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The human impact on the Espinho-Paramos coast in the 20th Century

El impacto humano sobre la franja costera Espinho-Paramos durante el Siglo XX

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Abstract

The relationship between man and coast has been for centuries marked by a "peaceful coexistence", something which has been neglected over the last generations. The evolution of the coastline does not depend solely upon natural factors but also upon the type of intervention and land use of man. The "advances" of the sea along the Portuguese coastal strip are not recent; however the maintenance of the position of the coastline using engineering structures to protect the coast from the intervention of the last generations has contributed significantly to an increase of erosion and related problems.

This paper describes an analysis demonstrating the influence of engineering structures on the evolution of the coastline by comparing and integrating information from cartographic documents and newspaper reports, which constitute the best source of information for the area under study. The analysis was conducted using cartography at different scales and from different sources over about a century, which allow us to estimate the advances and retreats of the coastline and determine changes in terms of the behaviour of the coastal strip in stabilised stretches.

Coastal erosion has been affecting the study area since the end of the 19th century and its increasing impact has been felt throughout the 20th century. The several experiences and projects of coastal protection adopted during the 20th century have not prevented the retreat of the coastline and they have in fact become ineffective, contributing to the amplification and propagation of the phenomenon, especially from the 1970s onwards, to the south sector of the study area, where erosion rates in the period 1998/2003 ranged between 1,5m/year and 5m/year. The average coastline retreat is 2 m/year, which demanded the need to maintain and reinforce protective structures, which means an expense of millions of euros during a period of a century constituting an economic and environmental loss.

Keywords: coastal erosion, engineering structures, multi-temporal monitoring, municipality of Espinho, Portugal.

Resumen

La relación hombre/costa ha tenido a lo largo de los siglos una "coexistencia pacífica" que las generaciones de hoy han ido abandonando. La evolución del litoral no depende solamente de cuestiones de orden natural, sino también del tipo de intervención y del

uso del territorio por parte del hombre. El "avance" del mar no es una novedad a lo largo de la franja costera de Portugal continental; sin embargo, la ansiedad por fijar el litoral mediante intervenciones de protección costera por parte de las recientes generaciones, ha contribuido de manera significativa a acelerar los problemas erosivos. En este contexto, este trabajo se propone desarrollar un análisis que demuestre la evolución del litoral, influenciado en especial por las construcciones de protección costera, comparando e integrando un conjunto de información cartográfica y de noticias en los medios de comunicación que constituyen la mejor fuente de conocimiento del área. El análisis está desarrollado en base a una cartografia de escalas y de fuentes distintas y para un período de alrededor de un siglo, lo que ha permitido calcular el retroceso y los avances del litoral y verificar las alteraciones del comportamiento de la franja costera en los sectores estabilizados.

La erosión costera en el área del estudio era ya una realidad a finales del siglo XIX que ha ido aumentando a lo largo del siglo XX. Las experiencias diversas y los proyectos de defensa costera adoptados durante el siglo XX no habían conseguido frenar exactamente la erosion costera, y llegaron a ser ineficaces, contribuyendo a la amplificación y a la propagación del fenómeno, en especial a partir de la década de 1970, para el sector sur del área del estudio, donde las tasas de erosión entre 1998/2003 comprenden valores entre 1,5-5 m/año. La tasa de retroceso medio del litoral es de 2 m/año lo que ha exigido la necesidad de consolidar las estructuras de defensa, habiendo invertido muchos millones de euros en los últimos 100 años, lo que constituye una pérdida económica y ambiental.

Palabras clave: erosión costera, obras de protección, monitorización multitemporal, municipio de Espinho, Portugal.

1. Introduction

Human development along the Portuguese coast is not a recent phenomenon, although it has increased since the beginning of the 1970s, causing profound changes and disruption to the coastal "balance" and landscape. Associated to the unsustainable development and chaotic management of space, coastal erosion problems, such as coastline retreat and frequent episodes of marine invasion, as well as the impact and type of anthropogenic interventions in terms of coastal stabilisation, give rise to the urgent need to promote a more effective monitoring of the coastal strip.

This combination of coastal erosion and loss of goods of high economic value (both for tourism and industry) has given rise to a conflict in terms of management of the space. This conflict has been solved since the beginning of the 20th century through the construction of protective structures. These structures consisted essentially in groyne and seawall systems, without any type intervention of compensation such as artificial nourishment.

The segment Espinho-Paramos located in the NW coast of Mainland Portugal, comprises approximately 5.8 km of linear coastline and characterised by an important anthropogenic intervention – almost continuous groyne and seawall systems (Dias, 1990; Dias *et al.*, 1997) (Fig. 1). Permanent human occupation dates from the mid- 19th century, with the settlement of families of fishermen from the neighbouring communities of Afurada and Ovar, which resulted in the establishment of three communities by the sea (city of Espinho, village of Silvalde and village of Paramos), which developed over the years due to the association of the activity of fishing with "*seawater baths for medical purposes*". Throughout the 20th century these communities were faced with problems related to coastline retreat, namely loss of land, properties and equipment.

The study area is set in the Occidental Mesocenozoic Border which corresponds to an old sedimentary basin located in the western border of the Hesperian Massif, (Carvalho, 1995; Granja, 1999), where the Pre-Cambian rocks, namely schists and metamorphosed granites dominate. The Quaternary deposits, in particular those of the Holocene (alluvium deposits, fine dune sands and beach sands), overlie these.

In the neotectonic map of Portugal (Cabral and Ribeiro, 1988) (Fig. 2) the study area is dominated by a NNE trending lineament, which probably corresponds to a fault which shows a neotectonic movement, from the Serra do Gerês south to Ovar and by a NNW-SSE trending fault. Another important structure is the NNE-WSW trending lineament which crosses the coastline where it inflects from NNW-ESE to NNE-SSW, precisely in Espinho (Araújo, 2002). This is an unfavourable factor, since it promotes the erosive action of the waves.

The NW coast of Mainland Portugal is exposed to a highly energetic wave climate (Coelho, 2005). According to Carvalho and Barceló (1966), the most frequent significant wave heights (45% of the occurrences analysed) range from 1m to 2m; maximum records of 11m have been observed in storms and especially during the months of December and January. Wave length ranges between 6s and 8s, remaining constant throughout almost the entire year, although it may decrease slightly in the summer months (June to August) (Coelho, 2005).

The most representative directions in the sector under study are WNW (88.4%) and NW (42.4%) (Fig. 3) in 91% of the records that Coelho (2005) analysed in the period between 1993 and 2003.

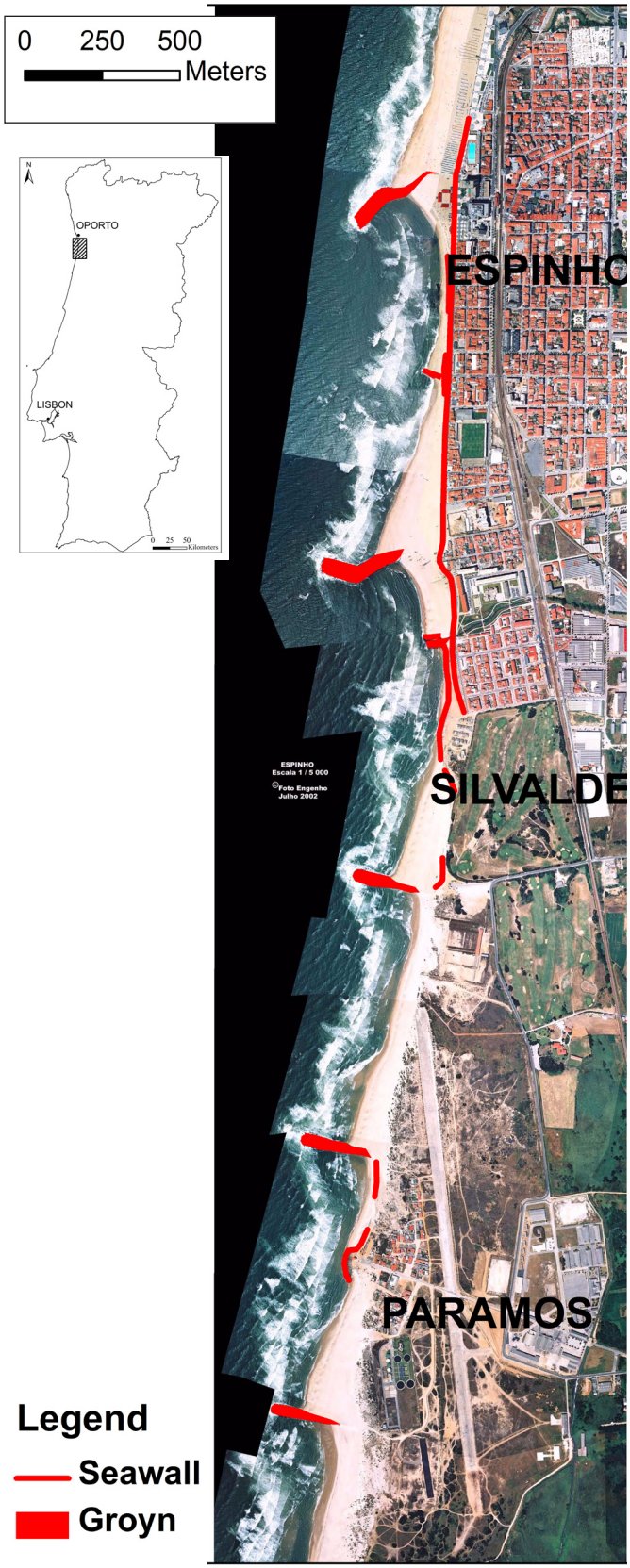

Fig. 1.– Location of the study area, municipality of Espinho and current position of the coastal protection structures.

Fig. 1.–Localización del área de estudio, del municipio de Espinho y situación real de la disposición de las estructuras de protección de la línea de costa.

The higher waves (8m to 11m) correspond to longer waves (8s) and they occur in the winter months, while shorter waves (=/< 6s) are associated to lower waves (1m to 2m), recorded in the summer.

Storms are more frequent between October and March, due to the advance of frontal systems and low pressures which produce violent waves for a brief period, with a medium wave height of 8 meters and periods ranging from 16 to 18 seconds (Ferreira *et al.*, 1995).

However, "episodes of marine invasion" do not depend solely upon the wave climate and the occurrence of storms; it is also necessary to take into consideration the type of tide. The combination of these phenomena may trigger many of the "episodes of marine invasion" that have already occured in the area.

The tidal regime in the sector under study is semi-diurnal, with four tides per day, with cycles of approximately 12h25m and an amplitude that can reach 4.0m. According to the Coastal Engineering Manual (2002) the sector under study is located in an area with a high mesotidal (2 to 3.5m) or low macrotidal (3.5 to 5m) range.

In this area the direction of littoral drift is mainly from north to south. Baptista (2006) presented a Table with estimates of sedimentary transport by the littoral drift to the sector comprised between Espinho and Cabo Mondego; the results range between 0.2 and $2{,}3 \times 10^6$ m^3/year. Ferreira (1993) considered as an average value $1{,}5 \times 10^6$ m^3/year, this is in agreement with the studies carried out by INAG and CEHIDRO (Baptista, 2006). The river Douro is the main supplier of sediments to the study area and transports approximately 1.6×10^6 m^3/year (Baptista, 2006).

Several studies have been published focussing on the problematic of coastal erosion in NW Portugal (Mota-Oliveira, 1990; Oliveira, 1993; Veloso-Gomes, 1987; 1991; 1993; Dias, 1990; Ferreira and Dias, 1991; Teixeira, 1994; Baptista and Bastos, 2004; Carvalho *et al.*, 2002; Veloso-Gomes *et al.,* 2002; Andrade *et al.*, 1996; Dias *et al.*, 1997; Baptista *et al.*, 2004; Baptista, 2006). These authors recognised a generalised retreat of the coastline due to natural causes, such as mean sea level rise, and anthropogenic causes, with special emphasis on coastal intervention and dam construction, which are indicated as having increased the negative effects of certain erosive processes. The objective of this study is to demonstrate that the solutions found to stop coastline retreat, and which have been implemented for over a century, have not been effective in the study area. In addition, we present a type of monitoring of the coastal strip through the multitemporal analysis of written documents and maps and by cartographic and image processing techniques. In the final part of the study we will try to quantify the impact of heavy engineering structures on the coast under analysis.

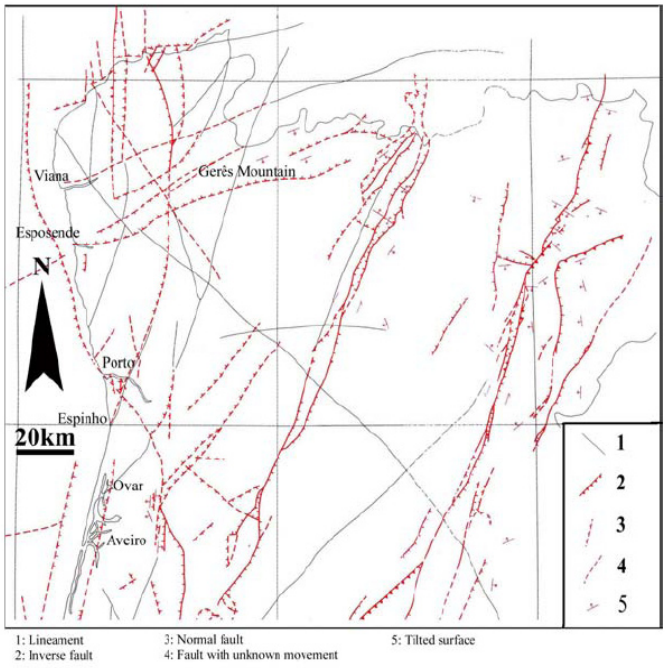

Fig. 2.– Neotectonic Map of the northern part of Portugal (Cabral and Ribeiro, 1988).
Fig. 2.– Mapa neotectónico del norte de Portugal (Cabral y Ribeiro, 1988).

2. Methodology

This study was based on the development of a database, which allows working with cartographic information and records of events reported in local and national newspapers.

Firstly, cartography of the late 19th century and contemporary was collected (Table 1) (provided by the City Council of Espinho, the Portuguese Geographical Institute and bibliography by Abel Teixeira), in order to gather the essential elements, such as the position of the coastline, the urban area and engineering structures.

The information, in paper format, was scanned and TIFF files were created, which were later corrected using the orthophotomap and the most recently updated vectorial map of the municipality of Espinho using ArcGIS version 9.0. software. The scanned information was georeferenced using known and common vector coordinates, adding at least 25 control points, and referenced to the projection system Datum 73 Hayford Gauss IGeoE.

The vectorisation of the main elements, already mentioned, was carried out very carefully so that the results obtained from this process were entirely reliable. The main difficulties encountered were that the procedures used to produce the older cartography (1880, 1900 and 1993) are unknown, thus, the outline of the coastline corresponded to the line indicating the limits of the emerged beach and, in the case of the orthophotmap, the coastline

Source	Year	Scale	Format
Military Topographic Map – Sheet	1998	1:25 000	Paper
Military Topographic Map – Sheet	1970	1:10 000	Paper
City Plant	1933	1: 4 000	Paper
City Plant	1900	1: 4 000	Paper
City Plant	1870	1: 4 000	Paper
Orthophotomap	June 2003	1:5 000	Digital
Vectorial Map	1993	1:25 000	Digital

Table 1.– The cartography used for the study.
Table 1.– Cartografia utilizada para el estudio.

corresponding to the wet/dry boundary. We have some reservations regarding its reliability, since the day, time, tide and height of the flight are unknown.

Using the Digital Shoreline Analysis System 3.1. software (extension for ArcGis 9.0), transects were established throughout the coastline of the study area to estimate rates of retreat. The result was a multi-temporal quantitative analysis of the changes in the coastline, proving the possibility to observe differential behaviour of various coastal stretches and for different time periods.

The cartographic information available was also complemented by additional data about the "episodes of marine invasion" gathered from news reports of the local newspaper "*Defesa de Espinho*" and the national newspaper "Jornal de Notícias", the Monografia de Espinho (Monography of Espinho) (Pereira, 1970) and the synthesis of "episodes of marine invasion" by Teixeira (1997).

3. Results

From the results of our study we observe that the front of the city of Espinho, where the nucleus of the old city was located since the late 19th century showed the first signs of coastal erosion. From the local press, we know that in 1890 Alegre Street (currently Street 1) was completely destroyed together with around 57 buildings located in the street. Considering the period between 1900 and 1933, the south sector of the city shows rates of retreat of around 1m/year, with a maximum beach loss of 40m, with the remaining sector remaining stable with rates of accretion of approximately 3.5m/year (Fig. 4). The 23 "episodes of marine invasion" also contributed to this erosion with evidence of destruction along 470 m of coast.

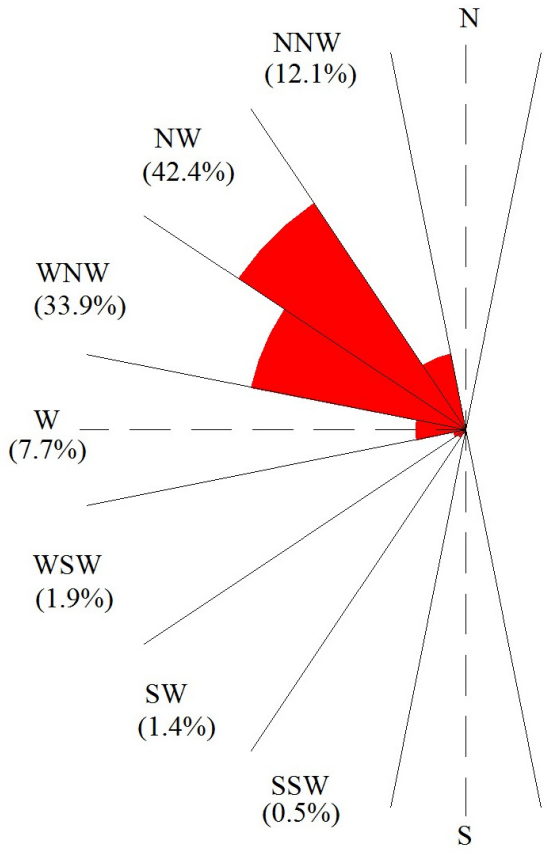

Fig. 3.– Dominant wave directional frequencies (Coelho, 2005).
Fig. 3.– Frecuencias dominantes en la dirección del oleaje (Coelho, 2005).

Although the average state in the study area is of accretion (Table 2), nevertheless, the damage has been great: destruction of the local market, of the Street 1 and over 57 houses. This required a structural intervention to promote the conservation of the built heritage. With regard to this we should point out the construction of a stone wall in 1909 (destroyed by the sea in 1911, (Fig. 5), 2 test groynes (in 1910), 2 groynes (between 1911 and 1912) and reinforcement repairs of the groynes in 1913 (Teixeira, 1997), which involved an investment of approximately 285 000 euros (based on the indications included in *Diário da República* (Portuguese Official Journal), Series I – B, nr. 85, 3 May 2006, Decree nr. 429/2006/Appendix.).

Despite the efforts, shown by comparing cartography of the same area between 1933 and 1970, it is possible to observe an accentuated increase of the retreat trend in the entire maritime front of the city of Espinho. This retreat reached 3.2 m/year in the North sector of the city and over 6m/year in the remaining maritime front, with maximum rates of retreat of over 8 m/year, corresponding to maximum losses in some sectors of around 326 m, where the beach and the dunes have been intensely destroyed, as well as buildings and streets of (Fig. 6) the old city nucleus.

Between streets 21 and 27 (transects 18 and 22) (Fig. 7), in the area most affected by "episodes of marine inva-

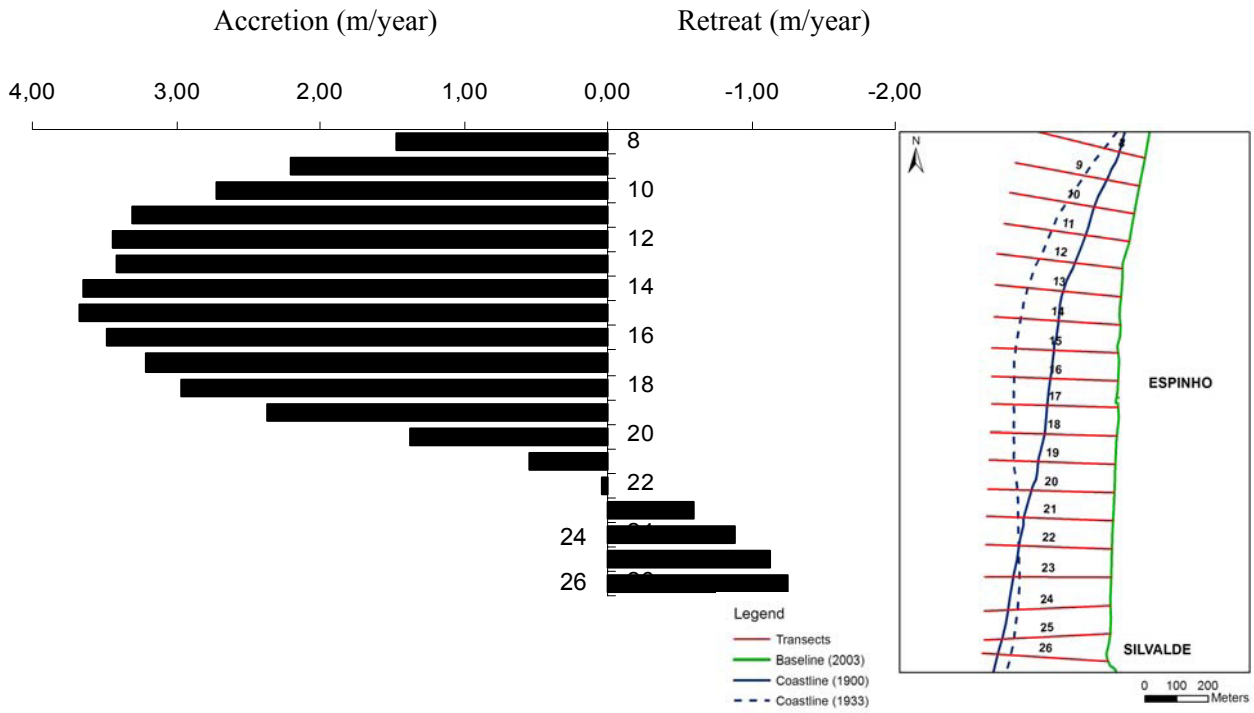

Fig. 4.– Retreat and rates of accretion the coastline in the front of the city of Espinho in the period of 1900-1933.
Fig. 4.– Valores de la tasa de retroceso y acreción de la línea de la costa en el frente de la ciudad de Espinho durante el periodo 1900-1933.

Sector	Period of 1900-1933		
	Average Rate (m/ year)	Nr. of marine invasions episodes	Nr. of coastal interventions
Front of the city of Espinho	1.8	22	5
Silvalde - Paramos	NA	NA	NA

Table 2.– Synthesis of the period of 1900-1933. The positive values in the average rate correspond to the situation of accretion in the coastline.

Table 2.–Síntesis para el período 1900-1933. Los valores positivos en el tasa media corresponden a la situación de acreción de la línea de costa.

since the beaches between groynes 1, 2, 3 and 4 experienced rates of around 3.5 m/year and 8 m/year and the coast south from groyne 4 of approximately 6m/year and 8.8 m/year (Fig. 8).

The phenomenon can be easily observed in the cartography from the 1970s, by the construction of a system of groynes in the front of Espinho, with these being located in the most sensitive areas and close to each other.

The objective was, according to the local press, to promote beach accretion between two groynes located closely together by the capture of sediments of the littoral drift, in order to stop coastal erosion. However, the results indicate that not only has the primary goal not achieved, but that the retreat of the coastline has actually increased between these structures. The need to build more structures or to reinforce the structures which were already

Fig. 5.– An example of the destruction caused by the sea in the seawall in 1910 (Dias *et al.*, 1994).

Fig. 5.– Ejemplo de la destrucción causada por el mar en 1910 en la estructura de defensa (Dias *et al.*, 1994).

sion", retreat rates ranged between 6 m/year and 8.3 m/year, with the maximum retreat being 307 m. The asymmetry in the evolution of the rates of retreat culminated in the 1940s with the destruction of part of the old block between Street 1 and up to the current Street 2 (over 250 m of loss of ground) – this area is nowadays submerged (zone "A" in Fig. 7).

Since then, there have been 14 "episodes of marine invasion" which have been "solved" by 12 interventions, namely through the construction of 2 groynes and a seawall in the areas most affected by the destruction. This strategy of construction of permanent, hard engineering structures has successively changed the circulation of sediments by littoral drift and has partially conditioned the type of response from the coastline. Coastal erosion had become much more accentuated in the south sector of the city of Espinho reaching considerable rates of retreat, built has been shown to be ineffective since the sector of the city of Espinho showed, in this period, an average rate of retreat around 6.8 m/year, showing a change towards an important rate of retreat (Table 3).

Based on the data available, it is estimated that more than 8 million Euros have been spent, although there is no available estimate of the amount of damage suffered by private losses (Table 4).

In the beginning of the 1980s, faced with the occurrence of "episodes of marine invasion" and the appeals of the local community, changes were introduced to the structures protecting the city of Espinho. Two curved groynes and located at a greater distance from each other, and a long continuous seawall; a groyne and a seawall in the freguesia (parish) of Silvalde and two groynes and one seawall in the maritime front of the freguesia (parish) Paramos were constructed.

Fig. 6.– The lifeguard Station destroyed in 1935, in front of the street 23 (Dias *et al.*, 1994).
Fig. 6.– Torre de vigilancia destruida en 1935, delante de la calle 23 (Dias *et al.*, 1994).

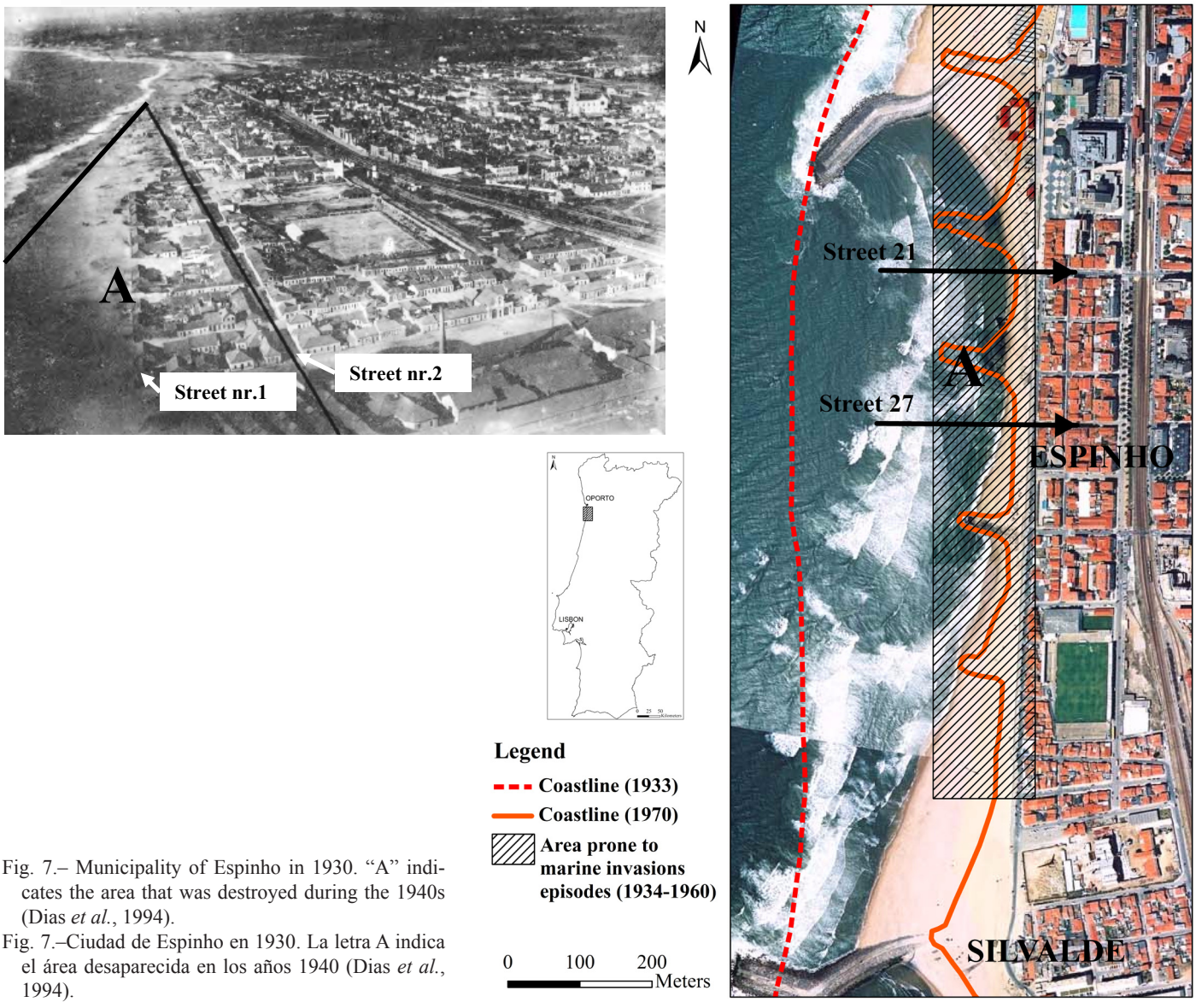

Fig. 7.– Municipality of Espinho in 1930. "A" indicates the area that was destroyed during the 1940s (Dias *et al.*, 1994).
Fig. 7.–Ciudad de Espinho en 1930. La letra A indica el área desaparecida en los años 1940 (Dias *et al.*, 1994).

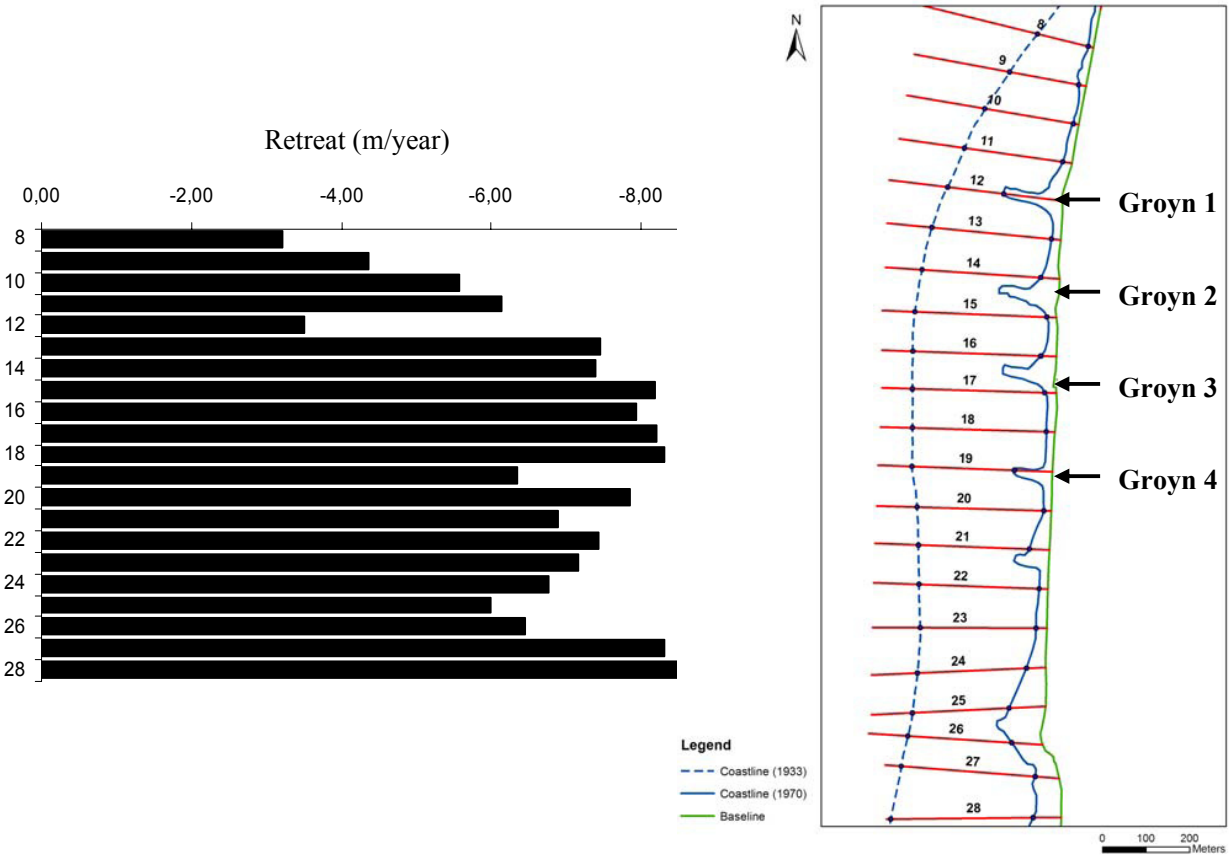

Fig. 8.– Rates of retreat of the coastline in front of the city of Espinho, in period of 1933 – 1970.
Fig. 8.– Tasa de retroceso de la línea de la costa en el frente de la ciudad de Espinho durante el periodo 1933-1970.

The strategic location of the structures was intended to protect certain types of installations, namely the swimming pool of Espinho, which had been hit several times and had been partially destroyed by the sea, the building by Street 2 between streets 21 and 33 (between transects 18 and 25), Bairro dos Pescadores in Silvalde, part of Fábrica Brandão Gomes (local factory in Silvalde), the landing strip of the local aerodrome and the Chapel of Paramos.

Analysing the results for the period between 1970-1993 together with the new structures it is possible to observe a slight stabilisation of the coastline in the front of the city with rates of accretion between 0.3 m/year and 4 m/year, especially by the pool to the north of the transect 12, where there were higher accretion rates. However, this was due to a reinforcement of the re-nourishment carried out in 1988, as there was no sign of beach recovery to protect the buildings in Street 2, and consequently the aesthetical and touristic potentialities of the area were being degraded (Fig. 9).

However, erosion has been amplified and moved to the south of these structures (between transects 30 and 78), where the maximum retreat reached 5.9 m/year. The more accentuated erosion rates were recorded between transects 42 and 78 (maritime fronts of Silvalde and Paramos) with rates of erosion between 2.4 m/year and 5.9 m/year, with losses of the available beach, in some sectors of greater than 110 m, thus increasing the exposure of the populations to the destructive action of the sea. The same structures, built in the front of the city of Espinho in the beginning of the 1980s, triggered the greatest rates of retreat found in this period; namely in the community of Paramos. There near the chapel the beach was over 150m wide before the 1970s (Fig. 10).

The retreat of the coastline, both in Silvalde and in Paramos, demanded the construction of further protection structures between 1984 and 1988. The asymmetry in the evolution of the coastline in the study area is easily observed, since to the south of the second groyne rates ranged between 1.8 m/year and 3.4 m/year, and of the groynes 3, 4 and 5 were more accentuated retreats, with maximum values between 4 m/year and 5.9 m/year (Fig. 11).

The average rate of retreat for the entire study area was -1.7 m/year. Nevertheless, in the front of the city of Espinho average accretion reached of 1.5 m/year whereas in the maritime front of the freguesias (parishes) of Silvalde and Paramos the average rate of retreat was – 2.8 m/year (Table 5)

Sector	Period of 1933-1970		
	Average rate (m/ year)	Nr. of marine invasions episodes	Nr. of coastal interven-tions
Front of the city of Espinho	- 6.8	14	12
Silvalde-Paramos	NA	NA	NA

Table 3.– Synthesis of the period of 1933-1970. The negative values in the average rate correspond to the situation of retreat in the coastline.

Table 3.– Síntesis del período 1933-1970. Los valores negativos en el tasa media corresponden a la situación de retroceso de la línea de costa.

Year	Money Spent (x10^3 €)	Year	Money Spent (x10^3 €)
1926	120.0	1942	50.1
1931	60.0	1946	117.1
1933	32.0	1948	108.8
1934	470.5	1959	6 698.1
1935	259.1		
1939	233.1	Total	**8 038.8**

Table 4.– The cost of the construction of the coastal protection structures in the municipality of Espinho (records from local and national newspapers).

Table 4.– Inversión económica para la construcción de las estructuras de defensa de la línea de costa en el municipio de Espinho.

This situation had a great impact on the Bairro dos Pescadores in Silvalde and in 1988 the waterline was regulated – Ribeira (small stream) de Silvalde - and the structures in front of the Bairro were reinforced. This impact was also accentuated in the community of Paramos, where the sea advanced across the dunes and caused significant damage to the chapel, streets and buildings, and contributed to the successive emergency interventions carried out between 1984 and 1986. These interventions have necesitated, according to the available data, expenditures of over 4 million euros (Table 6).

In the period between 1993 and 1998, the trend of coastal retreat remained stable especially to the south of the 2nd groyne with a yearly rate ranging between 0.5 m/year and 5.7 m/year (Fig. 12). In the study area by the 5 groynes there is a slight accretion to the north of the structure, although between the first two groynes (between transects 13 and 26) the accretion rate was higher, ranging between 4.5 m/year and 10 m/year, while to the north and by the rest of the groynes (between transects 27 and 78) the rate of accretion reached around 0.8 m/year and 6 m/year (Fig. 12). The irregularity in the configuration of the coast and its behaviour was accentuated as a result of the interference by the structures of the normal sedimentary transport produced by the littoral drift. Despite this phenomenon, the system of groynes has not provided an effective protection to the maritime fronts of the Bairro dos Pescadores of Silvalde where the rate of coastal retreat was around 2 or 3 m/year. The community of Paramos continues to have to deal with retreat rates of approximately 1.25 to 4.8 m/year (Fig. 12). Despite the significant rates of retreat recorded in the sector Silvalde-Paramos, the average rates in the entire study area were positive, indicating accretion, although with different rhythms (Table 7). Although the damage to private buildings has been controlled and thus there are no records of the total loss of buildings, as had happened at the end of the 19th century and the beginning of the 20th century, still the threat remains and justifies the type of interventions conducted between 1995 and 1998, especially in terms of the reinforcement of the groynes and the re-nourishment/sand movement on the beaches to compensate for the losses and decrease the locate sensitivity to the erosive actions of the sea.

However, this type of continuous intervention involves progressive costs. In 1997 the amount spent was estimated to be 2 533,9 million euros, a figure that may be much greater if we bear in mind that we do not know the amount of money spent in the interventions of 1998.

In the period 1998-2003 the data reveal that rate of retreat remained high in the entire sector under study, independently from the existence of structures. The front of the city of Espinho shows again its susceptibility with retreats of approximately 9 m/year; in the maritime front by the Bairro dos Pescadores in Silvalde. The losses ranged between 3 m/year and 4.5 m/year, with no records of accretion, although in the south part of the second the rate of retreat was greater than 10 m/year (Fig. 13). In the case of Paramos, the rates of retreat ranged between 3 m/year and 5 m/year almost uniformly. In this last period of analysis, the average rates in the study area show rates of retreat over the entire area (Table 8). This trend led to the new (and sometimes done during a state of emergency) interventions of reinforcement and extension were carried out between 1999, 2001 and 2003.

From the set of data collected, the effect of coastal erosion is easily perceptible and it is clear that it has become worse throughout the 20th century with the construction of successive protection interventions, especially in the south sector of the study area.

Fig. 9.– Aspect of the coastline in front of the city of Espinho in 1989 (Dias *et al.*, 1994).
Fig. 9.– Aspecto de la línea de costa frente a la ciudad de Espinho en 1989 (Dias *et al.*, 1994).

4. Discussion

From the end of the 19th century until the 1910s, the impact of anthropogenic interventions on the coastal system was relatively unimportant. Nevertheless, as shown, Espinho already was undergoing coastal erosion. According to the studies already conducted (Araújo, 1986; 2000; 2002; Carvalho, 1995; 2003; Carvalho *et al.*, 2002; Granja, 1999) the first erosional episodes are related to tectonic features and sea-level rise. There were studies suggesting that the area between Espinho and Paramos and extending until Esmoriz, corresponds to a tectonic depression from which all that remains nowadays is the small lagoon of Esmoriz. According to Carvalho (1995) and Araújo (1986; 2000; 2002), the Quaternary deposits have different thickness and different elevations, which may support the thesis of the existence of a depression. This fact may serve as an explanation of the high erosion rates from the late 19th century to the 1910s. On the other hand, the gradual rise of the mean sea-level, which took place after the end of the "*Little Ice Age*" (Dias *et al.*, 1997; Dias *et al.*, 2000; Baptista, 2006), in spite of only being responsible for only 10% of coastline retreat, may also have caused a greater compactation of the deposits of the Quaternary, leading to possible subsidence of all this area near the coast. Nevertheless, this hypothesis is not entirely proven, since the time interval considered (1869 to 1910) seems rather too small to validate it.

However, the effects of the mean sea-level rise are not completely understood. It is possible that its true effects will become clearer especially in periods of high energy such as during storms.

According to the collection of information in the local newspapers and the type of description found, it can

Fig. 10.– Situation of the chapel of Paramos (A) before 1970 and (B) currently.
Fig. 10.– Situación de la capilla de Paramos (A) antes de 1970 y (B) en la actualidad.

be stated that, in the beginning of the 20th century, the study area was affected by an average 1 - 2 storms/year (Fig.14).

The occurrence of storms was more frequent between October and March, as previously discussed. However, and despite the difficulty of establishing behaviour patterns of these episodes of marine invasion, we can conclude that these episodes coincided with the season when there were more storms. Moreover, although we know the date and the losses associated with each episode, the collection of data regarding the waves and tides is very difficult due to the scarcity or even lack of data. In fact, it is not known if these episodes were due to the occurrence of storms or the combination of the effects of storms, together with the occurrence of spring tides and/or high water.

On the other hand, the anthropogenic intervention in the coastal strip Espinho-Paramos intensified in the 1910s in three major ways: the progressive reduction of the sedi-

Sector	Period of 1970-1993		
	Average Rate (m/year)	Nr. of marine invasions episodes	Nr. of coastal interven-tions
Front of the city of Espinho	1.5	10	3
Silvalde-Paramos	- 2.8	4	3
Study Area	- 1.7	NA	NA

Table 5.– Synthesis of the period of 1970-1993. The positive values in the average rate correspond to the situation of accretion in the coastline and the negative to the retreat situation.

Table 5.– Síntesis para el período 1970-1993. Los valores positivos en el tasa media corresponden a la situación de acreción de la línea de costa y los negativos a la situación de retroceso.

Year	Money Spent (x10³ €)
1980	9.0
1988	2 085.7
1997	2 533.9
Total	4 628.6

Table 6.– The cost of the construction of the coastal protection structures in the municipality of Espinho (records from local and national newspapers).

Table 6.– Inversión económica para la construcción de las estructuras de defensa de la línea de costa en el muncipio de Espinho (datos tomados de la prensa diaria local y nacional).

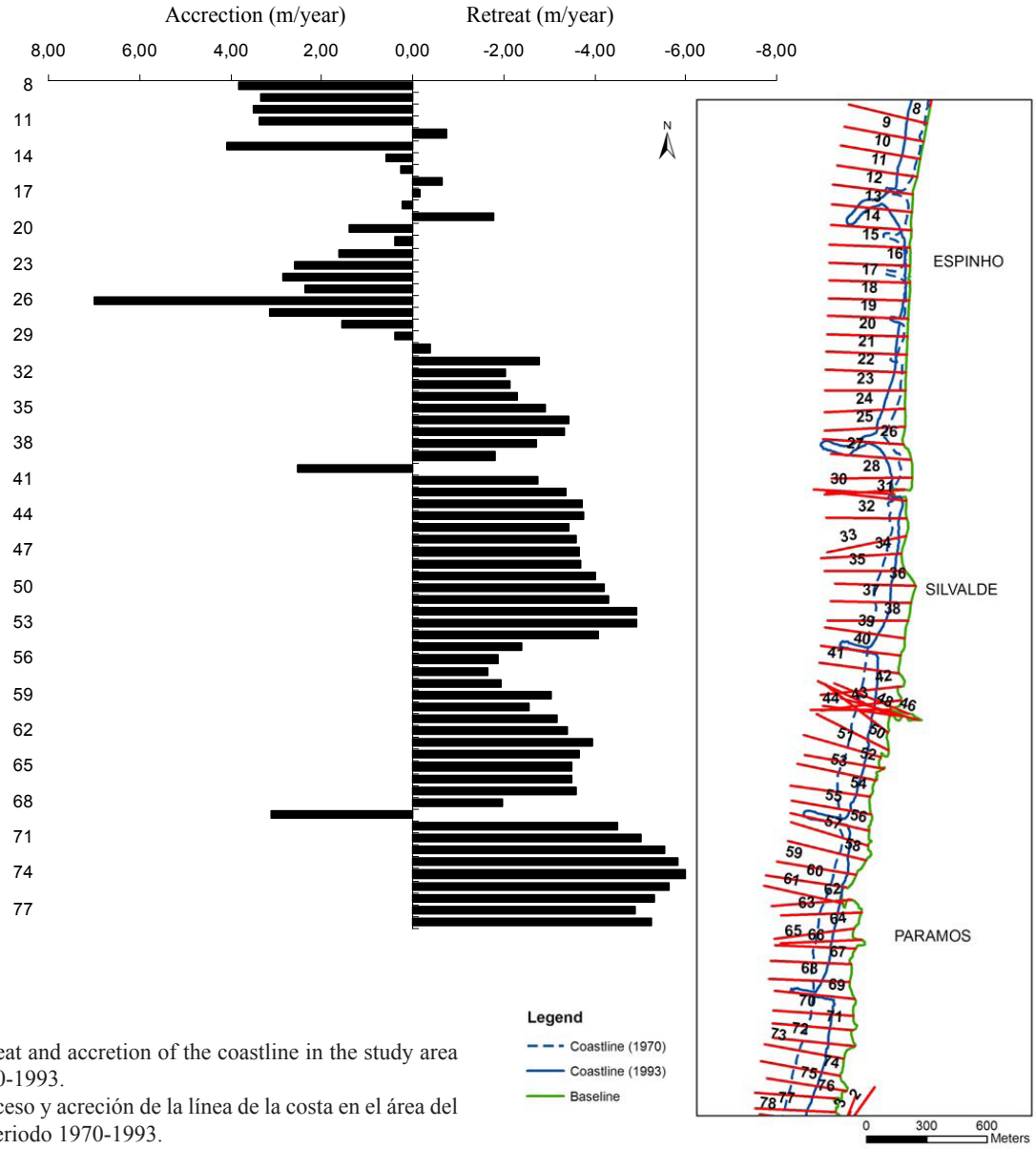

Fig. 11.– Rates of retreat and accretion of the coastline in the study area in the period of 1970-1993.

Fig. 11.– Tasa de retroceso y acreción de la línea de la costa en el área del estudio durante el periodo 1970-1993.

Sector	Period of 1993-1998		
	Average Rate (m/year)	Nr. of marine invasions episodes	Nr. of coastal inter-ventions
Front of the city of Espinho	9,16	2	4
Silvalde-Paramos	0,80	1	3
Study Area	2,9	NA	NA

Table 7.– Synthesis of the period of 1993-1998. The positive values in the average rate correspond to the situation of acrection in the coastline and the negative to the retreat situation.

Table 7.– Síntesis para el período 1993-1998. Los valores positivos en el tasa media corresponden a la situación de acreción de la línea de costa y los negativos a la situación de retroceso.

Sector	Period of 1998-2003		
	Average Rate (m/year)	Nr. of marine invasions episodes	Nr. of coastal inter-ventions
Front of the city of Espinho	-3,5	NA	NA
Silvalde-Paramos	-1,2	NA	3
Study Area	-2	NA	NA

Table 8.– Synthesis of the period of 1998-1903. The positive values in the average rate correspond to the situation of acrection in the coastline and the negative to the retreat situation.

Table 8.– Síntesis para el período 1998-1903. Los valores positivos en el tasa media corresponden a la situación de acreción de la línea de costa y los negativos a la situación de retroceso.

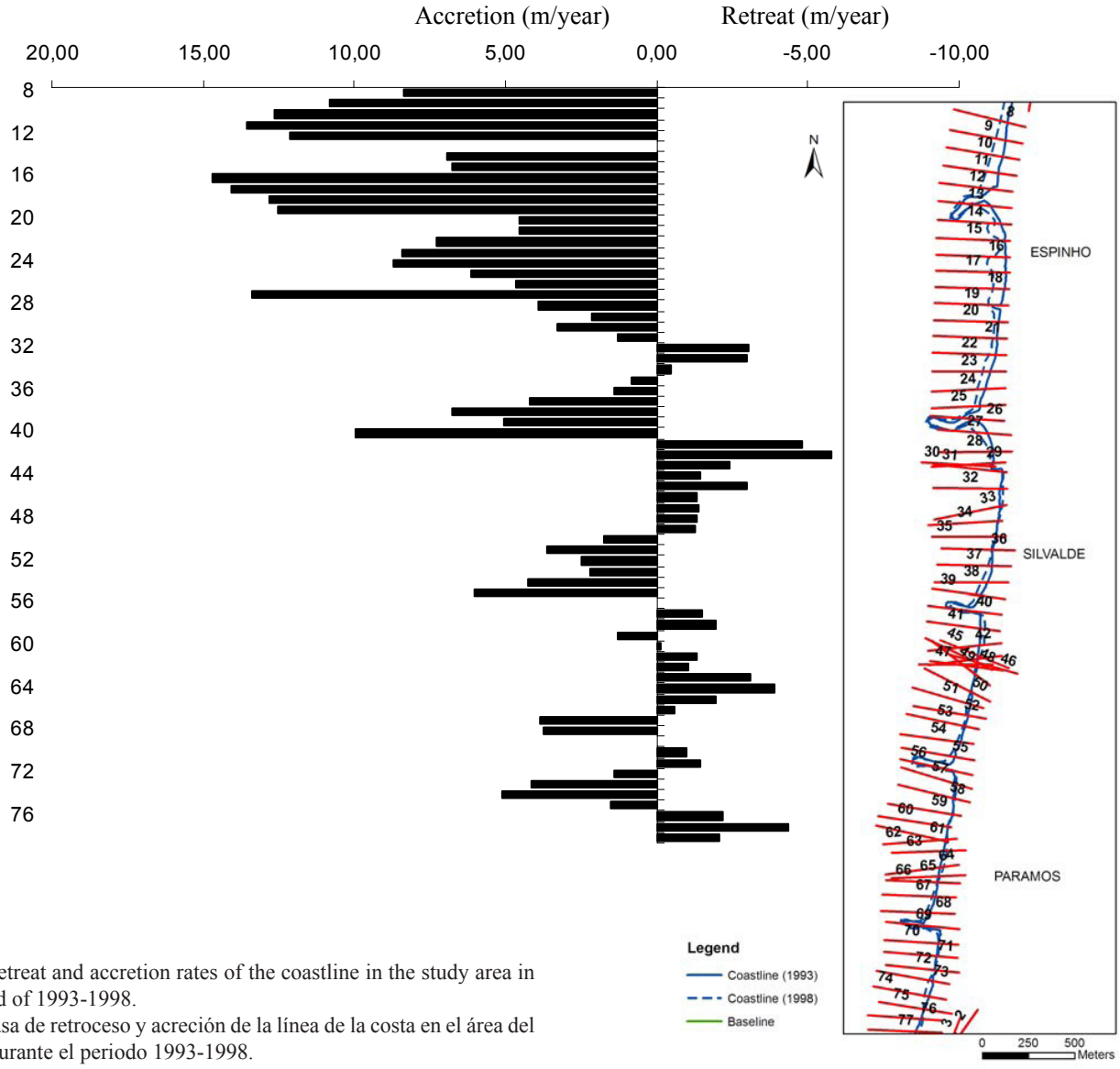

Fig. 12.– Retreat and accretion rates of the coastline in the study area in the period of 1993-1998.

Fig. 12.– Tasa de retroceso y acreción de la línea de la costa en el área del estudio durante el periodo 1993-1998.

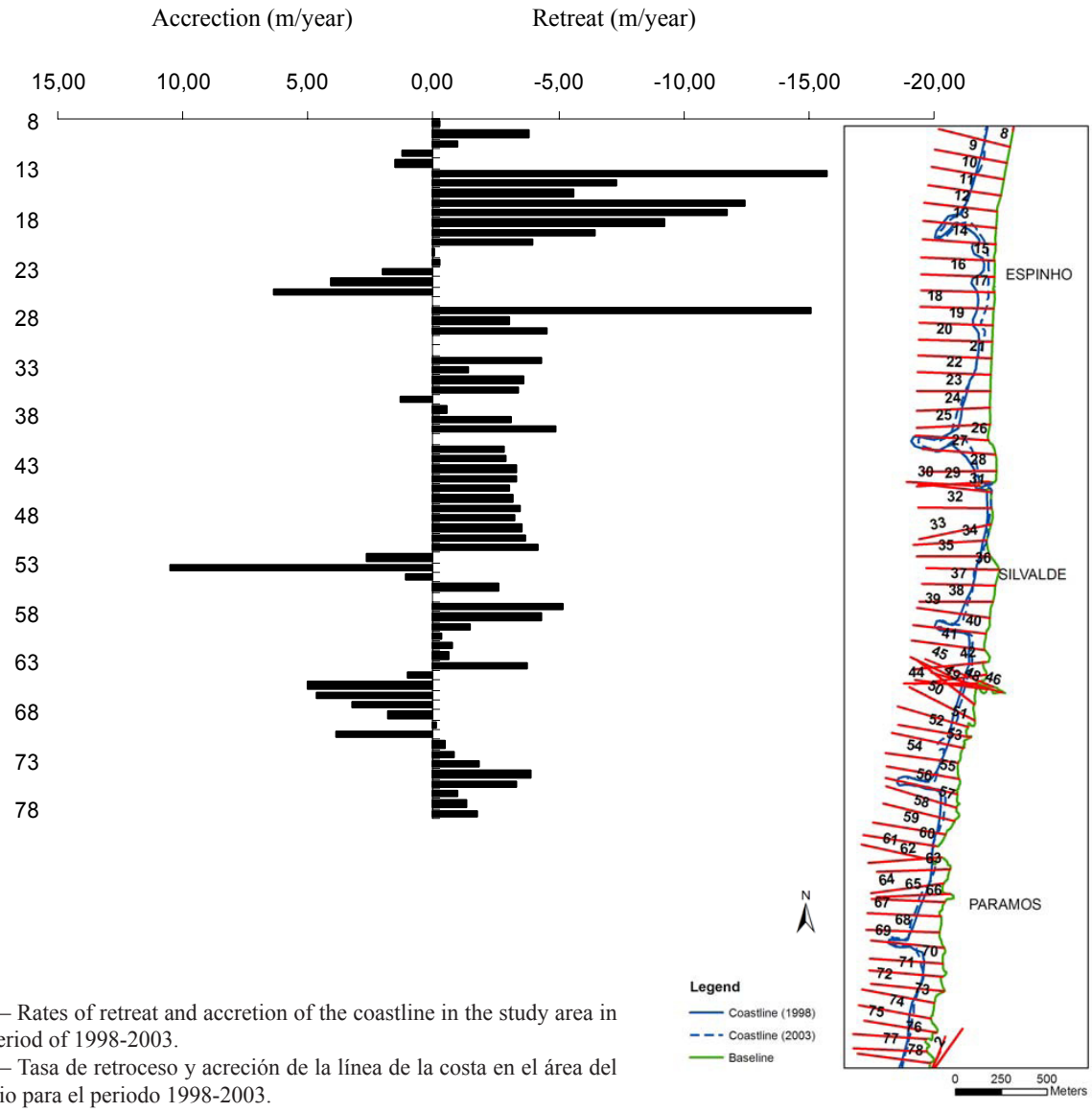

Fig. 13.– Rates of retreat and accretion of the coastline in the study area in the period of 1998-2003.
Fig. 13.– Tasa de retroceso y acreción de la línea de la costa en el área del estudio para el periodo 1998-2003.

mentary supply, the increase of human development with the consequent destruction of the dune morphology and the construction of coastal protective structures.

The reduction of the supply of sediment in the study area was due to a numerous factors, and only the most important of them are discussed here. The construction of dams for hydroelectrical utilisation induced significant changes in the sedimentary discharge of the rivers. Nevertheless, this cause may only be a possible explanation for the period from the 1930s onwards, when the first dam built in Portugal came into operation (Lindoso Dam in the River Lima). This factor became even more important from the 1950s onwards when the number of dams built in the Douro basin both in Portugal and Spain increase significantly (Table 9). Currently in the Douro basin there are 53 dams in Portugal and 97 in Spain (although the construction year of some dams in Spain is not known).

This type of anthropogenic intervention is responsible for a reduction of the volume of sediments supplied to the coast as occurred because of the constructions on River Douro, which under normal conditions transports ca. 1.8×10^6 m^3/year of sediments, but currently transports ca. 0.8×10^6 m^3/year (Dias *et al.*, 1994).

According to Dias (1994), there is a positive correlation between the construction of numerous dams and the retreat of the coastline, and the consequent problems of erosion. In this way, the objective of capturing sediments to restore the width of the beach and prevent coastline retreat, through the construction of groynes and seawalls, has not been achieved due to the decrease of the availability of sediments. Furthermore, protective infra-structures have caused even more erosion of the beaches to the south.

In addition, the effects of dredging activities, which despite the scarcity of data and monitoring, clearly constitutes a phenomenon of great relevance to the cause of the

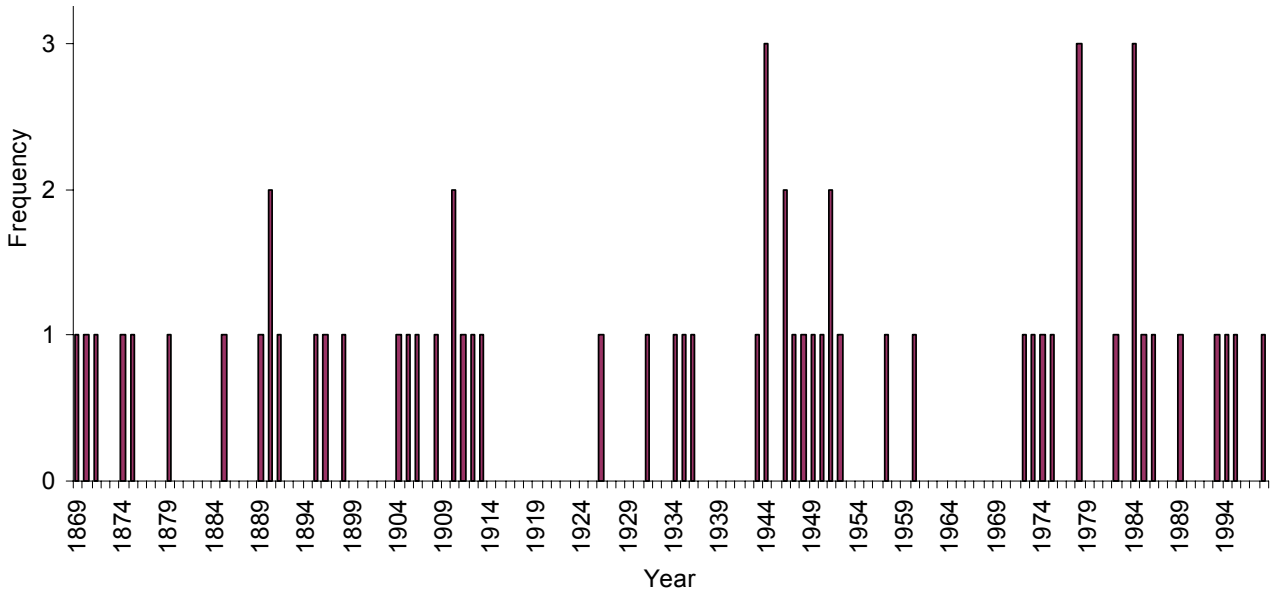

Fig. 14.– Frequency of episodes of marine "invasion" in the municipality of Espinho.
Fig. 14.– Frecuencia de los episodios de "invasión" marina en el municipio de Espinho.

reduction of sediment supply to the coast since the 1990s, when this type of activity in the lower branch of the River Douro has been responsible for the removal ca. $1.5x10^6$ m^3/year of the normally discharged sediments. However it is likely that this activity already had an impact in previous periods, although there are no records which allow the scale of this to be quantified.

In the beginning of the 20th century, the coastal areas were scarcely populated, as the historic records reveal (Pereira, 1970). Nevertheless, the community of Espinho underwent a considerable demographic growth, as a result of activities such as farming, fishing and "seawater baths for medical purposes", as it evolved from *freguesia* (parish) (1889) to a municipality (1899) in only a decade. Associated with this growth has been a new form of human development: the replacement of the movable dwellings made of wood (palheiros) (Fig. 15), so typical of the local fishing community, by permanent houses made of stone owned by the bourgeoisie. The permanent urban area, adjacent to the coast in Espinho, increased from 44 244 m^2 in 1870 to 111 409 m^2 in 1900 and to 395 092 m^2 in 2003, resulting in the progressive destruction of dunes and consequently to a greater exposure of the populations to the sea.

In this problem of coastal erosion, land management also plays an important role. There is an urgent need to change the patterns of land occupation in the coastal strip, in particular by implementing measures preventing the continuous construction of buildings and infra-structures. Within the scope of coastal management and planning, the coastal zone management plan was approved in 1988. This focused on the coastal space (except port areas), to control the management and regulation and the specific uses and activities on the coastal areas according to the principles of environmental and landscape development and to the preservation underlying the conservation of the ecosystem. Unfortunately, these principles and objectives have not always been followed due to other interests with more political infuence in the area.

By analysing the data available, it is possible to conclude that the amount of money spent on coastal protection structures, such as seawalls and groynes, quadrupled in the 1930s in comparison with the 1910s and 1920s, and increased exponentially in the 1950s. On the other hand, the need to conduct periodical works of maintenance, reinforcement and repair of the structures led to a greater investment, without any positive return, and was aggravated by the fact that these structures merely transfered the problem of erosion and coastal retreat further to the south of the study area, and then demanded even more interventions and the construction of reinforcement structures. There are doubts concerning the efficacy of these structures in the protection of the coast and the subsequent loss of the tourist and bathing features in this area is of growing concern.

5. Conclusion

The littoral constitutes an irreplaceable, finite, non-renewable resource which is in constant dynamic balance. The permanent occupation of the littoral - closer and closer to the sea - led to measures to protect the constructed

Year of Conclusion	Number of Dams in Portugal	Number of Dams in Spain	Year of Conclusion	Number of Dams in Portugal	Number of Dams in Spain
1902	0	1	1968	0	2
1921	0	1	1969	0	4
1923	0	1	1970	1	4
1930	0	2	1971	2	3
1931	1	1	1972	1	0
1933	0	1	1973	2	1
1934	0	1	1975	0	1
1940	0	2	1976	2	0
1941	0	1	1977	1	2
1946	1	0	1978	1	1
1947	0	3	1981	1	0
1949	0	1	1982	2	0
1950	1	0	1984	2	3
1951	0	1	1985	3	0
1952	1	1	1986	1	1
1953	0	4	1988	1	4
1954	0	3	1989	1	0
1955	1	0	1991	1	1
1956	0	2	1992	1	1
1957	0	1	1993	4	1
1958	1	1	1994	0	4
1959	0	1	1995	4	2
1960	1	3	1997	1	0
1961	1	1	1998	0	1
1962	0	3	1999	3	0
1963	0	5	2000	1	0
1964	2	0	2004	4	1
1965	1	2	2005	2	0
1967	0	1			

Table 9.– The dates of construction of the main dams in Northern Portugal (http://cnpgb.inag.pt/gr_barragens/gbingles/MapanorteIng.htm and http://hispagua.cedex.es/; http://www.mma.es)

Table 9.– Fechas de construcción de las principales presas en el norte de Portugal (http://cnpgb.inag.pt/gr_barragens/gbingles/MapanorteIng.htm y http://hispagua.cedex.es/; http://www.mma.es).

heritage.

This study demonstrates the potential of using and comparing cartographic and alphanumeric information in GIS, to collect information about the behaviour of the coastline throughout a century. It also revealed the influence of coastal protection interventions on coastal erosion. At the end of the 19th century, coastal erosion in the study area was around 1 m/year south of Espinho.

Fig. 15.– "*Palheiros*" – these were the type of dwelling of the fishing community of Espinho (Dias *et al.*, 1994)

Fig. 15.– "*Palheiros*" – tipo principal de habitación del núcleo de pescadores de Espinho (Dias *et al.*, 1994).

Nevertheless, the several "episodes of marine invasion" that took place between the end of the 19th century and the beginning of the 20th century, contributed to the significant and progressive destruction of the nuclear site of the old population resulting in the strategic construction of structures to protect the existing heritage. However, it is from the moment that coastal interventions were permanent and in a greater number, with the construction of more and closer groynes, that the coastline showed accentuated retreat in several sectors of the study area. In the period 1933-1970 the front of the city of Espinho showed an average retreat of approximately 6.8 m/year decreasing to 3.8 m/year in the period 1998-2003; although it still underwent some periods of accretion over stable periods against a background of retreat which has been attenuated by reinforcement efforts of the coastal structures and nourishment/movement of sand to the beach. From this analysis, it can be concluded that in the coastal sector Silvalde-Paramos, the moment when coastal erosion acquired greatest impact coincided with the structural interventions carried out from the 1970s onwards, since the average rates of retreat range between 2.8 m/year (1970-1993) and 1.8 m/year (1998-2003). Yet, there are still sectors in Paramos where the rate of retreat reached a maximum of 5 m/year and 4.5 m/year near the Bairro dos Pescadores in Silvalde. Clearly, the current situation reveals the inefficacy of this type of protection and the need to change the way that the coastal heritage is protected, since the reinforcement of the current protection schemes will only lead to a greater number of interventions and constructions of protective structures both in front of the city of Espinho and in the south-sector of the municipality.

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