IMPLICATIONS OF SEA-LEVEL RISE FOR PORTUGAL

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* This paper only considers the continental portion of Portugal. Madeira and Azores archipelagos are not analysed.
ABSTRACT

The Portuguese coastline presents a high diversity of coastal types, which will consequently react differently to sea-level rise. Estuaries and coastal lagoons will be the coastal areas most affected by a rising sea-level. Amongst these, the Sado and Tagus estuaries, and the Ria de Aveiro and the Ria Formosa coastal lagoons, are probably the ones where socio-economic impacts resulting from sea-level rise would be greater. Sandy shores will face increased erosion. However, it is likely that in this type of coasts other factors, such as sand deficiency caused by damming in river basins, will continue to play a larger role in erosion than sea-level rise. Hard rocky coasts will be the least affected by sea-level rise.

Specific mitigation policies to face sea-level rise impacts do not exist in Portugal. However, existing laws can be used to prevent and/or reduce socio-economic impacts of sea-level rise, if strictly applied. A strong commitment to global coastal management by Portuguese authorities is necessary in order to prevent and minimise future implications of sea-level rise.

Additional index words: Portugal, coastal impacts, sea-level rise, management
INTRODUCTION

A systematic study of sea-level rise and, to some extent, of the associated consequences started in Portugal in the end of the 1980s, beginning of the 1990s (e.g., DIAS and TABORDA, 1988, 1992; TABORDA and DIAS, 1989; ANDRADE, 1990; FERREIRA et al., 1990; TEIXEIRA, 1990). However, after this initial characterisation, no further detailed works were developed, namely on the characterisation and quantification of possible impacts. This paper will analyse recent coastal evolution in Portugal in order to define the main associated causes and the role of sea-level rise. Will also point out some of the main consequences of sea-level rise, for different Portuguese coastal types, defining areas of higher and lower vulnerability.

The Portuguese coastline has an extension of more than 900 km. It is morphologically diverse, having extensive sandy shores backed by dunes, rocky coasts with low and high cliffs, pocket beaches, bays, estuaries, lagoons, barrier islands, amongst other geomorphological features. Along the west and south coasts of Portugal a variety of physiographic alternations can be observed, particularly between rocky coasts and sandy shores. A simplification of Portuguese coastal types can be done defining three main types: sandy shores, cliffed coasts and low-lying rocky shores (Figure 1). Of these three, the cliffed coast is the dominant type while the low lying rocky shore is the least represented along the Portuguese coastline. Also shown on Figure 1 are the main Portuguese rivers, associated estuaries and coastal lagoons. The most important coastal lagoons are the Ria de Aveiro (Northwest coast of Portugal) and the Ria Formosa barrier island system (Algarve, southern Portugal). The main estuaries are associated to the Tagus and Sado Rivers, and are located on the central part of the Portuguese west coast.

The Portuguese coastal zone is highly populated. Most larger cities (Lisbon, Porto, Setúbal, Aveiro, Faro, etc.) are located near estuaries and lagoons. The morphological characteristics
of the coastal area combined with a mild climate, has transformed the Portuguese coast into one of the best natural resources of Europe, being extensively exploited for tourism since the 1960s. As a consequence important tourist villages and resorts are also located close to the coastline. As a result about 60% of the Portuguese population live in the coastal zone. During the summer around 80% of the permanent and fluctuating population (Portuguese and tourists) are placed within a narrow strip along the Portuguese coastline. A large fraction of the Portuguese economy is, therefore, generated near or at the coastal zone. Changes resulting from sea-level rise can have a direct impact on the economy, either on traditional activities (e.g., mariculture, fisheries, etc.) or recent ones (e.g., aquaculture, tourism). As a consequence, coastal studies and an integrated coastal management are of decisive importance in Portugal, including the definition of potential sea-level rise impacts and mitigation actions.

CLIMATIC CHARACTERISATION AND VARIABILITY

The effects of long-term coastal change should be analysed not only in the context of the response to sea level rise but on a wider framework including other aspects of coastal climate. In fact, climate change will affect relative sea level but also the magnitude of storms, temperature, rainfall, and evaporation rates, among others. Changes in these factors will also have a major influence on long-term coastal evolution. It is therefore necessary to define present climate conditions, past evolution and the expected climate changes to allow a global understanding of future effects on coastal areas.

Temperature and Precipitation

Portugal is located between the latitudes of 37 and 42° N, being in the proximity of an important limit in what concerns atmospheric circulation. In summer the influence of air masses related to the subtropical Azores anticyclone originates dry and stable weather. During
the winter, the influence of air masses related with the front systems of mid latitudes depressions produce rainy and unstable weather. Geographically the Portuguese weather can be divided in two main types: the Atlantic, characteristic of the northwestern part, and the Mediterranean, typical for the southern part. Annual temperatures are lowest in the north, averaging 10°C. The temperatures increase towards south, where they average annually at around 18°C (RIBEIRO and LAUTENSACH, 1988).

During the last century, the mean air temperature in Portugal showed an increasing trend that can be close fitted to a linear trend (ANTUNES, 1998). Disregarding the trend induced by the urban heat island effect, the analysis revealed that mean air temperature has been rising at a mean rate of 0.0074 ºC/year. This value (0.74 ºC in one century) is similar to the global temperature trend computed by PETERSON et al. (1999) and to the mean annual temperature rise recorded in Europe during the twentieth century (0.8 ºC, PARRY, 2000). According to this author, annual mean temperatures over Europe warm at a rate between 0.1 ºC/decade to 0.4 ºC/decade, with the greatest warming being observed in southern Europe. As a consequence, sea surface temperatures face a warming of several tenths of a degree Celsius in Europe (PARRY, 2000). A continuation or increase of the global warming will be, therefore, responsible for increased thermal expansion of the ocean, and consequent sea-level rise.

The mean annual rainfall in Portugal is around 1000 mm, ranging from about 2000 mm in the northwestern hydrographic basins to less than 500 mm in the southern inland ones (DAVEAU, 1977). An analysis of the longer precipitation time series of Portugal (Lisbon, Porto and Coimbra) by ANTUNES (1998) showed that, during the last century, there was no significant long-term trend. However, according to the results of the ACACIA project (see PARRY, 2000), some parts of southern Europe have dried by up to 20 per cent in the twentieth century. The general pattern of future change across southern Europe is for little change or a small decrease in annual precipitation at a possible maximum of –1 per
cent/decade (PARRY, 2000). Another expected climate change is the increase of seasonal differences in precipitation. Southern European winters will get wetter while summers will become dryer. This will lead to a possible decrease in annual stream flow at river mouths in Portugal. Because of an increased risk of summer drought in the Iberian Peninsula, an increase of water storage during winter is expected. Water storage is already an emergent problem in the Iberian Peninsula, leading to the construction of several dams and water reservoirs since the 1940s to present. By the end of the 1980s only 15% of the Portuguese river basins area was directly draining to the sea without dam effects (DIAS, 1990). Dam construction is still being carried on, namely with the construction of the Alqueva dam, which is expected to create the largest artificial fresh water reservoir of Europe. The existence of a well marked climatic asymmetry between the northern and southern part of the Iberian Peninsula allows the existence of water by-pass mechanisms, widely used in Spain and starting to be used in Portugal. This water transference strategy is also expected to increase in the near future. Due to water by-pass the water flow will probably increase inland on the southern rivers of Iberia. However, water retention at dams and its consequent use will further reduce the already limited water flow at both northern and southern Iberian river mouths. These actions will have a dramatic consequence on the natural flood/drought cycle of rivers, leading to a decrease on the sediment transport from rivers and estuaries to the coastal zone and increasing the ability of estuaries to act as a receptor of marine sediments. The overall decrease of sediment transport to the littoral and shelf systems will enhance coastal erosion.

Wave regime
In the west coast wind wave regime is dominated by swells from Northwest which occur during 73 % of the year, with a mean annual significant wave height of 2.2 m and annual average peak period of 11.3 s at Figueira da Foz (C. COSTA, 1994). The dominant
association between significant wave heights, peak periods and wave direction is: wave heights of 1 to 3 m, periods of 9 to 13 s and Northwest wave directions, accounting for 50% of the occurrences. Storms are a frequent phenomenon on the Portuguese coast, with often induce dramatic consequences on the littoral. On the west coast the most frequent storms (defined as significant wave heights superior to 5 m) are from WNW with the most frequent wave heights up to 6 m. A considerable number of storms (between 3% and 17%) have significant wave heights with more than 10 m (PITA and SANTOS, 1989).

The south coast is not exposed to the wave components predominant in the west coast, particularly to the swell generated in the north Atlantic. Consequently, wave conditions are less severe, with dominant significant wave heights between 0.6 m and 1.5 m and peak periods between 6 s and 11 s (M. COSTA, 1994). The most frequent storms on the south coast (defined as significant wave heights greater than 3 m) are from the SW, with significant wave heights generally smaller than 5 m but occasionally exceeding this value (M. COSTA, 1994).

An analysis of 127 years of wave regime data and information from newspapers by ANDRADE et al. (1996) showed that there is probably an increase in storminess on the Portuguese coast. However, the high decade-to-decade storminess variability and the poor data quality until the middle of the twentieth century did not allow the authors to be conclusive on this subject.

North Atlantic Oscillation

The North Atlantic Oscillation (NAO) represents the meridional contrast, north-south, of the sea level pressures between Azores and Iceland (HURREL, 1995) and is the dominant mode of winter climate variability in the North Atlantic region. As a consequence, large part of the short-term climatic variability over the Atlantic basin is related with NAO. This means that a substantial amount of the regional climate change, namely changes in circulation patterns,
high/low atmospheric pressure systems, variations in temperature and precipitation, can be related to the state of the NAO. For example, NAO has been related with evaporation and precipitation (HURREL, 1995), the climate circulation mode of the Western Mediterranean (VIGNUDELLI et al., 1999), and the trend in the North Atlantic surface wave heights, amongst others. In Portugal, NAO has been successfully related with short-term mean sea level (MSL) oscillations (GUERRA et al., 2000) but could not explain the upward trend of MSL series. These works highlight the potential of the NAO to act as a link between several climatic and oceanographic factors that have a major influence on coastal evolution, but also show that further studies are need to fully understand their relationships.

SEA-LEVEL RISE CHARACTERISATION

The analysis of coastal tide-gauges records has provided the main method by which sea levels have been measured during the twentieth century. In Portugal there are several coastal and island tide-gauges that acquire sea level data. However, most of these stations have a relatively short record (< 50 years) which is unsuitable for long-term mean sea level trend determination (DOUGLAS, 1991). A linear regression of the longer tide gauge records of Cascais and Lagos (Figure 2), of 104 and 78 years duration, respectively, revealed trends of 1.3 ± 0.1 mm/year and 1.5 ± 0.2 mm/year changes in mean sea level (DIAS and TABORDA, 1992). These results clearly indicate an effective and significant rise of the relative sea level during this century and are in the range of most estimates of global sea level rise for the twentieth century (e.g., BARNETT, 1984). The temporal structure of the Cascais tide gauge data suggests that relative sea level has not been rising consistently. From the end of the nineteenth century until 1920 mean sea level has dropped at a mean rate of 0.5 ± 0.4 mm/year. It is only from that period onwards that relative sea level has shown a net upward trend of 1.7 ± 0.2 mm/year. This shift might be related to the end of the “Little Ice Age”, by the turn of the
century (DIAS and TABORDA, 1992). The comparison of the Cascais tide-gauge data with the North Atlantic Ocean sea surface temperature records suggests that the thermal expansion of the ocean is responsible for a major part of the observed rise in Portugal (Figure 3).

DIAS and TABORDA (1988) predicted a sea-level rise for Portugal between 140 and 572 mm by the year 2100, according to different scenarios. These values are smaller than the 13 to 68 cm rise predicted by PARRY (2000) for the global mean sea-level elevation by the 2050s. However, the values for Portugal are based on the extrapolation of simple fits to the existing data, while the global values are based on a series of different rising scenarios, as a function of different temperature changes.

IMPACT AND VULNERABILITY TO SEA-LEVEL RISE

Recent coastal evolution in Portugal (general considerations and main causes)

At present, the Portuguese coastal zone is strongly affected by coastal erosion in association with an important sediment deficiency, which started at the beginning of the twentieth century, and was strongly increased after the 1940s-1950s. This lack of sediment is mainly related to a number of interventions in the river basins, in particular river flow modifications by dam construction (e.g., decrease of flood frequency and magnitude), sediment retention due to successive river damming, sand and gravel exploitation, extensive estuarine dredging for navigation, etc. These actions have had extreme consequences on the open sandy shore coastal stretches. Furthermore, the restricted sediment supply is often enhanced downdrift of harbour jetties, breakwaters and hard protection structures. Presently, shoreline retreat rates reach the order of a few metres per year in some locations of the Portuguese coastline, with maximums higher than 10 m/year south of Espinho, between 1980 and 1989 (FERREIRA and DIAS, 1991).
On the opposite, estuarine areas are subject to general infiling, since there is a reduced sediment exportation caused by the lack of natural river floods. The diminishing of stream flow also allowed waves and tidal currents to play a larger role in the evolution of estuaries, additionally transporting marine sediments into the estuaries. Hard rocky shores (cliffed and non-cliffed) have been less affected by changes on sediment nourishment since these coastal sectors were already facing a sedimentary deficiency. However, soft cliffs experienced an increase on the observed retreat rates.

Impacts on estuaries and coastal lagoons
The main impact of sea-level rise on wetlands and coastal lowlands will be their inundation but also the development of a natural trend for upward and landward displacement of these areas. This displacement is a natural response of estuaries, barrier island systems and coastal lagoons, to sea-level rise. If allowed, this displacement should not result in the destruction of the coastal system or in losses to the social and economical resources of these areas. However, since extensive lowland areas are occupied by fixed manmade structures, the landward migration of these systems is difficult and unlikely. As a result, the wetlands are becoming thinner, and much of their natural, social and economical value can be lost. The main coastal lagoon areas in Portugal (Ria de Aveiro and Ria Formosa) are facing erosion on the oceanfront and silting up on tidal channels and inner areas. A transgressive behaviour with inland displacement of barrier islands and peninsulas has been pointed out for the Ria Formosa system by several authors (e.g., DIAS, 1988; PILKEY et al., 1989; BETTENCOURT, 1994). Both areas are intensively occupied on their inland limit, including the existence of important coastal towns, such as Aveiro (Ria de Aveiro), Faro, Olhão and Tavira (Ria Formosa). As a consequence, the future evolution of these systems will be towards a reduction of their areas, probably accelerated by sea-level rise.
The small lagoons of the Portuguese coast (e.g., Esmoriz, Óbidos, Albufeira, S. Torpes, Melides, and Alvor) also faced an increased silting up during the twentieth century, both by fluvial and marine sediments. This silting up is a consequence of human actions (e.g., agriculture, discharging systems, etc.) and existing sea-level rise. Some of these lagoons are presently maintained open by dredging and in other cases (e.g., Esmoriz), they are almost closed and without significant water circulation.

Portuguese estuaries have experienced a reduction in the export of sediments to the ocean due to a reduction of the intensity of extreme floods because of the effect of river damming. The difficulty of exporting sediments to the shelf was further increased by the existing sea-level rise. As a result, transport of marine sediments to the river mouths and to estuaries was favoured and sand banks developed. Dredging of estuarine areas has become necessary to maintain navigational channels and the effectiveness of the river mouth in water exchange. The natural lateral expansion of the landward boundaries of estuaries, induced by sea-level rise, is not possible for the main Portuguese estuaries since these limits are artificially defined by harbours and coastal towns. Some of the most important towns of Portugal are placed on estuarine margins (e.g., Lisbon at the Tagus estuary, Porto at the Douro estuary, Setúbal at the Sado estuary). As a consequence the estuarine areas have been reduced.

In summary, the evolution of coastal lagoons and estuaries during the twentieth century was towards erosion on the ocean front, strong infilling of their internal areas and a reduction of the lagoon and estuarine areas. Land-loss by erosion of salt marshes was also observed but probably increased by direct human causes (e.g., navigation on tidal channels). The expected evolution for the twenty-first century is towards an increase of infilling processes and to a severe reduction on the lagoon and estuarine areas.

Impacts on sandy coasts
Sea-level rise is the main factor causing shoreline retreat in coastal areas facing dynamic equilibrium, i.e., where natural beach nourishment allows the potential and the effective littoral drift to be equal. However, on sandy shores, where the natural beach nourishment has been strongly reduced, the main cause of shoreline retreat is sediment deficiency. In such cases the littoral drift will be re-established by beach, dune and/or cliff erosion.

Retreat rates observed for the 1940s and 1950s (first decades from which vertical aerial photographs from the Portuguese coast are available and, therefore, shoreline evolution can be correctly determined) at Portuguese sandy shores do not consistently indicate erosion or accretion but pointed to a dominantly erosive behaviour. In some cases, where coastal engineering structures (e.g., jetties or groins) already existed the erosive or accretion rates were higher and related to the influence of the structures on coastal processes. In general, shoreline retreat values did not exceeded 0.5 m/year, with averages between 0.2 and 0.4 m/year. The observed shoreline evolution rates during the 1940s and 1950s can be considered as “natural” retreat rates, since sand deficiency was not yet significant at that time (even if a zero value can not be assumed). It seems, therefore, that direct and indirect consequences of sea-level rise were probably responsible for most of the shoreline evolution observed until the middle of the twentieth century, in general inducing low to moderate retreat rates.

Presently, erosion is mainly induced by sediment scarcity in coastal systems, being responsible for average shoreline retreat rates in the order of meters per year in several areas. Values computed by some authors applying the Bruun Rule (BRUUN, 1962) to the Portuguese sandy coasts (see ANDRADE, 1990; TEIXEIRA, 1990; and FERREIRA, 1993) point to average shoreline retreat rates directly caused by sea-level rise in the order of some tens of centimetres per year, which only accounts for 10 to 15% of the actual shoreline retreat. A further increase of direct and indirect coastal erosion induced by sea-level rise is expected. As a result an increase on erosion rates at sandy shores will occur. Predictions of future
shoreline retreat rates directly or indirectly caused by sea-level rise are extremely difficult to be made. However, it is to be expected that sediment starvation continues to be the dominant factor causing rapid coastal retreat in Portugal. Sea-level rise can be considered a secondary but even so important cause of shoreline retreat, specially in some particular situations that should be pointed out. For example, on sandy beaches backed by cliffs or by seawalls the beach profile will not be able to proceed with the natural upward and landward displacement. Therefore, there will be an increase in water depth, causing a reduction in cross-shore wave energy dissipation and increasing the amount of nearshore wave attack (SANCHEZ-ARCILLA et al., 2000). Due to the raise in wave energy at the nearshore, sand can be more intensively eroded and lost. A similar process can occur in places were sand starvation is extreme and, consequently, the entire beach profile does not have enough sand to provide a full displacement to maintain the initial form. This can result in the rupture of the natural dynamic equilibrium and the profile will be displaced further inland, without dune restoration.

Beach response to sea-level rise will enhance this process. Since low-lying coastal plains often exist landward to coastal dune ridges the complete destruction of the dune would expose those inland areas to oceanic actions. In such cases sea-level rise will increase the possibility of extreme coastal flooding and overwashes to occur, namely during storms. In the Portuguese coast two areas can be directly affected by this situation: the coast in front of Ria de Aveiro, particularly south of the Aveiro harbour jetties, and the coast of Ria Formosa.

Impacts on rocky and cliffed coasts

Cliffs and rocky coasts will not adjust instantaneously to changes in sea-level. There will almost certainly be lags in their response (BRAY and HOOKE, 1996). An increase in water depth at the nearshore in front of rocky coasts will occur with sea-level rise. Existing rocky platforms or low lying outcrops will be submerged by sea-level rise and energy dissipation
prior to wave incidence at the cliff toe will be smaller. As a result, cliff retreat rates can increase in the near future, in the direct dependence of a sea-level rise. The result will be, however, site-specific due to local factors governing cliff and rocky coast sensibility. Hard-rock and sheltered coasts will be less influenced by this change, while soft cliffs on exposed coasts will experience a higher degree of erosion.

The Portuguese rocky coast is composed of many different types of rocks, facing differently to wave incidence. This makes it difficult to express a simple relation between sea-level rise and impacts at this type of coast. However, some coastal areas will probably face increased erosion in relation to others. Specifically, the low-lying rocky coast of Minho (northwestern Portugal), where cliffs are generally not present to act as a buffer to wave attack, and the soft cliffed coasts (see Figure 1). In other areas with hard rocky coasts, immediate changes induced by sea-level rise might be negligible. In some cliffed and rocky coasts small sandy beaches are presently still preserved in front of the cliff or between outcrops. With a rising sea-level a reduction in the area of these sandy beaches and eventually their total disappearance is to be expected. This trend has already been observed in the last decades for several sandy beaches adjacent to rocky shores.

Synthesis of coastal vulnerability to sea-level rise in Portugal

The overall analysis of the aforementioned impacts of sea-level rise on the Portuguese coast enabled the development of a simplified vulnerability map (Figure 4), in which vulnerability is classified in three categories: low, medium and high. The different levels represent a qualitative global evaluation of the different expected impacts. Low-areas, estuaries, coastal lagoons and wetlands in general are considered as areas of high vulnerability, while hard rocky coasts are classified as low vulnerability. The association of vulnerability to sea level rise with human occupation is useful to define the areas with a higher potential coastal hazard
(including socio-economic consequences). For Portugal, these areas are the most occupied and exploited coastal lagoons (Ria Formosa and Aveiro) and the most populated estuaries (Tagus and Sado).

SOCIO-ECONOMIC IMPACTS

Knowledge on the socio-economic impacts of sea level rise on the Portuguese shore is still poor, based on a small number of studies resulting from the individual effort of a few researchers. Regarding direct and indirect economical and social impacts of sea level rise on estuaries, salt marshes, lagoons, etc., there are no quantitative, nor complete studies for Portugal. Because of the latter, potential impacts can only be estimated. Potential socio-economic impacts of sea-level rise were categorised by NICHOOLS and KLEIN (2000) as follows:

- direct loss of economic, ecological, cultural and subsistence values through loss of land, infrastructures and coastal habitats;
- increased flood risk of people, land and infrastructures;
- other impacts related to changes in water management, salinity and biological activity.

Most of these impacts are valid for the Portuguese shore, namely for the majority of estuaries, coastal lagoons and lowlands in general. Apart from the above expressed impacts site-specific ones can be pointed.

The risk of increasing flood and overwash was already mentioned for two regions (Ria de Aveiro and Ria Formosa), which have a fragile dune ridge as ocean defence and low lying occupied areas landward. This will affect all economic activities developed in these areas, including navigational, recreational, fisheries and mariculture.

The continuity of the present silting-up trend will lead to the reduction on water exchange and quality at coastal lagoons, and to increased difficulties in navigation and harbour exploitation.
This situation will be enhanced by the increase in overwashes, inducing transport of marine sands inside the lagoon and estuarine systems. As a result, mariculture and aquaculture will be strongly influenced by consequences of sea-level rise in Portugal. These activities are important on several Portuguese estuarine and coastal lagoon areas. The same siltation processes will reduce the ability of coastal systems to act as nursery areas, with direct consequences on fisheries. Moreover, navigation channels will be filled up, requiring additional maintenance programs.

Probable loss of salt-marshes and other wetlands will also directly affect bird nesting and bird migration. Since most of the Portuguese wetlands are recognised and classified according to international ecological conventions, this will result in the loss of important ecological values. Another important socio-economic impact in Portugal would certainly be felt in reduced tourism, since the increase in coastal retreat will cause a reduction or total disappearance of some sandy beaches. This consequence will be more detrimental in areas where the upward and landward profile migration cannot be achieved (e.g., artificialised coastlines and beaches backed by cliffs). Coastal areas the western part of Algarve, the most touristic of Portugal, can be severely influenced if no-action is taken, since the beach area reduction will cause a reduction on the touristic occupation capacity of each beach. Moreover, existing touristic-related buildings and facilities will be further threatened by consequences of sea-level rise and by general coastal erosion.

**MANAGEMENT APPROACHES**

Mitigation of expected socio-economic impacts resulting from sea-level rise implies the use of concerted policies by the Portuguese authorities. These policies will probably have to include major actions, defining general trends, but will also have to incorporate specific plans like dredging of navigational channels, beach nourishment, coastal defence, managed retreat,
etc., depending on each area and associated problem. It is therefore difficult to anticipate the type of solutions to be applied at each site. Moreover, a set of further studies is still needed prior to the adoption of such solutions.

There is currently no major national plan to assess vulnerability to impacts of sea level rise. In reality, the hazard is frequently considered minimum. This is mainly due to the lack of relevant studies and to a very restricted public awareness on the potential impacts of sea level rise. On the other hand, coastal managers are not particularly concerned with such hazards since coastal erosion due to sediment starvation and storm action are dramatic in Portugal, and cause direct short-term impacts at least one order of magnitude higher than those currently associated with sea level rise. Effectively, there are no current thoughts on the technical and institutional aspects of adaptation to sea level rise in Portugal. Consequently, the present policy perspectives do not include long-term evolution and associated sea level influence.

However, in opposition to the present public awareness, in some places sea level rise impacts can be as important as storm and coastal erosion ones if considered over the long-term. For instance, storm impacts are punctual and frequently reversible on a human scale (year to decades) if sediment starvation is naturally or artificially stopped (e.g., beach nourishment, dune building, etc.). On the contrary, direct and indirect consequences of sea level rise can be irreversible or extremely costly if no action is taken in due time. Therefore, mitigation actions must be taken earlier in order to prevent consequences some decades later.

Portugal has been a pioneer in the development of laws regarding the protection of the coastal zone, with the introduction of the Public Maritime Domain (Domínio Público Marítimo) by the end of the nineteen century. The law defined an area of protection along the entire Portuguese coastline, where permanent occupation could not occur and that could not be turned into private property. As a result the Portuguese coastline still is a public domain and the most of the coastal areas were preserved from occupation. Moreover, Portugal does have
relatively recent laws for coastal management, which should be able to minimise sea-level rise consequences if correctly and strictly applied. The law regarding the Public Water Domain (Domínio Público Hídrico) defines protection margins around the entire Portuguese coast and wetlands between 50 and 500 m wide. The entire coastline, including submerged areas, coastal wetlands and riverine areas, are also integrated on the National Ecological Reserve law (Reserva Ecológica Nacional). Both laws restrict occupation and tend to preserve the natural and the ecological values, defining rules for their use. Furthermore, a large part of the Portuguese coast belongs to Natural Parks and Reserves (Ministry of Environment) being under the protection of specific natural protection laws. All these laws define areas of restricted or no occupation at the front line and, therefore, should be able to minimise socio-economic impacts resulting from sea-level rise, namely by the reduction of coastal occupation. It has been observed, however, that opposite policies exist between local authorities (e.g., councils) and the central entities (e.g., Ministry of Environment). In fact, in opposition to what should be expected after analysing the existent laws, coastal occupation is still increasing, without respecting the defined protection lines or rules. This is even more obvious at tourist areas, such as the Algarve coast, south Portugal. The occupation is made by profiting from the exceptions considered in those laws, by exerting the possibility of occupation if defined and approved prior to the existence of the recent laws, and in some other cases by total disrespect of the law. Since the Portuguese judicial system normally takes several years to solve situations such as illegal construction, the law becomes ineffective. As a consequence, development of any future policy or the adaptation of the existent laws to face sea-level rise impacts must include a careful and effective control programme.

Simultaneously, a hard and long-term commitment has to be made in order to sensitise coastal managers and general public to impacts of sea level rise and associated direct and indirect social and economical impacts, as changes related with sea level rise are slow and almost
imperceptible. However, addressing this issue is urgent because actions to solve the problem will be prohibitive in cost if taken when a stronger urban occupation replaces natural habitats within coastal zones.

CONCLUSIONS

Potential implications of sea-level rise for Portugal are not expected to be as dramatic as in some low-lying countries around the world (e.g., Bangladesh, Maldives or Netherlands). Furthermore, it is also difficult to dissociate the consequences of sea-level rise from other coastal impacts resulting from human actions (e.g., coastal erosion due to sediment deficiency). In Portugal, these impacts are normally greater by about one order of magnitude than the ones caused by sea-level rise. This trend will probably not change in the near future. Consequently, the evolution of the Portuguese coast will be mainly dependent on the direct result of human actions. Sea-level rise can be considered as a secondary but important cause of coastal change.

The Portuguese areas that will be probably most affected by sea-level rise are the coastal lagoons of Ria Formosa and Ria de Aveiro, and the Tagus and Sado estuaries. For these wetlands, as in others of the Portuguese coast, possible consequences of sea-level rise include an intensification of silting up, a higher degree of marine action, an increase in the influx of marine sediments and a decrease of their area. The main impacts on sandy shores will be an increase in shoreline retreat rates and a decrease of sandy beach areas, when backed by fixed artificial structures or cliffs. Low-lying rocky shores will probably loose existing pocket beaches between outcrops, while cliffed areas will be subjected to higher wave energy levels. However, these coastal regions will be the ones facing smaller impacts induced by a sea-level rise. All the above expressed consequences will induce diverse socio-economic impacts, being the most affected areas navigation, tourism and traditional activities, such as mariculture.
The common practice to mitigate coastal erosion problems has been to combat the shoreline retreat by using hard protection structures (e.g., groins, seawalls, etc.) or, more recently, beach nourishment. So far, there are no plans for a planned retreat or adaptation. Since there is no general policy to face sea-level rise consequences, a future use of local mitigation policies rather than the use of a global approach can be expected. This will result in possible increase of sea-level rise impacts in some areas and on a long-term augmentation of general expenses to diminish coastal hazards. A correct use and application of existing Portuguese laws, such as the Public Water and Maritime Domains could be helpful in avoiding or reducing the potential socio-economic impacts. However, coastal management practice during the last decades frequently disrespected the basic concepts of such laws, leading to an aggravation of coastal hazards and associated socio-economic impacts. It is therefore necessary to implement a new coastal management concept and approach, including a national plan to mitigate sea-level rise impacts and to increase the public awareness to such problems.

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LIST OF FIGURES

Figure 1 – Location map, including main rivers, coastal lagoons, and different coastal types.

Figure 2 – Monthly mean sea level data at Cascais and Lagos tide-gauge stations. Superimposed are the linear least-squares best-fit lines.

Figure 3 – Five-year running mean of North Atlantic sea surface temperature (solid line, after Barnett, 1983) and mean sea level at Cascais referred to hydrographic zero (dashed line, after Dias and Taborda, 1992).

Figure 4 – Simplified map of coastal areas vulnerability to sea-level rise in Portugal.
Figure 1
Figure 3
Figure 4