooden pier, which was rapidly replaced by a larger one equipped with a crane (Figure 2). These first installations, although very simple and with lim-

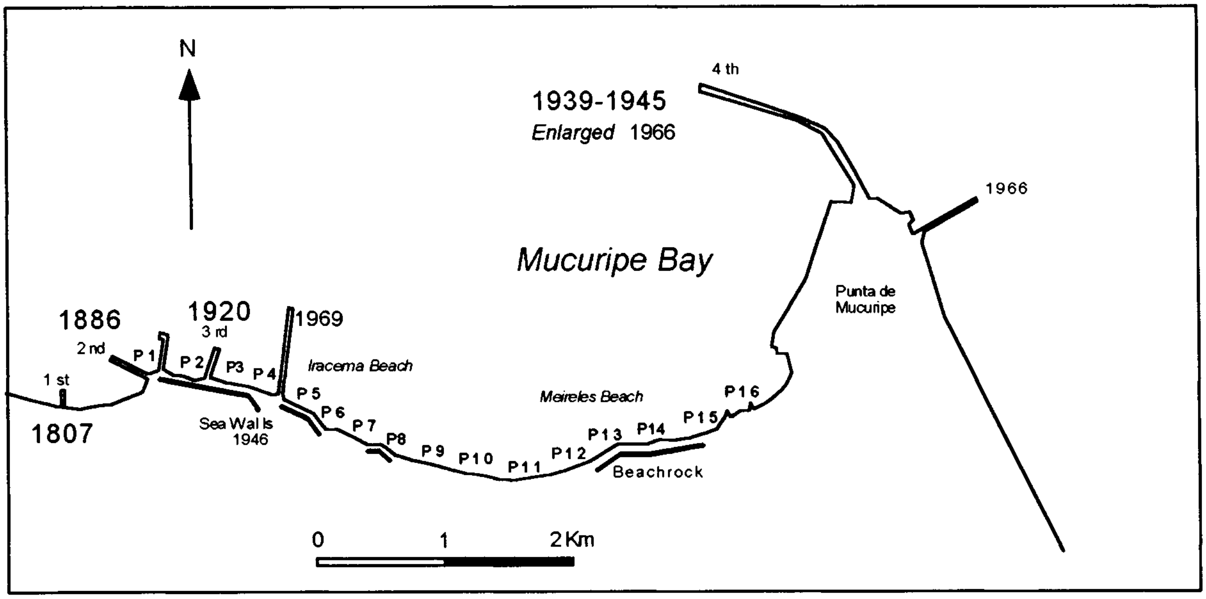

Figure 2. Map of Mucuripe Bay showing the different port construction and profiles locations.

ited dimensions, began to alter the littoral dynamics and they were rapidly disabled due to the induced sediment deposition which resulted in port siltation.

In 1825, the local bathymetry along Fortaleza was characterised by the presence of two large sand banks (Figure 3). A later bathymetric survey (1832) indicated that the local bathymetric characteristics remained similar, although showing some deepening at Punta del Mucuripe and shallowing waters towards the east. Although without too much accuracy, these data characterise the area as a zone with a large sediment supply and with a net longshore sediment transport directed towards the west.

Options to select a new port location were investigated. The original idea was to take advantage of the existing geomorphology to look for a sheltered zone and, at the same time, to select a location which minimised siltation.

At 1875 it was decided to build the new port around the reefs in the centre of the beach (Figure 2). This new project was finalised at 1886 and it consisted in a rocky breakwater built on the reefs with a total length of 670 m. It had two alignments, the first following the reef line, parallel to the coastline, with a length of 480 m and the second from its final point and following the direction E-W with a length of about 190 m (JOPPERT, 1936). During its construction, two important problems rapidly appeared: the formation of a very large bar upstream of the breakwater and the nearly complete siltation of the sheltered area.

In 1899, the coastline had advanced about 150 m along the breakwater and port facilities were no longer useful. To solve the problem, other construction was planned to block the sediment transport along the coast and to stop the sediment accumulation in the port. The coastal dunes were fixed (coastal dunes in the area are highly mobile with migration rates up to 10 m/yr) and several groins were built upstream of the port, but the problem persisted.

Due to these continuing problems, a new port configuration and location (the third) was selected and one pier was begun using steel piles around 1920–1926 (Figure 2). However, like the previous attempts, the installations were rapidly silted and ships with a draught greater than 4 m could not use it.

After this situation, new projects were presented to the local authorities to solve the question of where and how to design a port for Fortaleza, but due to technical and financial problems no action was taken until 1930, when the present port location was selected. This final location was the Punta de Mucuripe (Figure 2).

MODERN SITUATION

The new port at Punta del Mucuripe was composed by a main breakwater 1,400 m long, with a 10 m depth at the tip (Figure 2). The construction spanned the period 1939–1945 and at the time of construction three problems appeared simultaneously: (i) the breakwater was rapidly "filled" by sand, (ii) the breakwater did not shelter the area from eastern waves and (iii) beaches downstream of the port began to erode.

The main difference between this situation and the previous one is that during former times, the port influence was relatively local due to the dimensions of the installation and the location. However, with the most recent port site selected and its greater magnitude, a new boundary condition for the coastal stretch was introduced. In natural conditions, *i.e.* without the port, there was continuous sediment transport from the east part towards the west around the headland.

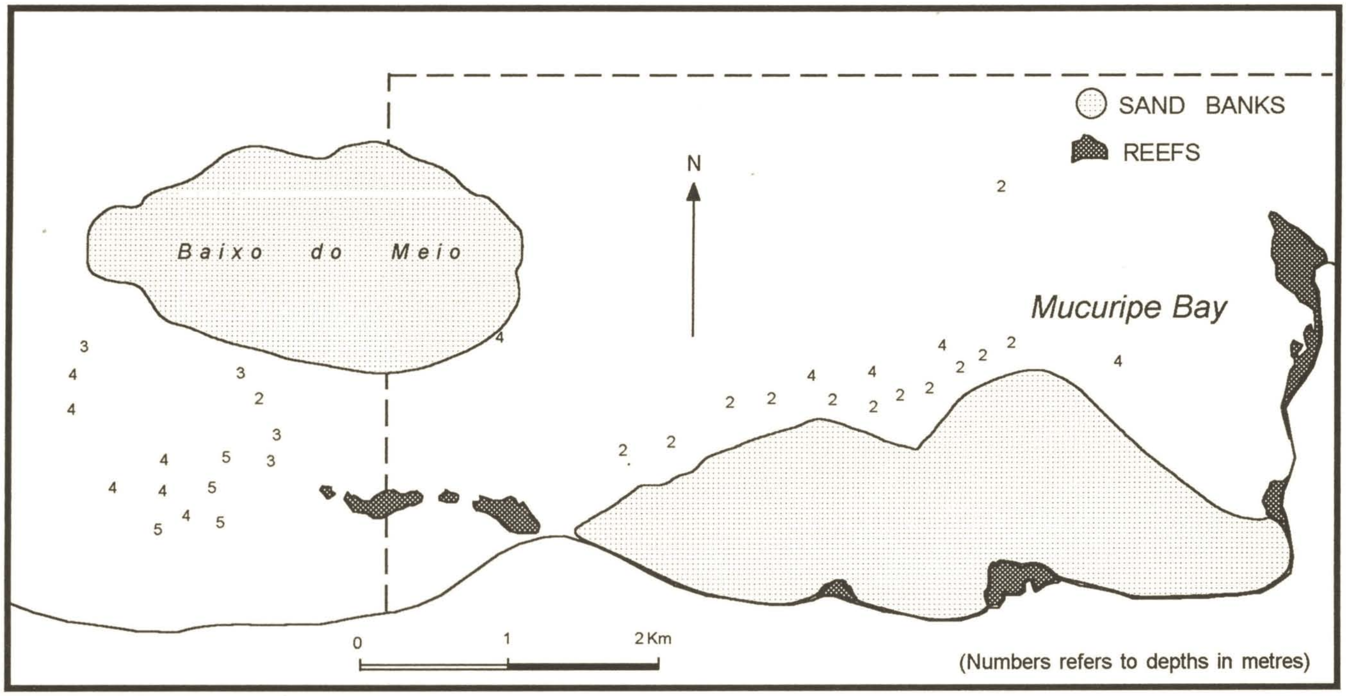

Figure 3. Bathymetry of the Fortaleza coast at 1825 (adapted from MORAIS, 1980), (dashed rectangle corresponds to Figure 2).

However, the construction of the port began to act as a barrier and to interrupt the longshore sediment transport.

Figure 4 shows the sediment blocking effect of the breakwater during its construction. At the beginning, the bathymetry was relatively parallel to the coast. As the breakwater was enlarged, the sediment was blocked and the shoreline advanced along the dike. Due to this shoreline advance, the sediment was able to bypass the breakwater, forming sand banks at the tip of the breakwater with a typical spit shape. This observed behaviour, typical of ports located in longshore sediment transport-dominated coasts (see *e.g.* WIEGEL, 1964), indicated that the sediment supply to the Bahia de Mucuripe beach had been cut off.

In order to analyse the induced changes along Fortaleza coastline after the most recent selection of the port location, 16 profile lines with a spacing of about 200 m along the coast have been selected (Figure 2).

Using the 1929 coastline as the baseline shore position representative of the situation before the Punta de Mucuripe port construction and comparing it with that just after the port construction (1947), large erosion is observed along the entire studied coastline (Figure 5). The average coastal retreat rate for this period is about 4.3 m/yr, with Iracema beach (profiles 7 to 9) the most affected zone with a maximum erosion rate of about 7 m/yr. At this location, several buildings and facilities were damaged due to the severe coastal erosion. The lowest recession was found at Meireles beach (profiles 12 to 14), with a shoreline recession rate of about 2 m/yr. This large difference in the shoreline behaviour was due to the presence of natural obstacles along the coast such as beachrock (Figure 2).

The interaction between the port and the existing littoral dynamics altered the natural sediment path along the coast, and large amounts of sediment were directed to deep waters from the tip of the breakwater, forming a linear sand bank parallel to the coastline at a depth of about 10 m, the original depth at the breakwater tip (see also BRUUN, 1981). The continuous growth of this bank as well as its behaviour (some migration was observed) altered the functioning of the harbour installations because the port approach channel was filled by sand bank movements.

The appearance of shoaling (Figure 6) as well as those associated with coastal erosion due to the damage of civil properties induced a new study to solve both questions. In concert with the study, several seawalls were built in the most eroded zones to reduce or control the coastal retreat. The study was performed on a physical model (SOGREAH, 1957) and the proposed solution consisted of the enlargement of the main breakwater and the construction of an additional groin eastwards of it to block the sediment by-pass. This construction was finalised in 1963.

If the situation after this construction (1964) is compared with the previous condition (1947) a generalised erosion is observed (Figure 5). The coastal retreat during this period decreased with respect to the previous one, reaching an averaged recession rate of 1.2 m/yr. This lower erosion was partly due to the implementation of the above-mentioned coastal protection works. However, in non-protected areas as

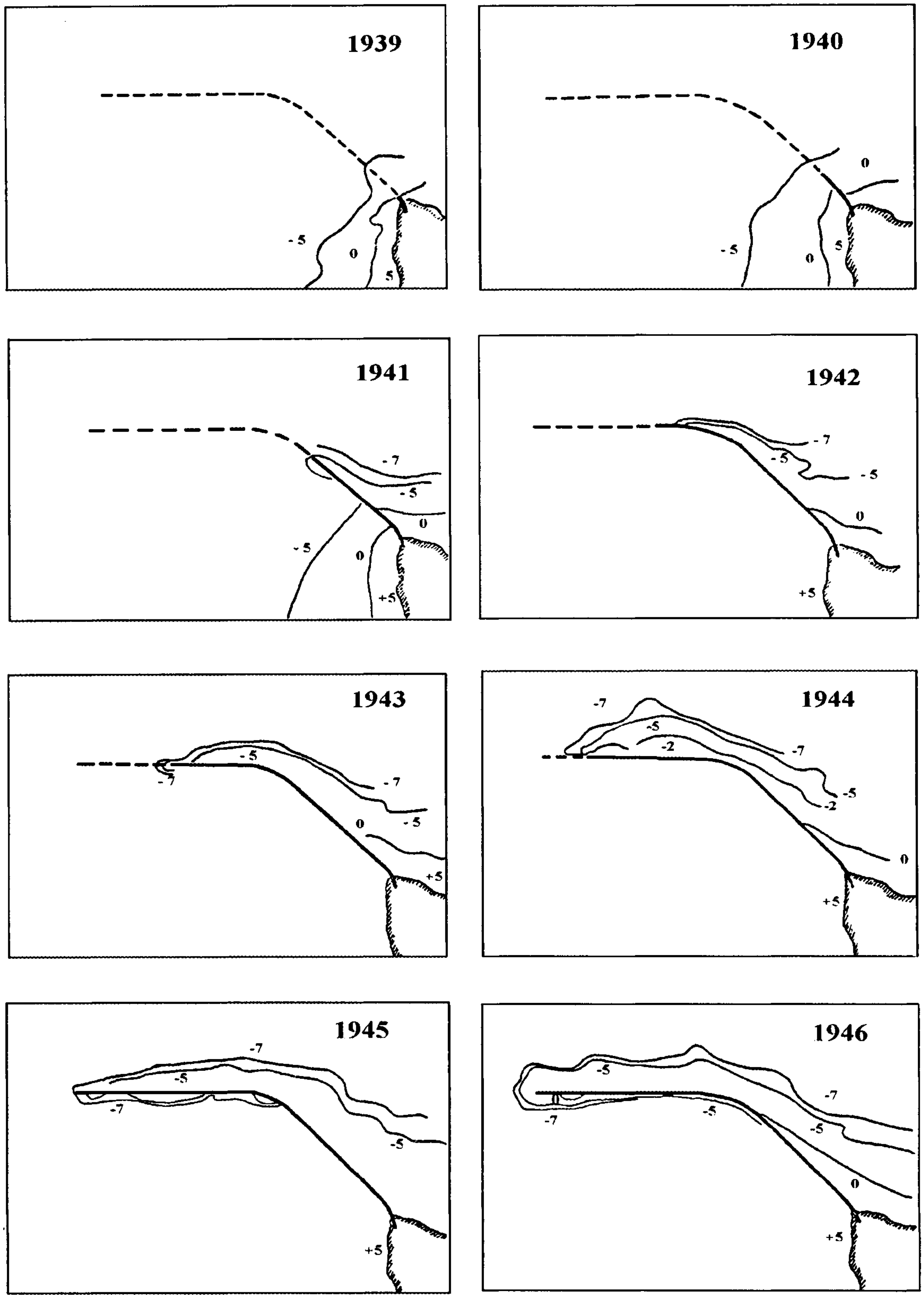

Figure 4. Bathymetric changes during the construction of the main breakwater of Port of Mucuripe (adapted from DNPVN, 1968).

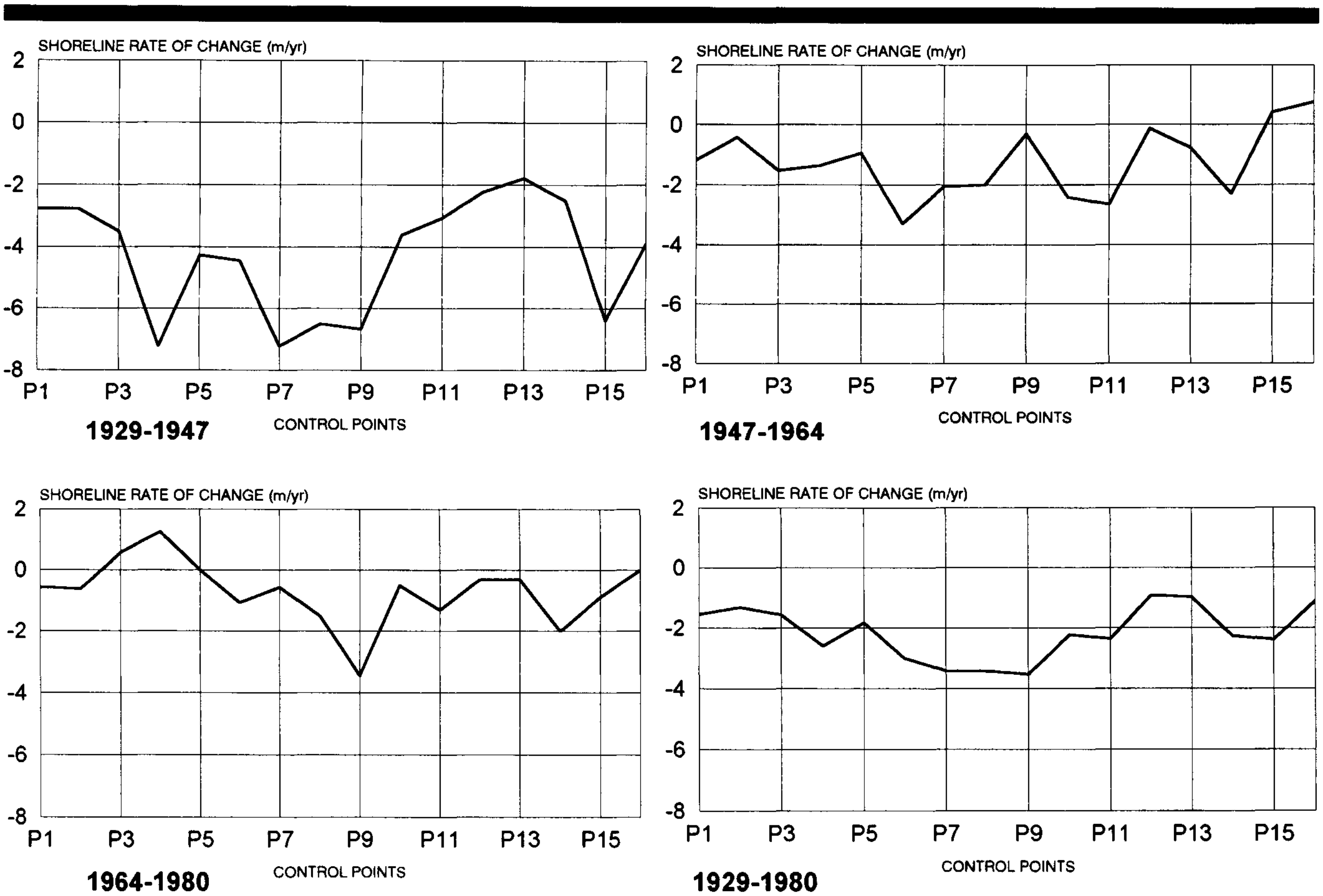

Figure 5. Shoreline rates of change along Mucuripe Bay.

Iracema beach, the coastal retreat was significantly larger reaching a value of about 3.3 m/yr.

Besides this erosive behaviour, in the sheltered area created at the leeside of the breakwater, the sediment began to be deposited, generating shoaling problems and local shoreline advance. This sediment deposition was produced by local currents induced by the diffraction of dominant eastern waves at the port breakwater this being a well documented mechanism for port siltation (see *e.g.* LEPETIT, 1976).

This wave diffraction induced current can be used to explain the migration of the Maceiozinho river mouth (see Figure 1 for location) from west to east, observed by MORAIS and PITOMBEIRA (1974), although these authors associated this migration with the sediment retention by the port.

From the harbour exploitation point of view, the breakwater enlargement as well as the building of the east groin improved the situation, although periodical dredging was required. However from the coastal stability point of view the erosive situation persisted and due to this, a new groin at the Iracema beach was built to mitigate coastal erosion.

During this last period, from 1964 to 1980, the coastline continued to erode, although at a lower magnitude, with an average recession rate of 0.7 m/yr (Figure 5). These lower values were due partly to the protective works and partly because some locations on the coastline reached a terminal condition, total disappearance of the subaerial beach (Figure 7). The accretion observed at the west part of the coast (points 3 and 4) was due to the construction of the groin at Iracema beach around the year 1969.

Because the problem was induced by the interruption of the longshore sediment transport, the selected coastal protection works, groins, only solved it from a local point of view but at the same time, they propagated the problem downdrift. This kind of solution led to the present situation in which the western city waterfront is protected by about 13 groins and the erosion is now taking place at the western neighbouring city of Caucaia.

DISCUSSION

The historical changes of the coastline of Fortaleza are intrinsically joined to the port development, as they are fully controlled by the net longshore sediment transport pattern which is an usual fact in worldwide coastlines (*e.g.* BRUUN, 1995). At former periods, this coastal stretch was characterised by a large sediment supply from the east. When the first port installations were placed on the Iracema beach, they

Figure 6. Sediment deposition in the leeside of Port of Mucuripe around 1950.

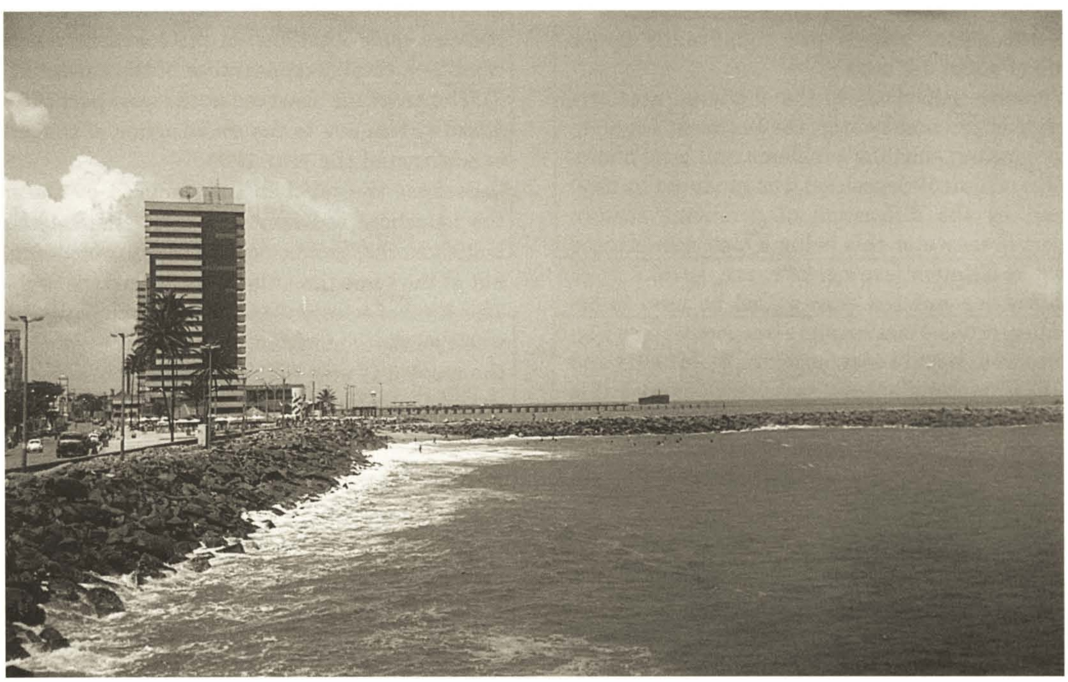

Figure 7. Waterfront at point 5 looking to the west showing a revetment and the absence of a beach.

were continuously shoaling, thus causing utilisation problems, but without inducing significant erosion problems.

At that time, the only interest was to obtain an operative port to promote commercial activities as well as to improve the city's maritime connections. During this period, the coastal management (if any) can be considered as port-use-oriented and all the efforts were devoted to this objective. Local coastal modifications were considered only inasmuch as they interfered with the port exploitation. In all the cases, the different choices for port location before the present one were badly exercised because in all of them siltation problems appeared instantaneously. Due to this problem, a new port location was selected at an optimum place only from the navigation point of view, without considering the possible coastal modifications.

The selected port location at Punta de Mucuripe changed the sedimentary balance because it acted as a barrier to the net longshore sediment transport and, at the same time, part of the sediment was directed to relatively deep waters. With the port construction, the westward coast began to erode severely and at the same time, the port installations shoaled. This situation introduced a new element in the local "coastal way of thinking" in the sense that under this scenario two problems had to be solved, port functioning and coastal erosion. Coastal erosion became a problem because it began to produce losses in the city infrastructure (roads and buildings were damaged) and then some protective works had to be implemented. The selected coastal protection measures, building of hard structures where severe erosion took place, were designed to try to solve the effects and not the origin of the problem (sedimentary deficit due to the blocking effect of the port). At this moment, the management is still port-oriented, although a small part of this management effort has to be devoted to protecting the coast.

The next step was again primarily directed to optimising the port facilities because due to the location selected, shoaling of the port continued. The solution adopted was to block the sediment by constructing a groin. This new solution was adopted without considering the coastal erosion already existing downcoast of the harbour, and because a more effective sediment blocking was achieved, coastal erosion problems persisted.

Moreover, due to the dominant wave climate (eastern waves) and the port orientation, wave diffraction induced currents were directed towards the sheltered port installations and, the shoaling continued although in this case related to these currents and not to the bypass of sediment from the eastern coast. This problem was solved in a specific manner by periodic dredging of harbour facilities.

Because coastal erosion continued, additional protection measures were taken, but as in previous cases, the solution was directed towards the effects rather than to the causes of the problem. Thus, more groins were built in such a way that erosion propagated towards the west and as result, the present city waterfront has 13 groins.

Although the described situation is regional, a paralelism with the scheme of ICZM implementation due to SORENSEN and MCCREARY (1990) can be done. This is relevant in the sense that as these authors recognized, ICZM may be initiated first at the regional scale before to extend to a national level.

The presented problem, common on many other coasts world-wide, is the result of a lack of integrated management of the coastal zone. This lack of planning can be assumed as normal in the earlier times, when the coast was not considered as a resource in itself but only as a door to commerce. During this stage, coastal city development is linked to port facilities and, all the efforts and priorities are devoted to improving harbour exploitation without any consideration of coastal stability. However, as described throughout the paper, because the interaction between use and resource was not considered, the use was inefficient since the original purpose (port service) was not achieved at any moment due to siltation problems. This situation can be described as a *no awareness* stage for ICZM because no attention was paid to manage coastal resources and uses.

As coastal erosion begins to affect the city itself as in the case described where some civil infrastructure was damaged (roads and some buildings), planners paid some attention to it. However, these problems were usually solved by looking to the effects and not to the causes. The reason for this was that the port continued to be the motor of city development and city planners' interest was still focused on it. This new situation can be described as an *incipient awareness* stage for ICZM and it was due to the appearance of coastal damages.

This approach to solve coastal erosion problems focusing on its effects and not on the origins, usually extends their magnitude. Thus, in the analysed case they locally solved the problems but at the same time they were also propagated along the coast, affecting a larger coastal stretch. Only when the coastal zone was seen as a resource to be conserved—as a consequence of tourism as a new use demanding resources—, did a real interest in coastal planning begin. This was because the new coastal use began (or expectation of) to be much more important for the city in economic terms than the port use. This can be described as an *incipient awareness* for ICZM although a step forward than before or, even, a *growing awareness* stage. It was due to the recognition of the existence of conflicts among different uses (port *versus* tourism) and to the extensive resource damage.

The ideal next steps in this history should be the *development of a program* for ICZM and finally its *implementation*. This would imply that a comprehensive study on coastal resources and uses would be launched to identify the factors controlling them, the links between them and the possible conflicts to be generated (or already existing). Finally, institutional arrangements to support the ICZM program must be created and implemented. An example should be the definition of a jurisdictional zone around the shoreline and the creation of some agency controlling coastal uses.

Although Brazil is implementing a National Coast Management Plan (CLARK, 1995), which is expected to create a framework to mitigate and/or avoid this kind of conflicts and problems, some inertia still exists. Thus, a plan to construct a port in Pecem, 50 km northwest of Fortaleza already exists. The location is a relatively virgin coastal area which is physically "identical" to the described here. In this sense, it is expected that the coastal problems observed in Fortaleza will be more or less reproduced in Pecem. Again, a specific coastal use is being favoured (the port will be used for fuel oil distribution and to deliver products of a steel industry to be also implemented) without paying attention to the existing coastal resources and possible future uses (the zone has a large potential for tourism development due to its unexploited natural characteristics).

CONCLUSIONS

The implementation of a coastal use (portuary in the described case) without considering the associated consumption or degradation of a coastal resource (coastal erosion and subsequent subaerial beach disappearance) will constraint new uses development (tourism) as well as adequate coastal resources management.

Moreover, when the coastal use is implemented without considering the intrinsic coastal system dynamics (the longshore sediment transport pattern in this case), the use itself can be strongly affected (port siltation) and even fully disabled (excessive limitation of ships draught).

Even in the case of a decreasing resource, when the economical benefits generated or expectation of them are a priority for planners, little attention is paid to the resource consumption (main interest to prevent port siltation and not to mitigate coastal erosion).

The interest in reversing or stopping the resource degradation only appears when a new coastal use, requiring the same resource, begins to be implemented (tourism). Unfortunately, in many cases the resource has already been extinguished (beach disappearance, see Figure 7) when this interest appeared.

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