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Anthropic impacts on the morphological and sedimentary processes in the coast of State of Paraná, in Southern Brazil: past and future perspectives

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ABSTRACT: This study aims to overview the anthropic impacts on the morphological and sedimentary processes on the coastal zone and propose studies and actions to contribute to coastal management. It also aims to present to a broad audience information about coastal works and projects only available in thesis and unpublished reports in Portuguese. This study analyzed historical documents and charts, aerial photographs and satellite images. The sites were visited to verify information on the field. The anthropization of the coast of State of Paraná, Brazil, was conducted without considering its effects on the coastal morphology, dynamics, and sedimentary processes; all past and present interventions have been proposed still disregarding these aspects. The dredging of channels to port access at sand bars composing ebb-tidal-deltas, which interrupts longshore drift, and consequently, sand deficit downdrift, can be considered the major impact on coastal dynamics. Moreover, natural and anthropic induced estuary silting represents a problem for navigation activities. A significant impact is caused by the obliteration of foredune ridges and urbanization over the beach dynamic fringe, which originates coastal erosion problems in several sectors in the region. The hard stabilization accelerates the process of sand beach loss; up to now, several beach erosion problems remain unsolved. In most of the cases, retreat occupation to release the beach dynamic fringe seems to be a viable solution, however, no projects considering this strategy have been proposed. Special attention is necessary to prevent interventions that could cause irreversible effects on coastal processes and result in more problems than solutions.

Keywords: coastal erosion, coastal management, erosion problems, foredune obliteration, coastal engineering works.

RESUMO: Este trabalho tem o objetivo de apresentar uma visão geral dos impactos antrópicos na morfologia e nos processos de sedimentação da zona costeira e propor estudos e ações que contribuam com o seu manejo. Também visa apresentar para uma audiência mais ampla informações sobre obras e projetos costeiros disponíveis apenas em português em dissertações, teses e relatórios inéditos. O trabalho foi desenvolvido a partir da análise de cartas e documentos

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históricos, fotografias aéreas, imagens de satélite e verificações de campo. A antropização da costa do Estado do paraná, Brasil, foi realizada sem considerar os seus efeitos na morfologia, dinâmica costeira e processos de sedimentação. Ademais, até o presente são propostas intervenções que não consideram estes efeitos. As dragagens dos canais de acesso aos portos, nos bancos que constituem os deltas de maré vazante, podem ser consideradas uma das ações antrópicas que maior impacto apresenta sobre a dinâmica costeira. Os profundos canais dragados interrompem a deriva litorânea e causam déficit de sedimentos a jusante. Também, o assoreamento natural e induzido dos estuários permanece como um problema para a navegação. Outro impacto significativo foi causado pela remoção dos cordões de dunas frontais e a urbanização sobre a praia e a faixa dinâmica da praia, o que tem gerado diversos problemas de erosão costeira. A estabilização com obras rígidas têm acelerado as perdas de areia das praias. Até o presente diversos problemas de erosão permanecem sem solução. Na maioria dos casos, o recuo da ocupação para liberar a faixa dinâmica da praia parece ser uma solução viável, porém não há projetos nesse sentido. Muita atenção é necessária para evitar que sejam executadas obras que gerem efeitos irreversíveis nos processos costeiros e causem mais problemas do que tragam soluções.

Palavras-chave: erosão costeira, manejo costeiro, problemas de erosão, remoção de dunas, obras de engenharia costeira.

1. INTRODUCTION

At present, the coast of State of Paraná, Brazil, presents a wide range of occupation showing high contrasting sites from natural to highly anthropized conditions. Throughout human occupation, the coast of Paraná has been submitted to different interventions such as deforestation and farming on the hydrographic basin; hydrographic net modification; estuary and inner-shelf dredging for navigation purposes; mangrove, foredune obliteration, and littoral fringe occupation for recreational activities; and coastline artificialization produced by engineering works. However, little attention has been given to the effects of anthropization on the coastal morphological and sedimentary processes.

This study aims to overview the anthropic impacts on the morphological and sedimentary processes on the coastal zone and to propose studies and actions to contribute to coastal management. It also aims to present to broad audience information about coastal works and projects only available in thesis and unpublished reports in Portuguese. This study analyzed historical documents and charts, aerial photographs, satellite images and field verifications.

There were analyzed actions and their effects related to estuary and inner-shelf dredging, estuary silting, mangrove obliteration and foredune obliteration, dynamic beach fringe occupation, coastline artificialization through engineering works and drainage system modification.

2. REGIONAL SETTING

2.1. Location

The coastal zone of the State of Paraná, is located at 25^{o}–26^{o} S latitude and includes seven municipalities: Guaraqueçaba, Morretes, Antonina, Pontal do Paraná, Paranaguá, Matinhos, and Guaratuba; which includes the harbor cities of Paranaguá and Antonia, the coastal touristic cities of Matinhos and Guaratuba and a continuous occupation by resorts along the open sea coast form Pontal do Sul to Barra do Saí (Figure 1).

2.2. Watershed

Regarding sedimentary processes, this coastal zone corresponds to watershed basins spanning an area of 6,000 km^2 (Figure 2). The drainage system is dominated by the watersheds of Paranaguá (~3.9 x 10^3 km^2) and Guaratuba (~1.9 x 10^3 km^2) estuarine complexes (Angulo, 1992) together with several smaller watersheds (Figure 2). These watershed basins are characterized by steep-gradient streams at the mountains and low-gradient streams at the coastal plain. Fluvial water discharge to Paranaguá bay has been estimated as 200 m^3/s during the raining season and suspended sediment discharge as 355 ton/day (Mantovanelli *et al.*, 2004).

2.3. Relief

The coastal zone is characterized by wide (up to 55 km) Quaternary coastal plains and large estuarine complexes, backed by mainland plateaus (800-1000 m high) and the Serra do Mar mountain range that reaches over 1500 m in altitude (Figure 3). The topographic gradient of the inner-shelf varies from 1/65 to 1/700 (Veiga *et al.*, 2004; Figure 3).

2.4. Geology

The coastal zone contains Achaean to Mesozoic crystalline rocks and Cenozoic continental and coastal sedimentary deposits. The coastal ones include present and paleo-estuarine, deltaic, tidal-deltas, tidal-flat, aeolian, beach, shoreface, and inner-shelf deposits (Angulo, 2004). Two regressive barriers are recognised;

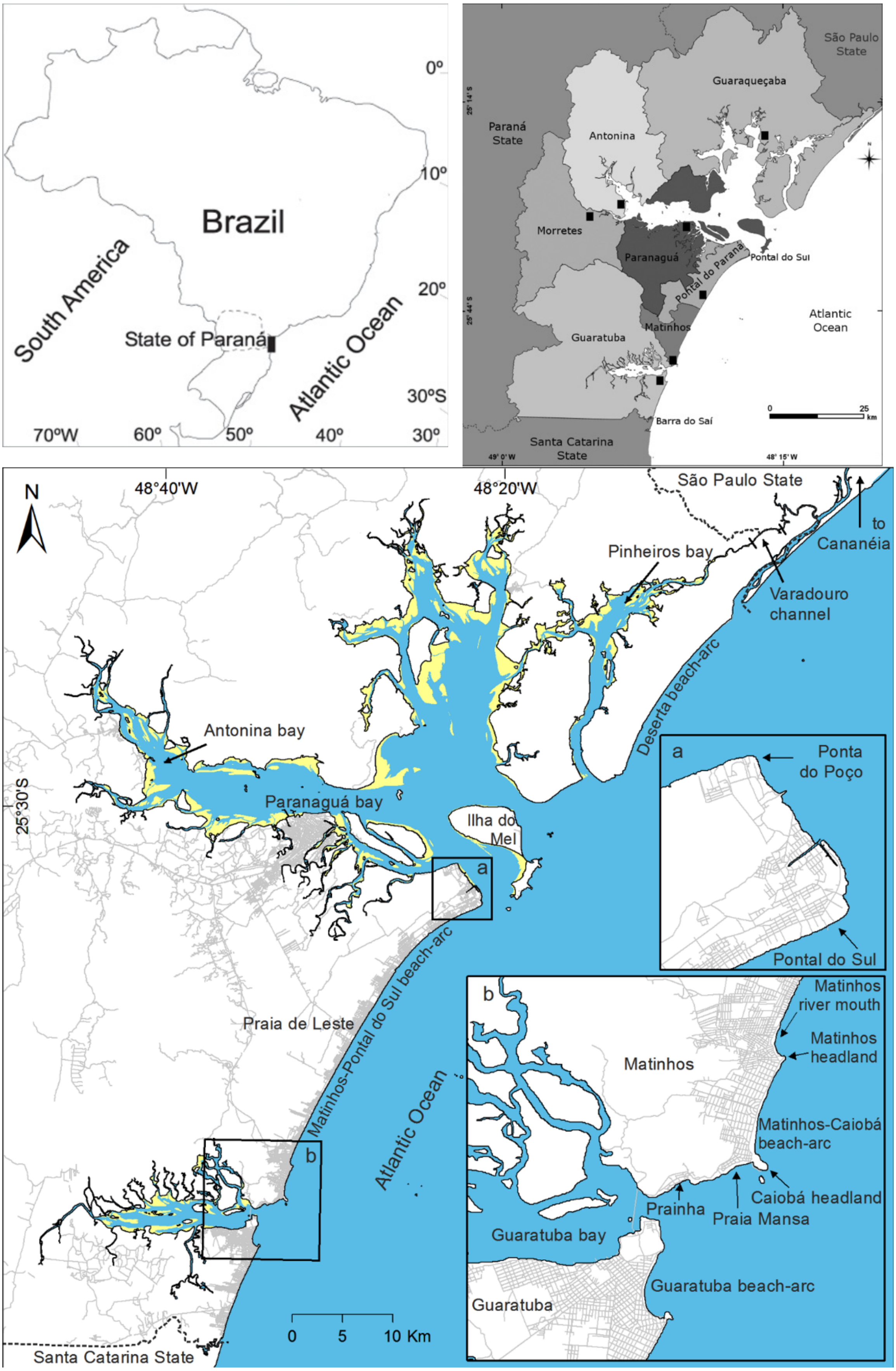

Figure 1. Location, municipalities, cities and main anthropized sectors of Paraná coastal zone (After IBGE, 2000 and Angulo *et al.*, 2018).

one corresponding to the last interglacial or 5e isotopic stage (~120,000 years BP) that can reach 13 km in width, and one corresponding to the last postglacial stage (7,000 years BP to present) that can be up to 5 km wide (Figure 4). The barriers associate with paleo-estuarine plains, and these plains bring evidence that estuarine sizes were larger when sea levels were higher than the current ones (Angulo *et al.*, 2009). The beach sediments are composed mainly of well-sorted medium to very fine quartzose sand with variable rates of heavy mineral and bioclastic carbonate (Bigarella *et al.*, 1966; Bigarella *et al.*, 1969; Bigarella *et al.*, 1970/71; Angulo *et al.*,

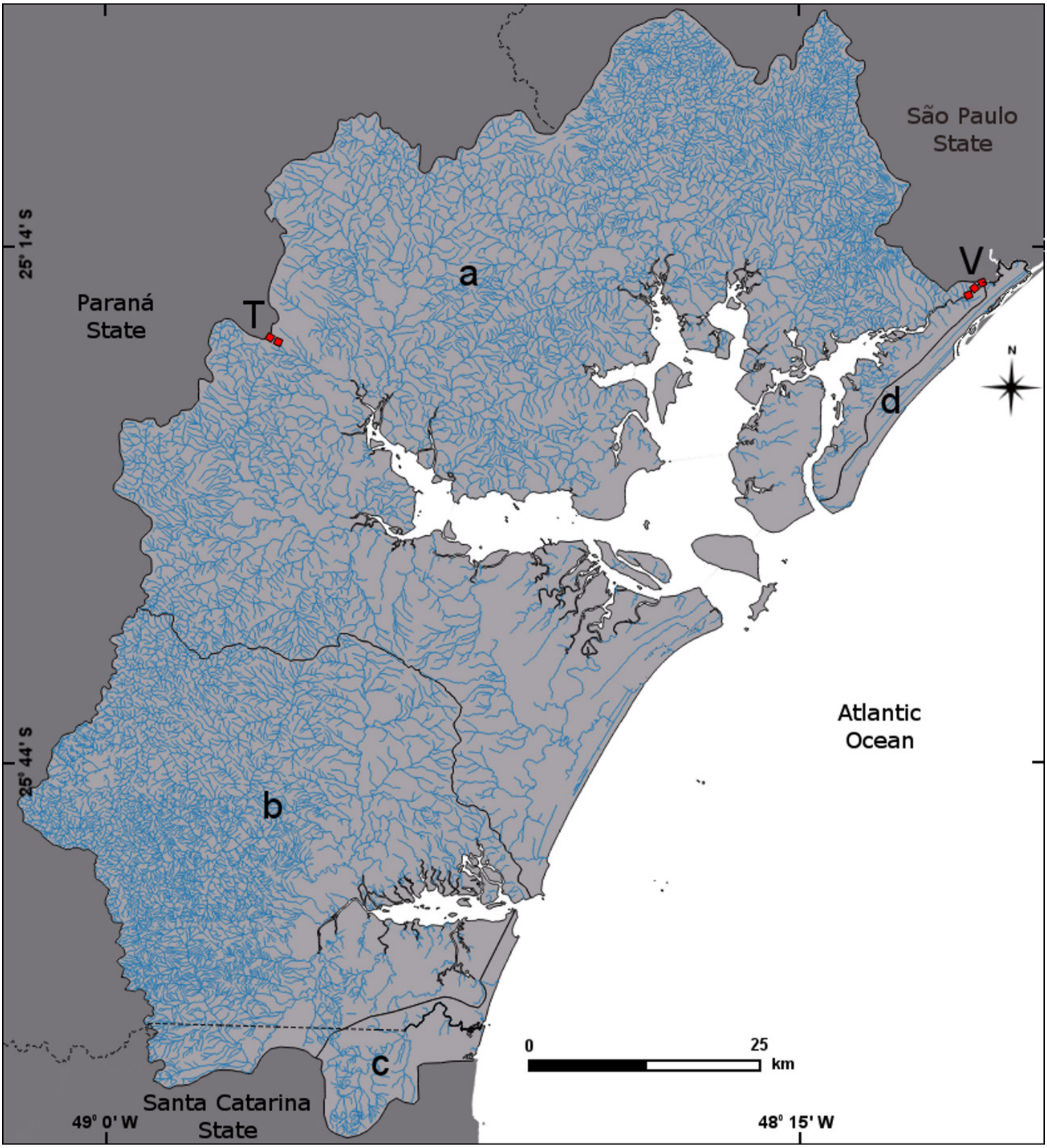

Figure 2. Watershed basins in the State of Paraná coastal zone: (a) Paranaguá, (b) Guaratuba, (c) Saí-Guaçu, and (d) Ararapira. (V) Varadouro artificial channel, (T) Capivari-Cachoeira watershed diversion (After Noernberg *et al.*, 1997).

1996; Mihály, 1997; Giannini *et al.*, 2004). The beaches are wave-dominated along the open coast and tidally-modified inside the estuaries (Angulo *et al.*, 2016). At the estuary mouths, large ebb-tidal-deltas influence the transport and sedimentary budget of beach sand, and cause shifts in hundreds of meters in the shoreline within periods of a few (less than 10) years (Angulo, 1993; Angulo *et al.*, 2016) and erosion rates until 200 m/year (Angulo *et al.*, 2018). Conversely, the open ocean coast, away from the influence of ebb-tidal deltas, has remained stable (less than 40 m shift) over the last 5-6 decades, with a maximum rate of 5 m/year, (Angulo *et al.*, 2018), which corresponds to erosive and depositional seasonal, annual or interannual periods related to wave climate variations, but remain stable at decadal periods.

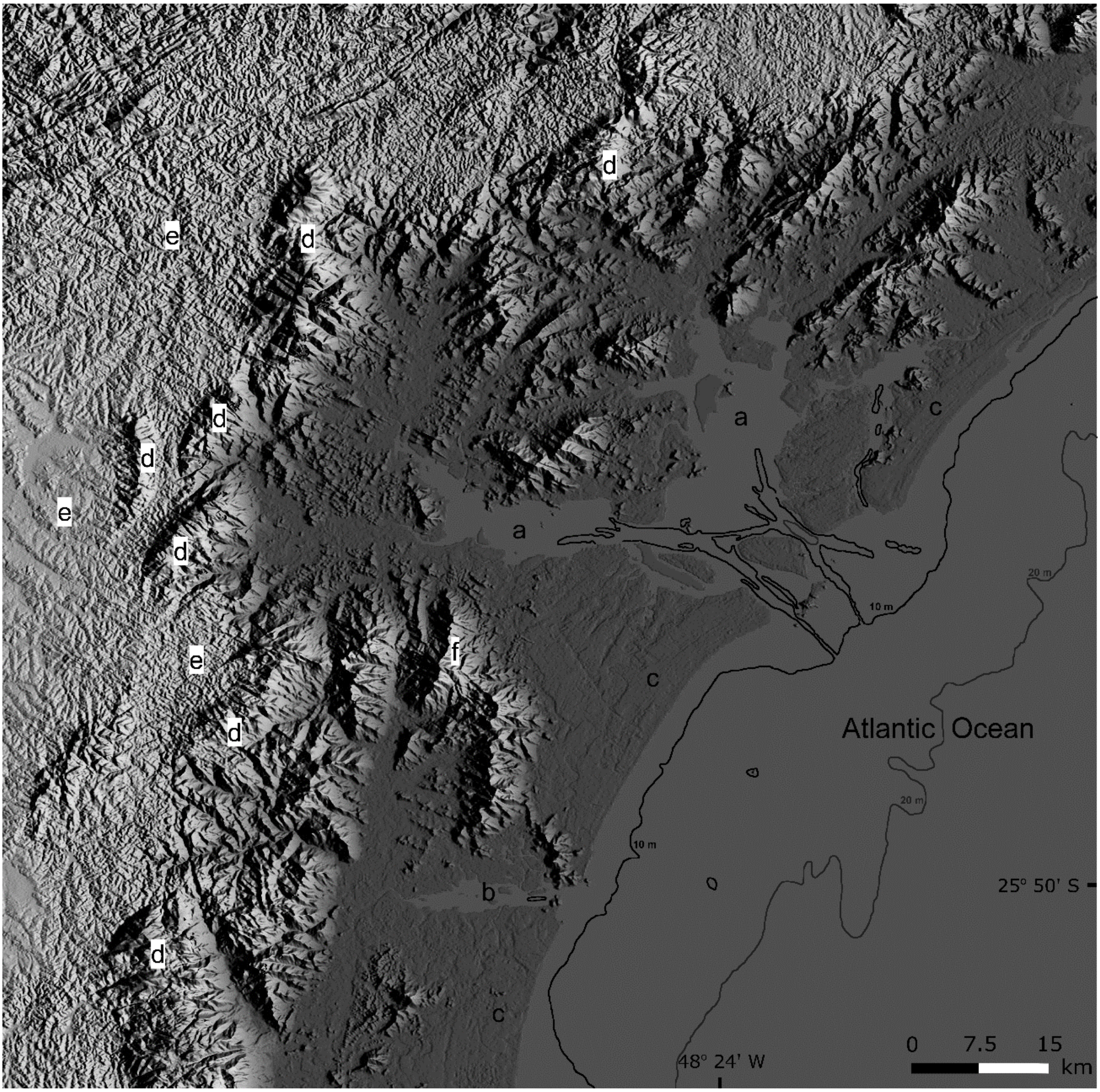

Figure 3. Relief of the State of Paraná coastal zone: (a) Paranaguá and (b) Guaratuba estuaries, (c) coastal plain, (d) Serra do Mar mountain range, and (e) Curitiba plateau (Sources: SRTM data – 90 m and DHN Nautical Chart – n. 1821).

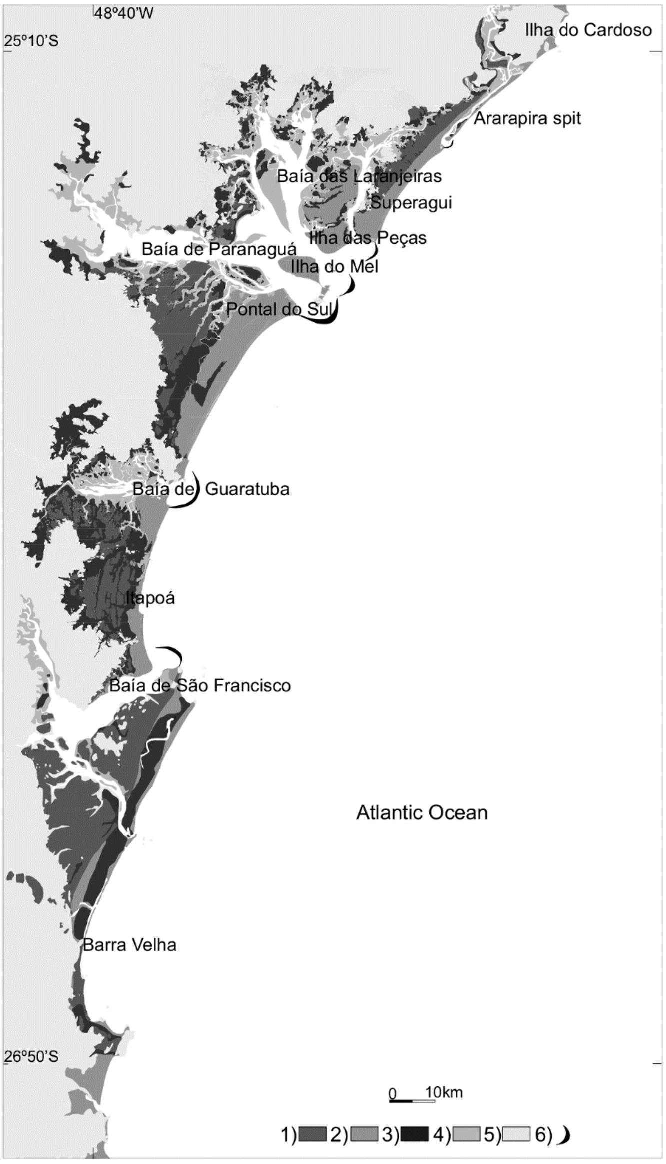

Figure 4. Quaternary geology from Barra Velha to Ilha do Cardoso coastal plains. (1) Pleistocene barriers, (2) Holocene barriers, (3) paleo-estuarine plains, (4) present tidal-flats, (5) other units, (6) ebb-tidal deltas (After Angulo *et al.*, 2009).

2.5. Climate

The local climate is controlled by the displacement of the semi-permanent anti-cyclone gyre in the South Atlantic, and by the passage of cold polar masses in the winter (Angulo *et al.*, 2016). The annual mean temperature is 21.5° C (Ipardes, 1995) and the mean annual rainfall was 2,363 mm between 1997 and 2003 (Vanhoni and Mendonça, 2008). The prevailing winds come from east, southeast, and south (Fomin, 2013).

2.6. Tides and waves

The tide along the coast of Paraná is semidiurnal. The spring tidal range is about 1.5 m and the tidal wave propagates into the estuaries as a progressive wave with a range increasing up to 2.2 m in the inner sector of the Paranaguá estuarine complex, transitioning from micro-tidal to meso-tidal conditions (Marone and Jamiyanaa, 1997). During storm surges, the water levels can reach up to 80 cm above astronomical tides (Marone and Camargo, 1994).

The mean significant wave height at the depth of 18 is 1.6 m with a significant wave height of 4.8 m, the mean peak wave period is 8.4 s and maximum of 17.8 s (Angulo *et al.*, 2016) The predominant wave direction, between July 2009 and June 2010, is south-southeast (28%), southeast (25%), south (21%) and east-southeast (16%) (Nemes and Marone, 2013).

2.7. Longshore drift

On the coast of Paraná, sand is transported by wave-driven longshore currents, toward both north and south, by the two opposing south-southeastern and east-northeastern wave systems (Angulo *et al.*, 2016). There are no confident measurements of longshore currents. The net longshore drift is not well-known; however, the best estimative indicates a northerly net sand transport at rates in the order of 10^4 –10^5 m^3 per year (Sayão, 1989; Lessa *et al.*, 2000; Lamour, 2000; Lamour *et al.*, 2006).

3. MATERIAL AND METHODS

This study analyzed historical documents and charts, which are indicated in the corresponding item along the text. The following material was used: digitalized aerial photographs from 1953-55 and 1980, scale 1:25.000, and 1963, scale 1:60.000; georeferenced IKONOS satellite images from August 8th 2002 and 4 m of spatial resolution; and Landsat OLI images from June 13th 2016 and 15 m of spatial resolution. The aerial photographs were georeferenced using the Envi 4.2® software to compare with IKONOS images. The mangrove areas were obtained through visual interpretation and field verifications. The sites were visited to verify information on the field.

4. RESULTS

The Paraná coastal zone was settled between 7,000 and 1,000 years ago by a prehistoric population called *sambaquieiros* (Gaspar, 1996), whose occupation left almost three hundred shell-middens along the Paraná coastal zone (Bigarella, 1950/51a; Bigarella, 1950/51b; Parellada and Gottardi Neto, 1994). These impressive landmarks could reach 20,000 m^2 in basal area and 17 m in height (Ipardes, 1995). Shell-middens were frequently built up near ancient coastlines, however, no evidence that they could have interfered with coastal dynamics have been found. Later on, the region was occupied by Carijós (Santos, 1850), a linguistic group related to Tupi-Guarani (Rodrigues, 1985), which left no landmark behind. At the beginning of the 16th century, Portuguese people arrived in the region and settled at Superagüi and Ilha da Cotinga at the inner part of the Paranaguá Bay (Maack, 1968, Figure 5). In that century, the harbor was located on Cotinga Island, and after that, in Antonina and Paranaguá (Maack, 1968, Figure 5). Subsequently, several villages of farmers and fisherman were settled in the region (Maack, 1968). In the 1920s, the occupation for summertime vacations began mainly represented by non-primary residences (Bigarella, 1991). A marked coastal anthropization has been occurring since the 1950s when the intensification of a summer recreation occupation occurred at the ocean shoreline with sandy beaches (Sampaio, 2006) and when several channels were dredged to improve navigation or to make drain wetlands a little drier.

Currently, the anthropic processes in the Paraná coastal zone are related to farming, power generation, harbor activities, tourism, and recreation. The main actions and their effects related to these processes are: (a) estuary and inner-shelf dredging, (b) estuary silting, (c) mangrove obliteration, (d) foredune obliteration and beach and dynamic beach fringe occupation, (e) coastline artificialization through engineering works such as sea-walls, groins, and jetties, and (f) drainage system modification by open artificial channels, which connect different watersheds (Figure 2).

4.1. Estuary and inner-shelf dredging

Dredging related to navigation activities was performed in the coast of Paraná. A channel was dredged along the Paranaguá-Antonina estuary and the inner-shelf navigation to give access to the ports (Figure 5). At the inner part of the estuary, dredging activities removed muddy contaminated sediments that were disposed of next (800 m) to the dredging areas without confinement (Lamour and Soares, 2007), which propitiated sediment return to the dredged areas. Dredged sediments were used to fill up reclamation areas to diminish or solve this problem in the Ponta do Felix harbor (Lamour and Soares, 2007; Figure 5). The building of artificial islands was also proposed use of disposed of dredged sediments (Lamour and Soares, 2007).

Part of the navigation channels was dredged on sand bars, which constituted ebb-tidal-deltas associated to the

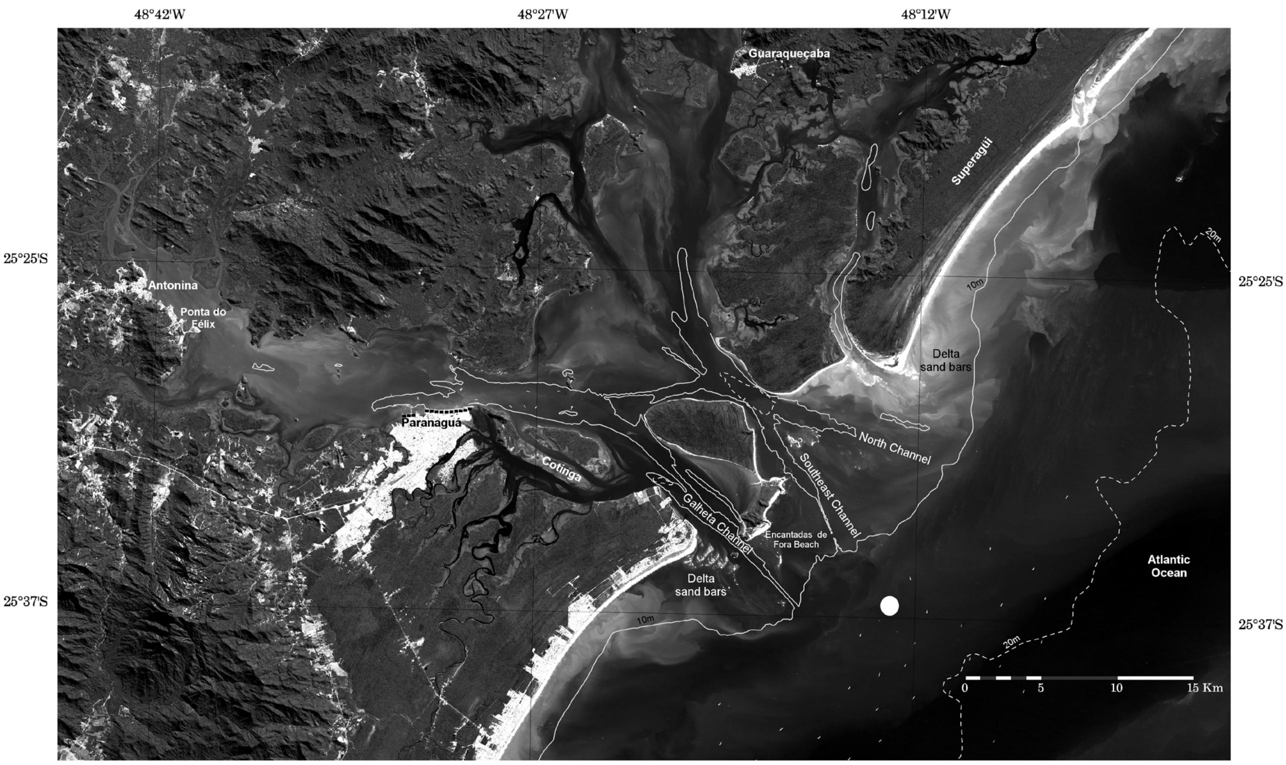

Figure 5. Paraná harbors, their access channels, and the authorized area for sediment disposal (white circle). Paranaguá harbor (dashed line). Notice the breaking waves (white areas) over the shallow (<10 m) ebb-tidal delta sand bars (Sources: Landsat 8 – OLI, July 12, 2016 and DHN Nautical Chart – N. 1821).

estuarine complex inlets (Angulo, 1999; Figure 5). At natural conditions, the top of the sand bars is 3-5 m below mean spring low-tide level. The sand bars were dredged to give access to the ports inside the estuaries, first in the Northern and Southeastern channels, and later in the Galheta Channel (Lamour and Soares, 2007; Figure 5). In 1930, the channel was dredged up to 8 m below mean spring low-tide level deep and progressively deepen until it reached 15 m below that level in 1998 (Lamour and Soares, 2007). The silting rates of this channel sector were estimated in 2.3 10^5 to 2.6 10^6 m^3 per year (Lamour and Soares, 2007). Under natural conditions, the sandy sediments are transported from south (Barra Velha at 25° 39'S) to the north (Cardoso Island at 25° 09'S) by longshore currents, forming ebb-tidal deltas as they bypass estuarine inlets (Lessa *et al.*, 2000, Figure 4) that was interrupted by the São Francisco do Sul and Paranaguá harbor access channels (Angulo *et al.*, 2006a; Figure 4). This interruption generated sand deficit downdrift in the São Francisco do Sul access channel, which was evidenced by the reduction of 7.7 x 10^6 m^3 of the sand volume in the downdrift part of the ebb-tidal-deltas and severe coastal erosion (Angulo *et al.*, 2006a). The dredged sand is usually disposed in the inner-shelf of authorized areas (Lamour and Soares, 2007; Angulo *et al.*, 2006a; Figure 5), and therefore, the sand is removed from the coastal system. This sand presents similar granulometric and compositional characteristics of that of sand beaches and is not contaminated; therefore, it could be used for beach nourishment or another function (Angulo *et al.*, 2006a; Simões Neto *et al.*, 2017). A particular situation was observed at the Ilha do Mel island, located down-drift to the Paranaguá harbor access channel where intense coastal accretion and progradation occur (Angulo *et al.*, 2016; Figure 6). This unexpected sand supply was attributed to the disposal of dredged sediment in shallow areas near the coast where they can be transported by longshore currents and deposited on the beach and foredunes (Angulo *et al.*, 2016; Figure 5).

4.2. Estuary silting

Estuaries are ephemeral physiographic features that are rapidly (thousands of years) filled up by natural sedimentation. In the Paraná coastal zone, the maximum extensions of estuaries occurred 6,000-5,000 years before present during + 3 m eustatic sea-level maximum (Angulo *et al.*, 2009). During sealevel fall the depth was reduced, and estuaries were partially or filled up (Angulo *et al.*, 2009). Currently, the high relief of the hydrographic basin and the warm and rainy climate provide high sediment availability and high erosion potential. Since the XV century, the estuary hydrographic basins were used for farming and mining (Maack, 1968). These activities increase sediment erosion and transport and favor estuary silting. In the 1970s, Bigarella *et al.* (1978) alert that the Serra do Mar mountain deforestation would cause an accelerated silting of the Paranaguá estuary complex, but no confident data is available. In the 1980s, several protection laws inhibited deforestation (Paraná, 1987; Ipardes, 1989) and decreased soil erosion and sediment supply to these estuaries.

In the 1970s, part of the Capivari River discharge was transposed to the Cachoeira River, which is a tributary of the Antonina estuary, due to construction to hydropower generation plant (Figure 2). This transposition increased the Cachoeira River annual mean flow from 21.1 $m^3 .s^{-1}$ to 31.5 $m^3 .s^{-1}$, which seems to have promoted the erosion of the river channel and bars and sedimentation in the estuary (Branco, 2004). In the Antonina estuary, which is part of the Paranaguá estuarine complex (Figure 2), a significant silting process was verified where 60 $.10^6$ m^3 of sediments were deposited in an area of 25 km^2 between 1901 and

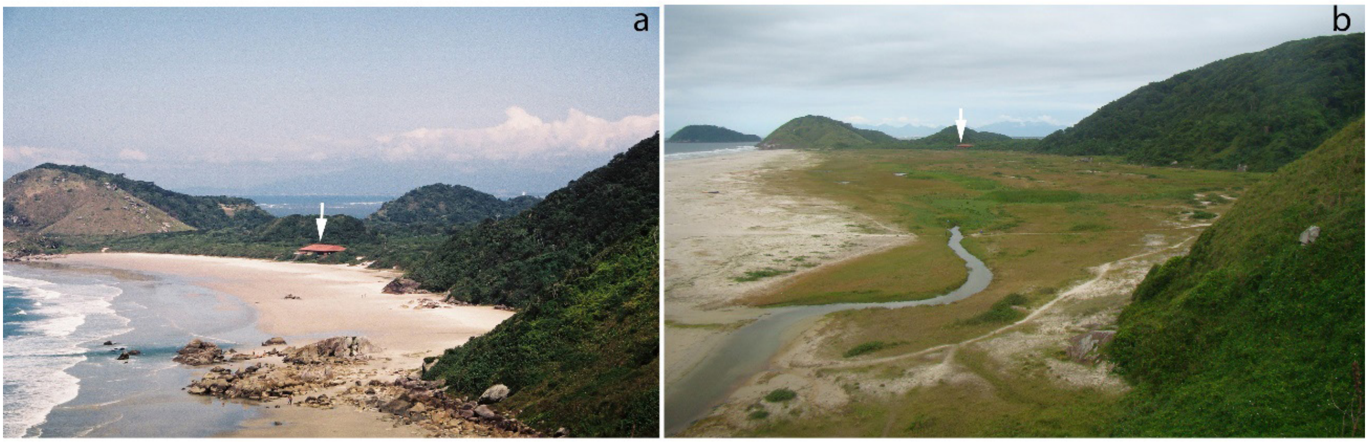

Figure 6. Encantadas de Fora beach at Ilha do Mel (a) in 2004 and (b) in 2016. The building (harrow) location is a reference to the intense coastal accretion (see location in Figure 5).

1979 (Odreski *et al.*, 2003). Therefore, the infilling of these estuaries resulted from natural and anthropic causes. Probably, the natural infilling was accelerated due to the use of basin areas, however, it is not clear which part of the estuary silting corresponds to natural or anthropic causes; the last one was generated mainly through deforestation and river transposition.

4.3. Mangrove obliteration

Most of the estuarine bars in Paraná are fringed by mangroves and tidal swamps covering an area of 377 km^2. These ecosystems are protected by strict environmental laws that prohibit their removal except for relevant social interest purposes (Brasil, 1965; Brasil, 2012). An area of 1.3 km^2 has been obliterated by harbor and recreation harbor activities in the coast of Paraná. The harbor expansion obliterated 0.1 km^2 of mangroves in Paranaguá (Figure 7) and 0.2 km^2 in Antonina. Moreover, irregular occupation expanded over mangroves areas obliterated 0.65 km^2 in Paranaguá city (Figure 8) and 0.05 km^2 in Antonina city. Guaratuba estuary mangrove areas have been removed for recreation harbors since the 1980s (Figure 9). In this sector, 0.22 km^2 of mangrove area have been removed until 2016 (Figure 9).

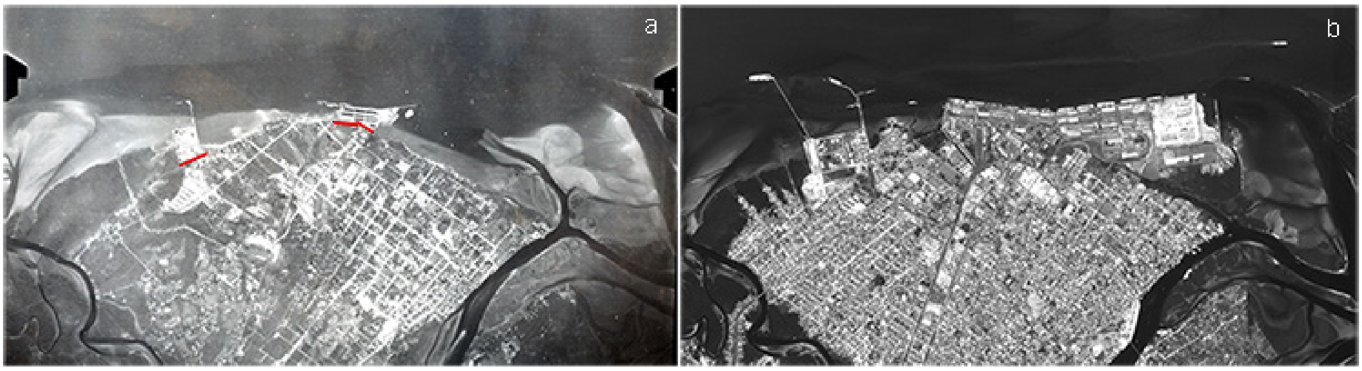

Figure 7. Paranaguá harbor (a) in 1953 and (b) 2002. Inferred natural former coastline (red solid line; see location in Figure 5).

Figure 8. Two views of (a) harbor facilities and (b) irregular urban occupations, over mangroves area in the west part of Paranaguá city in 1998.

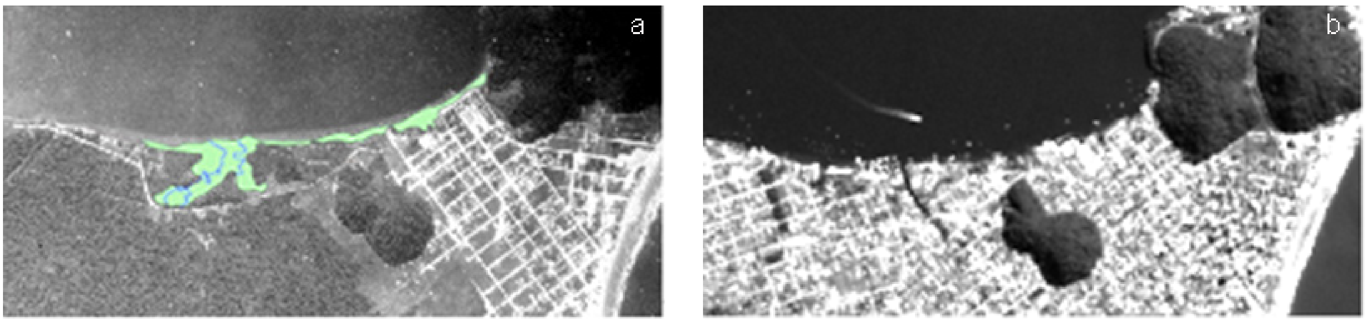

Figure 9. Estuarine Guaratuba city coast (a) in 1953 (mangroves highlighted in green) and (b) in 2016 (see location in Figure 1).

4.4. Drainage system modification

In the 1960s, the estuaries of Mar do Ararapira and Pinheiros Bay were connected through the construction of an artificial channel, named Varadouro, to facilitate navigation between the Cananéia and Paranaguá estuarine complexes (Figure 1). There are no studies about the possible alterations in tidal currents, sediment transport, and water interchange between these estuaries that were induced by this channel. A large system of drainage channels was dug at the central-southern coastal sector of the coast of Paraná, which changes dramatically the fluvial drainage of the coastal plain. In Pontal do Sul, the channel intercepts rivers and groundwater flows. At their mouth, the channel's flux interrupts the longshore drift and causes severe erosion downdrift (Figure 10). This effect was later increased by the implantation of a jetty. In other sectors of the coastal plain, the channel-network originated swamp areas as the result of the channels low slope (Figure 11).

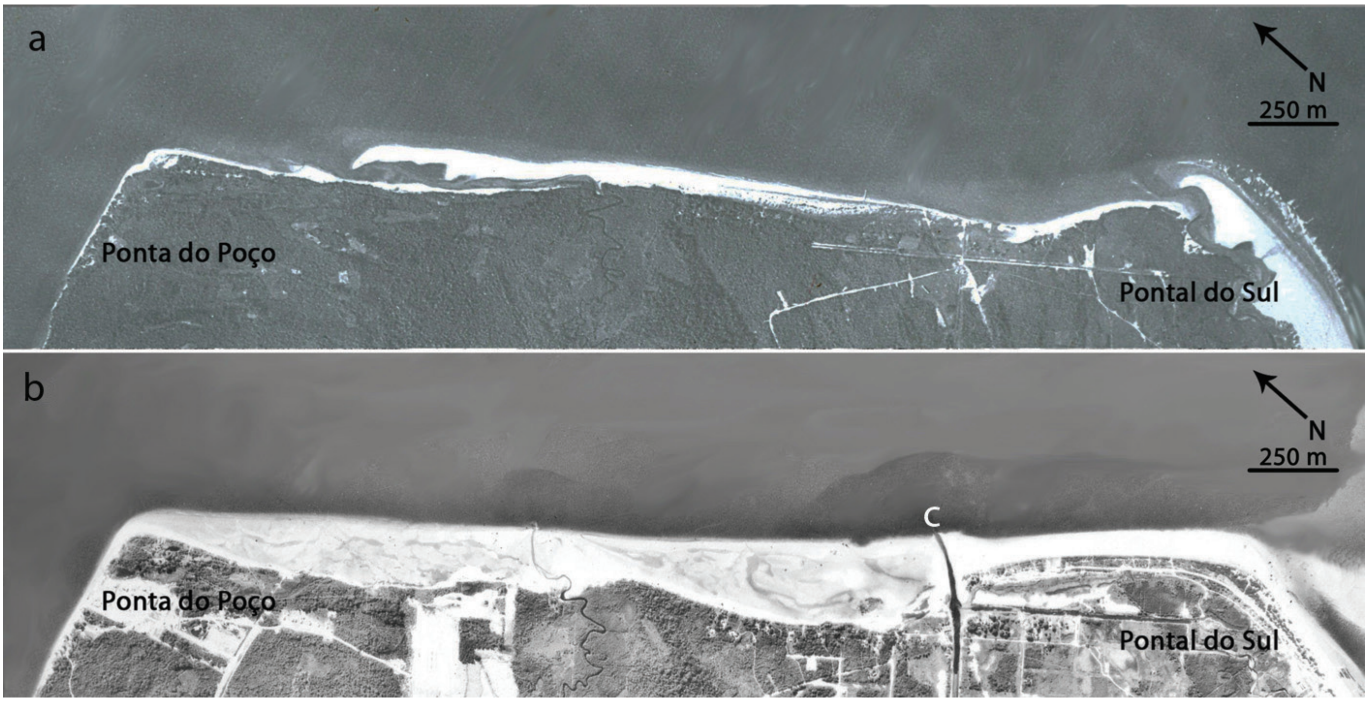

Figure 10. Estuarine coast between Pontal do Sul, and Ponta do Poço (a) in 1954 and (b) 1980. Note the spits oriented toward the estuary indicating the predominant drift direction. After the opening of the drainage channel, the littoral drift was interrupted causing intense coastal erosion downdrift and a change in the coastal morphology from beach to sand flat. (c) Artificial channel mouth (After Angulo *et al.*, 2006b; see location in Figure 1).

Figure 11. Swamp area generated by a low slope channel between Pontal do Sul and Praia de Leste in 2007 (see location in Figure 1).

4.5. Foredune obliteration and beach fringe occupation

Under natural conditions, the Paraná open-sea coast is fringed by several foredunes and paleo-foredune ridges, 1-8 m above mean sealevel. At the northern coast, foredunes and paleo-foredune ridges are preserved (Figure 12), however, most of them have been obliterated by urban occupation along the central-south sector. The removal of foredune ridges eliminates part of the sand stock of the foredune-beach system and inhibits the recovering of the beach profile after storms. Moreover, at several places of the central-south Paraná open-sea coast, the occupation invades the dynamic beach-fringe, where the coastline shifts along the years according to the dominant wave direction, and the beach itself, where sand is transported by the wave swash. During storms, part of the wave energy is reflected by sea walls and other urban infrastructure, and reinforce beach erosion, thus inhibiting the recovery of the beach profile after the storms, as verified at several open seacoasts (*e.g.* Dean and Dalrymple, 2002). Furthermore, erosion problems have also induced coastal defense works. The occupation of dynamic beach fringes includes areas emerged in the last 4-6 decades in highly dynamic coasts near the inlets, which can be eroded as soon as they emerged (Angulo, 1984; Figure 13).

4.6. Coastline artificialization

Hard coastal stabilization works were performed in the coast of Paraná for (a) harbor activities, (b) rivers and channels mouth stabilization, and (c) beach erosion control.

Figure 12: Foredunes and paleo-foredune ridges at Praia Deserta beach-arc, in Superagüi (see location in Figure 1).

4.6.1. Harbor activities

The harbor coastal sectors were anthropized by the building up of quays and piers. During harbor expansion, 1.2 km^2 of mangroves and shoals areas were replaced as reclamation areas (Figure 7). At Ponta do Felix, the harbor pier induces intense sediment deposition in the estuary. After the pier implantation, from the 1990s to 2013, 0.09 km^2 of new mangrove area have grown. An area of 0.21 km^2 of shallow estuary, upstream to the pier, was filled up and used for harbor activities (Figure 14).

4.6.2. Rivers and channels mouth stabilization

Jetties were built up at the Matinhos River to try to stabilize its mouth (Figure 15). They were built several times because they were often damaged by waves and currents. Occasionally, the river mouth shifts out of the channel, defined by the jetties, and the channel is frequently filled up with sand. Projects to build up larger and longer jetties to keep the river mouth open were considered in 2003 and following years (Gobbi *et al.*, 2003; Aquamodelo, 2008; Paraná, 2015; Figure 16). These jetties will interrupt the longshore drift and cause severe coastal erosion downdrift, as verified at many open sea coasts (*e.g.* Dean and Dalrymple, 2002). A proposal to by-pass sediment to avoid this problem was discussed (AMB, 2010), as has been done at other similar coastal zones (*e.g.* Dean and Dalrymple, 2002). It is interesting to notice that these jetties aimed to keep the river's navigability; however, the navigability is inhibited by a 200 m upstream low-level bridge (Figure 17).

Another rock jetty was built up at the artificial DNOS channel in Pontal do Sul. The jetty interrupted the longshore drift and caused severe coastal downdrift

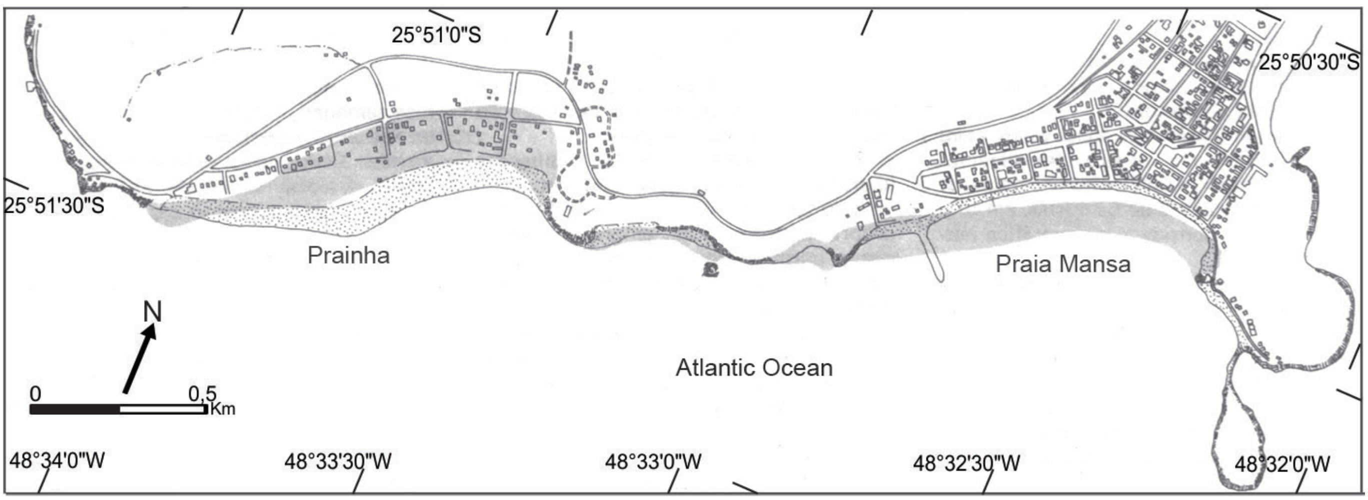

Figure 13: Area emerged between 1953 and 1980 and occupied in Prainha beach, near the Guaratuba inlet. Subaerial beach in 1953 (gray area) and 1980 (dotted area) (After Angulo, 1984) (see location in Figure 1).

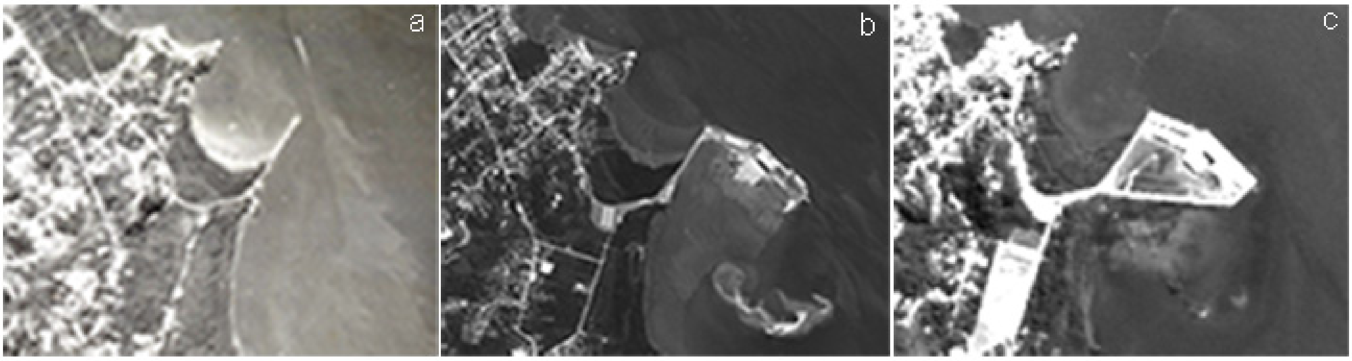

Figure 14: Ponta do Felix pier in (a) 1980, (b) 2002, and (c) 2016. Notice sand bars south of the pier in 2002, and the reclamation and mangrove areas south of the pier in 2016 (see location in Figure 5).

Figure 15: Jetties at Matinhos River mouth in 2016, (a) seen toward mainland and (b) toward the sea (see location in Figure 1).

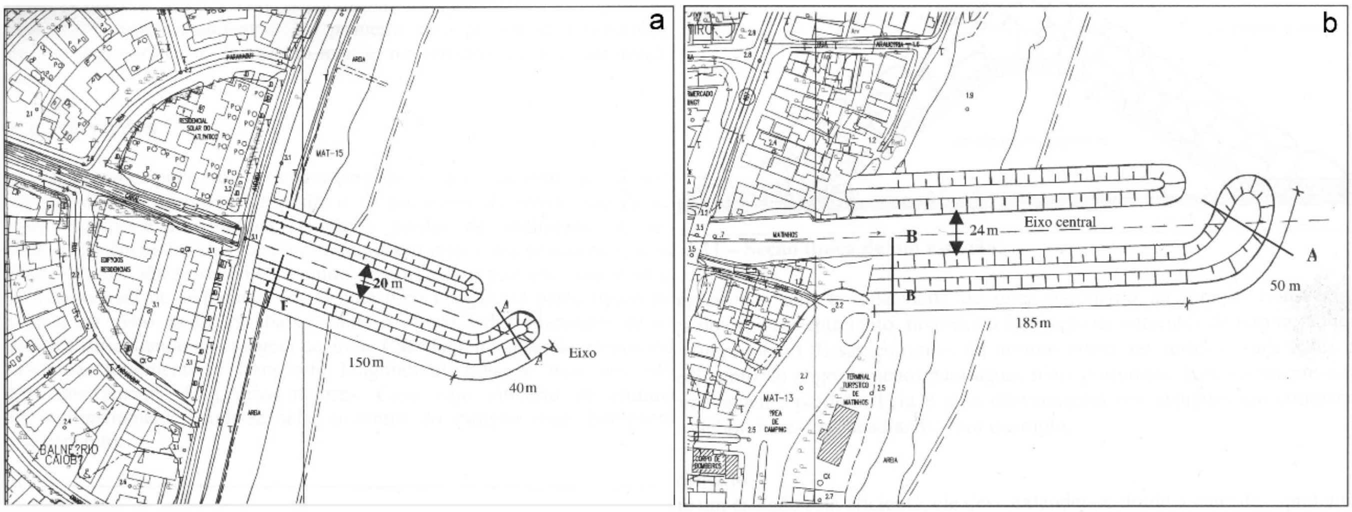

Figure 16: Sketch of proposed jetties for (a) Brava beach channel and (b) Matinhos River mouth (After Gobbi *et al.*, 2003; see location in Figure 1).

Figure 17. Low-level bridge near the Matinhos River mouth in 2009; which inhibits navigation until present (see location in Figure 1).

erosion where 37,000 m^2 of land was eroded between 1954 and 1996 (Krueger *et al.*, 1996; Figure 10) and the erosion continuous until the present time. In the beginning, sand accumulated upstream the jetty, however, when the progradation advanced toward deeper estuarine areas, sand was transported away by ebb-tidal-currents.

4.6.3. Beach erosion control

In the southern sector of the Paraná open-sea coast, several rock and gabion sea-walls and groins were built up in order to try to solve coastal and beach erosion problems. These works were performed at Praia Mansa, Matinhos-Caiobá, and Guaratuba beach-arches and in the southern sector of the Pontal do Sul-Matinhos beach-arc (Figure 18). Up to the present moment, these works remain controversial. The Praia Mansa gabion sea-walls and short groins (10 m long) were built along the coast in the 1970s after severe beach erosion (Lindroth, 2017; Figure 19). The beach recovered after this work and it was claimed that the sand deposition was induced by the built sea-wall and groins (Lindroth, 2017). Others claimed that the main cause of sand deposition was the 180 m long rock groin previously built at the end of the beach (Angulo *et al.*, 2016; Figure 20). Under natural conditions sand was transported around the small headland at the end of the beach-arc (LNEC, 1977), but the construction of the groin now intercepts the longshore current and promotes sand deposition updrift. Moreover, the dynamics of Praia Mansa is influenced by the Guaratuba ebb-tidal delta, which promotes rapid changes on beach sand balance (Angulo, 1993; Angulo *et al.*, 2006b; Figure 21). Hence, the causes of beach recovery are not completely understood; beach recovery probably results from a combination of natural and anthropic factors.

Supported by the apparent success of the gabion sea-walls and groins in the recovery of Praia Mansa beach, gabion sea-walls and groins were also built along the entire Matinhos-Caiobá beach-arc (Figure 22). Nevertheless, these works were severely damaged by high energy wave events; the plastic cover strings of gabions were abraded by gabion stones, the strings rusted, and the gabion did not resist the water pressure (Figure 23).

During the 1970' to 1990' years, the sea-walls and groins were damaged and rebuilt several times. In the southern part of the beach-arc, the Guaratuba ebb-tidal delta terminal lobe promotes wave refraction convergence and sand deposition (Figures 21 and 24), therefore, the erosion problem was not solved in the northern part of the beach-arc (Figure 25). Several rock sea-walls were built but the coastal erosion remains as the problem. In 2008 and 2015, proposals were presented to build large rock groins and jetties (100-200 m long), enlarged (35-50 m) at their ends and named headlands, to promote beach nourishment in the Caiobá-Matinhos beach-arc and the southern sector of the Matinhos-Pontal do Sul beach-arcs (Aquamodelo, 2008; Paraná, 2015; Figure 26). These projects have not been implemented yet.

In the Guaratuba beach-arc, a reinforced-concrete sea-wall was built along the coastline, which was damaged several times by urban drainage that discharge at several locations along the beach (Angulo and Andrade, 1981) and high energy waves. In this beach-arc, migratory sand spit (Figure 27) caused changes on the beach volume (Angulo *et al.*, 2016). These changes promote more effective attack of waves where the sand volume is reduced, promoting sea-wall damages.

Figure 18. Two views of Beach erosion at Praia Mansa in 1976 (After Emopar, 1978; see location in Figure 1).

Figure 19. Two views of sea-walls at Praia Mansa in 1978 (After Emopar, 1978; see location in Figure 1).

Figure 20. Praia Mansa in 1994. Notice the rocky groin built in the 1970s, which traps the sand transported by longshore currents. Before the groin built, sand was transported around the small headland (front), (see location in Figure 1).

Figure 21. Breaking waves over the ebb-tidal delta sand bars at Guaratuba bay inlet (white areas). The northern end of the ebb-tidal delta frontal lobe was located next to de Caiobá headland in 1953 (red line), at the southern end of Brava de Caiobá beach-arc in 1963 (yellow line) and farther north in 1980 (blue line) and 2014 (white line). (e) Groin (Sources: Google Hearth and aerial photography).

Figure 22. Gabion sea-walls, jetties and groins at Caiobá-Matinhos beach-arc in 1994 (see location in Figure 1).

Figure 23. Gabions sea-wall and groins damaged after a storm in 1994 in the northern sector of the Matinhos-Caiobá beach-arc. (see location in Figure 1).

Figure 24. Large sand deposition caused by convergent wave refraction related to the frontal lobe of the Guaratuba ebb-tidal delta in 2016 in the southern sector of the Matinhos-Caiobá beach-arc. (a) Breaking waves over sand bars and (b) former coastline location (see location in Figure 1).

Figure 25. Coastal erosion problem in the northern sector of the Matinhos-Caiobá beach-arc in 2016 (see location in Figure 1).

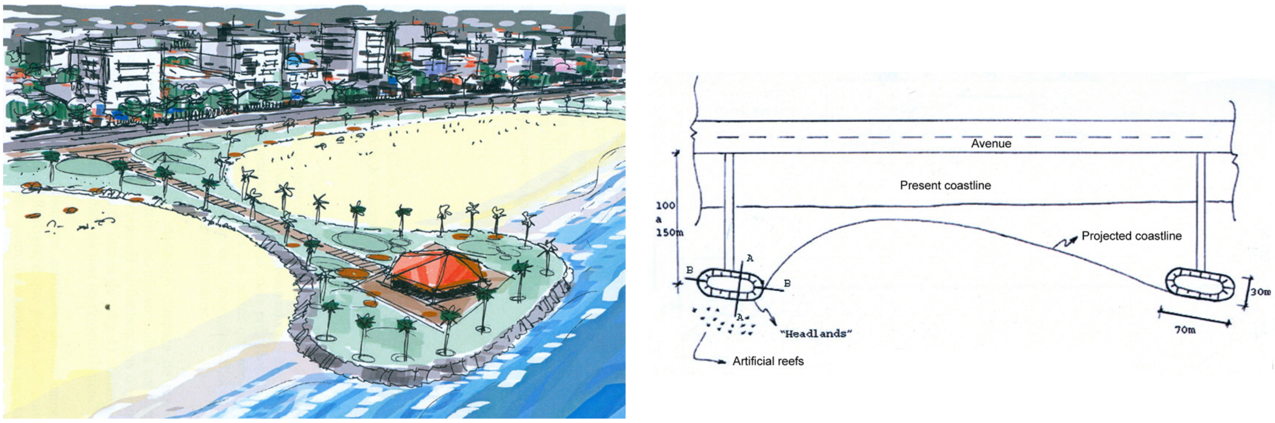

Figure 26. Sketch of proposed headlands or groins for the Matinhos-Caiobá and Pontal do Sul-Matinhos beach arcs (After Gobbi, 2007; see location in Figure 1).

Figure 27: View of the sand spit at the south part of the Guaratuba beach-arc in 1994 (see location in Figure 1).

5. CONCLUSIONS

The anthropization of the Paraná coastal zone was conducted without considering its effects on the coastal morphological, dynamics, and sedimentary processes. One of the main anthropic impacts is the dredging of channels for port access at the ebb-tidal-deltas, which interrupts longshore drift, and consequently, sand deficit downdrift. The sand disposal at authorized areas located in the inner shelf inhibits sand transport by waves and promotes sand deficit on the beach system. However, on the coast of Paraná, a large volume of irregularly disposed of sand at shoreface has caused unplanned intense progradation in some beaches. Alternative disposal areas and possible use of this non-contaminated sand need to be considered to avoid erosion problems and make use of this progressively scarce mineral resource.

Natural and anthropic induced estuary silting remains as a problem for navigation activities. Comprehensive studies on sedimentary contribution in estuaries, to determine silting rates, are still incipient and no solution on dredged estuarine sediment disposal have been implemented. Building up artificial islands or tidal-flats with those sediments, as previously proposed (Lamour and Soares, 2007), can be a viable solution for using non-contaminated sediments.

The anthropic actions obliterate 1.3 km^2 of mangroves in Paraná, which corresponds to 0.34% of the whole mangrove area in the state. There are no comprehensive studies about the impact of this obliteration on estuarine ecosystems. Nevertheless, the small percentage of the obliterated area allows inferring the effects of low impacts on the functions of estuarine ecosystems.

In the 20th century, the drainage system in the coast of Paraná was modified without considering the impact of modifications on coastal processes. In the present century, new projects propose large interventions on this coastal drainage system, including watershed interconnection, the opening of new inlets, and channel enlargement (Paraná, 2015) still without considering coastal dynamics and mainly the effects of these interventions on the longshore drift.

Another significant impact was caused by the obliteration of foredune ridges and urbanization over the beach dynamic fringe, which originates coastal erosion problems in several sectors. As is widely known (*e.g.* Dean and Dalrymple, 2002), hard stabilizations with rocks and gabion sea-walls accelerate sand beach loss. Up to now, several beach erosion problems remain unsolved. In most of the cases, a retreat occupation to release the beach dynamic fringe seems to be a viable solution; however, no projects have been performed using this strategy. Another aspect of coastal erosion problems is that the interventions are performed after the damages have occurred. There is no planning or monitoring of the foredune-beach sand volume, which could be useful to anticipate erosion problems and perform preventive actions.

The retreat of coastal occupation, which works to liberate the dynamic beach fringe in order to reestablish beach and foredune dynamics, is not a regular practice in the coast of Paraná. It was only applied after the high wave energy event associated with both spring tide and storm surge in Matinhos occurred in May of 2001 when an irregular occupation was damaged and removed later (Angulo *et al.*, 2016; Figure 28). After the building removal in 2004, the beach and foredune dynamics were naturally reestablished (Figure 29). The removal of residences and urban infrastructure from the dynamic beach fringe was proposed for some sectors of the Caiobá-Matinhos and Matinhos-Pontal do Sul beach arcs where coastal erosion problems remain unsolved; however, this action has not been implemented.

Engineering coastal works that try to solve coastal erosion problems to improve touristic capacity or stabilize river or channel mouths. Nevertheless, because

Figure 28. Damage caused by a high energy wave event associated with both spring tides and storm surge in Matinhos in May of 2001 (After Angulo *et al.*, 2006b; see location in Figure 1).

Figure 29. Beach and foredunes naturally recovered in Matinhos after buildings were removed in 2004 (After Angulo *et al.*, 2016; see location in Figure 1).

of different reasons, coastal engineering is one of the most controversial aspects of coastal anthropization. In the past, hard stabilization with rocks or gabion sea-walls, groins, and jetties was the strategy used to stabilize shorelines or recover beaches. A pioneering proposal of sand nourishment was made, however, not implemented to recover the Praia Mansa (LNEC, 1977). In this century, beach nourishment was proposed and not implemented in Matinhos coast (Gobbi *et al.*, 2003; Gobbi, 2007). The main problem of this project was to establish the width of dry sand beach resulting after nourishment (Aquamodelo, 2008; AMB, 2010). Also in this century, the construction of *headlands* or large groins and jetties was proposed to improve the touristic capacity and solve the coastal erosion problem in Matinhos coast (Aquamodelo, 2008; Paraná, 2015; Figures 15 and 25). The main problem with these structures is that they will interrupt the longshore drift and will cause severe coastal erosion downdrift. The coastal erosion will progressively advance northward along 30 km up to the end of the beach-arc in Pontal do Sul, and thus, break the natural dynamic equilibrium of the beach arc, which has remained stable for at least the last 5-6 decades (Angulo, 1993; Angulo *et al.*, 2016).

It can be concluded that up to present, the anthropization conducted in the Paraná coastal zone has disregarded its impacts on the morphological and sedimentary processes in this coast. The interventions proposed still disregard these aspects. Special attention is necessary to prevent projects that could cause irreversible effects on coastal processes and result in more problems than solutions. This work also allows to conclude that (a) sand dredged from the harbor access channels need to be used for beach nourishment and to reestablish the longshore drift; (b) a sand by passing system need to be implemented where jetties and inlets intercept longshore drift to avoid beach erosion; (c) foredunes must be protected and restored because they function as natural buffers to beach erosion; (d) actions to retreat the urbanized areas need to be considered to reestablish the natural coastal dynamics to avoid and to solve coastal erosion problems; (e) the natural beach-fringe and the beach itself must be preserved to minimize beach erosion; and (f) defense works or artificial inlets or channels must not be built without proper technical assessment.

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REFERENCES

AMB – Planejamento ambiental e biotecnologia Ltda. (2010) - *EIA/RIMA das obras de recuperação da orla marítima de Matinhos - PR*, 375 p., Curitiba. Unpublished.

Angulo, R.J. (1984) - As praias do Paraná: problemas decorrentes de uma ocupação inadequada. *Análise conjuntural IPARDES*, 6(1):1–4. Reprint in 2001 *Revista Paranaense de Desenvolvimento*, 99:97–103.

Angulo, R.J. (1993) - Variações na configuração da linha de costa no Paraná nas últimas quatro décadas. *Boletim Paranaense de Geociências*, 41:52–72.

Angulo, R.J. (1999) - Morphological characterization of the tidal deltas on the coast of the State of Paraná. *Anais Academia Brasileira de Ciências*, 71(4-II):935-959.

Angulo, R.J. (2004) - Mapa do Cenozóico do litoral do Estado do Paraná. *Boletim Paranaense de Geociências*, 55:25-42, maps in CD.

Angulo, R.J.; Andrade, J.J. (1981) - *Viabilidade de controle de erosão nas praias de Caiobá e Guaratuba*, 64 p., Curitiba, Ipardes.

Angulo, R.J. (1992) - *Geologia da Planície Costeira do Estado do Paraná*. 334 p., Tese de Doutorado, Pós-Graduação em Geologia Sedimentar, Universidade de São Paulo, São Paulo SP, Brazil.

Angulo, R.J.; Borzone, C.A.; Noernberg, M.A.; Quadros, C.J.L; Souza, M.C.; Rosa L.C (2016) - The State of Paraná beaches. In: Short, A.D.; Klein, A.H.F. (eds.) *Brazilian Beach Systems*, Coastal Research Library 17, Dordrecht, Switzerland, Springer, pp.419-464. ISBN: 978-3-319-30392-5, DOI 10.1007/978-3-3319-30394-9_16.

Angulo, R.J.; Giannini, P.C.F.; Kogut, J.S.; Prazeres Filho, H.J.; Souza, M.C. (1996) - Variação das características sedimentológicas através de uma sucessão de cordões litorâneos holocênicos na ilha do Mel, Estado do Paraná. *Boletim Paranaense de Geociências,* 44:77-86.

Angulo, R.J.; Souza, M.C.; Lamour, M.R. (2006a) - Coastal erosion problems induced by dredging activities in navigation channels of Paranaguá and São Francisco harbor, southern Brazil. *Journal of Coastal Research*, SI 39:1801–1803.

Angulo, R.J.; Soares, C.R.; Marone, E.; Souza, M.C.; Odreski, L.L.R.; Noernberg, M.A. (2006b) - Paraná. In: Muehe, D. (org.) *Erosão e progradação do litoral brasileiro*, Brasília, Ministério do Meio Ambiente, p. 347-400, ISBN: 85-7738-028-9.

Angulo, R.J.; Lessa, G.C.; Souza, M.C. (2009) - The Holocene barrier systems of Paranaguá and northern Santa Catarina coasts, Southern Brazil. In: Dillenburg, S. R.; Hesp, P. A. (orgs.) *Geology and Geomorphology of Holocene Coastal Barriers of Brazil*, Lecture Notes in Earth Sciences 107, Berlin, Springer-Verlag, pp. 135–176. ISBN: 978-3-540-25008-1.

Angulo, R.J.; Souza, M.C., Müller, M.E.J.; Noernberg M.A.; Oliveira L.H.S.; Soares C.R.; Borzone C.A.; Marone E.; Quadros C.J.L. (2018) - Paraná. In: Muehe D. (org.). *Panorama da erosão costeira no Brasil*, Ministério do Meio Ambiente, pp. 586-640.

Aquamodelo - Consultoria e Engenharia (2008) - *Projeto básico de recuperação da orla marítima de matinhos*, 48 p., Rio de Janeiro. Unpublished.

Bigarella, J.J. (1950/51a) - Contribuição do estudo dos sambaquis no Estado do Paraná, I - Regiões adjacentes às baías de Paranaguá e Antonina. *Arquivos de Biologia e Tecnologia*, 5-6(17):231-292.

Bigarella, J.J. (1950/51b) - Contribuição ao estudo dos sambaquis no Estado do Paraná, II - Regiões adjacentes à baía de Guaratuba, Curitiba, *Arquivos de Biologia e Tecnologia*, 5-6(18):293-321.

Bigarella, J.J. (1991) - *Matinho: Homem e Terra – Reminiscências...*, 212 p. Curitiba, Prefeitura Municipal de Matinhos/ Associação de Defesa e Educação Ambiental – ADEA.

Bigarella, J.J.; Alessi, A.H.; Becker, R.D.; Duarte, G.M. (1969). Textural characteristics of the coastal dune, sand ridge and beach sediments. *Boletim Paranaense de Geociências*, 27:15-80.

Bigarella, J.J.; Becker, R.D.; Matos, D.J.; Werner, A. (eds.) (1978) - *A Serra do Mar e a porção oriental do Estado do Paraná... Um problema de segurança ambiental e nacional*, 249 p., Curitiba, Governo do Paraná/SEPL/ADEA.

Bigarella, J.J.; Duarte, M.G.; Becker, R.D. (1970/71) - Structural characteristics of the dune, foredune, interdune, beach, beach-dune ridge and sand ridge deposits. *Boletim Paranaense de Geociências*, 28-29:9-72.

Bigarella, J.J.; Freire, S.S.; Salamuni, R.; Viana, R. (1966) - Contribuição ao estudo dos sedimentos praias recentes, II, Praias de Matinhos e Caiobá. *Boletim da Universidade Federal do Paraná, Geografia Física*, 6, 1-109.

Branco, J.C. (2004) - *Alterações morfológicas na foz do rio Cachoeira, estado do Paraná, com base na análise da evolução das unidades de planície de maré*. 70 p. Curitiba, Dissertação de Mestrado, Pós-Graduação em Geologia, Universidade Federal do Paraná. Available on-line at <http://hdl.handle.net/1884/670>.

Brasil (1965) - *Lei número 4.771/65, 15 de setembro de 1965*. Código Florestal, Brasília: DOU de 16 de Setembro de 1965.

Brasil (2012) - *Lei número 12.651/2012, de 25 de Maio 2012*. Novo código florestal, Brasília: DOU de 28 de Maio de 2012.

Dean R.G.; Dalrymple R.A. (2002) - *Coastal processes with engineering applications*. 475p., Cambridge University Press.

Emopar – Empresa de Obras Públicas do Paraná (1978). As praias paranaenses, 19 p. Unpublished.

Fomin, I. M. (2013) - *Estudo do estado médio e da variabilidade da atmosfera do litoral paranaense, utilizando dados da estação meteorológica de Pontal do Paraná*. Monografia, Curso de Oceanografia, Centro de Estudos do Mar, UFPR, 54p, https://acervodigital.ufpr.br/handle/1884/55646.

Gaspar, M. D. (1996) - Análise das datações radiocarbônicas dos sítios de pescadores, coletores e caçadores. *Boletim do Museu Paranaense Emílio Goeldi,* 8:81-91.

Giannini, P.C.F.; Angulo, R.J.; Souza, M.C.; Kogut, J.S.; Delai, M.S.A. (2004) - Erosão na costa leste da Ilha do Mel, Baía de Paranaguá, Estado do Paraná: modelo baseado na distribuição espacial de formas deposicionais e propriedades sedimentológicas. *Revista Brasileira de Geociências,* 34(2):231-242.

Gobbi, E.F. (2007) - *Ante-Projeto para Obras de Recuperação da Orla Paranaense*, 36 p. Curitiba, Relatório técnico. Unpublished.

Gobbi, E.F.; Gobbi, M.F.; Gonçalves, J.E. (2003) - *Detalhamento e Modelagem das Obras Complementares, Referentes aos Estudos e Projetos da Recuperação da Praia Brava, Central, e Balneário Flamingo e Riviera na Orla do Município de Matinhos e Prainha na Orla do Município de Guaratuba – Litoral do Estado do Paraná*, 113 p., Curitiba, Laboratório de Estudos em Monitoramento e Modelagem Ambiental – LEMMA, Relatório técnico nº 001/2003.

Ipardes – Instituto Paranaense de Desenvolvimento Econômico e Social (1989) - *Zoneamento do litoral paranaense*, 175 p., Curitiba, Ipardes.

Ipardes – Instituto Paranaense de Desenvolvimento Econômico e Social (1995) - *Diagnóstico ambiental da APA de Guaraqueçaba*, 166 p., Curitiba, Ipardes.

Krueger, C.P.; Soares, C.R.; Marone, E.; Riesemberg, C.E.; Pilati, F.P.; Krüger, M.M.; Prado, A.; Masuko, H.A. (1996) - Levantamento com GPS da linha de costa na área erosiva da Ponta do Poço (PR). In: Anais do 2º Congresso de Cadastro Técnico Multifinalitário e Gestão Territorial, 2nd, Florianópolis, 3:184-192.

Lamour, M.R. (2000) - Dinâmica sedimentar do Canal da Galheta via de acesso ao porto de Paranaguá, 162 p., Curitiba, Dissertação de Mestrado, Pós-Graduação em Geologia da Universidade Federal do Paraná.

Lamour, M.R.; Soares, C.R. (2007) - Histórico das atividades de dragagem e taxas de assoreamento nos canais de navegação aos portos costeiros paranaenses. In: Boldrini E. B., Soares C. R., Paula E. V. de (orgs.). *Dragagens portuárias no Brasil: Licenciamento e monitoramento ambiental*, Antonina, SEMA-PR/Ademadan/ Unibem, pp. 232-243. ISBN: 978-85-60764-00-5.

Lamour, M.R.; Angulo, R.J.; Soares, C.R. (2006) - Bathymetric evolution of critical silting sectors on Galheta channel, access way to Paranaguá port, Paraná state – Brazil. *Journal of Coastal Research*, *Journal of Coastal Research*, 23:49–58.

Lessa, G.C.; Angulo, R.J., Giannini, P.C.F.; Araújo, A.D. (2000) - Stratigraphy and Holocene evolution of a regressive barrier in south Brazil, *Marine Geology*, 165:1 (4):87-108, DOI: 10.1016/S0025-3227(99)00130-9.

Lindroth, G. (2017) - *Caiobá, um modelo em proteção e recuperação de praias atacadas pela erosão marinha*, 2017. Available on-line at <www4.netpar.com.br/Lindroth/mansapor.htm>.

LNEC - Laboratório Nacional de Engenharia Civil (1977) - *Combate à erosão na praia de Caiobá, Paraná*, 20 p., Lisboa, Relatório Técnico. Unpublished.

Maack, R. (1968). *Geografia física do Estado do Paraná*, 350 p., Curitiba, BADEP/UFPR/IBPT.

Mantovanelli A.; Marone E.; Silva E.T. da; Lautert L.F.; Klingenfuss M.S.; Prata V.P. Jr.; Noernberg M.A.; Knoppers B.A.; Angulo R.J. (2004) – Combined tidal velocity and duration asymmetries as a determinant of water transport and residual flow in Paranagua bay. *Estuarine, Coastal and Shelf Science*, 59:523-537.

Marone, E.; Camargo, R. (1994) - Marés meteorológicas no litoral do estado do Paraná: o evento de 18 de agosto de 1993. *Nerítica*, 8(1-2):73-85.

Marone, E.; Jamiyanaa, D. (1997) - Tidal characteristics and a variable boundary numerical model for the M2 tide for the Estuarine Complex of the Bay of Paranaguá, PR, Brazil. *Nerítica*, 11(1-2):95-107.

Mihály, P. (1997) - *Dinâmica sedimentar do litoral norte paranaense e extremo sul paulista*, 104 p., Curitiba, Dissertação de Mestrado, Pós-Graduação em Geologia da Universidade Federal do Paraná.

Nemes D.D.; Marone E. (2013) - Caracterização das ondas de superfície na plataforma interna do Estado do Paraná, Brasil. *Boletim Paranaense de Geociências,* 68-69:12-25.

Noernberg, M.A.; Lautert, L.F.C.; Araújo, A.D.; Odresky, L L. (1997). Base de dados digital do litoral paranaense em sistema de informações geográficas. *Nerítica*, 11(1-2):191-195.

Odreski, L.L.R.; Soares, C.R.; Angulo, R.J., Zem, R.C. (2003) - Taxas de assoreamento e a influência antrópica no controle da sedimentação da Baía de Antonina – Paraná. *Boletim Paranaense de Geociências*, 53:7-12.

Paraná (1987) - *Tombamento da Serra do Mar*, 169 p., Curitiba, Secretaria da Cultura e do Esporte, Coordenadoria do Patrimônio Cultural, Cadernos do Patrimônio, Serie Estudos 3.

Paraná (2015) - *Projeto de recuperação da orla de Matinhos*, Curitiba, Governo do Estado, Instituto das águas do Paraná, 2015. Available on-line at <https://youtu.be/AjaTCHdhbe8>.

Parellada, C.I.; Gottardi Neto, A. (1994) - Inventário de sambaquis do litoral do Paraná. *Boletim Paranaense de Geociências,* 42, 121-152.

Rodrigues, A. D. (1985). Relações internas na família lingüística Tupi-Guarani. *Revista de Antropologia,* 27-28:33-53.

Sampaio, R. (2006) - Ocupação das orlas das praias paranaenses pelo uso balneário. *Desenvolvimento e Meio Ambiente*, 13:169-186. DOI: 10.5380/dma.v13i0.9850.

Santos, A.V. (1850) - Memória histórica, chronológica, topográfica e decriptiva da cidade de Paranaguá e seu município, *Publicação da Secção de História do Museu Paranaense*, 1-2. Volume 1 printed in 1951 and volume 2 printed in 1952.

Sayão, O.J. (1989) - Littoral drift along some beaches in Brazil. In: *Proceedings of the* 6th *Symposium on coastal and ocean management*, Charleston – USA, American Society of Civil Engineers, New York, 4:3638–3746.

Simões Neto, J.A.; Souza, M.C.; Trzaskos, B.; Angulo, R.J.; Besser M.L. (2017) - Possibilidade de aproveitamento dos sedimentos de dragagem do porto de Paranaguá. *Quaternary and Environmental Geosciences*, 8(2):55-61.

Vanhoni, F.; Mendonça, F. (2008) - O clima do litoral do estado do Paraná. *Revista Brasileira de Climatologia,* 3-4: 49-63.

Veiga, F.A.; Angulo R J.; Marone E.; Brandini F.P. (2004) - Características sedimentológicas da plataforma continental interna rasa na porção central do litoral paranaense. *Boletim Paranaense de Geociências*, 55:67-75.