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Shoreline Changes and Coastal Evolution as Parameters to Identify Priority Areas for Management in Rio Grande do Sul, Brazil

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Abstract - About 80% of the Rio Grande do Sul coastline is undeveloped. The state Program of Coastal Management is incipient and has addressed only the northern coastal sector, which concentrates most of the developed beaches in the state. The central and southern coastal sectors show ideal conditions to the implementation of a regional management plan based on measures that regulate occupation and uses. This study identifies classes of management for RS beaches based on: (a) rates of population growth from 1991 to 2000, (b) intensity of beachfront development and the state of conservation of the beach system, (c) shoreline changes from 1997 to 2002, and (d) coastal evolution in the Holocene. Four classes of management are defined: (1) critical areas, are highly developed or show a recent trend of increasing population, are eroding or accreting with large magnitudes of shoreline changes, and require corrective measures; (2) priority areas, are low to moderately developed but show a potential for intensification of occupation and uses in the near future, are eroding and show large magnitudes of shoreline movements, they require urgent regulation to restrict development and uses; (3) areas of future concern, are not under pressure at present and consist of eroding shores located close to critical or priority areas, regulation measures are recommended, and (4) natural areas, are mainly preserved, eroding or accreting, with no signs of changes in the near future. About 198 km (32% of the RS coastal length) are classified as priority areas (located along the central sector), 178 km (29%) as natural areas (in the southern coast of São José do Norte and between Cassino and Albardão), 177 km (29%) as critical areas (northern sector, Cassino, and between Chuí and Hermenegildo), and 65 km (10%) as areas of future concern (beaches from Hermenegildo to Albardão).

Keywords - beach erosion, coastal management, DGPS.

INTRODUCTION

The impacts of growing population and development along the coastal zones worldwide have been greatly discussed in the literature (*e.g.* Cendrero, 1989; Turner *et al.*, 1996; Nicholls & Small, 2002; United Nations, 2003). Recent estimates show that 1.2 billion people are living within 100 km of the shoreline in altitudes below 100 m, where population densities are about 3 times higher than the global average (Small & Nicholls, 2003). The low-lying coastal areas are exposed to a variety of natural hazards (*e.g.* Small & Nicholls, 2003; Doornkamp, 1998; Turner *et al.*, 1996) that have caused millions of deaths in the last centuries and are increasingly affecting the economic development of coastal communities as population increases (Small & Nicholls, 2003). Considering that population growth along the coast is a current process and economic development is desirable, in the last decade major efforts have been applied to implement programs based on integrated coastal management (ICM) principles. The ICM aims to define strategies to promote sustainable use, development, and protection of the coastal and marine resources, addressing conflicts of use to search for the harmonization between the physical environment and human activities (Cicin-Sain & Knecht, 1998). However, implementation of ICM requires a certain degree of understanding about the environment from which its interrelationships with socio-economic and cultural assets can be drawn and the potential for use or preservation can be determined.

Understanding coastal processes and beach morphodynamics to forecast shoreline changes in the future is not only a scientific goal but also a requirement to support coastal management plans (Galgano & Leatherman, 1991; Honeycutt *et al*., 2001; Pajak & Leatherman, 2002). ICM is more efficient when established at a regional scale (Stockdon *et al*., 2002)

mainly because coastal processes are continuous alongshore and changes at one place can cause a range of effects in adjacent coastal and marine environments. Therefore, the need to provide information useful for coastal managers associated with the new technology that allows detailed data collection in large areas resulted in a shift in the interest from local to regional studies. Results from monitoring efforts at a regional scale have supported implementation of management plans at state (such as in the US states of Florida, New Jersey, California, etc.) and national levels (such as in the Netherlands). In Brazil, the National Plan of Coastal Management (PNGC) was officially created in 1988 (Law 7.661, from 16/05/88) and detailed in 1990 by Resolution No. 01/90 of the Interministerial Comission for Marine Resources (CIRM). The PNGC is available online at the Ministry of Environment (MMA) web site (http://www.mma.gov.br/port/sqa/projeto/gerco/planocac.html). The establishment of the PNGC has increased the interest of government authorities and scientists on coastal monitoring, resulting in the development of several large-scale projects. Examples of integrated coastal projects at national level are Orla and Atlas of Coastal Erosion (supported by the Ministry of Planning) and at a regional/international level there is the project Coastal Erosion: Causes, Risk Analysis and its Relation with the Genesis of Mineral Resources (supported by the Organization of the American States), addressing the coast of Rio Grande do Sul (RS), Uruguay, and Argentina (Martins *et al*., 2002).

The implementation of ICM is a complex process based on the interrelationships between the physical environment, natural resources, societal demands, economic, and cultural aspects (NOAA, http://icm.noaa.gov/story/icm_mgt.html). Thus, this study does not intend to present a comprehensive evaluation of all the major aspects addressed in a management plan. The main goal here is to describe, at a regional level, the present conditions of the RS coast (Figure 1) based on factors that are important to define classes of management, including: rates of population growth from 1991 to 2000, intensity of beachfront development, the state of conservation of the dune-beach system, short-term shoreline changes, and coastal evolution in the long term. The RS coast is then classified into four classes of management, defined as areas of critical management, priority areas, areas of future concern, and natural areas.

METHODS

The objective of this study is to define classes of management along the RS beaches based on:

(1) rates of population growth from 1991 to 2000 provided by the Instituto Brasileiro de Geografia e Estatística (IBGE), available at http://www2.ibge.gov.br/pub/censos/censo_demografico_2000),

(2) intensity of beachfront development and the state of conservation of the beach system according to data presented in Esteves *et al*. (2003a). In this study, developed beaches refer to areas where at least 30% of the beachfront length is developed,

(3) shoreline change rates estimated for the period 1997 to 2002 by the linear regression method applied to shoreline position data obtained from DGPS monitoring (Esteves *et al*., 2003b, 2004a), and

(4) coastal evolution in the Holocene according to Dillenburg *et al*. (2000).

Considering the parameters above, a regional analysis was conducted to classify the RS beaches into four classes of coastal management as follows:

Critical areas include highly developed beaches that show a recent trend of increasing population growth, occupation, and use; are subjected to erosion and/or destruction of coastal structures during storms or are accreting but magnitudes of shoreline changes exceed the mean width of the dry beach; foredunes were destructed or considerably reduced; corrective management is required.

Priority areas are under growing pressure where urge the implementation of management plans based on regulation and restriction of development and uses; coastal development can be low or moderate; rates of population growth are usually above the state's average; there is evidence of recent intensification of uses (tourism, values of real estate, demand for resources, conflicts of uses); beaches are eroding in the long or short term and show large magnitudes of shoreline movements. Priority areas usually are (a) adjacent to areas of ecological importance (i.e. National Parks), (b) close to critical areas, and/or (c) had access recently facilitated or created.

Areas of future concern have a preserved or nearly preserved beach/dune system; are mainly undeveloped; are usually eroding or show large magnitudes of shoreline movements; are not under great

pressure at present but preventive measures are recommended to avoid development in hazardous areas.

Natural areas have their natural characteristics preserved, are undeveloped, show low pressure of use and no signs of increasing pressure in the near future, and can be eroding, stable or accreting.

STUDY AREA

The RS shoreline is dominated by exposed sandy beaches. This shore is part of a large coastal plain that was formed and shaped by Quaternary sea level fluctuations resulting in a complex system of coastal lakes and lagoons (Villwock *et al*., 1986). The lagoon system traps sediments from fluvial discharge, reducing the sand volume reaching the shore (Tomazelli *et al.*, 1998). Waves are the main hydrodynamic process along the RS coast where the maximum tidal variation is 0.5 m (Tomazelli *et al.*, 1998). Waves from east and northeast dominate but southerly waves are the strongest and determine a net longshore sediment transport to the north (Esteves *et al.*, 2004a). This coast is often affected by storms associated with the passage of cold fronts, especially in fall and winter months (Calliari *et al.*, 1998).

In the State Program of Coastal Management (GERCO/RS), the State Foundation of Environmental Protection (FEPAM) divided the RS coast into four major sectors: (a) the northern, (b) the central-east, and (c) the southern include coastal municipalities along the ocean and municipalities that are adjacent to them, and (d) the central-west includes municipalities along the western margin of the Patos Lagoon (FEPAM, 2000). This study addresses only the 16 municipalities along the ocean coast, dividing them according to the GERCO/RS sectors, except that Rio Grande is included in the southern sector. Thus, here the RS coast is divided into three sectors (Fig.1): (1) the northern sector extends about 120 km south of the Santa Catarina state border and includes the highly developed beaches of Torres, Arroio do Sal, Terra de Areia, Capão da Canoa, Xangrilá, Osório, Imbé, Tramandaí, Cidreira, and Balneário Pinhal; (2) the central sector comprises the mainly undeveloped beaches of Palmares do Sul, Mostardas, Tavares, and São José do Norte, and is limited south by the Patos Lagoon inlet, and (3) the southern sector extends 220 km from the Patos Lagoon inlet to Chuí at the Uruguayan border, and includes the shores of Rio Grande and Santa Vitória do Palmar. Aspects of population growth, beachfront development and uses, coastal evolution, and shoreline changes in the short-term are described in the next sections.

COASTAL POPULATION GROWTH IN RIO GRANDE DO SUL

The encroachment of population along the coast is a world process that has been aggravated with time, increasing the number of people exposed to natural hazards (*e.g.*, Nicholls & Small, 2002). Brazil is no exception to the rule, as population density decreases considerably from east to west and from south to north (Moraes, 1995). A regional analysis indicates that the non-coastal Northern and Central-West regions presented the fastest population growth in Brazil from 1991 to 2000. However, a detailed analysis shows that the coastal population grew faster than the average of their respective states, except in Pará, Rio de Janeiro, and Sergipe. The RS can be described as atypical amongst other Brazilian coastal states, as colonization started inland and population density at the coast is lower than the state's average (Moraes, 1995). At present, only about 4.5% of the RS population lives in coastal cities, but seven of the ten municipalities showing larger population growth from 1991 to 2000 are located at the coast (Esteves *et al.*, 2003a). These municipalities show mean annual rates of population growth four to six times greater than the state's average, representing an increase from 54% to 91% of their total population (Tab.1).

Considering the mean annual rates of population growth from 1991 to 2000, the sixteen coastal municipalities in RS can be divided into three groups: (1) group I includes the seven municipalities showing rates above 4%: Balneário Pinhal, Cidreira, Tramandaí, Imbé, Xangrilá, Capão da Canoa, and Arroio do Sal (all located in the northern sector); (2) group II comprises four municipalities showing rates of population growth around 2-3% (still above the state's average) and includes: Torres and Osório (in the northern sector) and Mostardas and Palmares do Sul (in the central sector); and (3) group III includes municipalities showing rates of population growth between 0.5% and 1.1% (below the state's average), which are Terra de Areia, Tavares, São José do Norte, Rio Grande, and Santa Vitória do Palmar (Tab. 1). It is clear from these groups that the geographic location along the coast strongly determines the rate of population growth in RS coastal municipalities. The ones included in group I are all located in the northern sector (and are amongst the

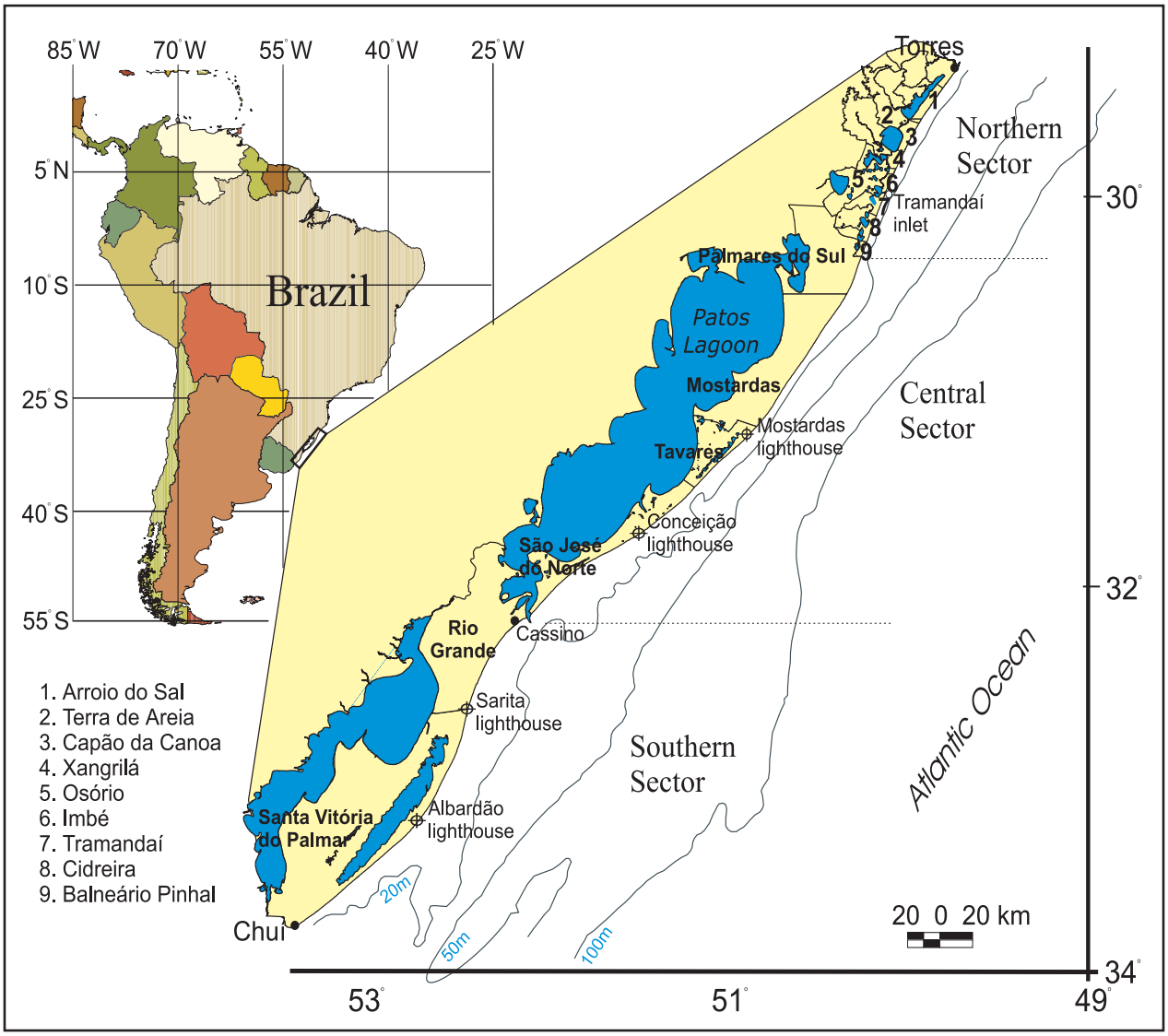

Figure 1 - The study area showing three major coastal sectors of Rio Grande do Sul: (a) northern, (b) central, and (c) southern.

ten fastest growing in the state). Conversely, the four southernmost coastal municipalities are included in group III (Tavares, São José do Norte, Rio Grande, and Santa Vitória do Palmar).

COASTAL DEVELOPMENT AND USES

Only 19.9% or 123.4 km of the RS coastline is developed with urban centers concentrated mainly in the northern coastal sector (Tab. 2). Few urban areas and small fishing villages account for less than 30 km of developed beaches present along the southern and central coastal sectors. The difference in the intensity of development along the state shoreline is due to two factors: (a) the distance from the largest populated areas in RS (i.e., the metropolitan area of Porto Alegre and the Northeast region), and (b) the facility of road access to the coast (Esteves *et al*., 2003a). The northern coastal sector is close to the most densely populated areas of the state and can be easily reached at least by two fast routes (BR101 or RS786). The central sector is located in a coastal barrier that separates the Patos Lagoon of the Atlantic Ocean (Fig. 1), so the access from inland to the coast is impeded by the presence of the lagoon. In the north-south direction, the central sector can be reached through the recently paved BR101 (except the southernmost 50 km) linking Mostardas and Tavares to the northern sector. The beaches of São José do Norte can only be accessed driving along the beach or through the unpaved BR101 which is well-known due to its bad conditions especially after rainfalls. The southern sector is located in one of the least developed areas of the RS,

Table 1 - Fixed population and rates of population growth for the sixteen coastal municipalities in Rio Grande do Sul for the period 1991 to 2000.

Group	Municipalities (ranking of population growth in the RS)	Population		Rates of population growth from 1991 to 2000 (%)	
		1991	2000	Annual geometric mean	Overall
	Brazil	**146,825,475**	**169,799,170**	**1.64**	**15.65**
	Rio Grande do Sul	**9,138,670**	**10,187,798**	**1.23**	**11.48**
I	Balneário Pinhal (1)	3,892	7,452	7.56	91.47
	Cidreira (2)	4,979	8,882	6.71	78.39
	Arroio do Sal (3)	3,031	5,273	6.41	73.97
	Imbé (4)	7,352	12,242	5.89	66.51
	Capão da Canoa (7)	19,473	30,498	5.16	56.62
	Xangrilá (8)	5,282	8,197	5.05	55.19
	Tramandaí (9)	20,130	31,040	4.98	54.20
II	Mostardas (34)	9,089	11,658	2.83	28.26
	Palmares do Sul (56)	8,836	10,854	2.33	22.84
	Torres (61)	25,423	30,880	2.20	21.46
	Osório (66)	30,050	36,131	2.09	20.24
III	Terra de Areia (144)	10,407	11,453	1.08	10.05
	Rio Grande (166)	172,422	186,544	0.89	8.19
	São José do Norte (169)	22,071	23,796	0.85	7.82
	Santa Vitória do Palmar (186)	31,240	33,304	0.72	6.61
	Tavares (201)	5,075	5,342	0.58	5.26
	Coastal municipalities	**378,752**	**453,546**	**3.46**	**19.75**
	Inland municipalities	**8,759,918**	**9,734,252**	**0.36**	**11.12**

Data source: Population Census of 1991 and 2000 (IBGE).

and access exists only to the developed beaches of Cassino (at the northernmost end), Hermenegildo, and Chuí (at the southernmost end). West-east access to most of this shoreline is hampered by the presence of Mangueira lagoon and large wetlands (i.e., Taim). So the only access to about 200 km of undeveloped coastline is driving along the beach.

Coastal development in the northern sector consists mainly in second houses which are occupied only in the summer months, when seasonal population increases considerably. Thus, most services and business are active only from December to March, responding to the fluctuations in the seasonal population. Along the central sector, fishing villages are more important than tourist resorts and tourism along this shoreline is often related to fishing activities. One of the major attractions in the central sector is the Lagoa do Peixe National Park, one of the most important sanctuaries of migratory birds in South America (Ramsar, 2002). This Park has an area of 34,400 ha where 182

species of birds can be seen, including 26 species of migratory birds from the Northern Hemisphere and 5 species from the Southern Hemisphere, apart from other animals such as capivaras (Hydrochoerus hydrochoeris) and one endangered species of alligator (Caiman latirostris). Despite its natural attractions, the Park receives only about 2,500 visitors per year (Ramsar, 2002), probably due to the difficult access and the lack of infrastructure for tourists. In the southern sector, Cassino beach concentrates beach goers from inland cities located in southern Rio Grande do Sul, while Hermenegildo and Balneário Chuí are occupied by local population of Santa Vitória do Palmar and Chuí, respectively, and few tourists from Uruguay. Traffic along the beach is common between these beaches. In this sector, there is the Taim Ecological Station, a wetland protected by law that serves as natural habitat for wildlife, including migratory birds, capivaras, and the endandered *Caiman latirostris*.

About 54% of the beachfront properties in RS were built on top of the dunes (Tab. 2), resulting in the removal of the vegetation and partial or total destruction of the frontal dunes. Coastal protection works such as revetments and seawalls are a common sight along retreated beaches (i.e. Cidreira, Balneário Pinhal, and Hermenegildo), especially where frontal dunes were destructed. In some beaches, projects of dunes reconstruction have been implemented (i.e., Atlântida Sul, Imbé, and Cassino). Afforestation of *Pinus elliotis* too close to the beach is another activity that has been affecting the local water table (Seeliger *et al*., 2000) and dunes dynamics (Silva & Tagliani, 2000) along the southern and central sectors. The impact of such activity on the sediment balance in the short and long terms is still unknown. Extraction of heavy minerals from the dunes in the area of Bujuru (central sector) is another potential impact on the local beach system. In 1998, a project to extract ilmenite from the dunes in Bujuru (an investment of about U$ 516 million to produce synthetic pigments of rutile and titanium) was halted by federal attorneys (Ministério Público Federal) due to environmental concerns. Another economic activity that affects the RS shoreline is the development of the Port of Rio Grande located at the Patos Lagoon estuary. It is the third largest port in Brazil and the most important for the trade between MERCOSUL countries. At present, the two 4km long jetties that fix the navigation channel are scheduled to be extended in association with the deepening of the channel to allow larger ships to access the port. Therefore, although the RS coastline is mainly undeveloped, according to Esteves *et al*. (2003a) several human activities have impacted this shore, altering the natural conditions along 31.6% of its length (Tab. 2). According to the FEPAM, the major environmental problems along the RS coast are: (1) drainage of wetlands (for irrigation purposes), (2) removal of the dunes vegetation, (3) destruction of the active dunes, (4) afforestation of exotic plants, (5) unplanned occupation along the lagoon margins, (6) drainage, land reclamation, and private ownership of the lagoon margins and wetlands, (7) water pollution by domestic sewage, (8) inadequate agriculture and use of pesticides in areas occupied by the Atlantic Forest, (9) pressure of urban, industrial, and port development on the Patos Lagoon, (10) conflicts on the demand of water usage, and (11) solid waste management (FEPAM, http://www.fepam.rs.gov.br/qualidade/litoranea.asp).

Table 2 - Classification of the Rio Grande do Sul shorelines according to the length of developed shorelines, development on top of the dunes, afforestation, and altered (impacted) shores.

Coastal Sector	Length	Developed beaches		Developed Dunes		Afforestation		Altered Shores	
	km	km	%	km	%[1]	km	%	km	%
Northern	123	94.3	76.7	51.6	54.7	47.7[2]	38.8	98.1	79.8
Central	275	21.1	7.7	10.6	50.2	59.3	21.6	40.3	14.7
Southern	220	8.0	3.6	4.2	52.5	63.7	28.9	56.7	25.8
Total	618	123.4	19.9	66.4	53.8	170.7	27.6	195.1	31.6

[1]Percentage refers to the length of urbanized shores.
[2]Includes landscaping at the dunes and introduction of exotic vegetation. (modified from Esteves *et al.* 2003a).

SHORELINE CHANGES IN THE LONG AND SHORT TERMS

The long-term changes in shoreline position are presented here as the evolution of coastal barriers in the last 5 ka described by Dillenburg *et al.* (2000). Data on short-term shoreline changes are based on (a) DGPS shoreline monitoring from 1997 to 2002 (Esteves *et al.*, 2003b, 2004a) and (b) analysis of aerial photos taken in 1974, 1989, and 2000 (Esteves *et al.*, 2004b). Results from these studies are summarized here to describe the long-term trends and short-term magnitudes of the shoreline changes in RS.

According to Dillenburg *et al.* (2000), progradation of coastal barriers in the Holocene occurred along concave shorelines (large-scale coastal projections) where substrate is steeper, and barrier retreat occurred along convex shorelines (embayments) where substrate is gentler. Thus, the alongshore variability in the barriers behavior can be explained by long-term gradients of wave energy caused by the shape of the shoreline and the steepness of the inner shelf (Dillenburg *et al.*, 2004). In the northern sector, a long-term barrier progradation was observed from Torres to Tramandaí and stability from Tramandaí to Mostardas (Dillenburg *et al.*, 2000). Rates of shoreline change obtained from the DGPS monitoring and from aerial photos also show beach accretion from Torres to Xangrilá although indicate a trend to stability from Xangrilá to Tramandaí and to erosion southwards (Esteves *et al.*, 2004b). These results suggest that the area from Xangrilá to Tramandaí represents a transition between the barrier to the north that is accreting in the long and short terms and the barrier to the south that is stable in the long term and eroding in the short term. This shift in the trends of coastal changes is also evidenced by the width of the modern transgressive dune fields (Esteves *et al.*, 2004b). South of Xangrilá the transgressive dune fields are wider then in the north, covering the entire Holocene barrier and extending on top of the Pleistocene barrier from Tramandaí to Mostardas (Dillenburg *et al.*, 2000; 2004).

Along the central sector, receded barriers dominate from Mostardas to Estreito while progradation occurred from Estreito to Verga lighthouse in the Holocene (Dillenburg *et al.*, 2000). Evidence of long-term erosion in this segment includes exhumation of relict lagoonal muds and peat along 60 km of beaches around the Conceição lighthouse to Estreito and the destruction of the Conceição lighthouse during a storm in 1993, where foredunes scarps have retreated in an average rate of 2.5 m a^{-1} from 1975 to 1995 (Tomazelli *et al.*, 1998). Analysis of DGPS data shows that annual shoreline changes along the central sector are characterized by oscillatory movements, with alternating adjacent areas of erosion and accretion occurring at scales in the order of 30 km to 90 km (Esteves *et al.*, 2004a). Thus, rates of change in the short-term vary accordingly to the time interval comprised by the data, especially when estimated by the end-point method (Esteves *et al.*, 2003b, 2004a). Accretion was observed from 1997 to 2002 along the beaches from Conceição lighthouse to Estreito, while erosion was registered when rates were estimated by the end-point method for the 1998 to 2002 period (Esteves *et al.*, 2004a). Additionally, magnitudes of changes tend to be greater along the central sector than in the other coastal segments, enhancing the importance of short-term changes to define management strategies for this sector.

In the southern sector, long-term coastal evolution was dominated by progradation in the embayment between Estreito and Verga lighthouse, stability from Verga to Albardão lighthouse, and erosion from Albardão to Chuí (Dillenburg *et al.*, 2000). In the short term, accretion was registered from Estreito to Albardão while alternating areas of erosion and accretion in the order of 200 m to 1.5 km occur south of Albardão. In the area of Hermenegildo beach, a 5km long erosion spot is present (from 10.3 km to 15.3 km north of Chuí). Longer segments showing accretion (in the order of 6 km and one 19 km long segment) occur in a 40km long coastal stretch starting at 36 km north of Chuí. This segment is coincident with the area known as *Concheiros do Albardão*, where bimodal sediments formed by fine sands and bioclastic gravel (shell fragments) dominate (Calliari & Klein, 1993).

IDENTIFICATION OF MANAGEMENT CLASSES

In this section, RS beaches are classified into four classes of management according to their present conditions of population growth, coastal development and uses, coastal evolution, and short-term shoreline changes as described above. Classes of management are: (1) critical, (2) priority, (3) future concern, and (4) natural, which are detailed in the Methods section. The analysis was conducted in a municipal to regional level and the results are presented in five maps at the approximate scale of

1:450,000 for the northern (Figs. 2 and 3) and central sectors (Figs. 3 and 4) and 1:400,000 for the southern sector (Figs. 5 and 6).

Northern Sector

Municipalities along the northern coastal sector show rates of population growth higher than the state's average, (groups I and II, Tab. 1), Terra de Areia (group III, Tab. 1). Observe that the two lowest rates of population growth in the northern sector (Osório and Terra de Areia) occur in municipalities that have the shortest shoreline length in the state, only 3 km long (Tab. 3), indicating that they might be less dependent on beach activities than other coastal municipalities. About 77% of the beachfront along the northern sector are moderately or highly developed and beach uses are intense in the summer months, resulting in a shoreline that is mainly altered (Tab. 2). About 55% of beachfront development occurs in foredunes areas (Tab. 2), which have been totally removed along the most intensely developed beaches, such as Tramandaí, Imbé, and Capão da Canoa. In eroding beaches, constructions on top of the foredunes are usually protected by seawalls or revetments such as in Cidreira and Balneario Pinhal. Undeveloped beaches consist mainly in short segments (usually 300 m to 500 m long) between adjacent developed areas, although longer segments exist as shown in figure 2.

Beaches in the northern sector are classified as areas of critical management (Figs. 2 and 3), where corrective measures are already needed to mitigate impacts of unplanned occupation. However, these beaches show different trends of shoreline change in the long and short terms. Figure 2 shows that a long-term barrier progradation dominates along the northern coastal sector with a trend to stability south of Tramandaí (Dillenburg *et al.*, 2000), while shoreline changes in the short term indicate beach accretion dominating from Torres to Xangrilá and erosion to the south (Esteves *et al.*, 2003b). It is worth to emphasize that alternating areas of erosion and accretion occur along this shoreline, so short seg-

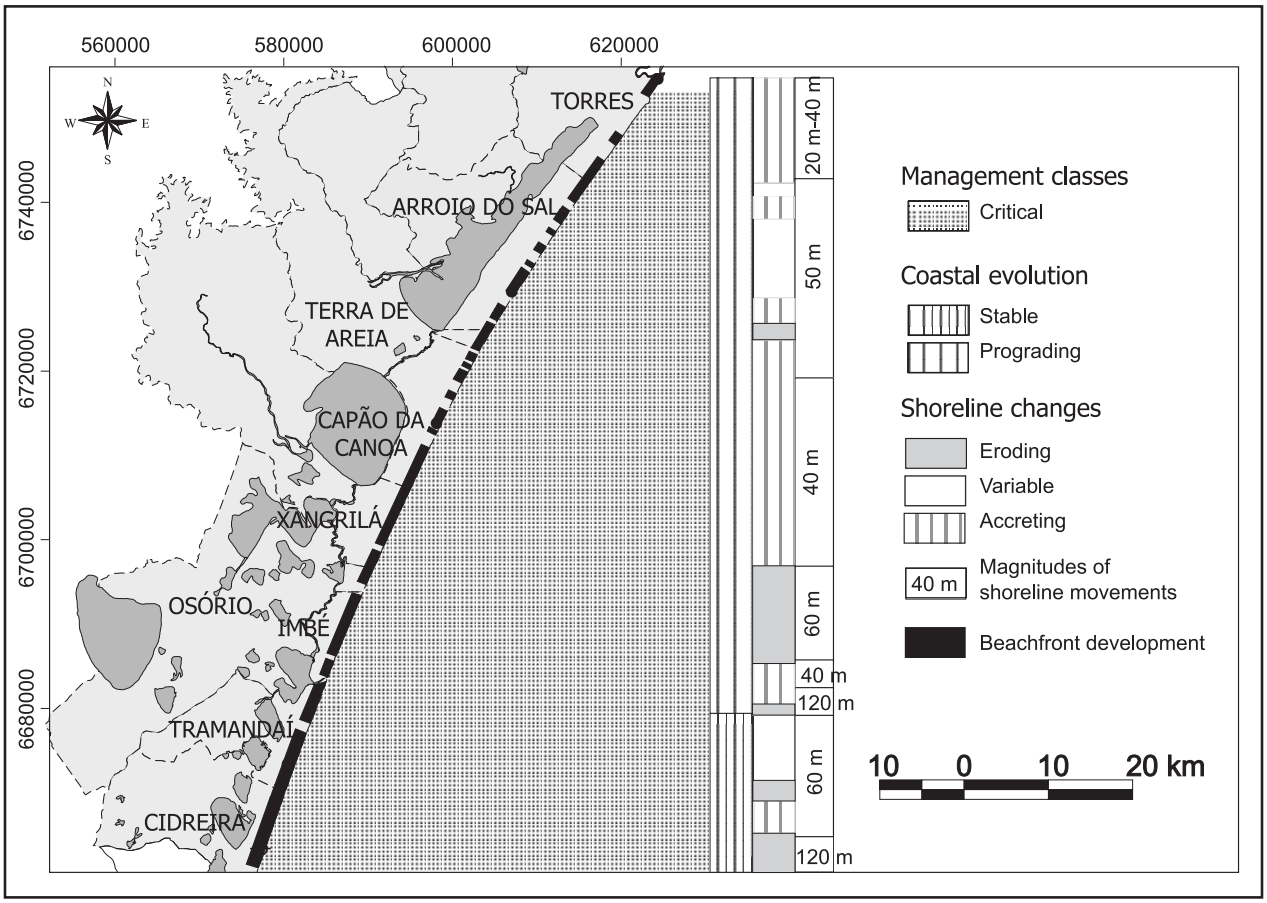

Figure 2 - Beaches from Torres to Cidreira (northern coastal sector) are classified as areas of critical management. These beaches are highly developed, mainly prograding in the long term, while eroding beaches dominate south of Xangrilá in the short term. Areas presenting alternating short segments of erosion and accretion are represented as areas of variable shoreline changes.

ments of eroded beaches occur in the areas where accretion dominates and *vice-versa*. Due to restrains of the scale, alternating areas of erosion and accretion are represented in figure 2 as areas of variable shoreline changes. Table 3 shows mean annual rates of shoreline change estimated for the 1997 to 2002 period for each coastal municipality and discriminate the length and percentage of accreted, eroded, and stable segments. From Torres to Xangrilá, the mean shoreline change rates are always positive (accretion), and eroded segments occur

Table 3 - Mean annual rates of shoreline change and distribution of accreted, eroded, and stable beach segments in RS from 1997 to 2002.

	Length km	**Rates[1] ma^{-1}**	**Accretion km**	**Erosion km**	**Stable km**	**Accretion % of length**	**Erosion % of length**	**Stable % of length**
Torres	11.5[2]	3.6	10.5	1.0		91.3	8.7	
Arroio do Sal	21.0	1.5	13.1	7.0	0.9	62.4	33.3	4.3
Terra de Areia	3.0	2.3	2.2	0.5	0.3	73.3	16.7	10.0
Capão da Canoa	18.5	3.7	17.0	1.0	0.5	91.9	5.4	2.7
Xangrilá	10.5	1.2	7.0	3.0	0.5	66.7	28.6	4.8
Osório	3.0	-3.7		3.0			100.0	
Imbé	11.0	-0.7	3.0	8.0		27.3	72.7	
Tramandaí	14.5	0.0	6.5	8.0		44.8	55.2	
Cidreira	15.5	-3.6	3.0	12.5		19.4	80.6	
Baln. Pinhal	9.0	-3.5		8.5	0.5		94.4	5.6
Northern	117.5	0.8	62.3	52.5	2.7	53.0	44.7	2.3
Palmares do Sul	23.0	-7.6		23.0			100.0	
Mostardas	90.0	-4.3	13.0	77.0		14.4	85.6	
Tavares	49.0	7.6	40.5	6.0	2.0	82.7	12.2	5.1
SJ Norte	113.0	18.4	113.0			100.0		
Central	275.0	6.6	166.5	106.5	2.5	60.5	38.5	
Rio Grande	64.0	14.0	64.0			100.0		
Sta Vitória	156.0	9.7	132.5	23.5		84.9	15.1	
Southern	220.0	11.9	196.5	23.5		89.3	10.7	
RS	612.5	7.5	425.3	182.0	5.2	69.4	29.7	0.8

[1] Rates of shoreline change estimated through linear regression.
[2] The beaches north of Itapeva were not considered in this study.

in less than one third of the shoreline length (Tab. 3). From Osório (Fig. 2) to Balneário Pinhal (Fig. 3), mean annual rates are negative (erosion) and eroded segments occur along most of the shoreline length, except for Tramandaí that has a mean annual rate equal zero and erosion in nearly 45% of the shoreline length (Tab. 3). Additionally, magnitudes of shoreline change tend to be larger from Cidreira to the south than along the northernmost beaches (Esteves *et al*, 2004a) as displayed in figures 2 and 3. Therefore, coastal management needs to be addressed differently and implemented more urgently in the area of Osório to Balneário Pinhal than in the beaches from Xangrilá to Torres.

Central Sector

At present, only 21.1 km or 7.7% of the shoreline along the central sector is developed (Tab. 2), concentrated mainly along the beaches of Palmares do Sul and few small fishing villages spread to the south (Fig. 3). The two northern municipalities, Palmares do Sul and Mostardas, had mean annual rates of population growth above 2% from 1991 to 2000 (group II, Tab. 1), while the two southern municipalities, Tavares and São José do Norte, showed rates of population growth below 1%, amongst the lowest along the coast (group III, Tab. 1). Access to these beaches was difficult until 1998 when the BR101 started to be paved linking Palmares do Sul and Mostardas to the most populated areas in the state. According to Page (1998), intensification of tourism and recreation depends on the transport infrastructure, in a way that easy access and good road conditions usually result in over exploitation of resources. Thus, the recently paved road provides easy access to the mainly undeveloped shore of Palmares do Sul, Mostardas, and Tavares what might enhance tourism and development in a pristine area characterized by dunes, wetlands, and lagoons, including

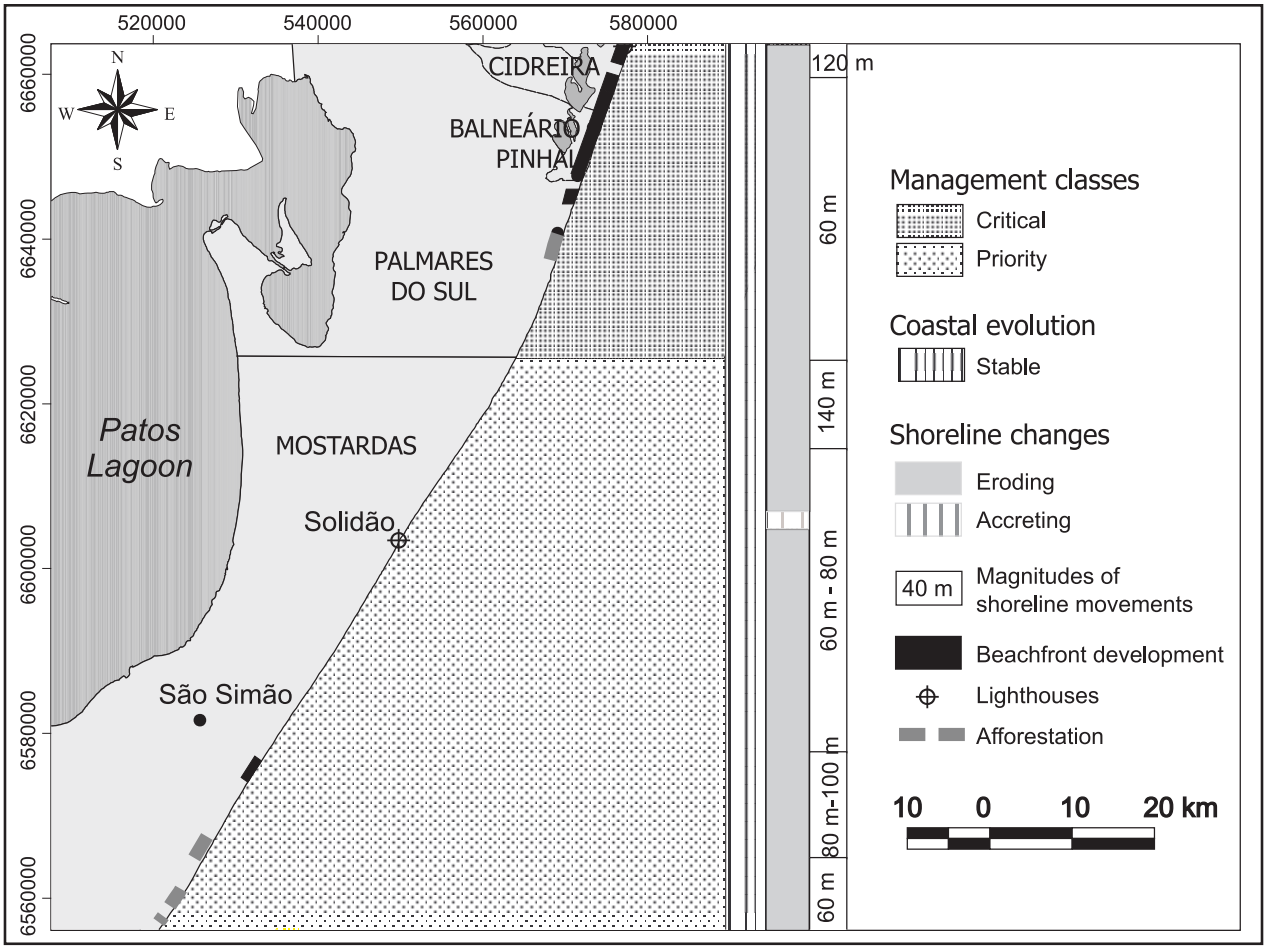

Figure 3 - Beaches from Cidreira (northern coastal sector) to Palmares do Sul (central sector) are classified as areas of critical management, while beaches of Mostardas are classified as priority areas. Although these beaches are stable in the long term, they are mainly eroding in the short term.

the Lagoa do Peixe National Park. Conversely, the unpaved southernmost 50 km of the BR101 makes access difficult to the beaches of São José do Norte inhibiting development and tourism in this area.

Similarly to Cidreira and Balneário Pinhal (Fig. 3), the coastline of Palmares do Sul and Mostardas have been stable in the long term and are eroding in the short term (Tab. 3), while from Mostardas to Estreito the barrier has been eroding in the long term (Fig. 4) and accreting in the short term (Tab. 3). Important to reinforce here that shoreline changes along the central sector are characterized by alternating areas of erosion and accretion that have shown opposite trends in consecutive years (Esteves *et al.*, 2004a). Considering that 100% of the Palmares do Sul shoreline is eroding (Tab. 3), its high rate of population growth (Tab. 1), the potential for increasing pressure in the next few years due to the proximity of the developed beaches of the northern sector, and the recently paved road, this shore is classified as critical areas (Fig. 3). The mainly undeveloped beaches from Mostardas (Figs. 3 and 4) to Estreito in São José do Norte (Fig. 4) are classified as priority areas. Unplanned occupation in these areas should be avoided through delimitation of risk zones and set-back lines for coastal constructions because these beaches (a) are eroding in the short (*i.e.* Mostardas) or in the long term (*i.e.* from Mostardas to Estreito), (b) are subject to large magnitudes of shoreline changes, (c) show lower pressure of development and less impacted beaches but the recently paved BR101 has facilitated access to an area of pristine beaches, (d) are adjacent to areas of environmental protection (*i.e.* Lagoa do Peixe National Park), or (e) show potential for mineral extraction (*i.e.*, heavy minerals in Bujuru). Beaches south of Estreito are accreting in the short and long terms, are mainly undeveloped, show low rates of population growth, and have difficult access. These characteristics indicate natural areas (Fig. 4) showing low risk of increasing pressure in the near future. However,

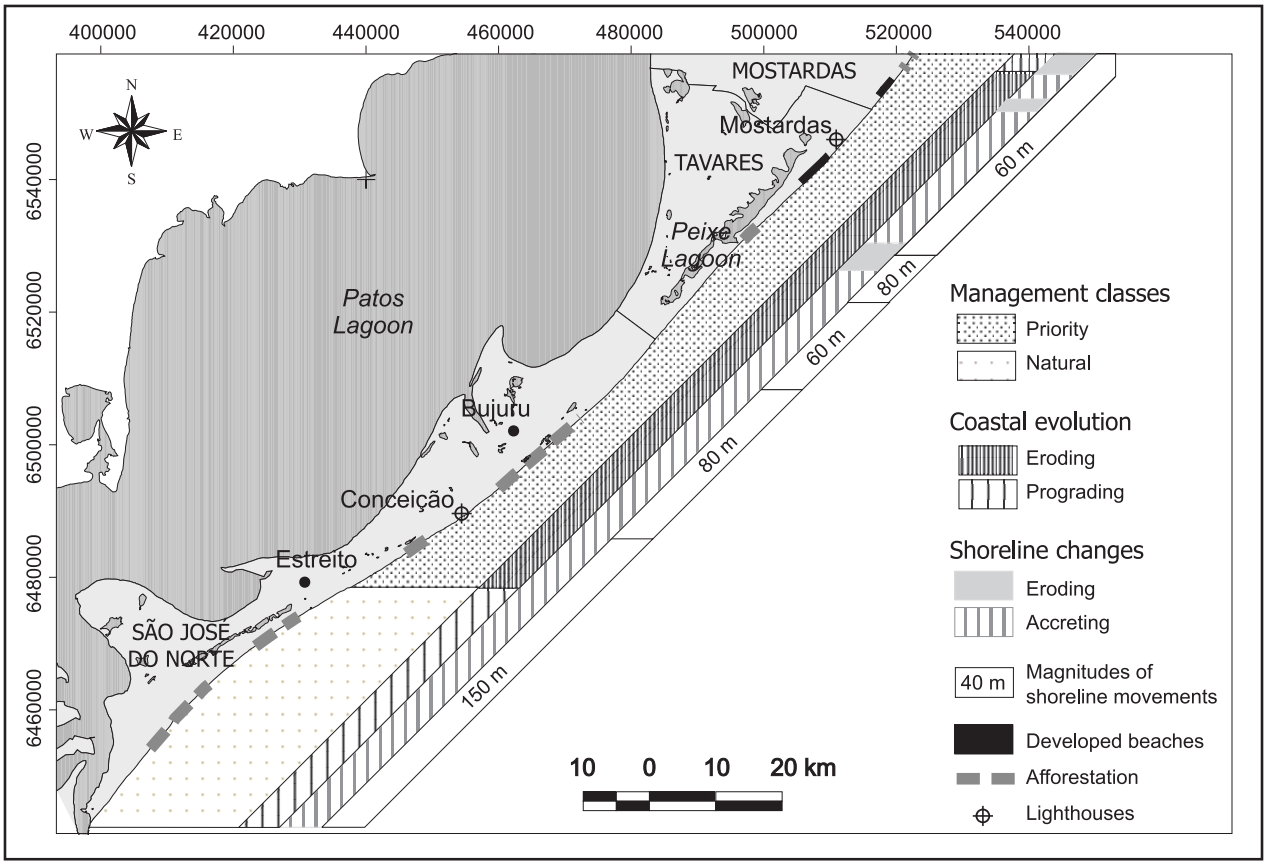

Figure 4 - The shores from Mostardas to Estreito, in São José do Norte (central sector), are classified as priority areas as they are eroding in the long and/or in the short term. Beaches south of Estreito are accreting in the long and short terms and are classified as natural areas but the impacts of the jetties the afforestations on the local sediment budget and dynamics of the beach system should be better evaluated.

these beaches should be monitored to evaluate the effects of afforestation at the dunes area and the impact of the jetties at the Patos Lagoon mouth on the local sediment budget.

Southern Sector

In the southern segment, only 8 km or 3.6% of the shoreline length is developed (Tab. 2) concentrated mainly at the northernmost (Fig. 5) and southernmost ends (Fig. 6). In Santa Vitória do Palmar, developed beaches represent 2.3% of the shoreline length and occur from Barra do Chuí to Hermenegildo, where beachfront properties are built on top of the dunes (Esteves *et al*., 2003a). In Cassino and Querência (Rio Grande), the well-developed dunes have shown a decrease in size and height partly because they were often cut to facilitate the access of vehicles to the beach and used as sand source for land fill or construction uses. Since 1986, projects of dune restoration have recovered the dunes along 2.5 km of the Cassino beach (NEMA, http://www.octopus.furg.br/nema/dunas/dunas.htm). Santa Vitória do Palmar and Rio Grande show rates of population growth lower than the state's average 0.72% and 0.89%, respectively (group III, Tab. 1). There are no signs of enhancing population growth or development along the southern sector in the near future as the access is difficult to great part of this shoreline and southern RS is one of the most undeveloped areas in the state. Possibly, the only change the southern coast may experience is related to the expansion of the Rio Grande Port, what can cause some impact in Cassino beach. The consequences of unplanned occupation are reflected by the destruction of coastal properties during storms in Hermenegildo, and by beach traffic

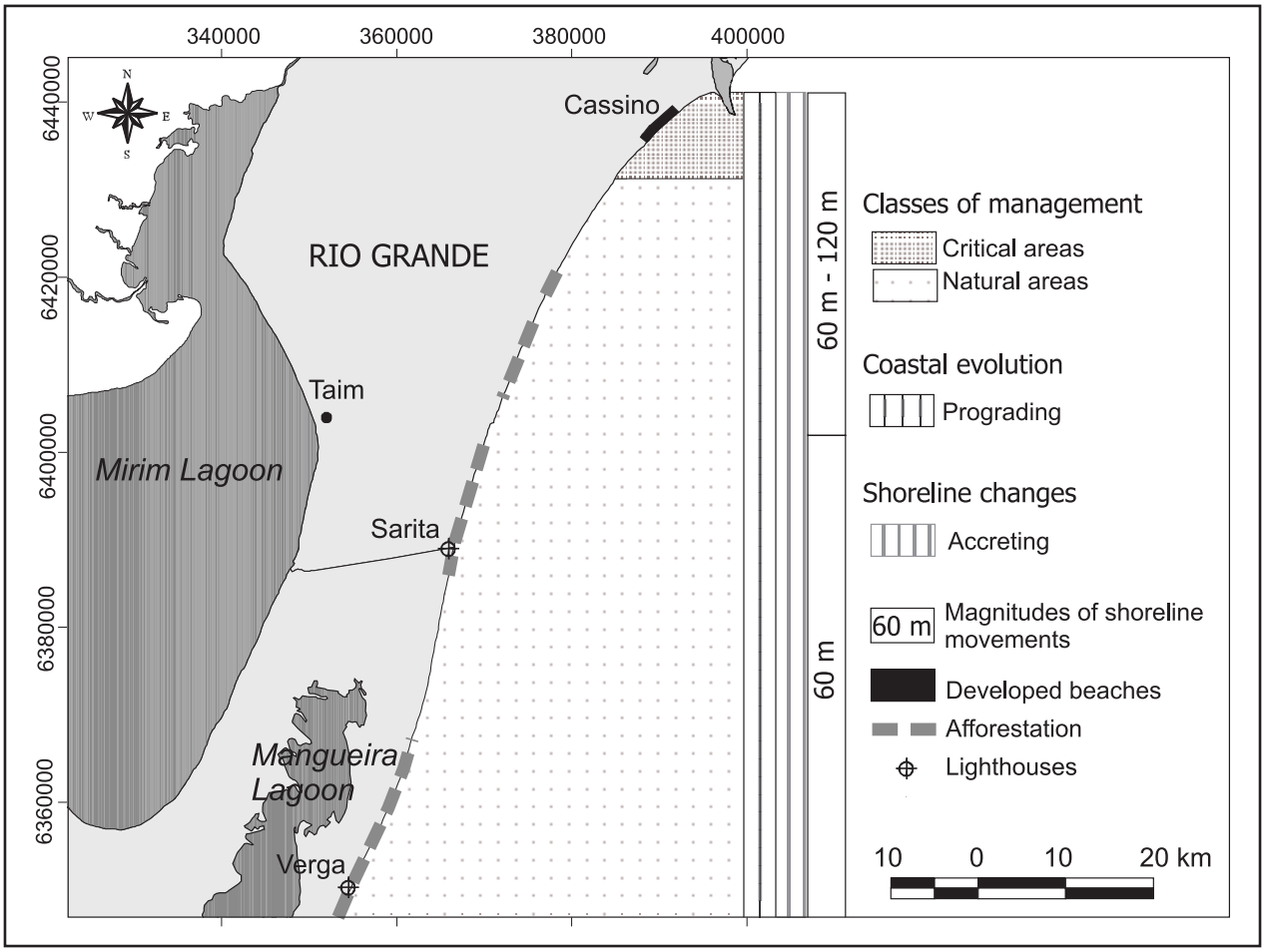

Figure 5 - The northernmost 15 km of the Rio Grande coastline (southern sector) are classified as critical areas due to the alteration of the beach-dune system while other beaches are classified as natural areas. However, the impacts of afforestations too close to the dunes should be better evaluated to determine whether a setback line should be implemented for this activity.

and contamination of coastal waters in the summer in Cassino. The use of the undeveloped beaches in this segment is minor, showing some traffic along the beach and fishing activities (commercial boats and line fishing). The major human activity along this shoreline is the presence of Pinus elliotis afforestations located too close to the active dunes extending along about 64 km alongshore (Tab. 2).

From Rio Grande to Albardão lighthouse, beach accretion has dominated in the long and short terms (Fig. 5). South of Albardão, barrier retreat has been observed in the last 5 ka and alternating areas of erosion and accretion were registered from 1997 to 2002 (Fig. 6). The northernmost 15 km are classified as area of critical management (Fig. 5) due to the alteration in the natural conditions caused by human activities (e.g. beach traffic, jetties, destruction of dunes, pollution). A great part of the southern sector (about 124 km) is classified as natural areas as beaches are undeveloped, there is no evidence of increasing population or occupation, and there is a trend to accretion in the short and long terms (Figs. 5 and 6). However, further studies are required to assess the potential impacts of the afforestation too close to the beach and to determine whether a set-back line should be applied to this activity. The proximity of these beaches to the Taim Ecological Station support regulatory measures to restrict uses that would pose a threat to the preservation of the wetland. This could be implemented either by extending the preservation area to incorporate the beach or restricting uses to activities such as ecotourism, which are usually less damaging to the environment and could be taxed to provide financial resources to support management of the area. About 65 km of undeveloped beaches between Albardão and Hermenegildo are classified as areas of future concern (Fig. 6), where regulation should restrict occupation along eroded beaches. The southernmost 16 km are classified as critical areas (Fig. 6) due to the impacts of unplanned occupation adjacent to eroded shorelines, including undeveloped beaches where regulations of beach use and occupation should be implemented. Beach erosion has threatened Hermenegildo resulting in economic degradation due to costs of coastal protection, destruction of structures during storms, and

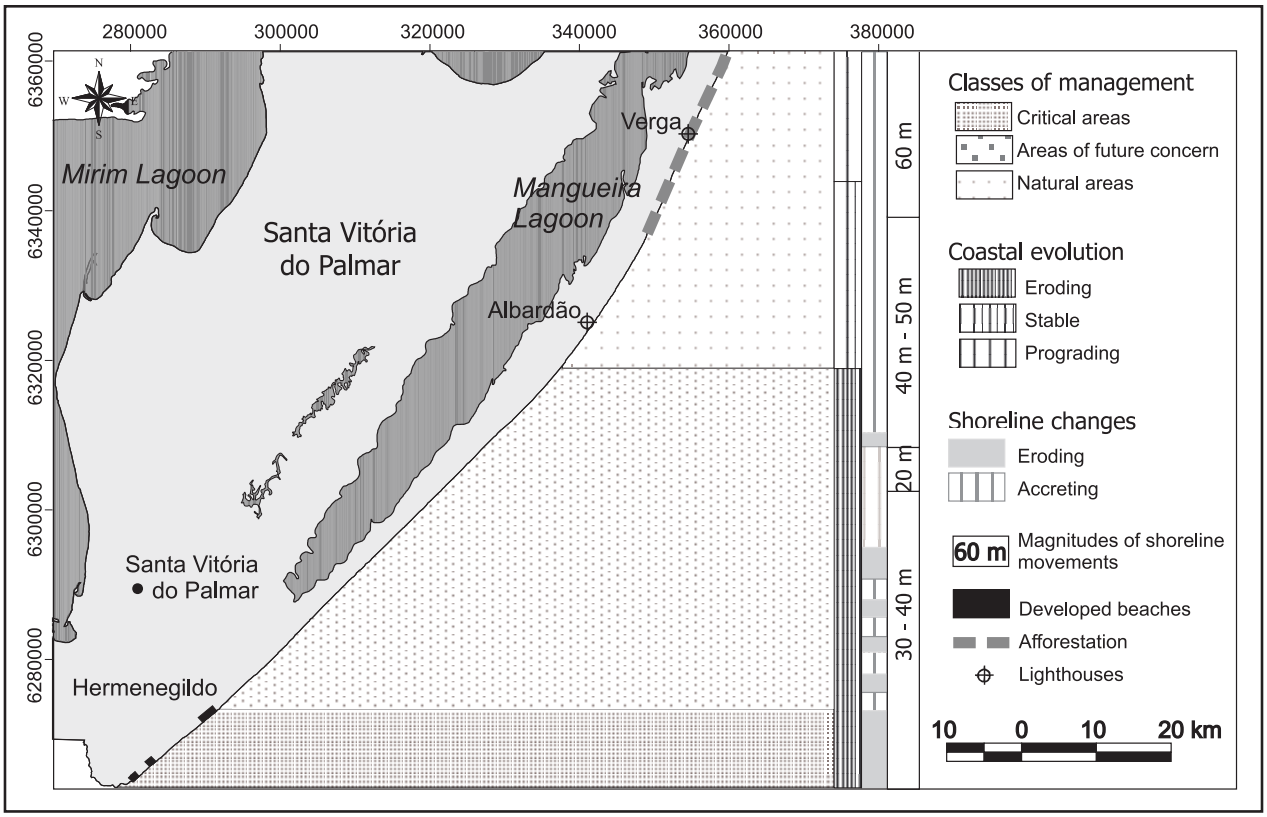

Figure 6 - Along the shores of Santa Vitória do Palmar, the beaches from Verga to Albardão are classified as natural areas, from Albardão to Hermenegildo beaches are classified as areas of future concern, and from Hermenegildo to Chuí as areas of critical management.

depreciation of beachfront property values (Esteves & Santos, 2001). Although Barra do Chuí is located downdrift of a stabilized inlet, it is not experiencing significant erosion in the short term, probably due to the bidirectional character of the longshore currents (Nicolodi *et al*., 2000; Esteves *et al*., 2004a) and the short extension of the jetty.

DISCUSSION

According to Moraes (1995), occupation along the Brazilian coast is a recent process that is mainly unplanned and chaotic demanding major efforts in corrective management. The author emphasizes that the fragility of the coastal ecosystems and the pressure of accelerated development set priority for management plans in two areas: (a) in the surroundings of established urban centers, and (b) the creation of new development in pristine coasts. These two conditions are represented in RS especially by the northern coastal sector and the northern half of the central sector, respectively. Development is intense along the northern coastal sector and the consequences of unplanned occupation have been aggravated by the accelerated population growth in the last decade. As problems due to the increase in the demand for resources and space along the northern sector are exacerbated, tourists tend to escape to the nearest available area, i.e. the central sector. The central coastal sector has shown a recent trend of accelerating population growth and new developments are to be established in pristine areas. Although both areas need urgent implementation of management plans, the northern sector demands mainly corrective measures while the central sector requires preventive management. Preventive management is usually more effective, less expensive and easier to implement than corrective measures and tends to reduce critical areas in the future. However, preventive management is usually applied to areas where development is absent or incipient and natural conditions are still preserved. Fortunately, most of the RS coast fits in this category.

The FEPAM decided that the GERCO/RS should address first the northern sector because it is the most developed coastal area (FEPAM, 2000). The GERCO/RS defined 14 Ecologic and Economic Zones (ZEE) for the northern sector, presenting their characteristics, restrictions of uses, and activities to be promoted (FEPAM, 2000). As an example, it has been defined for the developed beaches that (a) foredunes should be preserved or restored, (b) a setback line for coastal constructions should be set 60 m inland of the foredunes baseline, and (c) recreation, tourism, and development should be promoted. There is no doubt that a management plan has to be established along intensely developed shorelines, the question here is whether the priority should be given to these areas. Considering that about 77% of this shoreline is developed, from which half the length represents constructions built on top of the dunes (Tab. 2), it seems to be less effective to establish control construction lines and dune preservation along the northern sector than along the mainly undeveloped central and southern sectors. Additionally, beaches along the northern sector are mainly accreting in the long and short terms while erosion is observed in areas where further (or new) development will mean an increase in the number and length of critical management areas with time. Defining the ZEE and establishing setback lines and restrictions of use along undeveloped areas under erosion or ecologically important areas appear to be the faster and most efficient way to reduce efforts of corrective management in the medium and long terms. Therefore, the importance of understanding shoreline changes in different time scales to help in the identification of the priority areas for coastal management.

About a decade ago, Tagliani (1995) has drawn attention for the need to define strategies for a planned development along the coastal sector on time to mitigate the environmental problems associated with unregulated occupation and uses. The author includes the present beach-dune system as conservation areas and lists the identification of erosion zones along the coast and lagoon margins amongst the most important aspects that need to be addressed to improve management in that sector. Thus, results presented in this study contribute towards a better understanding of some of the parameters that are important to define the best management practices for different sectors of the RS coast at a regional scale. The best management practices are defined also according to social, economic, and cultural issues that need to be evaluated at a local scale. Priority areas represent about one third of the RS coast and are concentrated in the central sector. The best alternative to these areas is to implement management policies to promote their natural characteristics. For example, the areas adjacent to the Lagoa do Peixe National Park show a great potential for ecotourism, an expanding activity that attracts half million tourists and generates R$ 500 million and 30,000 direct jobs per year in Brazil (MMA, http://www.mma.gov.br/

port/sds/ecotur/corpo.html). Regulating occupation and uses along the central sector is crucial to preserve its natural resources. Critical areas represent 29% of the RS coast and include mainly developed beaches and their surroundings. The southernmost critical area comprises the beaches from Chuí to Hermenegildo, where development is not intense and is surrounded by long undeveloped shorelines. Thus, management strategies there should differ from the ones applied to the highly urbanized shores of the northern sector. For example, relocation or planned retreated should be evaluated as possible responses to the erosion problem in beaches such as Hermenegildo, where there is enough undeveloped area either alongshore or inland and beachfront properties are not worth an expensive protection measure. The same problem in the area of Tramandaí and Cidreira should be addressed in a different way as there is no room for relocation and tourism and beachfront properties represent significant economic revenue that needs to be protected.

CONCLUSIONS

This study points different classes of management for RS beaches based on the following factors: (a) rates of population growth from 1991 to 2000, (b) intensity of beachfront development and the state of conservation of the beach system, (c) shoreline change rates estimated for the period 1997 to 2002, and (d) coastal evolution in the Holocene. The RS beaches were classified into four classes of management: (1) areas of critical management occur along about 177 km or 29% of the RS coastal length, (2) priority areas are found along 198 km or 32% of the RS coastal length, (3) areas of future concern occur along 65 km or 10% of the coastal length, and (4) natural areas along 178 km or 29% of the RS coastal length.

Beaches along the northern coastal sector were classified as areas of critical management as they are highly developed (about 77% of the beachfront), show the highest rates of population growth (mean annual rate above 4%), and the beach-dune system is intensely altered. Beaches south of Xangrilá are eroding in the short term, demanding a management strategy different from the one designed for the accreted beaches to the north. Most of the central sector (198 km or 72%) is classified as priority areas, including the shores of Mostardas, Tavares, and the northern coastline of São José do Norte. About 23 km or 8.4% of the length of the central sector were classified as critical areas (Palmares do Sul), and 54 km or 19.6% of its length as natural areas (southernmost São José do Norte). Palmares do Sul and Mostardas show high rates of population growth (mean annual rate above 2%), but the first one was classified into the critical management class because it is located closer to the critical areas of the northern sector, is more intensely developed, and already shows problems due to unplanned occupation. The priority areas are mainly undeveloped with a preserved beach-dune system, show a potential of increasing pressure in the near future (due to recently facilitated access), and are eroding in the long or short term. Natural areas are pristine shores that are not threatened by population growth or accelerated development, and are mainly accreting. The southern coastal sector is dominated by natural areas (124 km or 56% of its length), although 65 km or 30% of its length are classified as areas of future concern (beaches from Hermenegildo to Albardão), and 31 km (14%) are classified as critical areas (from Chuí to Hermenegildo and Cassino).

It is discussed in this study that priority areas should be addressed first in a longer term state program of coastal management because preventive management is easier and less expensive to implement, and is more efficient as it reduces the number and length of critical areas in the medium to long terms. Additionally, data related to short-term shoreline changes and coastal evolution are presented and used to define classes of management. The identification of eroding beaches in the long or short terms is especially important because these areas need to be addressed more urgently than accreting beaches to prevent development in risk zones. Management measures applied for eroding areas need to include setback lines and restriction zones for development and uses.

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