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Beachfront Owners Perception of Beach Erosion along an Armored Shoreline in Southern Brazil

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Abstract - Brazil has about 8500 km of coastline that is mostly undeveloped. However, the pressure of fast-growing coastal urban centers is already impacting the shore. This paper characterizes shore protection works in Hermenegildo Beach, evaluates their efficiency to protect property against the impact of storm events, and presents the response of beachfront owners to erosion. Hermenegildo is a beach village located 12 km north of the border with Uruguay in Rio Grande do Sul, the southernmost state in Brazil. Several factors contribute to beach erosion in Hermenegildo: storm surge, redistribution of wave energy, rising sea level, the presence of an underlying layer of impermeable peat, and human activities. The shoreline is heavily armored with about 61% of beachfront houses protected by revetments (30%), seawalls (18%), or a combination of both (13%). A strong storm struck the Rio Grande do Sul coast in 16 April 1999 and resulted in severe beach erosion and destroyed 22 houses, besides all concrete structures, half of the quarrystone revetments, and 80% of the timber seawalls. Shore protection structures in Hermenegildo are threatened by erosion because: (1) they were built too close to the water, (2) shoreline retreat has been observed, and (3) armoring has reduced beach width. Most of the beachfront owners are aware of the severe beach erosion problem and appear to understand basic coastal dynamics. About 82% of the interviewed beachfront owners lost property due to erosion; 88% subsequently built protection structures to prevent further loss. Surprisingly, 88% of those who did not experience property damage also built defense structures. Armoring is commonly an initiative of beachfront owners who build low-budget structures without consultation by technical experts.

Keywords - shore protection, storm, property loss, Rio Grande do Sul

INTRODUCTION

Brazil has about 8500 km of coastline, from which only 17% is densely populated (Egler & Muehe, 1997). Although there are long coastal segments still undeveloped, the pressure of fast-growing, coastal urban centers is already impacting the shore. Since colonization times, urbanization has occurred in a chaotic way (Moraes, 1995). Presently, the consequences of unplanned coastal developments are aggravated because the coastal population is growing faster than necessary basic infrastructures (*e.g.* sewage, electric power, drinking water supply, and sanitary landfills) are available. In addition, the perception of coastal erosion as a problem has increased as development occurs indiscriminately along eroding shorelines.

Brazil's southernmost state (Fig. 1), Rio Grande do Sul (RS), has one of the least developed shores of the country. Its 600-km shoreline is dominated by long and continuous straight sandy beaches. Unlike all other Brazilian coastal states, its colonization was more intense inland than along the coast. Even today, RS is the only state where the average population density is higher in inland cities (35 inhabitants/km^2) than in coastal ones (24 inhabitants/km^2) (Moraes, 1995). About 4% of the RS population live on the coast and most of the coastal cities are concentrated in the state northern shores. To the south, development is concentrated in a few beach villages separated by long undeveloped shore segments. Despite that, erosion can be observed along several shore segments from north to south in front of developed and undeveloped beaches.

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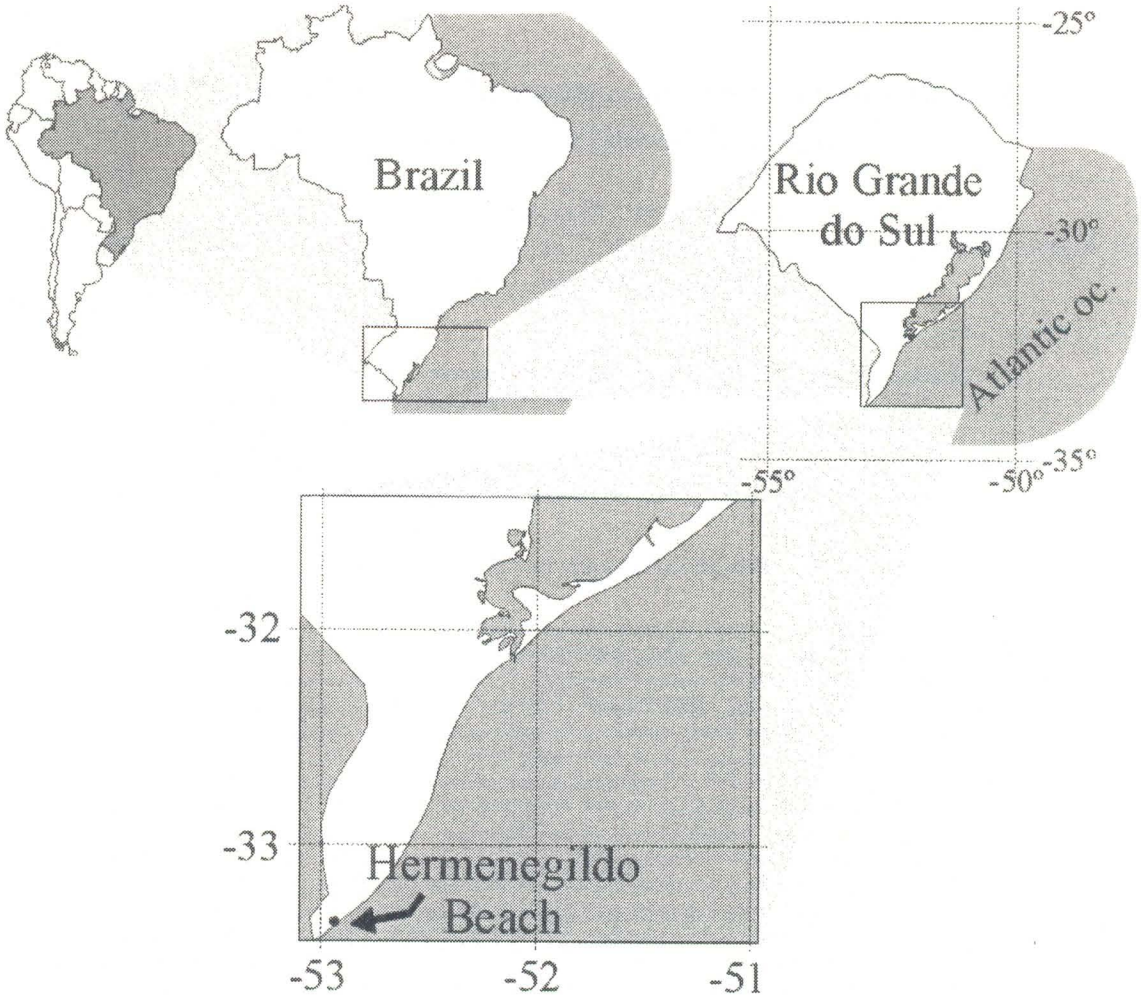

Figure 1 - Location of the study area. Hermenegildo is a beach village located in the state of Rio Grande do Sul, southern Brazil.

Beach erosion has been widely observed and studied in Brazil, including along the RS beaches (Tomazelli & Villwock, 1989; Toldo Jr., 1994; Tomazelli *et al.*, 1995; Barletta, 1997; Calliari *et al.*, 1998; Pimenta, 1999; Toldo Jr. *et al.*, 1999). However, only a few recent studies have addressed coastal protection works (Esteves *et al.*, 1999a,b,c), and nothing has been published regarding the social perception of erosion (response, expectations, and coastal knowledge of beachfront owners and local authorities). This paper characterizes the shoreline of Hermenegildo Beach, a small village at the southernmost part of Brazil, based on the presence and type of coastal protection structures and their efficiency in protecting properties from a high-energy event. Additionally, it presents a preliminary analysis of the beachfront owners perception and response to erosion.

STUDY AREA

The study area comprises the urbanized shoreline of Hermenegildo, a beach village located in southern Brazil (12 km north of the border with Uruguay), town of Santa Vitória do Palmar (Fig. 1). About 1600 m of its 4500-m long shoreline is developed, while the remaining 2900 m are occupied by coastal dunes. The RS coastal area comprises a long and broad coastal plain presenting several lagoons, including two large ones that comprise the hydrographic system Patos-Mirim. Local (and regional) geomorphology resulted from natural coastal processes, mainly related to sea level fluctuations, that have shaped the RS coast since the Pliocene.

Occupation of this area started in 1890 and, since then, unplanned urbanization has occurred. As an example, houses were built over the frontal

dunes and, in some places, dunes were partial or totally removed. Moraes (1995) described that coastal development in Brazil was intensified in the 1960s and 1970s through the construction of summerhouses. This trend applies to Hermenegildo, too. The majority of property owners live in Santa Vitória do Palmar, 18 km from the beach. Hermenegildo has not developed much. There is no official data, but local authorities have estimated its fixed population at about 500 people, mainly fishermen and retired people. However, population in summer (from December to March) is ten times greater, as summerhouses are occupied. Besides the summerhouses owners, the area is often frequented by tourists from Uruguay.

The maximum tidal amplitude in this area is about 0.40 m. Thus, waves are the dominant hydrodynamic factor. Winds from NE are the most frequent, while S-SE winds are the strongest and result in higher waves. According to the morphodynamic classification of beaches described by Wright & Short (1984), Hermenegildo Beach is classified as intermediate, having a high mobility of the backshore, which indicates great susceptibility to changes in sand volume (Calliari & Klein, 1993; Tozzi, 1999). Severe problems of beach erosion have been observed at least during the last two decades. The beach width averages about 12 m and is often completely submerged due to the action of strong southern winds. Such winds pile water over the shore and, in association to high waves, and high springtide, are responsible for the most intense erosive events, sometimes damaging beachfront properties. As a result, the 1,600 m of urbanized shoreline is heavily armored.

METHODS

The urbanized shoreline of Hermenegildo was mapped in February and March 1999 to determine the extension, distribution, and type of its shore protection structures (Esteves *et al.*, 1999c). Beachfront properties and protective works were measured, classified, and a photographic record was taken. Part of the shoreline mapping and classification is presented in figure 2. Topographic beach profiles were measured using the method of stadia (Birkemeier, 1981). Additionally, beachfront owners were interviewed in an attempt to understand their perception and response to the erosive processes.

Properties were classified as unprotected, when there is no shore protection structures or the structure is partially or totally damaged (Fig. 2a), or protected. Protected properties were subdivided into three groups, according to the type of structures: (1) protected by revetments (Fig. 2b), (2) protected by seawalls or bulkheads (Fig. 2c), and (3) mixed (Fig. 2d), when a combination of structures was used. Groups 1 and 2 were subdivided according to the material used to build the structure. Revetments were subdivided in (a) quarrystone revetment, when blocks of rocks were used as the dominant material, and (b) other, when any other type of material was used. Seawalls were made of (a) wood, and (b) concrete. The third group consisted in wood or concrete seawalls that had a toe protection of quarrystone revetment.

In April, after a strong storm struck the coast, the same mapping procedure was repeated. Mapping results from before and after the storm were analyzed to determine how shore protection works responded to a high-energy event (Table 1). A topographic beach profile was measured after the storm and compared to previous profiles to estimate sand volume changes. Calculations of such changes were obtained from the application of the software *Interactive Survey Reduction Program* – ISRP (Birkemeier, 1984).

Interviews were conducted to every beachfront owner met during the three field trips (February 11, March 11, and April 30, 1999). Questions in the interviews were elaborated to reach three objectives: (1) to understand how beachfront owners perceive erosion, (2) to know how many have lost property due to erosion, and (3) how they have responded to this threat. Collection of data was an attempt to provide researchers with a way to see a coastal problem through the eyes of the people who are experiencing it. It is an effort to provide a closer interaction between community and scientists, in a way that community members have an active part in the study.

CAUSES OF EROSION IN HERMENEGILDO BEACH

Natural and human factors contribute to beach erosion in Hermenegildo. Several studies point that most of the observed shoreline retreat in the area is due to natural processes, including: storm surges, relative sea-level rise, concentration of wave

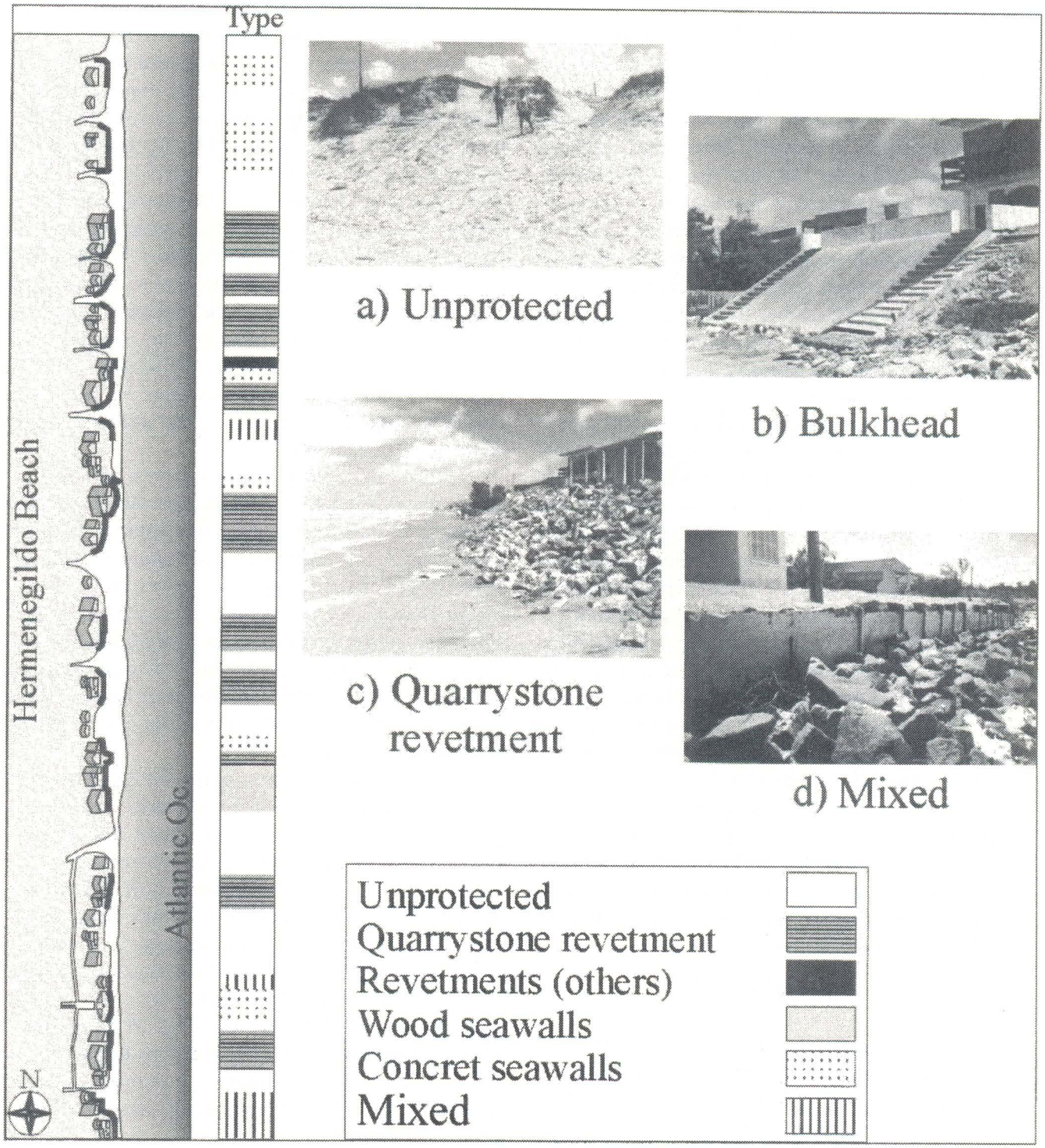

Figure 2 - Mapping of beachfront properties along part of the Hermenegildo urbanized shoreline, displaying the classification of shore protection structures. Pictures are examples of (a) unprotected property, (b) bulkhead, (c) quarrystone revetment and, (d) mixed structures.

energy due to refraction, and the low permeability of beach deposits. Some of the most important findings of recent studies are summarized below.

Pimenta (1999) suggests that the complex bathymetry of the inner shelf adjacent to Hermenegildo causes a concentration of wave energy at certain points along shore. The location and configuration of two depressions and three rises promote wave refraction in a way that results in the convergence of wave rays. Consequently, as wave energy increases onshore and sediment transport becomes more intense. Recent ongoing studies indicate that wave refraction and concentration of wave energy might be a major cause of erosion in Hermenegildo (Speranksi, *personal communication* in 22 December 1999).

The contribution of relative sea-level rise to shore erosion in southern Brazil is not yet quantified. However, some studies (*i.e.* Tomazelli & Villwock, 1989; Tomazelli *et al.*, 1995) have indicated that the observed shoreline retreat might be the result of a rise in sea level based on sedimentological and morphological evidence, including: (1) the exposure of holocenic peat deposits in the beach along several coastal segments of the state, (2) truncated depositional features in the internal margins of the Patos Lagoon, and (3) landward migration of dune fields over backshore and lagoon deposits.

As noted above, many segments along the Rio Grande do Sul shoreline have underlying peat deposits that are exposed during storm events. In the study area, these deposits are about 20 cm thick and were radiocarbon dated at 2470 ± 60 years (Buchmann *et al.*, 1997). Mud layers also have been observed and exposed in Hermenegildo during storms. The presence of underlying layers of peat and mud reduce beach permeability and increase backwash flow, enhancing erosion as described in Klein & Calliari (1997).

Storm surges in southernmost Brazil are caused by southerly winds associated with the passage of cold fronts (Calliari *et al.*, 1998). These winds push water to onshore as a result of the Ekman transport. Exceptional storms occur at least once a year, frequently in April (such as in 1995, 1997, and 1999) and July (1993 and 1996). These events bring high energy waves to the coast, generally on the top of a storm surge of about 1 m. When they occur during high spring tides, extreme erosion is likely to follow (Barletta, 1997).

Besides the natural processes, several human activities contribute to the erosion problem in Hermenegildo. Houses were built too close to the water, over the foredunes. Coastal development did not leave much space for the natural beach dynamics to take place. As a result, several houses were destroyed during storms and the shoreline has been heavily armored in an attempt to restrain further property loss. Structures built on the beach and in dune areas have interfered with the local balance of sand exchange, causing a sediment deficit. Contributing to the sand deficit, coastal sand has been historically removed from the system for use in civil engineering projects or as fill to rise low lands. The artificial closure of natural washouts might be another anthropogenic change that tampers with local sand balance. These washouts drain water that accumulates, by overwash or a rising groundwater table in and behind the dunes. Some washouts are permanent features but others are temporary and are a function of rainfall. Several washouts in Hermenegildo were artificially closed for road construction. These streets are often destroyed during storms when the washouts are temporarily reactivated.

THE IMPACT OF A HIGH-ENERGY EVENT IN HERMENEGILDO BEACH

On April 16, 1999, after a typical passage of a cold front, a cyclonic atmospheric disturbance with a two-day life span in a sub-synoptic scale, started to form off the Uruguayan coast (Castelão & Saraiva, 1999). According to records of the meteorological station at the Port of Rio Grande, about 200 km north of Hermenegildo, this high-intensity mesoscale cyclogenesis (Fig. 3) struck the RS coast with average wind velocities of about 75 km/h (reaching gusts of 115 km/h), resulting in a storm surge of 0.8 m. A significant wave height of 5 m, and maximum wave height of 8 m was registered at a depth of 15 m.

The analysis of beach profiles measured before and after the storm showed that about 45 m^3/m of sediments were eroded. The difference between the storm and the swell profile configuration is represented in figure 4a. Studying beach profiles measured in Hermenegildo from 1991 to 1996 (Fig. 4b), Tozzi (1999) noted that the average volume change was about 50 m^3/m. He also noted that the maximum changes in sand volume

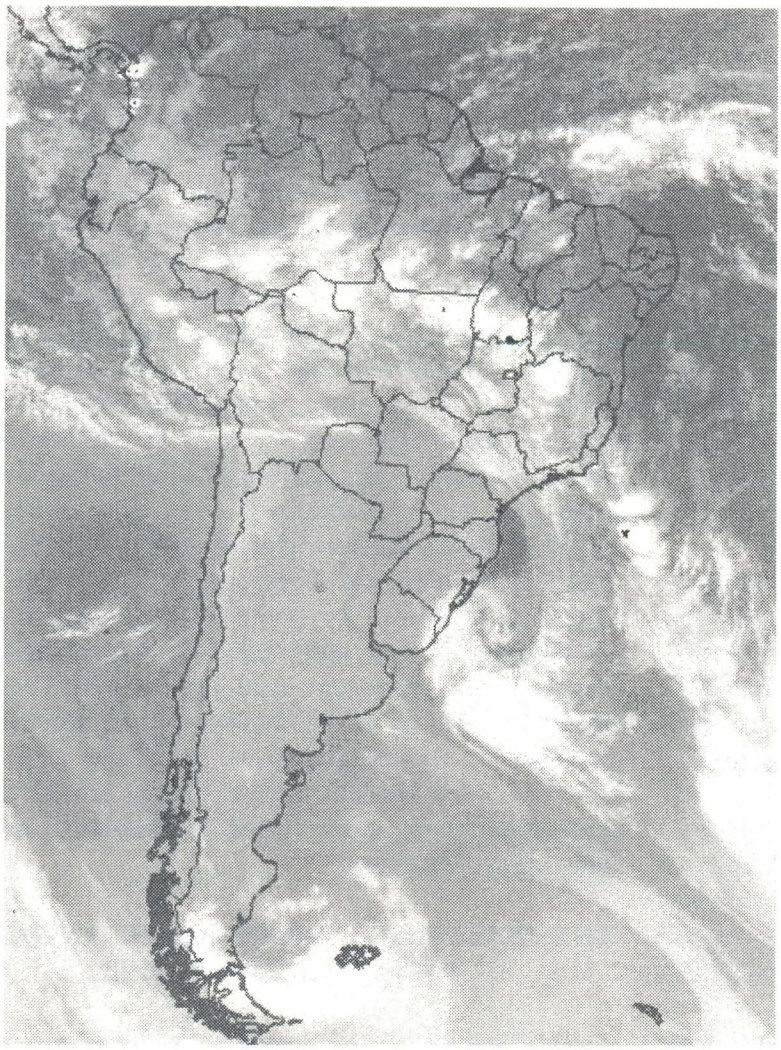

Figure 3 - High-intensity mesoscale ciclogenesis of 04/17/99 at 08:45z – GOES 8 – channel 4 showing South America (CPTEC/INPE).

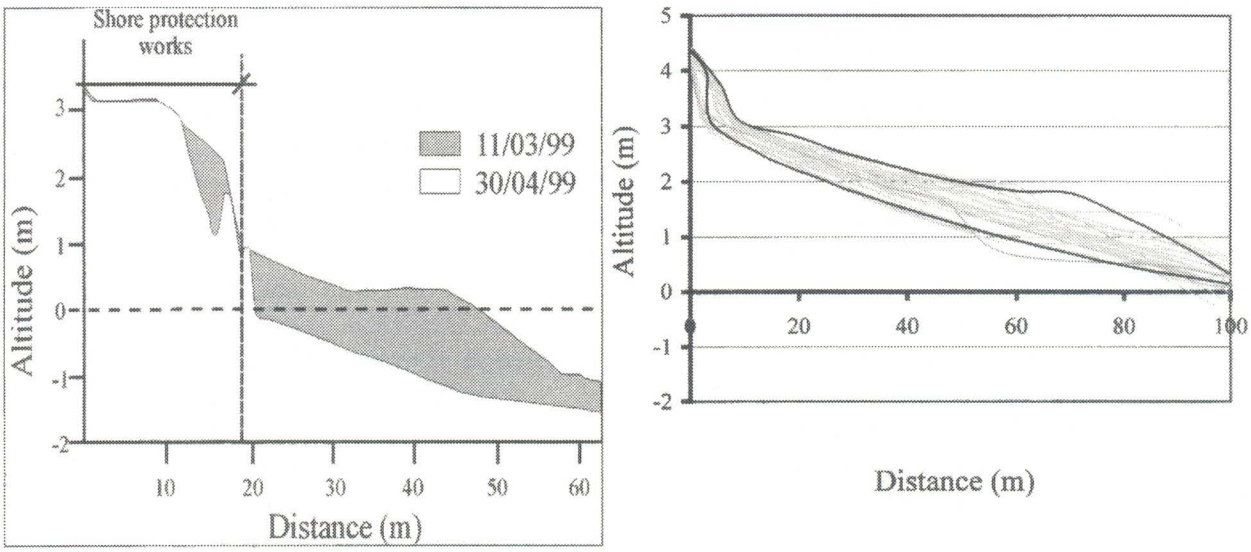

Figure 4 - Beach profiles measured at the central part of the urbanized shoreline of Hermenegildo, (a) representing a swell and a storm condition as observed before and after the storm described in this work, and (b) beach profiles measured from 1991 to 1996 (Tozzi, 1999).

Table 1 - Distribution of shore protection structures in Hermenegildo before and after the storm of April 16, 1999.

	Structure Type	Material	Number of properties (%)	
			Before	After
Unprotected	–	–	43 (39%)	65 (74%)
Protected	Revetments	Quarrystone	31 (28%)	16 (18%)
		Concrete	02 (2%)	0 (0%)
	Seawalls/Bulkheads	Wood	10 (9%)	02 (2%)
		Concrete	10 (9%)	0 (0%)
	Mixed	Wood or concrete seawalls with Quarrystone revetment	14 (13%)	5 (6%)
	TOTAL		110	88

occurred when the first Fall storms (from March to June) eroded the accreted profile built during the Summer months (from December to March). According to Tozzi's results, the storm of April 1999 was a typical example of the high-energy events that threat Hermenegildo at least once a year. Due to the intense beach erosion and the higher water level, beachfront structures became more susceptible to wave attack and were destroyed during the storm.

Table 1 summarizes the distribution of coastal protection structures in Hermenegildo before and after the storm of April 16, 1999. In February and March, 1999, there were 110 beachfront houses in the urbanized area of Hermenegildo. Most of them were built over the foredunes and are about 2.5 m above the mean sea level. Some landowners had removed the dunes before building their houses.

About 61% of beachfront properties were protected (30% by revetments, 18% by seawalls, and 13% by a combination of both). Revetments are the dominant structure, mainly made of large blocks of rocks (quarrystone revetment), except in two cases where they were made of concrete. The quarrystone revetments were usually made of only one size of blocks and had no filter layer. Revetments were placed directly over the original dune scarp, without an adequate slope. Bulkheads were made of wood (50%) or concrete (50%), placed adjacent to the dune and had none or very shallow foundations. Mixed structures consisted in wood or concrete bulkheads protected by a quarrystone revetment. Those shore protection structures were apparently built with little or no technical expertise. It was not unusual for a variety of materials (tires, rubbish, rubble, fishing nets) to be added to the quarrystone revetments in hopes of provide extra protection (certainly it was not to improve the aesthetic quality of the landscape!).

All types of structures built to protect beachfront houses were affected by the storm. Twenty-two houses were destroyed, besides all concrete structures, half of the quarrystone revetments, and 80% of the wood seawalls. The concrete structures were made directly over the dune scarp and had very shallow foundations, if any. Thus, the erosion of large volumes of sand from the beach profile is probably the main cause of structural collapse. As quarrystone revetments were built with no filter layer, water infiltration was able to removed sand from behind and below the structure. Additionally, the frequent contact with water, results in the movement of the large blocks to the toe of the structure, where they end up partially or totally buried in the sand. Eight (36%) of the 22 destroyed houses were not protected, while the remaining 14 houses (64%) were protected. The impact of such a high-energy event resulted in an increase of 51% of the number of properties without protection, and reduced by three times the number of houses that remained protected.

COASTAL EROSION THROUGH THE EYES OF BEACHFRONT OWNERS

Beachfront owners met during the field trips were asked to answer some questions that would contribute to better understand the erosion problem in Hermenegildo. A total of 50 people were interviewed, 33 before and 17 after the storm of April, 1999, representing 45% of the total number of beachfront houses before the storm. Most of the people that live temporarily or permanently in Hermenegildo were born in the town of Santa Vitória

do Palmar, 18 km from the beach. The close proximity from their home is the main reason they go to Hermenegildo. Additionally, these people like the quiet atmosphere and the beach free of pollution. From the 50 interviewees, 21 were permanent residents and 29 were seasonal residents, from which the great majority spends most summers on this beach.

As weather and beach morphodynamic conditions were quite different during the field trips before (summer, accreted profile) and after the storm (winter, storm profile), answers obtained from both situations could not be analyzed together. The interviews had three objectives: (1) to evaluate how beachfront owners perceive erosion, (2) to know how many have lost property due to erosion, and (3) their response to the problem. The main findings are summarized below.

Perception of Erosion

All interviewees perceive beach erosion as a problem in Hermenegildo, with about 45% recognizing that erosive events have occurred for more than ten years. It is remarkable that about two-thirds of the seasonal residents were cognizant of the fact that erosion is manifested in the beach landscape at least in the last five years, while only one-third of the permanent residents had the same perception.

Many beachfront owners cited natural processes and human activities as contributing factors of beach erosion in Hermenegildo, including sea-level rise (20%), strong winds (19%), the artificial closure of natural washouts (16%), construction too close to the water (13%), waves and tides (4%), rainfall (3%), depletion of the ozone layer (3%), and frequency of the cold front passage (1.5%), El Niño (1.5%), and tsunamis (1.5%). About 16% had no idea or did not answer this question. Most people cited more than one factor, recognizing that beach erosion results from a combination of processes. In general, the interviewees appeared to have a basic understanding (or at least, intuitive concept) about beach dynamics. Some respondents discussed rising sea level due to the greenhouse effect and melting of polar ice sheets, or erosion during storms as a result of storm surges. Similarly, those that identified strong winds as a major cause of erosion explained that southerly winds push water to the shore (storm surge) and bring high waves.

Property Loss Due to Beach Erosion

About 46% of the beachfront owners said they were aware of an erosion problem when they bought/built their land/house; 39% did not know that the beach was eroding, and 15% have inherited their property. The results of how many interviewees lost property due to beach erosion and how many built shore protection structures are displayed in table 2. About 82% of the interviewed beachfront owners lost property due to erosion, 50% lost land and 32% lost land and part of their houses. Considering that the data actually represents 45% of the total number of beachfront properties, it means that erosion damaged property of at least 37% of the total beachfront owners.

It is worth noting that 17 people (34%) were interviewed about two weeks after a strong storm, late April. At this time of the year, people on the beach are probably permanent residents, not tourists. Additionally, people on the beach were probably there to check for the storm damage, or to rebuild their houses and protection structures. Thus, there was little opportunity to interview someone who had not lost property at that time. This bias may have affected the results shown in Table 2, increasing the percentage of people that had experienced property loss. About 27% of the 33 people interviewed before the storm had not lost property, while all 17 people interviewed after the storm had lost land or part of their houses.

The Response of Beachfront Owners to Erosion

Forty-four of the 50 or 88% of the beachfront owners that contributed to this study used shore protection structures to fight erosion (Table 2). Armoring was the response of all property owners that lost land and part of their houses, while defense structures were built by 80% of the ones that had only lost land. Surprisingly, 88% of the interviewees that did not experience property loss also protected their properties. Loss due to erosion was at the same percentage for both protected and unprotected properties, respectively 82% and 83%. However, lost unprotected properties consisted only in land loss while 36% of the protected properties presented damages to the house (Figure 5). There was no conclusions weather that difference is due to some effect of the presence of protection structures enhancing erosion or just a consequence of

Table 2 - Number of beachfront owners that had property loss and the implementation of coastal defense in Hermenegildo.

Property Loss	Shore Protection Structures		Total
	Yes	No	
None	8 (16%)	1 (2%)	9 (18%)
Only land	20 (40%)	5 (10%)	25 (50%)
Land and part of the house	16 (32%)	-	16 (32%)
Total	44 (88%)	6 (12%)	50 (100%)

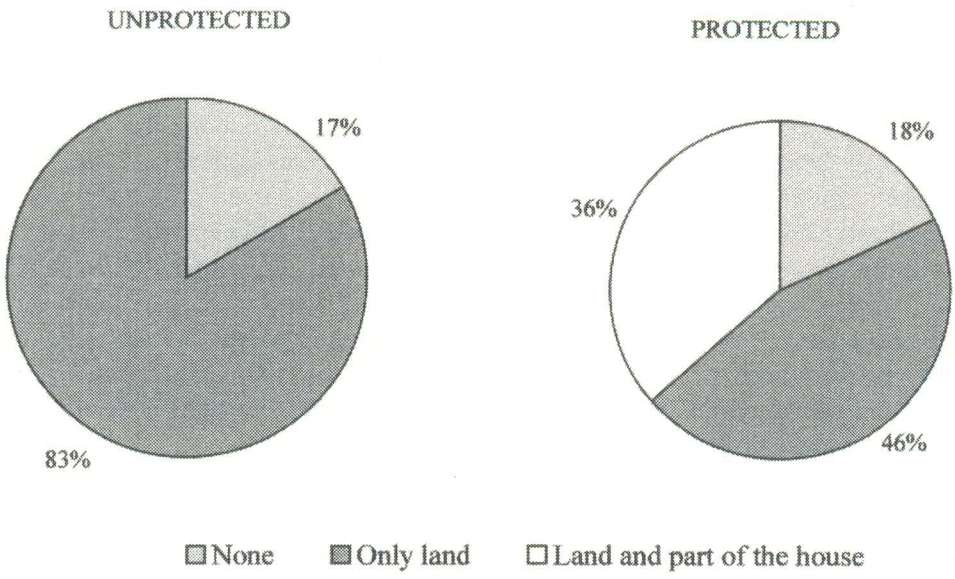

Figure 5 - Percentage of land and/ or property loss due to erosion for protected and unprotected beachfront residences according to the answers in the interviews.

protection placed in front of developed lots, so percentage will be proportionally higher.

First time visitors to Hermenegildo might wonder how this small beach village ended up with such a heavily armored shoreline. According to the beachfront owners, building a structure to protect their property was their own idea (58% of the answers). Some said the initiative came from local authorities (8%), from a neighbor (8%), consultation with neighbors (8%) or with local authorities (4%). About 2% did not answer and 12% did not protect their property (because shore protection structures are expensive). Structures were built without technical expertise or support (*i.e.* engineering project, structure design, and maintenance program). Usually, the only expertise obtained was from a "more experienced" neighbor. Some sort of regular maintenance was performed by 61% of the interviewees. However, field observation indicates that most structures are poorly maintained.

Only half of the interviewees answered how much they spent to protect their property. A few have protected properties at no cost, as they used any available material or rock blocks bought by local authorities. Beachfront owners spend, in average, U$ 1,000 to U$ 1,500 in shore protection structures. These values represent only a rough idea on coastal defense costs, as it was not clear whether maintenance costs were included or not.

CONSIDERATIONS ABOUT THE BEACHFRONT OWNERS PERCEPTION OF EROSION

Interviews were conducted in two different conditions. About 66% of all surveys were obtained during summertime, when tourists and seasonal residents are enjoying their vacation by the beach. At that time, the beach had an accreted profile due to the mild weather, and storms were only a distant reminiscence. The remaining 34% of data were collected after a strong storm, in April, a time when only permanent residents stay at Hermenegildo. The storm caused severe beach erosion and resulted in the destruction of about 20% of the total number of beachfront houses. Thus, people met at the beach were, most probably, permanent residents or someone checking for storm damage or trying to

rebuild their property. The effects of a storm were literally present. The difference in time period experienced after a strong storm might have influenced the beach dweller perception of erosion. It is apparent that the information obtained in April reflected specifically the most recent storm, not only their protection efforts and costs, but their perception too. It is hard to imagine that someone who lost property due to erosion very recently would answer that did not notice the process. Data collected before the storm were more likely to represent a longer history of experiences, as residents were not concerned to rebuild their properties and clean the wreckage from the beach.

Another intriguing result was that a higher percentage of the seasonal residents than permanent residents said to recognize erosion for more than ten years. At the first moment, it was expected that permanent residents should know better the beach behavior, and they probably do. However, people that see the beach constantly changing, might get used to it and not perceive the gradual erosion or accretion trend. Summer residents visit the beach sporadically and seem to easily picture the changes. Additionally, beachfront owners might not want to see long-term beach changes as it will make the great pleasure to live near the water to become a threat. As they appreciate the beach, they just do not want to believe that it might not be a pleasant place to live someday (Smith, 1994).

Smith (1994) discusses the changes in the residents perception in a time period after a major erosive event. He points that the usual thought is that there could never be a worse storm than the one they had just experienced. It means that the answer about the intensity of the storm and its consequences will probably change as the storm gets in the past. Following the same line, Smith (1994) says that coastal residents totally denied any possibility that a storm will really devastate their beach. However, once severe erosion takes place, people disregard is suddenly replaced by concern that progressively grows to alarm, and sometimes pure panic. As erosion ceases, reaction then changes to acceptance, complacency and, within a year or so, chances to experience another devastating storm returns to zero.

People in Hermenegildo have passed through the stage described by Smith (1994). They have experienced so many catastrophic erosive events that they begun to believe that only changing attitude will get them out of the cycle of rebuilding houses and structures year after year. This was perceived by the authors in an open meeting organized by local authorities held in 29July 1999, in Santa Vitória do Palmar, to discuss the beach erosion problem. A group of researchers (including the authors) explained their findings, answered questions, and exchanged ideas with the audience. Surprisingly, community members and local authorities were very cooperative and ready to join forces to find the best solution. They appear to have learned that armoring will not solve their problem in a medium to long-term, if not for the researchers explanation, by their own experience. Amazingly, they were very receptive even when the idea of relocation was proposed. Although the meeting did not result in a concrete commitment to implement any of the discussed ideas, a research project to analyze different alternatives to find the best management practice to Hermenegildo was elaborated and submitted to obtain financial support from the state government.

EFFECIENCY OF SHORE ARMORING IN HERMENEGILDO

Hermenegildo's beachfront constructions are located over the dunes and shore protection structures were built in front of the dunes. Only one storm resulted in great destruction of structures, including 20% of all beachfront houses (Fig. 6), from which 64% were protected. Structures were not efficient to protect properties against the impact of a high-energy event because: (a) they were not properly built, (b) they were not properly maintained, or (c) when properly built and maintained, were not adequate to the type of protection desired. Smith (1994) points that proper maintenance of defense structures is a major factor to obtain desired protection. However, he observed that residents are unconcerned, not only in maintaining their walls, but also in appreciating that the walls even require maintenance at all.

Beachfront owners built shore protection structures without technical expertise. Bulkheads have very shallow foundations and revetments consist of a unique layer of large rock blocks. Quarrystone revetments were built with layers of large blocks of granite that allow water infiltration and do not retain the sand layers underneath. Thus, erosion of large sand volumes during storms results

Figure 6 - Examples of the structures and properties before (right-hand side) and after (left-hand side) the storm of April 16, 1999. The second pair of photographs shows the burying of boulders in the sand.

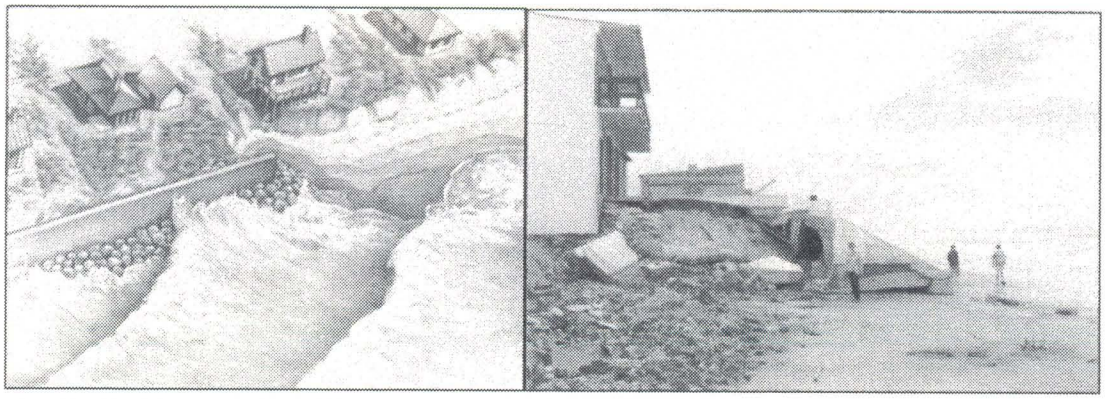

Figure 7 - Destruction of properties and structures through the exposed unprotected end. (a) Schematic drawing showing how protected property are threatened by erosion through the end of its structure (Modified from National Geographic, 1997, vol. 192, 2, p. 17) and (b) example from Hermenegildo after the storm of April 16, 1999.

in the collapse and failure of structures. Besides the intense erosion during storms, the narrow beach allows water to be often in contact with the structures. This causes the heavy blocks to sink in the sand, giving place to the movement of other blocks that might result in an unnoticed failure of the structure.

Destruction of structures occurred always through their southern end, and was more intense when the adjacent southern property was not protected. It shows that armoring requires an endless construction cycle, meaning that when one sector of the shore receives a hard engineering structure, adjacent shore segments must be protected too to show some efficiency (Fig. 7). It is possible to conclude that shore protection structures have aggravated erosion problems in Hermenegildo, as they protect properties behind them but reduce beach width, increasing the risk of structure damage. Additionally, properties are threatened by erosion because: (1) they were built too close to the water, and (2) shoreline retreat is observed.

Based on the information provided by residents, they spend from U$1,000 to U$ 2,000 in shore protection. This will result in an average cost of about U$ 83,000 to U$ 167,000 per kilometer of shoreline, as beachfront properties are 12 m wide in average. This might not seem much, but Hermenegildo is a small and poor village that has experienced severe erosion about once a year. Considering that they will have to pay that amount every year, it becomes an impressive amount to a place like Hermenegildo. Besides that, armoring has not been efficient to provide the protection desired and has caused reduction of beach width. Thus, costs and inefficiency are good arguments to make people choose a different response to beach erosion.

CONCLUSION

Hermenegildo has a critically eroded and heavily armored shoreline. Once a year its coast is struck by high-energy storms that result in severe beach erosion and damage to structures. Coastal defense works have not provided the desired protection because they were built too close to the water, without an appropriate design and/or material, and were not properly maintained. Beachfront owners have been aware of the erosion problem for at least a decade, some even before they have built or bought their property. They seem to have a good knowledge of coastal processes, but are reluctant to recognize that living near the water might not be as pleasant as they would imagine. However, many have learned through their own experiences that rebuilding houses and armoring in the same place is a never-ending cycle.

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