Revista de Gestão Costeira Integrada

Journal of Integrated Coastal Zone Management

Volume 20(1): March 2020

ISSN 1646-8872

ASSOCIAÇÃO PORTUGUESA DOS RECURSOS HÍDRICOS

Editor-in-Chief Prof. Francisco Taveira Pinto

Revista de Gestão Costeira Integrada

Journal of Integrated Coastal Zone Management

Volume 20, Issue 1
March 2020

RGCI/JICZM (ISSN: 1646-8972) is published quaterly
by an editorial pool composed by APRH, FEUP, CIMA, UNIVALI, UFRN, UPORTO and IUC
Correspondence: aprh@aprh.pt

Publishers
Editorial consortium comprising:

- APRH - Associação Portuguesa dos Recursos Hidricos, LNEC, Av. do Brasil, 101, 1700-066 Lisboa, Portugal.
  e-mail: aprh@aprh.pt. web page: http://www.aprh.pt
- CIMA - Centro de Investigayao Marinha e Ambiental, Universidade do Algarve, Faculdade de Ciencias e Tecnologia, Edificio 7, Campus Universitario de Gambelas, 8005-139 Faro, Portugal.
  e-mail: cima@ualg.pt. web page: http://www.cima.ualg.pt
- UNIVALI - Universidade do Vale do Itajai, Rua Uruguai, 458 - Centro, Itajai, SC, 88302-901 , Brazil
  web page: http://www.univali.br
- UFRN - Universidade Federal do Rio Grande do Norte, Caixa Postal 1524, Natal, RN, 59078-970 Brazil
  web page: https://www.sistemas.ufm.br
- FEUP/UPORTO - Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, s/n 4200-465 Porto Portugal. web page: https://sigarra.up.pt/feup/pt/web_page.inicial
- IUC - Imprensa da Universidade de Coimbra, Rua da Ilha, n° 1, 3000-214 Coimbra
  e-mail: imprensauc@ci.uc.pt. web page: http://www.uc.pt/imprensa_uc

Secretariat
Ana Estêvão (APRH), André Cardoso (APRH)

Copy editing
Francisco Taveira Pinto, Paulo Rosa Santos, Tiago Ferradosa

Formatting and pagination
André Cardoso (APRH)

Web page
André Cardoso (APRH)

SciELO DTD markup
André Cardoso (APRH)

Cover design
Flatland Design

ISSN: 1646-8872

Revista de Gestão Costeira Integrada
Journal of Integrated Coastal Zone Management

20(1) – March 2020

Table of Contents

Articles

Journal of Integrated Coastal Zone Management / Revista de Gestão Costeira Integrada 20(1):5-25 (2020)
http://www.aprh.pt/rgci/pdf/rgci-n197_Angulo.pdf | DOI:10.5894/rgci-n197

Revista de Gestão Costeira Integrada
Journal of Integrated Coastal Zone Management

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

Rodolfo José Angulo[@] [1], Maria Cristina de Souza[2], Mauricio Almeida Noernberg[3]

[@] *Corresponding author: fitoangulo@gmail.com*

[1] *Laboratório de Estudos Costeiros - LECOST, Departamento de Geologia, Setor de Ciências da Terra, Universidade Federal do Paraná*

[2] *Laboratório de Estudos Costeiros - LECOST, Setor de Ciências da Terra, Universidade Federal do Paraná. Email: cristinasouza2527@gmail.com*

[3] *Laboratório de Oceanografia Costeira e Geoprocessamento - LOCG, Centro de Estudos do Mar - CEM, Setor de Ciências da Terra, Universidade Federal do Paraná. Email: m.noernberg@ufpr.br*

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

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

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

** Submission: 12 JUN 2018; Peer review: 23 SEP 2018; Revised: 16 MAR 2020; Accepted: 16 MAR 2020; Available on-line: 25 MAY 2020*

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

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

1. INTRODUCTION

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

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

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

2. REGIONAL SETTING

2.1. Location

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

2.2. Watershed

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

2.3. Relief

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

2.4. Geology

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

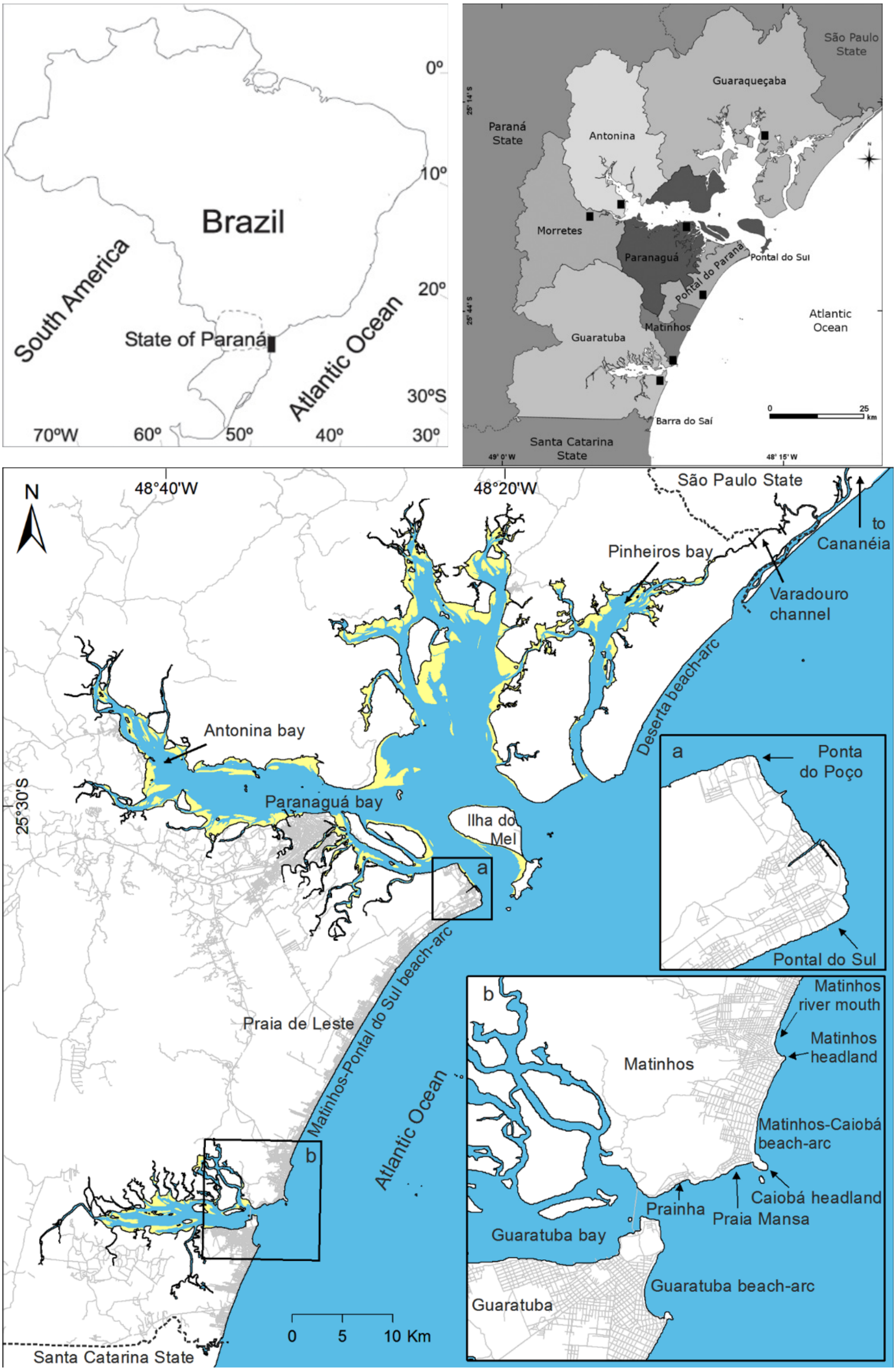


Figure 1. Location, municipalities, cities and main anthropized sectors of Paraná coastal zone (After IBGE, 2000 and Angulo *et al.*, 2018).

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

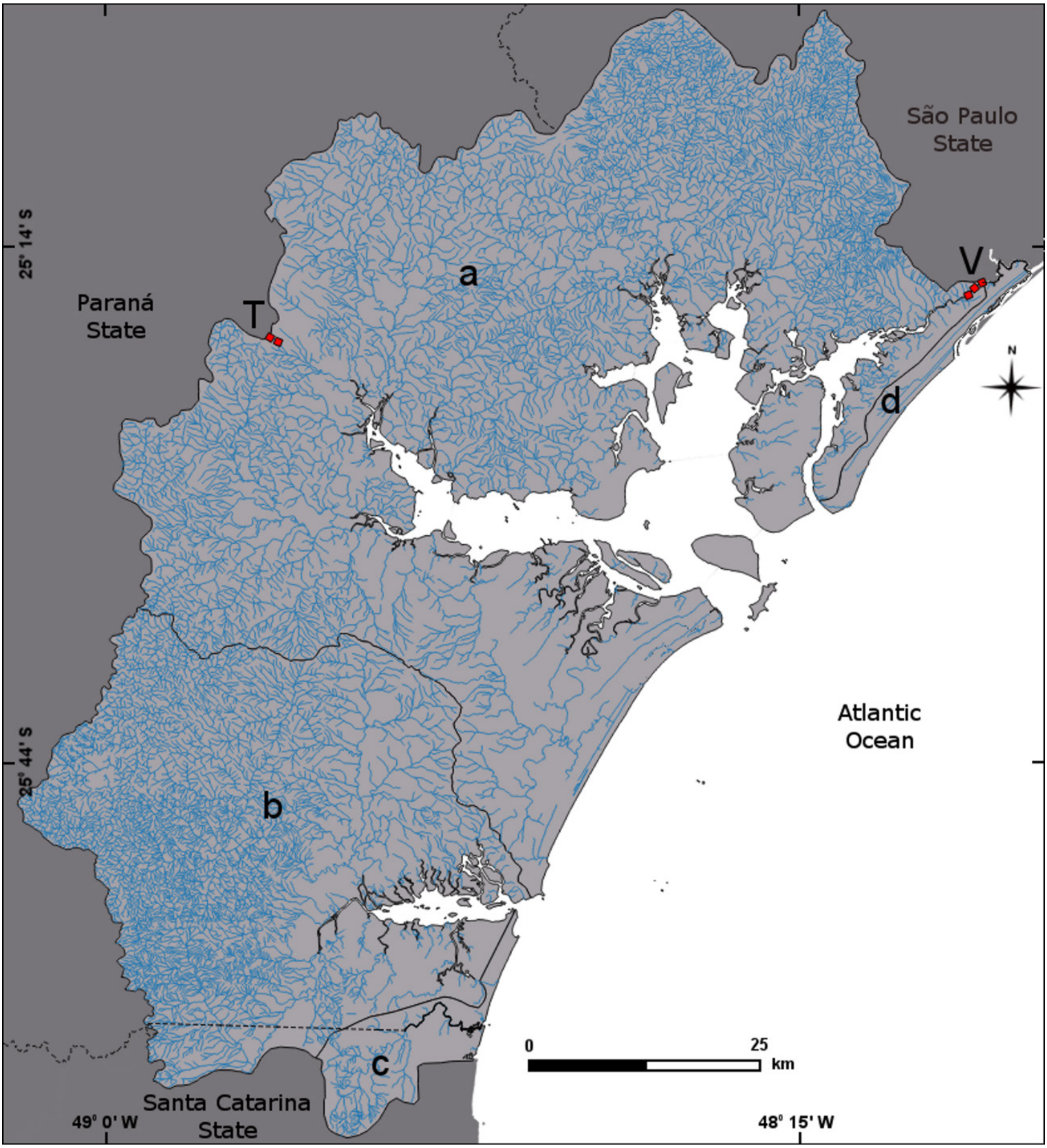


Figure 2. Watershed basins in the State of Paraná coastal zone: (a) Paranaguá, (b) Guaratuba, (c) Saí-Guaçu, and (d) Ararapira. (V) Varadouro artificial channel, (T) Capivari-Cachoeira watershed diversion (After Noernberg *et al.*, 1997).

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

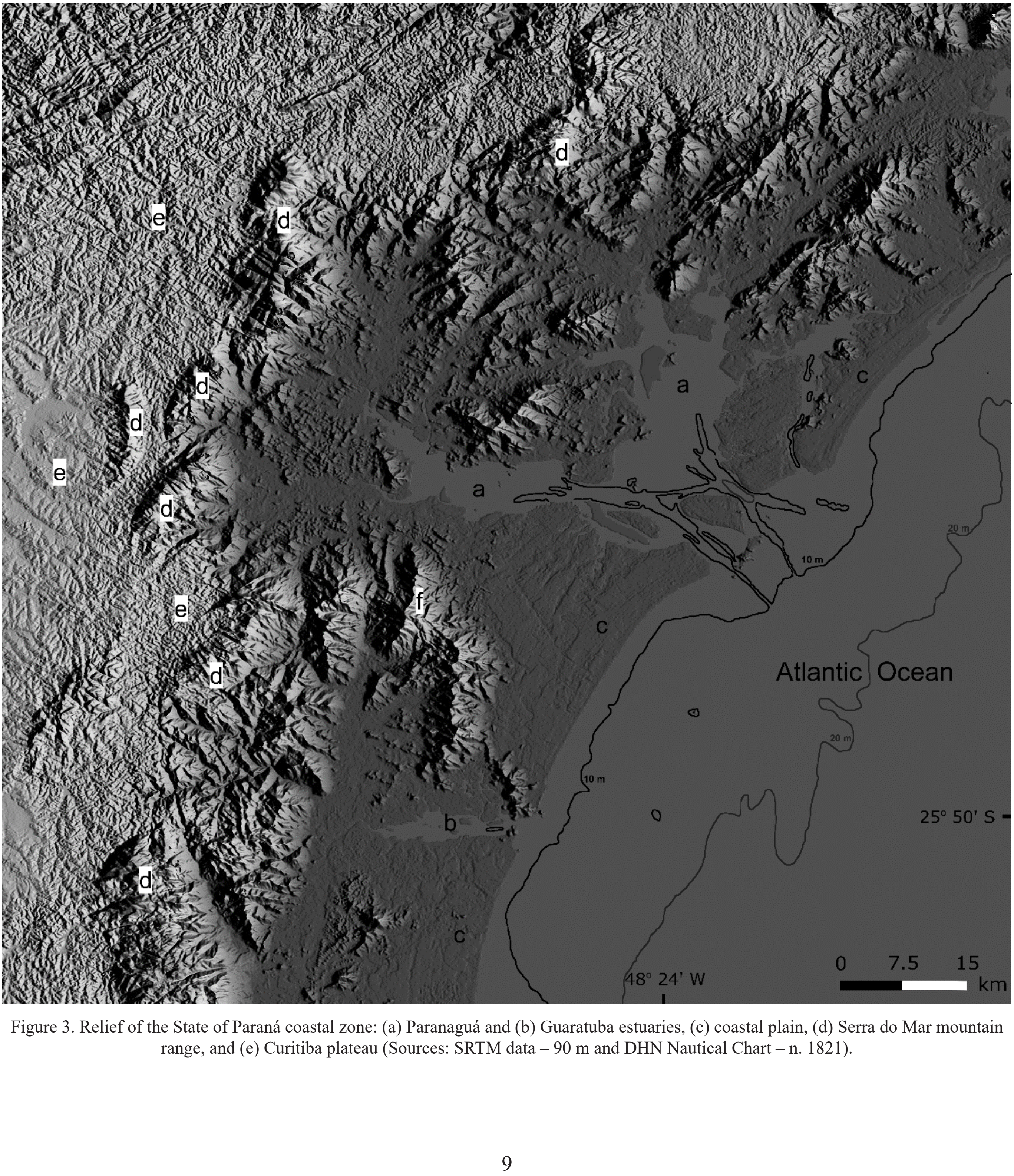


Figure 3. Relief of the State of Paraná coastal zone: (a) Paranaguá and (b) Guaratuba estuaries, (c) coastal plain, (d) Serra do Mar mountain range, and (e) Curitiba plateau (Sources: SRTM data – 90 m and DHN Nautical Chart – n. 1821).

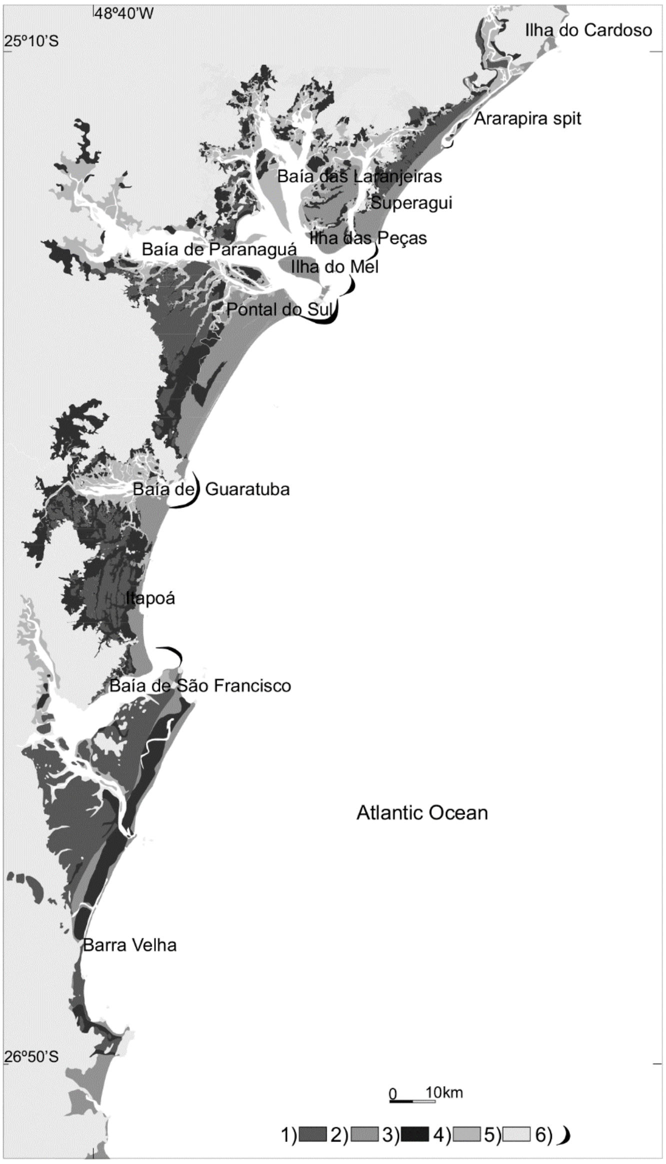


Figure 4. Quaternary geology from Barra Velha to Ilha do Cardoso coastal plains. (1) Pleistocene barriers, (2) Holocene barriers, (3) paleo-estuarine plains, (4) present tidal-flats, (5) other units, (6) ebb-tidal deltas (After Angulo *et al.*, 2009).

2.5. Climate

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

2.6. Tides and waves

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

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

2.7. Longshore drift

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

3. MATERIAL AND METHODS

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

4. RESULTS

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

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

4.1. Estuary and inner-shelf dredging

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

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

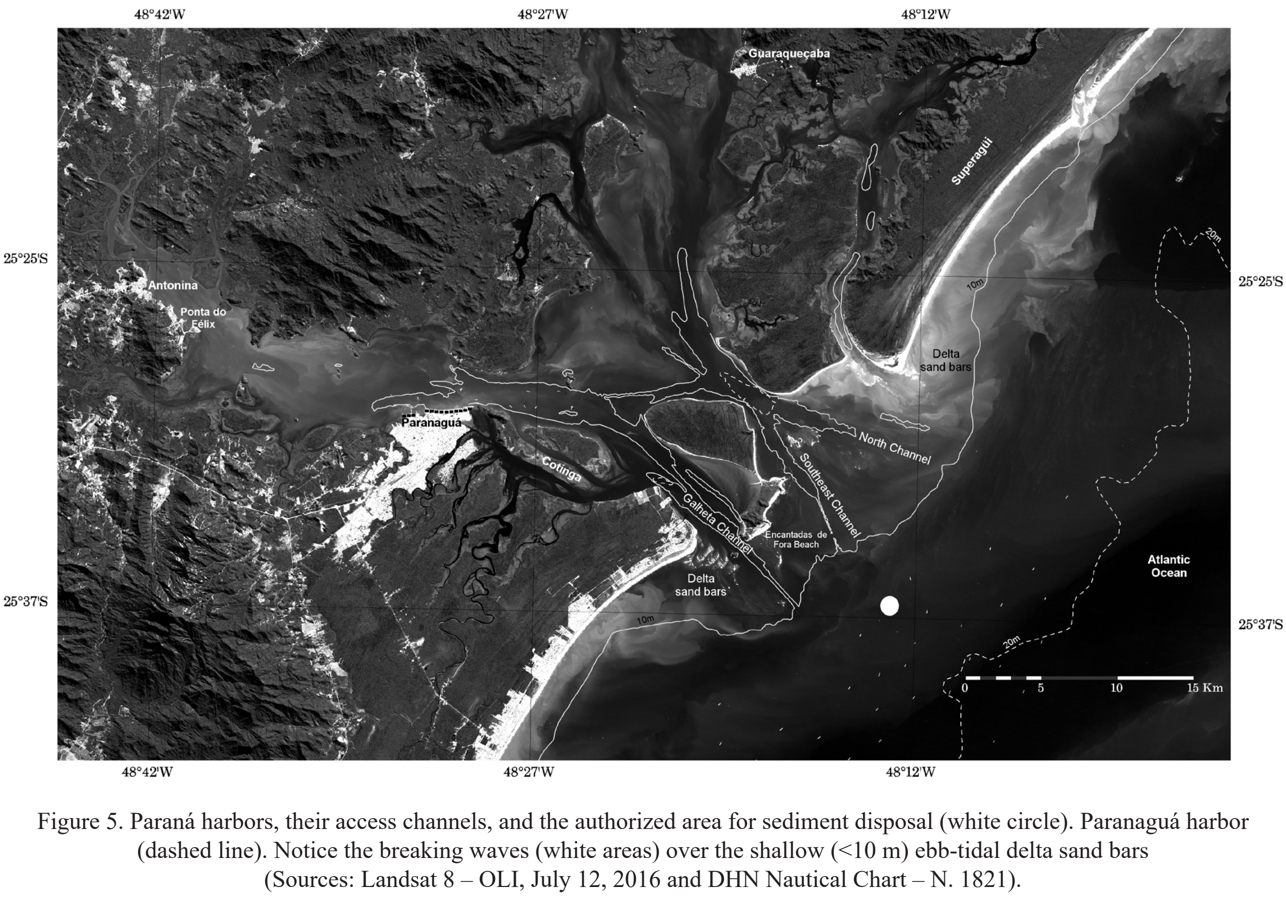


Figure 5. Paraná harbors, their access channels, and the authorized area for sediment disposal (white circle). Paranaguá harbor (dashed line). Notice the breaking waves (white areas) over the shallow (<10 m) ebb-tidal delta sand bars (Sources: Landsat 8 – OLI, July 12, 2016 and DHN Nautical Chart – N.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

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

4.2. Estuary silting

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

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

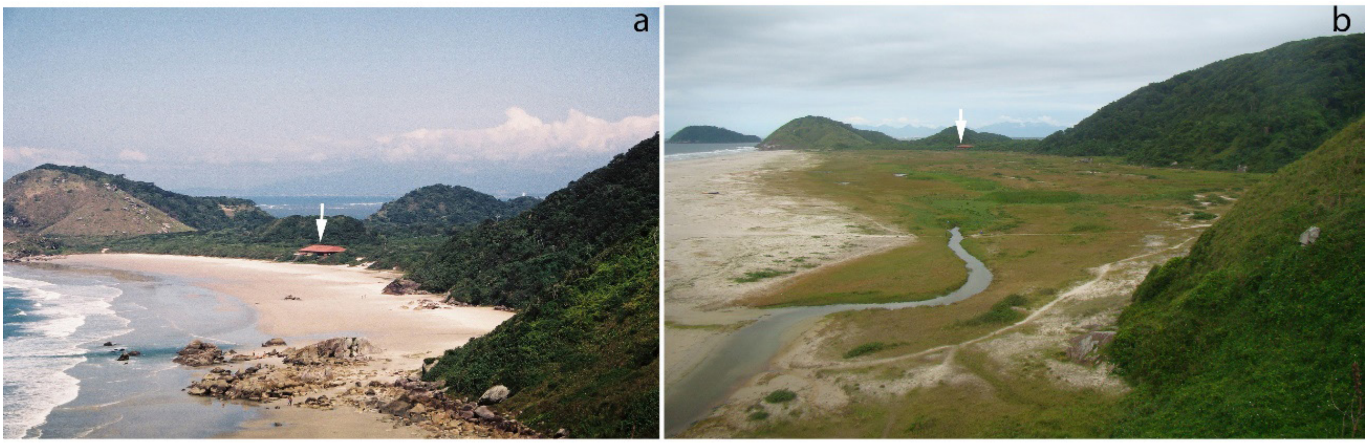


Figure 6. Encantadas de Fora beach at Ilha do Mel (a) in 2004 and (b) in 2016. The building (harrow) location is a reference to the intense coastal accretion (see location in Figure 5).

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

4.3. Mangrove obliteration

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

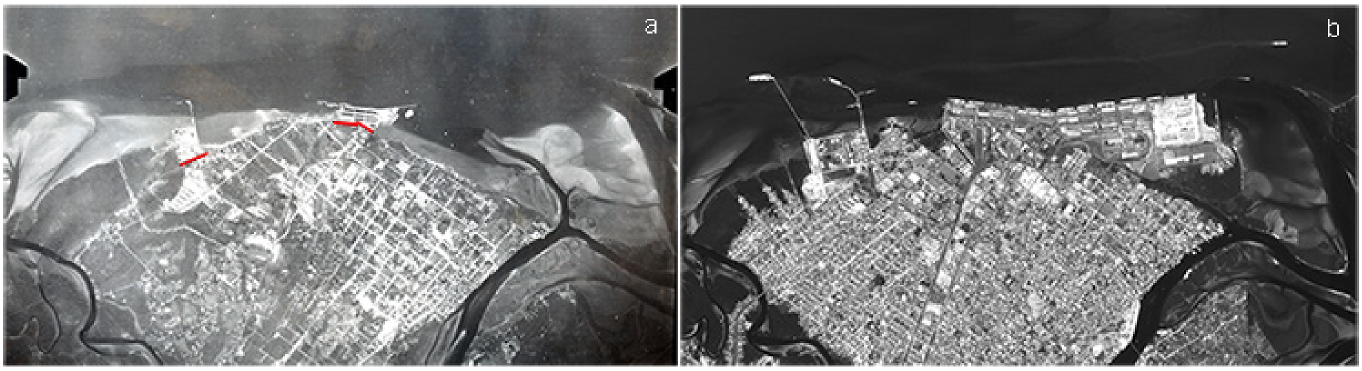


Figure 7. Paranaguá harbor (a) in 1953 and (b) 2002. Inferred natural former coastline (red solid line; see location in Figure 5).

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

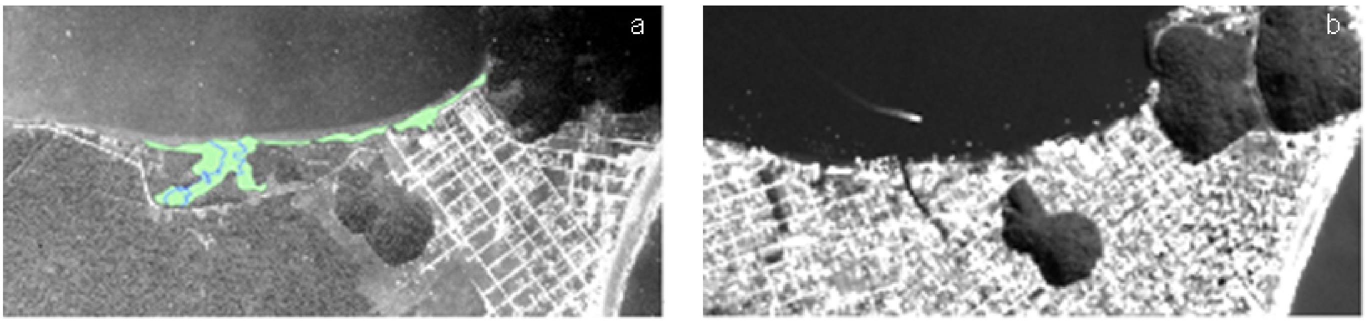


Figure 9. Estuarine Guaratuba city coast (a) in 1953 (mangroves highlighted in green) and (b) in 2016 (see location in Figure 1).

4.4. Drainage system modification

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

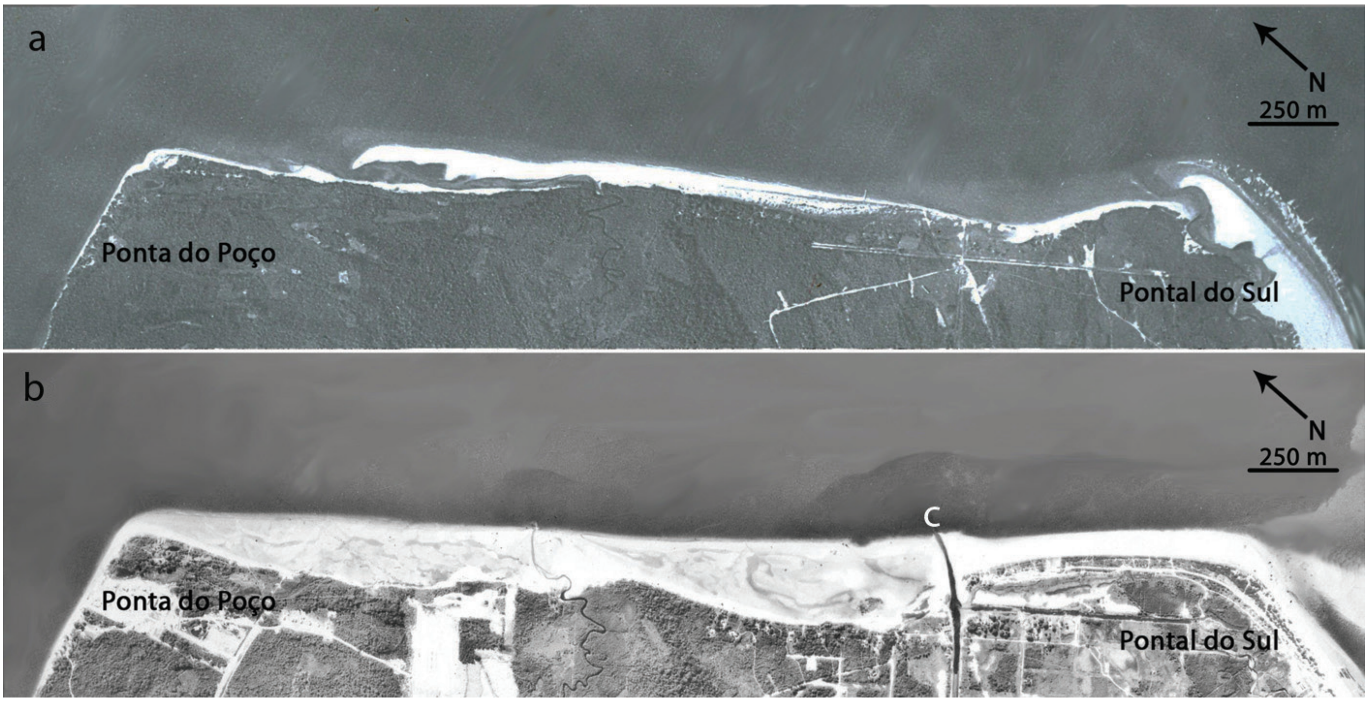


Figure 10. Estuarine coast between Pontal do Sul, and Ponta do Poço (a) in 1954 and (b) 1980. Note the spits oriented toward the estuary indicating the predominant drift direction. After the opening of the drainage channel, the littoral drift was interrupted causing intense coastal erosion downdrift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

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

4.5. Foredune obliteration and beach fringe occupation

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

4.6. Coastline artificialization

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

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

4.6.1. Harbor activities

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

4.6.2. Rivers and channels mouth stabilization

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

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

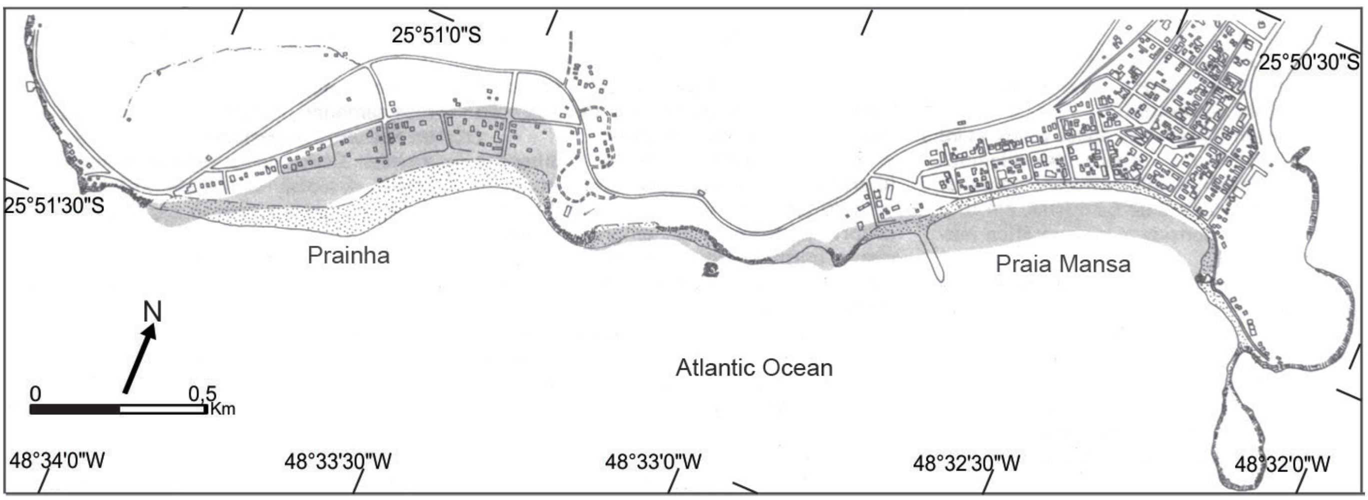


Figure 13: Area emerged between 1953 and 1980 and occupied in Prainha beach, near the Guaratuba inlet. Subaerial beach in 1953 (gray area) and 1980 (dotted area) (After Angulo, 1984) (see location in Figure 1).

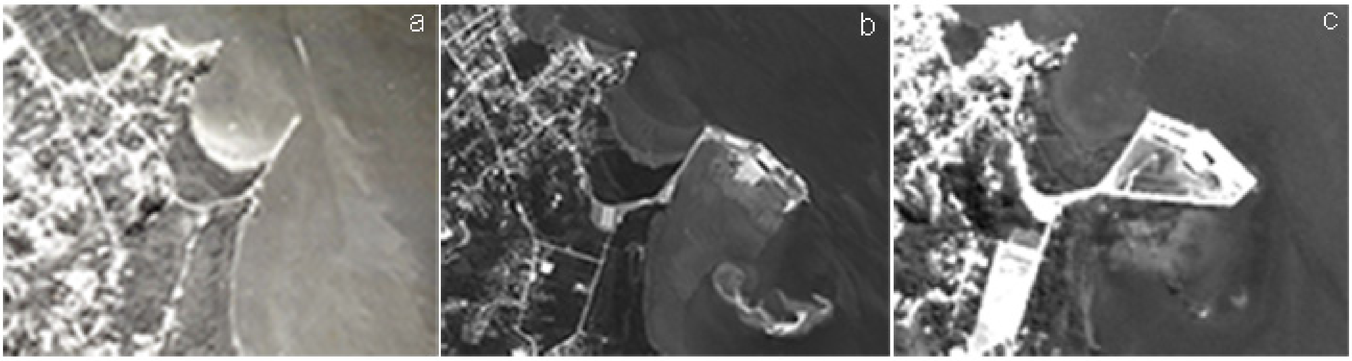


Figure 14: Ponta do Felix pier in (a) 1980, (b) 2002, and (c) 2016. Notice sand bars south of the pier in 2002, and the reclamation and mangrove areas south of the pier in 2016 (see location in Figure 5).

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

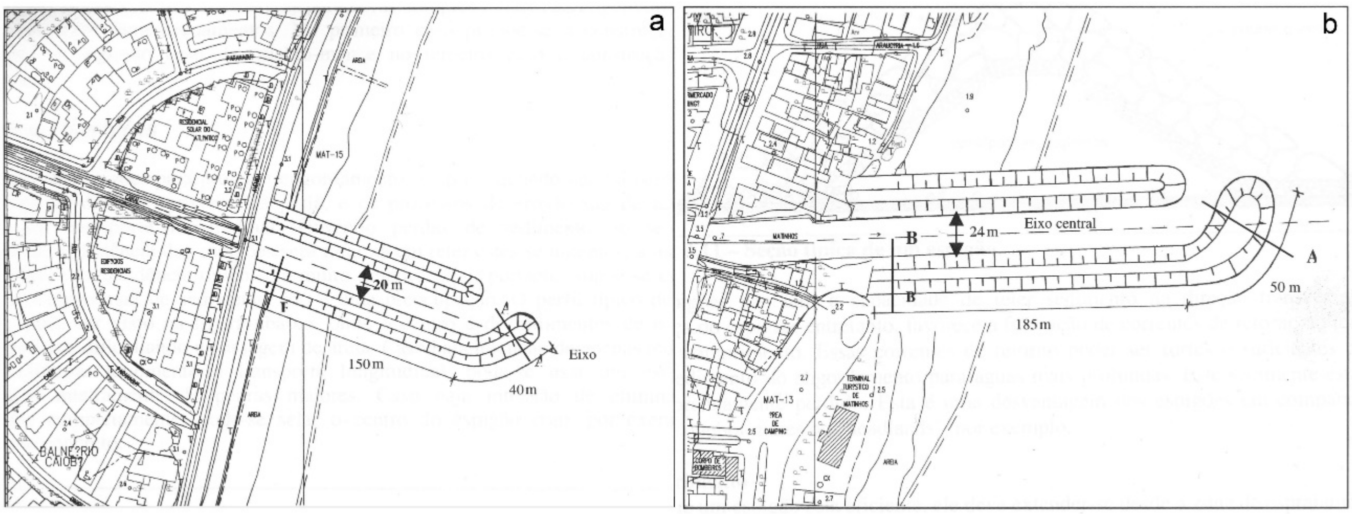


Figure 16: Sketch of proposed jetties for (a) Brava beach channel and (b) Matinhos River mouth (After Gobbi *et al.*, 2003; see location in Figure 1).

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

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

4.6.3. Beach erosion control

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

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

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

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

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

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

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

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

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

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

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

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

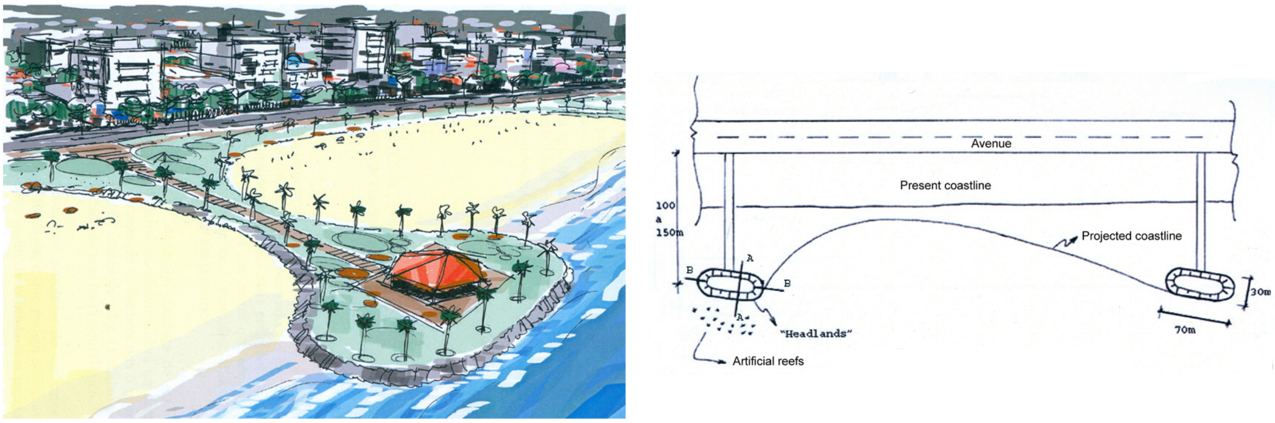


Figure 26. Sketch of proposed headlands or groins for the Matinhos-Caiobá and Pontal do Sul-Matinhos beach arcs (After Gobbi, 2007; see location in Figure 1).

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

5. CONCLUSIONS

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

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

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

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

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

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

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

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

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

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

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

5. ACKNOWLEDGMENTS

RJA and MCS were sponsored by CNPq scholarships (303940/2014-0, 302913/2018-1 and 305691/2014-7). RJA was sponsored by the Fundação Araucária with a senior scholarship (45725). This study was supported by CNPq projects 472897/2010-1, 477945/2012-0, and 471039/2013-6.

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Journal of Integrated Coastal Zone Management / Revista de Gestão Costeira Integrada 20(1):27-48 (2020)
http://www.aprh.pt/rgci/pdf/rgci-n213_Oliveira.pdf | DOI:10.5894/rgci-n213

Revista de Gestão Costeira Integrada
Journal of Integrated Coastal Zone Management

The evolution of the European framework for coastal management, linked to the new environmental challenges. The Portuguese case

Sónia Oliveira[@], Delminda Moura, Tomasz Boski

[@] *Corresponding author: saoliveira@ualg.pt*
University of Algarve, Centre for Marine and Environmental Research (CIMA), Portugal.

ABSTRACT: The sharing of space by various human activities leading to social conflicts and threats to ecosystems, alongside increased awareness of the threats to coastal zones has created the need to legislate on coastal planning and integrated management by developing international guidelines. A new management challenge has emerged due to climate change that had not previously been considered in legislation or policies. Therefore, the European tools and frameworks applied in Portugal, their implementation and effectiveness will be analysed. Extensive bibliographic data was analysed including EU directives and policies, and Portuguese governmental documents from national to a municipal level. We found that all the European Union guidelines and frameworks are being implemented in the Portuguese Governmental planning and are very well substantiated, whereas the base of all land management instruments (IGT), have a questionable implementation, mainly due to the number of entities involved and the long implementation process.

Keywords: Integrated Coastal Management; Europe, Portugal, Directives, Climate Changes.

RESUMO: A partilha de espaço por várias atividades humanas que levam a conflitos sociais e ameaças aos ecossistemas, juntamente com o aumento da consciencialização sobre as ameaças às zonas costeiras, criou a necessidade de legislar o planeamento costeiro e a gestão integrada, desenvolvendo diretrizes internacionais. Um novo desafio de gestão surgiu devido às alterações climáticas, que não haviam sido consideradas anteriormente na legislação ou nas políticas. Por conseguinte, serão analisadas as ferramentas e quadros europeus aplicados em Portugal, a sua implementação e eficácia. A base bibliográfica estudada foi extensa, incluindo diretivas e políticas da UE e documentos governamentais portugueses, de nível nacional a municipal. Evidenciámos que as diretrizes e quadros de referência da União Europeia estão a ser implementados no planeamento do Governo Português e são muito bem substanciadas, enquanto a base de todos os instrumentos de gestão territorial (IGT) tem uma implementação questionável, principalmente devido ao número de entidades envolvidas e o longo processo de implementação.

Palavras Chave: Gestão Costeira Integrada; Europa, Portugal, Diretivas, Alterações climáticas.

** Submission: 19 SEP 2018; Peer review: 15 OCT 2018; Revised: 21 APR 2020; Accepted: 21 APR 2020; Available on-line: 25 MAY 2020*

1. INTRODUCTION

Coasts worldwide extend for 20% of the Earth's surface and half of the world's population live within 60 km of the coastline (Nicholls, 2007; Collet and Engelbert, 2013).

Several kinds of classification have been used to group coastal areas according to their morphostructural characteristics or genesis (*e.g.*, Suess, 1888; Johnson, 1919; Shepard, 1973; Inman and Nordstrom, 1971; Finkl, 2004). For instance, aiming to develop a comprehensive coastal classification, Finkl (2004) proposed an approach based on morphological units subdivided in terms of litholoy of the substratum, age, geodynamics, climate, relief and erosional-depositional processes and forms.

Littoral morphology and evolution depend on the nature of the bio-physical support, sedimentary balance, marine climate and exposure to waves, sea level changes, inherited morphology and the time during which littoral zones are being acted upon by morphodynamic agents. Due to climate change, the increase in mean sea level (MSL) is expected to accelerate, making the management of the growing occupation of the coast a priority. Governments facing with MSL rise have recognized the urgency in promoting integrated coastal management (Antunes and Taborda, 2009; IPCC, 2013).

The European Commission describes coastal zones as attractive, productive areas with diverse valuable habitats and ecosystem services (European Commission, 2013a). Coastal zones support a diverse range of related industries such as fisheries, tourism and oil industries that in turn provide enormous economic interest (Cummins *et al.*, 2003). Densely populated coastal regions due to excessive anthropogenic pressure can also be dynamic environments posing hazards to ecosystems, human life, and the economy by imposing stress on finite coastal systems and resources (Rabenold, 2013; Cummins *et al.*, 2003). Therefore, an integrated management of all actions that share the coastal area is necessary and imperative to safeguard the sustainable development and the maintenance of ecosystem services, reinforcing the need to legislate on coastal planning and integrated management.

For coastal management, the European Commission defines as coastal area/region: i) a region with a sea border (382 EU regions meet this criterion); ii) a region where more than half of the population is living less than 50 km from the sea (63 further regions satisfy this criterion); and, iii) the Hamburg region, which was added to the list of EU coastal regions due to its strong maritime influence. Therefore, in 2013, coastal regions accounted for 40% of European Union territory, with a total of 446 coastal regions in 23-member states (including the United Kingdom), being considered the most desirable places to live and work in, and being in high demand for leisure activities (Rabenold, 2013).

1.1 Ecology and Human Occupation

The dense population of coastal regions and over exploitation of the sea can damage ecosystems, leading to the limitation of public access to the foreshore, erosion, siltation and, in the worst cases, render coastlines more vulnerable to storms and natural disasters (Nicholls, 2007; Cummins *et al.*, 2003). By 2013, 58.1% of fish stocks were being fully exploited, 31.4% depleted, overexploited or recovering, with the remaining 10.5% being underexploited or moderately exploited (FAO, 2016). The development of engineering structures and human housing along the coastline restricts the ability of inter-tidal habitats to move landward as sea levels rise. Water quality is affected by pollution from ships, coastal industries and from land-based sources such as agriculture and industries that release waste into rivers (GESAMP, 2001). The explosive growth of the population in the coastal zone, partly due to tourism, has increased the pressures on the coast, especially along the French, Spanish, and Portuguese coasts, and the southern coast of the United Kingdom (RIKZ, 2004).

Aiming to systematise the planning strategies, due to common problems, Connolly *et al.* (2001) categorised coastal zones taking into account the main processes that contribute to their evolution, based on the Irish example as follows: i) coastal development, pressure imposed by social and economic driving forces such as urban expansion, retirement, second homes and tourism industry; ii) coastal agriculture, one of the biggest sources of pollution which has led to a reduction in semi-natural habitats and to a decrease in biological diversity (McGarrigle, 1999); iii) coastal erosion and floods, pressure imposed by high demographic numbers and infrastructures inducing a greater erosion of the coast by the retreat of cliffs and the breakup of the sediment budget (see examples in Teixeira, 2014; Kwasi, 2014); iv) tourism and recreational use, increase in tourist numbers has been shown to threaten areas of high ecological and resource value in coastal marine environment; v) coastal industry, ports and harbours, releasing high volumes of chemicals in the water, increasing the damage to several habitats; vi) fishing and aquaculture industry, sustainability of fisheries has become questionable; vii) water quality, direct discharge of urban wastewater, domestic and industrial sewage into coastal waters via drainage networks and aquifers; and, viii) offshore resources, that may lead to the loss of landscape and seascape as a result of accidental spills (see example in Cummins *et al.*, 2003).

Most of the above-mentioned impacts occur worldwide in coastal areas, reinforcing the need to achieve an effective, integrated coastal management. Therefore, international guidelines on integrated coastal management need to be further improved, despite the efforts already made.

1.2 Purpose and organisation

This work aims to review the European tools and frameworks on Integrated Coastal Management (ICM) and evaluate their implementation and effectiveness, using Portugal as a case study.

First, European guidelines and management tools to achieve integrated coastal management are analysed, followed by an assessment of their adaption to the impact of climate change on coastal systems. Later sections assess the Portuguese legal and administrative settings and how Portugal is dealing with EU demands for achieving good integrated coastal management. For organisational purposes and better understanding, the Portuguese acronyms are presented throughout the manuscript in italic.

The EU produces a range of official documents to implement and support policies and legislation. Obligations for the Member States are introduced through legislative documents while others are set with a non-binding effect. According to Qiu and Jones (2013) the EU Law can be organized in “primary” and “secondary” with treaties establishing the basic rules for decisions and actions that must be included in secondary legislation such as regulations, directives and decisions.

To aid in the better understanding of this manuscript, a short description of some of these documents is made bellow (EU Monitor, 2020):

i) Treaty is a legal binding agreement, subject to international law, between countries on any given subject.

ii) Regulation is a binding legislative act applied entirety across the EU.

iii) Directive is a legislative binding act that establishes a set of objectives which all member states must fulfil, but each state can decide how.

iv) Decision is binding act in its entirety, unless explicitly stated otherwise.

v) Act is an instrument in writing to verify a legislative act being used sometimes as foundation for a treaty.

vi) Protocol is annexed to a treaty and stipulates detailed measures or actions on a specific part of that treaty.

vii) Green Paper is a document published to stimulate discussion on given topics at European level and may serve as a basis for later legislative proposals.

viii) Communication is a policy document with no legal effect, a way for the European Commission to voice their opinion on an issue.

ix) Recommendation does not impose any legal obligation on those to whom it is addressed. It allows the institutions to make their views known and to suggest a line of action.

x) Guidelines are non-binding acts that set out a framework for future acts in a policy area.

xi) Reports are issued by the European Commission to report and assess current policies. A report may provide a basis for policy development.

2. EUROPEAN GUIDELINES AND TOOLS TO ACHIEVE INTEGRATED COASTAL MANAGEMENT

The awareness established in the scientific community and among high ranking government officials about coastal issues has allowed for the discussion and creation of several necessary international policies, some of which have already been referred to in previous sections. The earliest efforts in this regard were made by developed coastal nations, as coastal zones became degraded due to inappropriate development and poor planning (Vallega, 1996; Cicin-San and Knecht, 1998).

Within Europe, the first implementation of coastal policies was done in 1973, with the conclusion of the Council of Europe Committee of Ministers Resolution on the Protection of the Coastline. This resolution officially stated that Europe’s coastlines were at risk and that member states should join forces to protect them.

To reduce or eliminate problems resulting from densely populated coastal regions and overexploitation of the sea and coastal zones, the now widely recognised concept of Integrated Coastal Management (ICM) was consolidated. The ICM concept was an attempt to resolve the increasing anthropogenic pressures on coastal resources, prompting countries internationally to take an interest in the quality and management of their coastal environments. Previously known as Integrated Coastal Zone Management (ICZM), within Europe the concept was defined in 1976 and ratified by the Council of the European Union in 2010 (Millemann, 1995; Council of the European Union, 2008).

In the literature, several definitions and explanations can be found for the ICM concept, but the underlying principle is always the same: manage the coast taking into consideration all the different components and stakeholders. The definition of ICM varies according to the different authors, with some based on the use while others place emphasis on processes (Knecht and Archer, 1993; Olsen *et al.*, 1999; Olsen and Nickerson, 2003; Cicin-Sain and Knecht,1998; Ehler, 2003). All conclude that integrated coastal management is an extremely complex process concerning the balance between the resilience of natural ecosystems and the needs of human society (Cicin-Sain and Knecht, 2000).

The concept of ICM was embraced by nations around the world as a central concept in the management of coastal zones and ocean areas as one of the principal recommendations of Agenda 21, which was adopted at the United Nations Conference on Environment and Development (UNCED) – the Earth Summit – in Rio de Janeiro, 1992. It gave both international prominence and political legitimacy to the concepts of ICM and sustainable development. Coastal states were required to provide an integrated policy and decision-making process, including all involved sectors, to promote compatibility and a balance of uses in the coastal area to guaranty the present and future generation's needs (Robinson, 1992).

The main principals of ICM as identified by the EU include: a wide-ranging view of inter-related problems; decision making based on good data and information; working with natural forces; involving all stakeholders and all relevant parts of the administration; and, use of a range of instruments (laws, plans, economic instruments, and information campaigns). This will contribute to ensure coherence between policies, plans and programmes, and the effective nesting and implementation of plans and programmes at different scales of intervention. The overall result should be clear for policy and decision-making in order to facilitate the sustainable development of maritime economies and enhance the livelihoods of coastal communities (European Commission, 2007b).

In Agenda 21 of 1992, not only the ICM was defined but also the capacity building concept. This concept involves human resource development, the creation of coastal organisations and promotion of an overall policy environment to generate appropriate responses to emerging needs (UNDP/UNDOALOS, 1994). Agenda 21 also aimed to create infrastructures, encourage people capacitation, produce training materials (*i.e.* texts, notes, cases), and work with academics to aid professionals in spreading the regional and global importance of protecting the coasts (Cicin-Sain *et al.*, 2000). This goal also imposed changes in education, research centres and governmental councils.

Before the acceptance of the concept and guidelines imposed by Agenda 21, different disciplines concerned with the study of oceans and coasts operated independently, using different languages and different underlying worldviews and structures (Cicin-Sain *et al.*, 2000). The study and analysis of oceans and coasts and government policies were oriented around single disciplines and single sectors. For example, geology was applied to coastal problems such as beach and cliff erosion, sedimentary balance between fluvial input and alongshore drift; physical oceanography was used to determine the magnitude and direction of the ocean currents and waves that affect the coastal morphodynamic processes, pollutant dispersion and ecosystems and, social sciences were applied to determine the behaviour of coastal residents and user groups. The study of a region was independent according to each scientific theme but, with the ICM, the frontiers between disciplines are supposed to be breached and the evaluation of an area embraces all disciplines and the interaction between them. Integrated coastal management, in effect, represents a new paradigm of management for the managers, and a new way of thinking and educating for the scientists (Cicin-Sain *et al.*, 1995).

In parallel to the previous concepts and developments, between 1973 and 1981, the First European Community action programmes on the environment were launched with special care concerning matters of ecological management in coastal areas. In 1975, the Wetlands Convention, also called the Ramsar Convention, was enforced, an intergovernmental treaty adopted in 1971 that represents the first of the global treaties on conservation. Also, the Birds Directive 79/409/EEC adopted in 1979, is the oldest piece of EU legislation on the environment, that emphasises the protection of habitats for endangered and migratory species and that was amended in 2009 becoming the Directive 2009/147/EC.

The First European Community action programmes also led to the European Coastal Charter, which was prepared by the Conference of Peripheral Maritime Regions in Europe and led in 1982 to the Resolution of the European Parliament (European Communities, 1982). Both underlined the need for integrated planning of coastal areas and therefore, in 1983, the European Regional/Spatial Planning Charter was adopted by the Conference of Ministers Responsible for Spatial/Regional Planning – CEMAT (Council of Europe, Committee of Ministers, 1984). The CEMAT did further work establishing the Model Law on Sustainable Management and the European Code of Conduct for Coastal Zones (Council of Europe, 2000). Hence, establishing the general management principles to achieve sustainable development and preservation of environmental values in coastal areas.

In 1985 the Environmental Impact Assessment (EIA) Directive was adopted by the European Economic Community, which applies to a wide range of public and private projects, which are defined in Annexes I and II of the same directive (85/337/EEC). The projects in Annex 1 have mandatory guidelines related to infrastructures, defining, for example, structures for hazardous waste disposal and that airports must have a basic runway length ≥ 2100 m. For projects listed in Annex II, the national authorities must use a screening procedure and decide whether an EIA is needed. The directive was amended three times, in 1997, 2003 and in 2009, the latter due to the increasing amount of carbon dioxide added to the atmosphere by anthropogenic emissions which introduced the need to include this variable in the directives, adding projects related to its transport, capture and storage.

Between 1992 and 1994 the Council Directive 92/43/EEC was adopted. It concerns the conservation of natural habitats and of wild fauna and flora also known as the Habitats Directive – SCI (Council of the European Union, 1992). Habitat loss and degradation are the most serious threats to the conservation of wild birds and landscapes. Accordingly, the directive places great emphasis on the protection of habitats for endangered and migratory species. It established a network of Special Protection Areas (SPAs) including all of the most suitable territories for these species. In the European Union, under the Birds Directive, the Important Bird and Biodiversity Areas (IBAs) are identified through the application of international scientific criteria and constitute a network of sites essential for the conservation of birds with unfavourable conservation status, which were used as the basis to designate SPAs. Since 1994, all SPAs are also included in the Natura 2000 ecological network, set up under the Habitats Directive 92/43/EEC.

In parallel to the previous concepts and developments, the Ecosystem Approach (EsA) emerged, initially in the late 1980s and early 1990s as a topic of discussion in research and policy communities working on the management of biodiversity and natural resources (Hartje *et al.*, 2003). It aimed to manage the ecosystems, based on the multiple functions that they perform and the multiple uses that they may have, and to optimise the use of an ecosystem without damaging it (Haines-Young and Potschin, 2011). The EsA is transversal to various policies, including ICM and Marine Spatial Planning (MSP). The ICM depends on the EsA's approach to guaranty a broad-scale approach in research and management that considers people's behaviour and their relationship to the environment.

Several efforts have been made to develop international guidelines and protocols on integrated coastal management that guarantee the best conduct in coastal areas. Cicin-Sain and Knecht (1998), assume that the central aspect of ICM is integration and that several dimensions of integration are involved in ICM (Fig. 1).

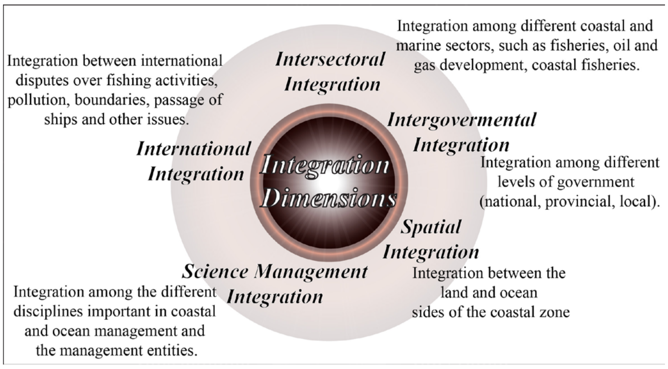


Figure 1. Conceptual scheme according to Cicin-Sain and Knecht 1998.

The integrated management along the dimensions referred to in Figure 1 is difficult to achieve due to the involvement of oceans, coasts and international divergent sectoral government agencies, and governance at different levels, each with their own interests, mandates, and perspectives. To aid in achieving integrated management, Cicin-Sain and Knecht (1998) and Cicin-Sain *et al.* (2000) emphasise the importance of having incentives that promote continued collaboration among ICM entities. It is also important to provide training and education programmes based on coastal and ocean activities, uses, natural systems, and physical processes. This way developing the appropriate mind sets and skills that coastal managers and the general population need (Vallega, 1999), while also providing technical information about sustainable coastal zone management, and stimulating a broad debate among the various stakeholders. This would hopefully lead to a consensus regarding the measures necessary to stimulate Integrated Coastal Management in Europe (Fig. 2). This resulted in two documents; the first was a Communication on "Integrated Coastal Zone Management: A Strategy for Europe" in which six overarching ideas for ICZM were proposed by the European Parliament. This document recommended a wide-ranging perspective, building on an understanding of specific conditions, working with natural processes, using participatory processes, ensuring the support and involvement of all relevant administrative agencies, and using a combination of instruments and approaches (European Commission, 2000a). The second document was a proposal for European Parliament and Council Recommendation concerning the implementation of Integrated Coastal Zone Management in Europe (European Parliament, Council of the European Union, 2002). The recommendation defines the essential characteristics of ICZM focussing on integration across sectors and knowledge-based approach (European Commission, 2000b).

In 2000, the EU Water Framework Directive (WFD), establishing a framework for the community action in the field of water policy, entered into force (European Parliament, Council of the European Union, 2000). Some amendments have been introduced into the Directive since 2000 but the Directive still focuses on 8 key aspects of the implementation: i) Coordination in international river basin districts; ii) Risk assessment of surface water bodies; iii) Groundwater management; iv) Artificial and modified water bodies management; v) Establish a value for waters; vi) Monitoring programmes; vii) Establish a common scale for Europe's waters; and, viii) Reducing dangerous chemicals in Europe's waters. Although these principles do not directly concern the coastal zones, the quality of coastal habitats are related to the quality of the water coming from the drainage basins and adjacent aquifers. Therefore, they are very important to consider.

Taking in consideration the WFD, in 2001 the Strategic Environmental Assessment (SEA) was enforced and applied to a wide range of public plans and programmes (European Parliament, Council of the European Union, 2001). It is mandatory for programmes and plans that (i) apply to agriculture, forestry, fisheries, energy, industry, transport, waste/water management, telecommunications, tourism, town and country planning or land use; and (ii) have been determined to require an assessment under the Habitats Directive; therefore setting the framework for future development consent of projects in the EIA Directive.

Between 2007 and 2008 a green paper was adopted in Europe, launching 'An integrated maritime policy for the European Union' (European Commission, 2007a). This policy aims to educate and enhance Europe's knowledge and awareness of maritime affairs, development and sustainable growth and the sustainable use of oceans and seas, stressing the importance of coastal regions. Moreover, the European Union adopted the Marine Strategy Framework Directive (MSFD) which aims to protect the marine environment and natural resources and creates a framework for the sustainable use of marine waters.

In 2011, the Biodiversity Strategy was adopted by the EU establishing 6 targets and 20 actions to help stop global biodiversity loss by 2020. This reflected the commitments taken by the EU in 2010, within the International Convention on Biological Diversity. Furthermore, in 2013 an additional Proposal Directive of the European Parliament and of the Council established a Framework for Maritime Spatial Planning and Integrated Coastal Management to promote the sustainable growth of maritime and coastal activities and the sustainable

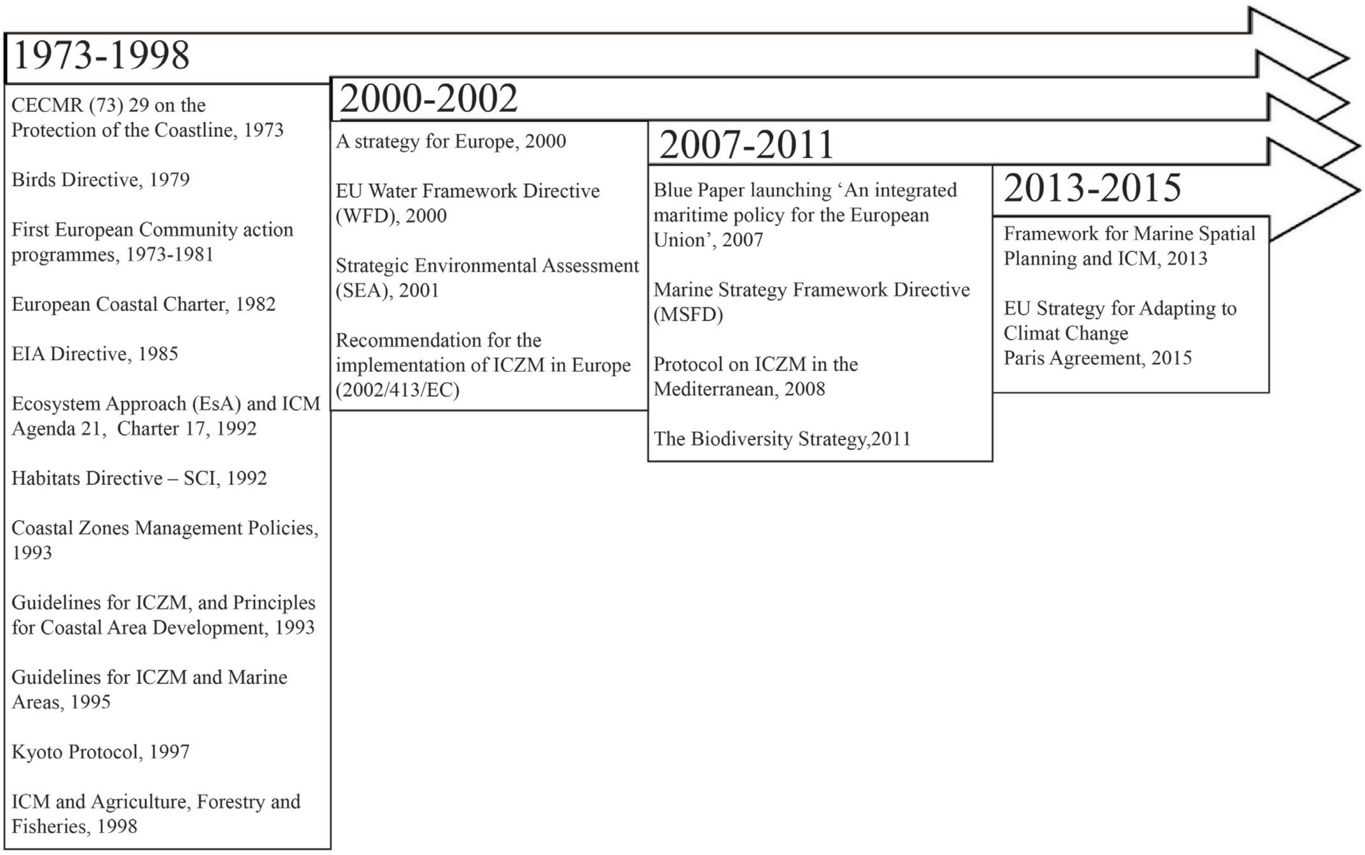


Figure 2. Scheme of the key European policies for the management of coastal zones, from 1973-2015.

use of coastal and marine resources. The Proposal Directive of the European Parliament and of the Council requires the mapping of all human activities at sea, identification of future spatial development, spatial plans and coordination of relevant policies in integrated coastal management strategies. It employed an approach that respects the limits of ecosystems, including the assessment of plans and strategies in accordance with the provisions of Directive SEA on strategic environmental assessment, economic activities and hazards in coastal areas that will improve interaction between land- and sea-based activities. This would also help the regional implementation of several other EU policies relevant for marine and coastal areas, such as Marine Strategy Framework Directive, the Water Framework Directive, the Natura network, Habitats Directives and the Biodiversity Strategy.

In addition to emitting guidelines and frameworks, the EU financially supports the implementation of integrated management projects, depending on the nature of the project. Funding possibilities are vast under the structural funds and the cohesion policy of the EU. Some of the funding tools are the EU's funding instrument for the environment (LIFE+), the European Agricultural Fund for Rural Development (EAFRD), the Development Cooperation Instrument and the Intelligent Energy programmes. To aid in the distribution of information to the general and scientific population, two information platforms were also created; OURCOAST and Coastal Wikipedia. The OURCOAST database provides case-studies and best-practice examples to support ICZM implementation while the Coastal Wikipedia gathers coastal management knowledge, research and results of the EU co-funded research project ENCORA.

Coasts worldwide differ due to physical, social, economic, biological and cultural factors therefore there is no one standard for implementing an ICM solution. On the contrary, ICM must be adapted to each region. For instance, the ICZM Protocol on Integrated Coastal Zone Management in the Mediterranean was used to achieve a dynamic process for the sustainable management and use of coastal zones. To achieve this, the fragility of coastal ecosystems and landscapes, the diversity of activities, their interactions, uses and their impact on both the marine and land parts had to be taken into account (UNEP/MAP/PAP, 2001; UNEP/MAP/PAP, 2008). Other strategies to maintain and guarantee integrated management are to create working groups across Europe with the main goal to access and guarantee the equilibrium of the regional ecosystem. For example, in 2010, a common working group was created between the Baltic Marine Environment Protection Commission (HELCOM) and Visions and Strategies around the Baltic Sea (VASAB), to cooperate in the ICZM and Maritime Spatial Planning of the Baltic Sea.

In general, the implementation of an ICM policy, programme or project in a region requires several integrative stages. Olsen *et al.* (1998) breaks these several stages into five steps: (i) identification of issues; (ii) plan preparation; (iii) formal adoption and funding; (iv) implementation; and, (v) monitoring and evaluation. The interactive nature of the ICM process requires feedback among the stages, which may alter the sequence or require repetition of some stages (Cummins *et al.*, 2003). The evaluation of the regional and country management plans is an excellent strategy to maintain the care of the area and guarantee the implementation of the directives, protocols and laws of the EU that will be discussed further on in this work using Portugal as a case study.

3. INTEGRATED COASTAL MANAGEMENT AND CLIMATE CHANGE IMPACTS ON COASTAL SYSTEMS

Climate change is a key threatening process to biodiversity and natural systems evolution (Krockenberger *et al.*, 2003; Gonzalez *et al.*, 2010; Sommer *et al.*, 2010) and it will exacerbate many already existing threats (Auld and Keith, 2009; Tanner-McAllister *et al.*, 2017). Climate change may cause serious impacts on human and environmental systems. This issue for which scientific evidence exists challenges the world (IPCC, 2014). It is reported that the changing climate may result in increasingly extreme events worldwide, leading to heavier socioeconomic damages (IPCC, 2012; Rummukainen, 2012). This issue has been receiving more attention from both the public and, especially, governments, and researchers have been devoted to exploring effective measures to mitigate adverse consequences (Yuan *et al.*, 2017).

The 2015 United Nations Climate Change Conference, held in Paris, negotiated the Paris Agreement, a global plan for the reduction of the effects of climate change, with parties setting the limit of temperature increase to be below 2ºC, aspiring 1.5ºC (UNFCCC, 2015). In 2016, 174 countries began adopting it within their own legal systems aiming to limit global warming to below 2 °C.

At the European level, developments started with the most prominent document being the EU Strategy for Adapting to Climate Change by the Commission Communication COM (2013) 216 (European Commission, 2013b). This instrument gave new impetus to the adaptation dimension in the field of climate policy and encouraged member states which did not yet have a climate change adaptation policy to develop one or, as in the case of

Portugal, to deepen existing policies and move from a more analytical dimension of the problem towards a more operational dimension and the application of adaptation measures. Also, EU Regulation 525/2013 reinforced reporting obligations on climate change related issues and introduced, for the first time, the obligation to systematise and report on adaptation-related information to all member states, both in terms of internal adaptation efforts and in terms of international support to the third countries (Article 15 and 16 of European Parliament, Council of the European Union, 2013). Finally, reference should be made to an effort to systematise and make available information relevant to the development of adaptation policies by the European Environment Agency in the European Climate Adaptation Platform/Climate-Adapt (http://climate-adapt.eea.europa.eu/) which, since 2012, has collected and made available information on each member state as well as results of relevant European research projects per theme.

4. THE PORTUGUESE CASE

Portugal is the westernmost country of mainland Europe, located on the Iberian Peninsula in southwestern Europe (Fig. 3.A). From an administrative point of view, the country consists of 18 districts, further divided into 308 municipalities. Portugal also has two autonomous regions, Azores, and Madeira, with their own regional governments. The Portuguese mainland is bordered to the west and south by the Atlantic Ocean and to the east and north by Spain. The coastline stretches between the Minho and Guadiana estuaries along approximately 987 km with a morphologically diverse coast. Portugal operates in a highly centralised way, organised in Nomenclature of Territorial Units for Statistics (NUTS) in accordance with EU regulation (EU statistical office- Eurostat), which implies that, in practice, the municipalities have relatively limited responsibilities. NUTS are hierarchically sub-divided into three levels according to their demographic dimension (in Portugal: 3 NUTS I, 7 Nuts II and 25 NUTS III).

Portugal has 13 Natural Parks of which 5 are located on the coast (Litoral Norte; Sintra-Cascais; Arrábida; Sudoeste Alentejano e Costa Vicentina; and Ria Formosa). In Portugal there are also 165 sites (50895 km^2) in the Natura 2000 network composed of sites under the Habitats Directive (*SCIs*), the Birds Directive (*SPAs*) and the Ramsar Convention, according to which they were divided by the Portuguese state into Special Protection Zone (*ZPE*), Sites of Community Importance and National List (*SIC*) and Ramsar sites (Fig.3.B.). Most of them overlap and more than 50% of the national sites have at least part of their area, if not the entire area, within the coastal zone. This reflects the biodiversity and the need for conservation of the Portuguese coasts.

In continental Portugal, the recent and abrupt growth in activity related to recreation and economic activities, including increasing marine and coastal industries, live and non-live resource exploitation and aquaculture, led to the cluttered expansion of the urban centres and scattered construction, which contributes to the mischaracterisation and devaluation of the landscape (APA, 2016). About 60% of the population inhabits the coastal zone near larger cities but it rises to 80% in the summer months (European Commission, 2016). Considering data available from the Database of Contemporary Portugal (PORDATA-https://www.pordata.pt/), in 2018, nationally there was a total of 10 283 800 inhabitants and 3 604 407 buildings. The increased occupation of the coast and the diversity of activities often leads to incompatibility with the natural dynamics. This results in numerous and increasingly frequent situations of conflict, leading to contradictory intervention strategies, increased erosion, decreased water quality and degradation of ecosystems. Considering all the impacts categorised by Connolly *et al.* (2001), Portugal is a good case study to evaluate integrated coastal management and the efforts taken to establish the international guidelines.

4.1 Coastal legal and administrative framework

The threat caused by human pressure, agricultural intensification, industrialisation, high urban growth, increased tourism, unsustainable exploitation of resources and the lack of investment in literacy and preservation led to the need to protect the coast and, therefore, regulated standards arose to legally protect, plan and develop the entire system.

Close to a hundred entities (6 ministries, 11 secretaries of state, 27 institutes and general directors and 51 municipalities) currently decide about what is happening on the coast, including the Portuguese Environment Agency (*APA*), the Port Administrations, the Institute for Nature Conservation and Forests (*ICNF*), the Administration of Hydrographic Regions (*ARH*), and the National Commission of the National Ecological Reserve (*CNREN*) (Schmidt *et al.*, 2014).

The European Regional/Spatial Planning Charter that presented and suggested criteria for the guidance of planning and regional planning to improve the quality of life, effective distribution of activities and protect the environment was adopted by Portugal in 1990.

In 1995, the combination of the Coastal Zone Management Plans (*POOCs*), public water reservoirs

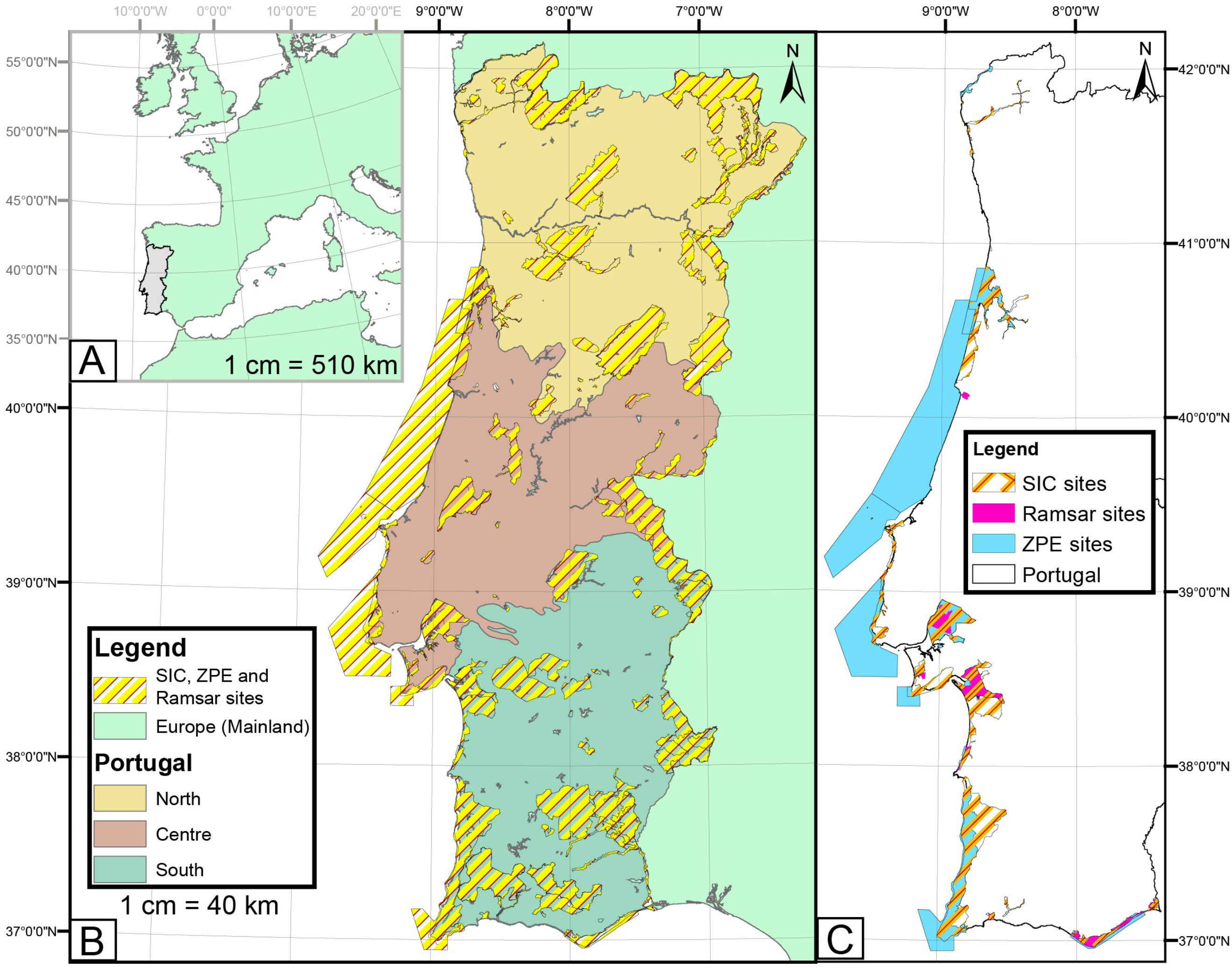


Figure 3. Location of the study case. A) Portugal's location within Europe. B) Portugal with natural parks, SIC, ZPE and Ramsar sites. C) SIC, ZPE and Ramsar sites at the coast.

(*POA*, Water Supply Management Plans) and of protected areas (*POAP*, Protected Area Management Plans), into a special set of plans called Special Plans of Spatial Planning (*PEOTs*) was approved, aiming for a more integrated management.

By the end of the 1990s, almost all municipalities in the country either had, or were developing, a municipal director plan and were approving regional spatial plans. The first Framework Act of Land Use, Spatial Planning and Urbanism Public Policy (*Lei de Bases Gerais da Política Pública de Solos, de Ordenamento do Território e de Urbanismo - LBPPSOTU*) appeared in 1998, indicating the duty to ensure proper organisation and sustainable use of national space, valuing the economic, social and cultural level (Law No. 48/98). The territorial management system was organised into three distinct levels (national, regional and municipal) being adjusted in 2007 with the simplification of plans approvals and the addition to the *PEOTs* of the special plan for estuaries, *POE* - Estuary Management Plans (Portuguese Law No. 54/2007). In 2014, Portuguese Law No. 31/2014 cancelled the previous legislation, putting in place a new law on general grounds of the LBPPSOTU. This new basic law relies on an inclusion of environmental policies on spatial and urban planning, an incentive for inter-municipal cooperation and the intention to simplify and streamline the operation of the system planning. The approach to planning via Territorial Management Tools (*IGT*) is divided into four areas (national, regional, intermunicipal and municipal) and is indicated as IGT plans and planning programmes (Fig. 4.C.). The plans set out the options and concrete actions for the planning and organisation of the territory, also defining land use, while the planning programmes set out the strategic framework for territorial development, with programme guidelines defining the spatial distribution of national policies to consider at each level of planning.

Several tools and baselines were created in Portugal such as the National Programmes for Spatial Planning (*PNPOT*), a territorial development tool of strategic nature which sets out the main options relevant to the organisation of the national territory. It constitutes the reference framework to consider in the development of other land management instruments and is an instrument of cooperation with other member states for the territorial organisation of the European Union (Portuguese Law No. 58/2007).

The growth in coastal zones led to the creation of the National Strategy for Sustainable Development for 2005/15, which consists of a coordinated set of actions that sets a 12-year horizon to ensure rapid and vigorous economic growth, greater social cohesion, and a high and increasing level of environmental protection. Furthermore, the National Strategic Tourism Plan (*PENT*), was revised by the Resolution of the Council of Ministers No. 24/2013, and aimed, by 2015, to ensure a sustainable increase in the contribution of tourism to the national gross domestic product (GDP), increase skilled employment and accelerate the growth of the sector.

The National Strategy for Integrated Coastal Zone Management (*ENGIZC*), approved by Council of Ministers Resolution No. 82/2009, complies with Recommendation 2002/413 / EC of the European Parliament, which lays down the general principles and options for an Integrated Strategy for Integrated Coastal Zone Management in Europe. The new Strategy should incorporate the Marine Strategy Framework Directive (MSFD) and new benchmarks addressing the need to ensure a clear articulation with the planning and management of maritime space and with the conservation of the marine environment. ENGIZC brought some national clarity to physical aspects, not only for planning policies, but also for coastal zone management and planning. These are defined as: Littoral, Coastal Zone, Coastal Border, and Coastline. ENGIZC established as vision to be achieved by 2029 a developed and sustainable coastal zone, based on a systemic approach and valorisation of its resources and identity values, supported by scientific knowledge and managed according to an integrative model (Resolution of Council of Ministers No. 82/2009).

The national maritime space extends from the baselines to the outer limit of the continental shelf beyond 200 nautical miles; a large area that must be managed. Therefore, several strategies and plans must be in place to ensure its safety. The National Strategy for the Sea (*ENM*) - Council of Ministers Resolution No.163/2006 of 12 December, was reviewed and published for the period of 2013-2020. Its aim is to ensure better use of the resources of the ocean and coastal zones, promoting the economic and social development in a sustainable and environmentally friendly manner, through coordinated efficient, accountable and committed organisation, that actively contributes to International Oceans Agenda (DGPM, 2013). Projects identified in the 2008 National Strategy for the Sea action plan included the establishment of a National Network of Marine Protected Areas (*e.g.* the Important Bird and Biodiversity Areas (IBA)), and bureaucratic simplification of Portuguese Maritime Spatial Planning. It aimed to simplify administrative procedures related to sea activities and focus on four areas: maritime transport, recreation, living resources, and non-living resources.

Furthermore, with the approval of the Water Law in 2005, a new approach to spatial plans regarding water resources was adopted, transposing the European legal EU Water Framework Directive, laying the foundations and institutional framework of sustainable water management (European Parliament, Council of the European Union, 2000). Portugal created Regional Hydrographic Administrations (*ARH*) to oversee the management and implementation of the Regional Hydrographic Management Plans (*PGRHs*) that integrated into a river basin district. The first PGRHs developed under this legal framework were in force from 2009 to 2015 and to be reviewed and updated by 2015 and thereafter every six years. The Continental Portugal *PGRHs* for the period 2016-2021 were only approved in November 2016 while the *PGRH* for the autonomous regions are still pending. Additionally, the National Programme for the Efficient Use of Water (*PNUEA*) has as its main purpose the promotion of the efficient use of water in Portugal, especially in urban, agricultural and industrial contexts, contributing to minimise the risks of water scarcity and to environmental conditions in water resources (Governo de Portugal and APA, 2012a).

4.1.1 Sectorial and Special Plans

The sectorial plans (*PS*) are also established at the national level, according to the sectorial European policies establishing the territorial impact of the programming or implementation of public policies in the various sectors of the central government. Every sector within Portugal has its own legislative specifications but the base is the same. When giving detailed examples, this work will use as its example the Algarve area, between Odeceixe and Vilamoura (Figs. 4.A. and B).

The sectorial plan most relevant for ICM is the Maritime Spatial Plan (*POEM*) with the goal of managing potential and existing maritime uses and activities, being complementary to coastal zone management. Marine

Strategy Framework Directive (MSFD) implementation and effective articulation with the EU Water Framework Directive was coordinated by the Portuguese national water authority (ex-INAG, currently APA-https://www.apambiente.pt/) and the team also included representatives such as the Task Group for the Extension of Continental Shelf and Seas Affairs and organisations such as the Institute for Nature Conservation and Biodiversity (*ICNB*) and the Portuguese Agency for the Environment (*APA*). This emphasised the strategic importance of wide representation in the development of Marine Spatial Planning (MSP). Based on the international experience, the Portuguese MSP involved a baseline study and analysis, followed by scenario development leading to preliminary plan proposals (Calado *et al.*, 2010). Additionally, the Portuguese MSP team developed a website to encourage active stakeholder participation, ensuring efficient communication between the MSP team and the public (https://www.msp-platform.eu/countries/portugal).

Furthermore, to safeguard and enhance the Habitats Directive (*SCI*) and the Special Protection Areas (*SPAs*) of the continental territory, as well as the maintenance of species and habitats in a favourable conservation status, Portugal established the Sector Plan of the Natura 2000 Network (PSRN2000).

The Portuguese Special Plans of Spatial Planning (*PEOTs*) establish the means by which the government can intervene in special areas by defining the measures and actions permitted, restricted or prohibited per the objectives of each programme, to safeguard the natural resources and values.

According to European Directives and importance of biodiversity hotspots the Natural Parks (*POPN*), the Sector Plan of the Natura 2000 Network and the Important bird and Biodiversity Areas (IBA) must be considered as sectorial plans and policies having specific legislation focusing on protection and conservation of species. Each POPN has a Strategic Plan for Integrated Requalification and Enhancement that established the development of an integrated and coordinated policy for coastal areas.

Also following European policies, resumed in Figure 2, the Portuguese Decree-Law No. 349/93, regulated the preparation and approval of Coastal Zone Management Plans (*POOCs*), these plans have greatly contributed to the management of coastal areas. They aim to establish the protection of natural resources and system values, ensuring sustainable land use and supporting the integrated management of coastal areas (Portuguese Decree-Law No. 380/99 and Resolution of Council of Ministers No. 33/99). Therefore, they arose as a framework instrument for the improvement, upgrading and management of the present resources on the coast. These plans are concerned with the valuation of existing resources and the conservation of environmental and landscape values,

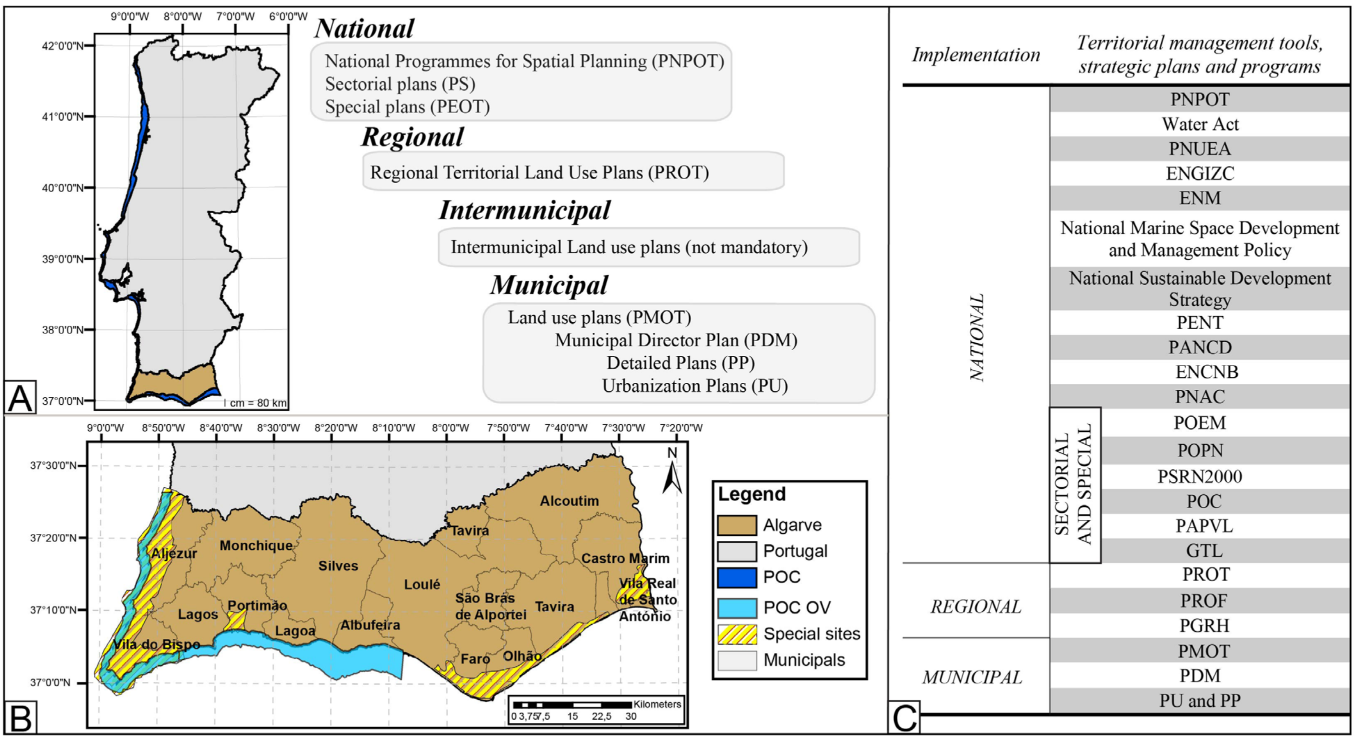


Figure 4. A) Portugal and Algarve with the scheme of the management regime of the rocky coast land territory, according to Law No. 31/2014. B) Algarve and its administrative division in municipalities and the POC OV boundary, C) The territorial management tools, strategic plans and programmes that contribute, interfere and govern the establishment of POC Odeceixe – Vilamoura.

especially with the protection and integrity of biophysical space, so that there is some compatibility between the protection of natural heritage and landscape. To achieve these goals, the *POOCs* have been established for nine sectors in Portugal and are intended to manage the system and regulate the Public Maritime Domain, except areas under port jurisdiction, and their implementation occurred between 1998 and 2005 (see Fig. 5.A.). These plans define specific coastline activities, regulating the beach use, protection and conservation of nature, the socio-economic development, efficient use of space and protection of the environment and natural resources, and establish the defence and promotion of historical and cultural heritage. The main goals are: i) defining safeguard regimes; ii) protection and management by establishing preferred uses; iii) conditional and prohibited uses in the intervention area, and, iv) articulation and harmonisation, of intervention schemes and measures contained in other IGT and planning instruments of coastal and inland marine waters (Article paragraph 3, point 1, Portuguese Decree-Law No. 309 / 93).

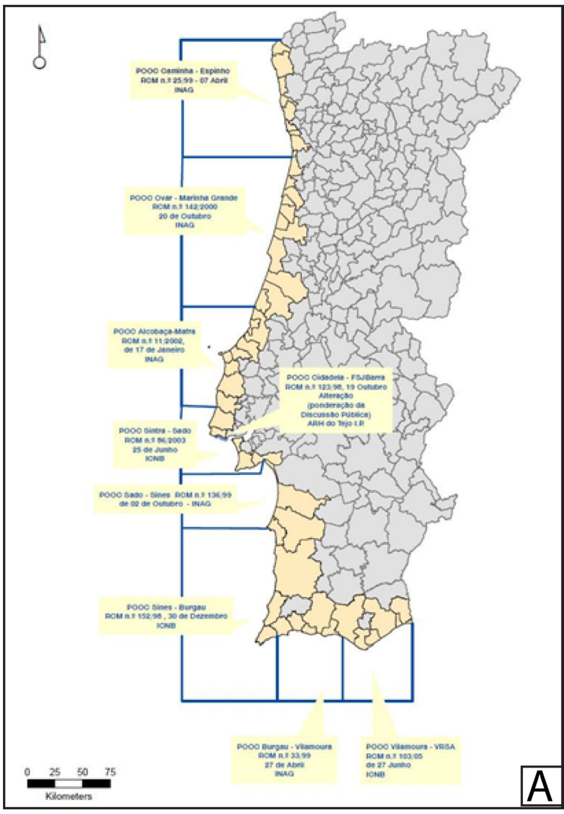
The *POOC* covers a strip along the coast, which is known as land protection zone, which is 500 m wide onshore and can extend to 1000 m when justified by the need to protect coastal biophysical systems, and a maritime range up to 30 m of water depth, with the exception of areas under port jurisdiction (Portuguese Decree-Law No. 309 / 93). The preparation of a *POOC* must be considered nationally and take into account the community guidelines on integrated management of coastal zones and water resources, including the Water Framework Directive, the Marine Strategy Framework Directive and the National Strategy for Integrated Coastal Zone Management (*ENGIZC*). The latter reinforced the integrative vision for the protection of the coastal zone, considering the Water Framework Directive and the Marine Strategy Framework Directive. In doing so they guarantee its articulation with the planning and management of the maritime space and with the conservation of nature, for a period of 20 years (Resolution of Council of Ministers No. 82/2009). The various sectors that play an important role in the coastal zone (tourism and leisure, maritime transport, fisheries, port activity, energy production, scientific research, among others) are joined to promote cross-sectorial policies (Ferreira *et al.*, 2015). Therefore, *POOCs* must include the values described in *ENGIZC* and contribute directly to their implementation strategy. The main objectives of the coastal planning plans were: the planning of the different uses and specific activities of the coast, the classification of beaches and regulation of beach use, valuation and qualification of beaches considered strategic for environmental reasons or tourism and the defence and conservation of nature. In this context, it can be said that the management of Portuguese coastal zones is achieved through *ENGIZC* and *PEOTs*, which follow the guidelines of the European policy for integrated coastal zone management and, considering the jurisdiction area of the *PEOTs* in force in the coastal zone, a total of 27 instruments will be relevant for coastal management.

Associated with subsequent changes in the legislation, institutional framework and evaluation made to *POOC* in 2012, the Decree-Law No. 159/2012 was published, regulating the development, review and implementation of *POOC*. This decree imposed a new approach to the coastal zone, in a logic of greater flexibility and integrated management, covering the entire coastline, including areas under port jurisdiction. In addition, interventions under the *POOC* must meet measures envisaged under the Regional Hydrographic Management Plans (*PGRH*), to improve the ecological status of water bodies. Also the POC has to be articulated with the provisions of the Sector Plan of the Natura 2000 Network with the adoption of measures for the conservation of habitats and species and their rationale, with the main frame being the files and cartographies.

In 2014, with the publication of the Framework Act of Land Use, Spatial Planning and Urbanism Public Policy (*LBPSOTU*), the land management system was changed (Law No. 31/2014). According to the new basic law, the special plans (which include *POOC*, *POA* and *POAP*) shall be renamed Coastal Zone Management Programmes (*POC*) maintained nationwide, but taking a more programmatic level, establishing exclusive safeguard schemes for natural resources and values through guiding principles and standards of management.

Currently, almost all of the continental POOC are being revised, which will result in the development of five *POCs*, using the limits of the 5 river basin districts and giving rise to the new programmes, as shown in the Figure 5.B. (APA, 2016).

The revision of the *POOCs* were decided due to their evaluation in 2006 by the Ministry of Environment, Spatial Planning and Regional Development that determine the need to review the provisions of these land management instruments, the upgrade of plan proposals, unequal treatment of land and sea tracks protection, lapses, inaccuracies and cartographic disabilities, inflexibility of beach plans and non-execution of the operating units of planning and management (APA, 2016). The results and insights obtained in the ENACC, 2013 report on adaptation to climate change and the Coastline Work Group (GTL) final report were also incorporated in the creation of the *POC*. The results of this report point to the need to adopt a new strategy, adaptation, which



POOC (in force)		**Basins**	**Future POC**
Caminha-Espinho	RCM n.º 25/99, of the 7th of April.	North	Caminha – Espinho
Ovar – Marinha Grande	RCM n.º 142/2000, of the 20th of October.	Center	Ovar – Marinha Grande
Alcobaça – Mafra	RCM n.º 11/2002, of the 17th of January	Tejo	Alcobaça – Cabo Espichel
Cidadela – S. Julião da Barra	RCM n. º 123/98, of the 19th of October Rectified on the 3rd of October in RCM n.º 82/2012.		
Sintra - Sado	RCM n.º 86/2003, of the 25th of June		
Sado - Sines	RCM n.º 136/99, of the 29th of October	Alentejo	Espichel – Odeceixe
Sines-Burgau	RCM n.º 152/98, of the 30th of December		
Sines-Burgau	RCM n.º 152/98, of the 30th of December	Algarve	Odeceixe – Vilamoura
Burgau-Vilamoura	RCM n.º 33/99, of the 27th of April		
	RCM n.º 103/2005, of the 27th of June		

B

Figure 5- A) First Generation of POOCs Source: APA-APA – Planos de Ordenamento de Orla Costeira, at http://www.apambiente.pt/index.php?ref=16&subref=7&sub2ref=10&sub3ref=94, on 24-05-2018. B) Sectors of Portugal's POOCs, the Council of Ministers approval and the future POC.

integrates other types of responses beyond protection, namely relocation and accommodation. The combination of these three strategies proves to be the most appropriate solution since it allows for greater sustainability of the social, economic and environmental options. The main goals of the POOCs are still imposed in the new *POC* but are restructured and enhanced, being organised around a set of key components: i) the Spatial component, through mapping the areas to be protected and safeguarded; ii) the strategic component, associated with the principles set for an approach able to establish the mitigation actions; iii) the normative component, based on the provisions of the Legal Regime of Territorial Management Instruments; and, iv) the management component, associated to the programming and monitoring of the implemented actions. This way the *POCs* should be prepared using the assumption that it is necessary to require safeguards and articulate different territorial management tools as well as a set of other legislation, projects and programmes focusing on the intervention area.

For instance, associated to the spatial component there are noticeable differences between the old (Fig 6.A) and new beach plans (Fig 6.B.), with an improvement in detail due to the inclusion of extra data to guarantee knowledge of all the hazard areas such as safeguard areas through all the sector instead of only the beach area. Also carrying capacity has been defined for each beach plan taking into consideration the beaches available safe bathing zones per beach typology. These plans are more accurate and have a more integrated approach.

4.1.2 Regional and Municipal

The Regional programmes set out the strategic choices of the regional territory organisation and the appropriate regional structure model, defining the major options of public investment with positive regional impact (Fig 4).

The Regional Spatial Plans or Regional Programmes (*PROT*) established guidelines and occupancy standards, usage and transformation of soil in a sustainable manner in the region under the general guidelines established in the National Programme for Spatial Planning Policy (*PNPOT*). The territorial model and the guidelines set out in *PROT* are also a key benchmark for the different sectorial policy interventions affecting the planning of the regional territory. Furthermore, the policy options set out in *PROT* provide guidance for plans to lower hierarchical order as the Spatial Planning Municipal Plans (*PMOT*) that incorporated the set of plans of a local scope Municipal Director Plan, *PDM* (CIEO, 2009; APA, 2016).

The Coastal Protection and Appreciation Action Plan for 2012-2015 (*PAPVL*), published in June 2012, results from the process of analysis and review of the Plan of Action for the Littoral 2007-2013 (Portuguese Government and APA, 2012 and APA, 2016). The *PAPVL* presents the priority types of intervention such as: i) Coastal Defence and Risk Zones; ii) Studies, Management and Monitoring; and, iii) Intervention Plans and Requalification Projects. The *PAPVL* 2012-2015 report provides a total of 303 actions, with most of the actions of high priority in the Coastal Defence and Risk Zone type (Portuguese Government and APA, 2012). The Office of the Secretary of State for the Environment of the Ministry of the Environment, Territorial Planning and Energy created the Coastline Work Group (*GTL*) through Order no. 6574/2014 of 20 May (GTL, 2014).

Furthermore, within each municipality there are Spatial Planning Municipal Plans (PMOT) that incorporate the set of plans of a local scope Municipal Director Plan (*PDM*), the Urbanisation Plans (*PU*) and the Detailed Plans (*PP*).

The *PDM* are mandatory and indicate the municipal territorial development strategy, the territorial model, infrastructure location options, collective equipment use and interdependencies with neighbouring municipalities. Although municipality interdependencies are stated in the *PDM* and can lead to conflicting decisions the intermunicipal programmes are of optional elaboration. Within the *PDMs*, the *PU* provides the framework for the application of urban policies such as land use regime and land transformation criteria while the *PP* defines the detailed occupation of any specific area of the municipal territory. These municipal plans and programmes are very useful for regional sustainability but as the governance is mainly national with municipalities having relatively limited responsibilities, the best decisions are not always achieved when related to specific areas.

4.2 Climate change specific legislation and tools

The EU Commissioner for Environment, Maritime Affairs and Fisheries assessed that the Portuguese mainland is mainly at risk of Sea Level Rise (SLR) and changes in both, the direction and the power of waves and storm surges. Consequently, they establish that Portugal's coastal zones are very vulnerable to flooding, erosion, freshwater shortage, and potential loss of ecosystems.

The steps for managing climate change began with the National Programme for Climate Change (*PNAC*) of 2006 that set up the instrument of Government policy that supports compliance with the Kyoto Protocol by the Portuguese State (Canaveira and Papudo, 2013). Now the PNAC 2020-2030 has as goals to: i) promote the transition to a low-carbon economy, generating more wealth and employment; ii) to ensure a sustainable GHG emissions reduction path to reach a target of -18% to -23% by 2020 and -30% to -40% by 2030, compared to 2005, ensuring compliance with national commitments and putting Portugal in line with the European objectives and the Paris Agreement; and, iii) to promote integration of mitigation objectives into mainstreaming policies.

In 2010 the National Climate Change Adaptation Strategy (*ENACC*) was approved with the first report being available in September 2013 (Resolution of Council of Ministers Nº. 24/2010). Although many adaptation initiatives were already underway at both sectoral and local levels, the strategy allowed the public administration and sectors to reflect together and articulate both the awareness of climate change and its impacts, based on up-to-date scientific knowledge, as well as on the identification of the measures that Portugal will have to take to minimise the effects of climate change (Canaveira and Papudo, 2013). Furthermore, there is a strong commitment to link the stakeholders and the literacy of the population in general. Reports were produced outlining the predicted climate change and what should be done.

For the coastal areas where the previous *POCs* have actions, it was announced that due to the extension, environmental value, morphological diversity and vulnerability of the continental coastal strip, combined with the fact that it concentrates about 75% of the Portuguese population and 85% of GDP, the adoption of a Sector Strategy on Adaptation to Climate Change Impacts (*ESAAC-RH*) was fully justified. The latter results from the sectoral particularisation of the lines of action and the general adaptation measures defined in the framework of the *ENAAC* and most of these actions are starting to be incorporated in the management policies (Canaveira and Papudo, 2013).

In the light of the monitoring carried out by the entity responsible for the management of the water resources of the Municipal Plans of Territorial Planning involved in the coastal and estuarine borders, the approaches carried out, to a greater or lesser extent, have gradually considered climate change and adaptation in their regulations. The second generation of *POOCs* will explicitly introduce the incorporation of climate forcing scenarios and their adaptation measures for defined time horizons (50 and 100 years), which is an example of the ongoing review of the *POOCs*. The risk / safeguard bands contained in some *POOCs,* although not initially designed to absorb the impacts of climate change (*e.g.*, intensification of the erosion process), have been projected as preventive risk mitigation functions, thus constituting an adaptation

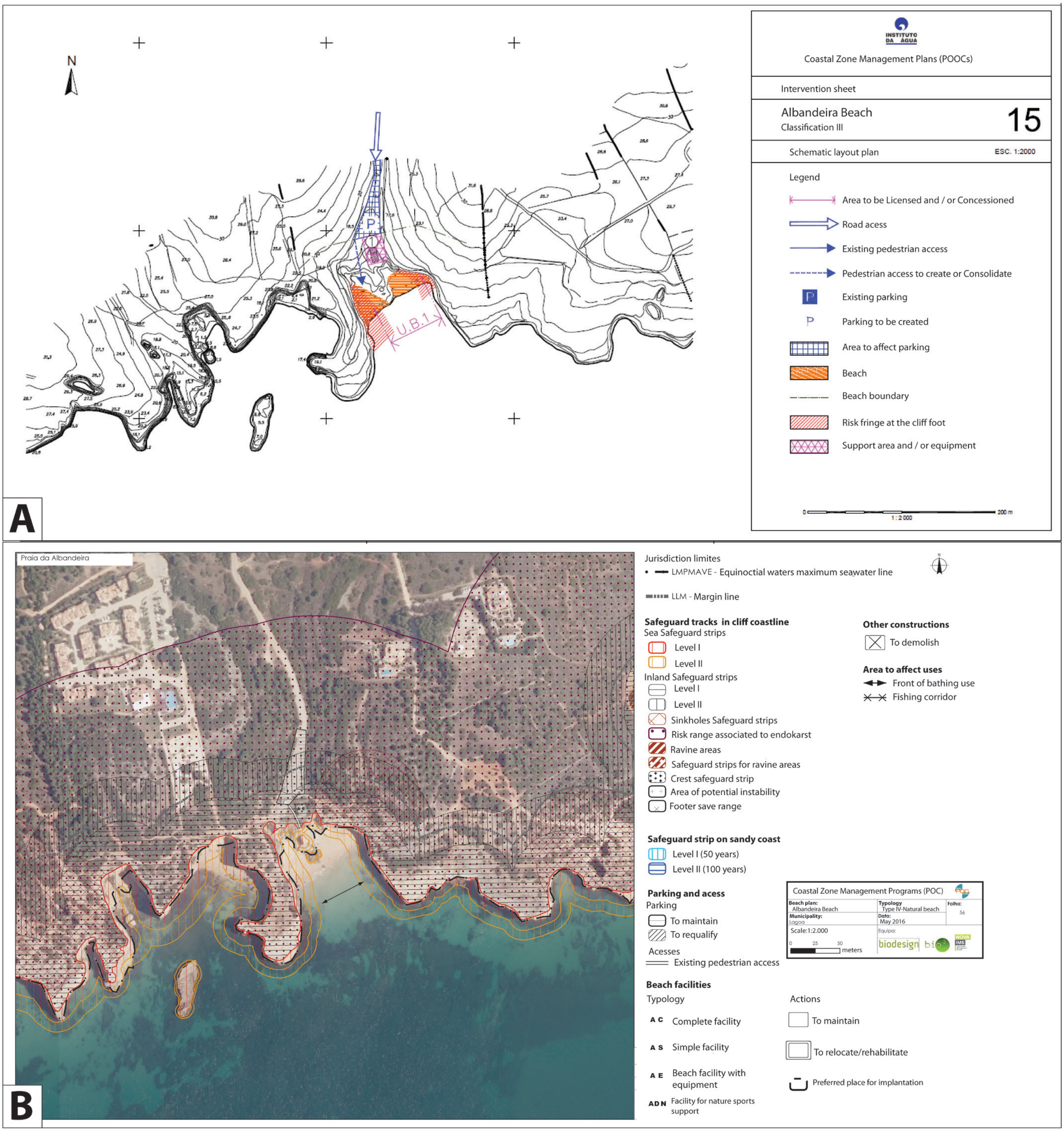


Figure 6. Example of beach plans. A) Beach plan in the POOC (adapted from POOC available at https://www.apambiente.pt/index.php?ref=x146); B) Beach plan in the POC (adapted from APA, 2016).

measure. The calculation and dimensioning of risk and protection bands in the sandy coast, which incorporates the expected impacts in a scenario of climate change (*e.g.*, mean sea level rise), which translates into a figure of planning, adaptation and preventive risk management over a minimum time horizon of 50 years is now to be included in the management plans (Canaveira and Papudo, 2013). At a local level, the Network of Municipalities for Local Adaptation to Climate Change (ClimAdaptPT.Local) was formed in 2017 and includes 30 Municipalities of Portugal, as well as other public and private entities directly linked to climate change. The first annual seminar was on the 24th November 2017 and featured the active presence of several national and international experts on climate change adaptation, who, together with local authorities and decision makers from all over the country and other participants, addressed a wide range of key issues in this area.

The ClimAdaPT.Local project aims to initiate a continuous process of elaboration of Municipal Strategies for Adaptation to Climate Change (*EMAAC*) and its integration in the tools of municipal planning such as *POOCs* and *PDM*. The aim is to achieve this objective by training the municipal technical staff, raising awareness of local stakeholders and developing tools and products to facilitate the elaboration and implementation of *EMAAC* in participating municipalities and, in the future, in other Portuguese municipalities (available at http://climadapt-local.pt/). For instance, in the Algarve region, the municipalities came together through the association of municipalities of the Algarve (*AMAL*) with the collaboration of universities and research centres. To create models used to simulate the evolution of the coastline at various time scales, with reference to the IPCC 2013 scenarios by characterising the various activities and variables (precipitation, heat waves, MSL rise, coastal erosion, lack of sediment supply) to create and adapt protection and defence strategies.

4.3 Socio-economic impact studies and tools

The Coastal Zone Management Programmes (*POC*) report of June 2016 produced by the Portuguese Agency for the Environment also includes several SWOT analyses with strengths, weaknesses, opportunities and threats per thematic sectors (*e.g.* Resources and natural values; Coastal Dynamics; Marine beaches; etc). The SWOT analyses was the only one that was mentioned in the report, but several others could have been done with more detail and precision.

A Political, Economic, Social, Technological, Environmental and Legal Factors (PESTEL) analysis can also be applied as a situation analysis, it is used to identify the key external forces that might affect an organisation and has been used in several types of studies such as Tourism (Mayaka and Prasad, 2011; Gregorić, 2014) and integrating ICZM (Ballinger and Rhisiart, 2011). Although not generally applied to coastal management, this model can represent an important tool for organising and evaluating possible effects of a coastal intervention. It also provides a simple framework to organise and identify the major forces affecting the studied area (Yuksel, 2012). Normally the PESTEL analysis is the base for the SWOT analysis but in the POCs there is no mention of it, so it is questionable if it was used or not.

Another framework used by the European Environment Agency (EEA) is the Driver-Pressure-State-Impact-Response (DPSIR) framework according to which there is a chain of causal link starting with 'driving forces', through 'pressures', to 'states' and 'impacts' on ecosystems (environment and anthropic systems), eventually leading to political 'responses' (Kristensen, 2004). Both models may be defined and adjusted to address concerns that may be of special interest for different scaled study sites.

5. IMPLEMENTATION ANALYSES OF EUROPEAN AND PORTUGUESE DIRECTIVES

According to all the above statements, the European Union guidelines and frameworks are being implemented in the Portuguese Governmental planning and are very well based, but the implementation and clarity of land management instruments (*IGT*) is questionable.

The European Commission's Integrated Coastal Zone Management evaluation identified the following Portuguese strengths and weaknesses (European Commission, 2007b): i) strengths – the developing national strategy mainly supported European guidelines; legal support is already in place with some consistency and long-term perspective; adaptive management is gradually being integrated; the importance of working with natural processes and using a wide range of planning and IGTs have been recognized; ii) weaknesses – the lack of climate change and sea-level rise consideration in monitoring processes; measures too general for the protection of vulnerable coastal areas; unclear stakeholder engagement; inadequate educational information; insufficient international cooperation; and a need to improve regional policies. The first problem seems to start with the current institutional framework of the coast. With a high number of entities having a say in the matter, it encourages a fragmentation of competencies and has been criticised for allowing a "divide-and-rule" policy. Furthermore, it creates a bureaucratic panorama progressively unreadable for citizens and ungovernable for policy makers (Schmidt *et al.*, 2014). However, according to the Secretary of State for Spatial Planning, concentrating everything on a single entity would not be the solution. The Portuguese ICZM strategy is implemented via a governance model which operates on three levels (Alves *et al.*, 2013): i) political platform; ii) operational platform; and, iii) knowledge platform that, for instance, due to the high institutional centralisation (government) and the omission of both social/public and market elements in the model, are not as recommended by literature on governance (*e.g.* Olsen *et al.*, 2006, 2011). The governance is mainly national with municipalities having relatively limited responsibilities, leading to management decisions that do not consider the specific problems according to lifestyles and necessities of specific municipalities. Broader public information sessions and involving different stakeholders throughout all phases of planning, programme, and project developments, with the necessary socioeconomic analysis via a SWOT is not enough.

Furthermore, the marine spatial planning (MSP) report and the expert conference in 2015 that discussed the Portuguese MSP legal framework acknowledged the Portuguese government's merit and effort to regulate such an important and complex matter as MSP of its Maritime Space. However, the main conclusion reached by the congress was that both the Proposal and its development process have been unnecessarily opaque and may promote, rather than avoid, conflict, suspicion, legal uncertainty, and waste of time. They lack a solid legal framework and the necessary societal consensus. Stating that it is vital to improve the current legal framework, namely in terms of the proposed system's actual capacity to promote the public interest, and to improve its clarity and its capacity to ensure the sustainability of future planning and management actions. Therefore, a conference report detailing all summarised aspects was sent to the Portuguese authorities on 30 January 2015, but the Proposal was officially published virtually unchanged (Ferreira *et al.*, 2015). Parties in the National Parliament have already demanded its further discussion with the conference organisers interested in collaborating with the law-making authorities to improve the current legal framework. Reflecting the unstable bridge between governmental and scientific analyses.

Portuguese coastal zone spatial planning and management assumes an adaptive approach that allows the use of existing information to adapt the plan to the knowledge evolution and accommodate to the new circumstances, but there is a long process for approval and implementation of the management tools. For example, the *POOCs* were evaluated and it was decided in 2014 that they had to be revised and updated. Only one has been approved, while the POC Odeceixe-Vilamoura (*POC OV*) was only available for public discussion in 2016 and it is still not in force. According to the *POC OV* documents, there are actions (expected cost € 52,518,768) to be implemented from 2016 until 2021. In 2018, the new POCs are not yet in force so these plans have already been affected and delayed and the actions taking place on the Portuguese coast are still related to the outdated *POOCs.*

Furthermore, in the new *POCs*, the beach plans were reviewed, and detailed geological characterization and mean sea level rise projections were included but there are inconsistencies in methodologies and assumptions. For instance, the beaches carrying capacity, calculated per beach plan to establish the allowed number of beach support infrastructures and parking area, does not take into account the seasonality, in several sectors in the summer months the carrying capacity is well exceeded. Therefore, how to enforce this limitation is an important question. There are several beaches that are so popular that people lie down under hazardous cliffs and on boat runners; there should be an applied study in these sectors to establish the accurate seasonal carrying capacity and management procedures based on it. Moreover, the calculation of the carrying capacity in the *POCs* is based on the typology of the beach and are simply the beaches available safe bathing zones/X m^2 with X varying according to the typology established in the Portuguese Decree n. º 159/2012. This is a very simplistic and inaccurate methodology considering the complexity of the coastal systems. According to Cifuentes *et al.* (1992) the calculation of the carrying capacity should consider several parameters, such as the area available per visitor, the weather conditions, the erosion rate of biophysical substrate, the possible influence of humans on flora and fauna and the frequency of maintenance works that might disturb visitors. The process consists of three levels: the physical load capacity (CCF), the actual load capacity (CCR) and the effective load capacity (CCE). In the Portuguese case, the three levels have not been considered, neither in the carrying capacity calculation nor in the definition of the beach typology and if it was, it is not mentioned in any document. Furthermore, all the coastal sectors should be analysed including the rocky cliffs next to the beach area; these are highly sought by tourists due to the elaborated landscape and the views.

Generally, Portugal is still in a research and monitoring phase of climate change but at policy level, climate change considerations are being taken into account and some of the strategies adopted aim at minimising the impacts in the long run. To date, the main policy actions are the National Climate Change Programme (*PNAC*) and the National Climate Change Adaptation Strategy (*ENACC*). The Network of Municipalities for Local Adaptation to Climate Change (ClimAdaptPT.Local) although still at a beginning stage seems to be a good and solid bet for new and accurate policy making not only at the Municipal Director Plan level but also at national level. The incorporation of Sea Level Rise (SLR) in the coastal management programmes will improve the effectiveness of the plans and sustainability of the coastal sectors.

Furthermore, the management of coastal building in hazardous areas, as those affected by SLR, is very difficult, due to the lack of these guidelines in the past, depending on when the building was built and what legislation was in force at the time. For instance, now an infrastructure would not be built close to the cliff, but older plans did not use accurate estimation of coastal retreat: It is difficult to destroy existing buildings due to legal and monetary compensation issues, but now many infrastructures are planned to be destroyed, including council buildings and emblematic restaurants situated on the cliffs. This leads of course to disputes and judicial processes that may take several years to be resolved delaying these measures.

Analysing several sectors of Portugal, it is also visible that the implementation of dams, contained rivulets with several types of rubbish, and their lack of management is affecting the coast negatively. These impacts are not always assessed using the ecosystemic approach and considering how adjacent sectors and wildlife are affected.

Concerning management and dissemination tools, in Portugal, several singular instruments could be combined and used for an integrated coastal management and/or dissemination to stakeholders and the public in general. For instance, the National System of Resources Information of the coast (SNIRLit) is a platform with coastal information (geology, beaches and water of the coast) that has, however, never been completed and that has not been updated since 2003 (available at http://geo.snirh.pt/snirlit/site/index.php). While the InterSIG that should cover the entire national territory and autonomous regions of the Azores and Madeira is not available (http://intersig-web.inag.pt/intersig/). Another potential source of information are the live beach cams that have been placed on beaches (mainly to aid surfers by showing the sea conditions). There are 38 beaches in Portugal equipped with these cameras (available at http://beachcam.meo.pt/pt/livecams). The Centre of Science of the Algarve (https://www.ccvalg.pt/) is also involved in citizen science. They invested in photographic posts, where tourists and locals can take photographs in specific spots and post them on the internet (available at http://sciencepost.pt/index.php). This will allow researchers to have access to photographs of the coastal conditions, even when they cannot be surveyed.

In order to ensure updating, maintenance and dissemination of information on *PMOT* a database was created, which compiles all the data related to the regional Land Management Plans (this available at http://idealg.ccdr-alg.pt/localizacoes.aspx); yet this database was last updated in September 2015. The areas are delimitated in several cartographies available to the public but there is still no mapping of building and building type available.

Controlling and mitigating coastal management problems will not be an easy task since coastal regeneration is a complex and time-consuming process. This issue, which must be a national design, can only be addressed with a knowledge-based management, identifying the causes, recognising their dynamics and intervening in favour of nature. Field observation techniques, comprehensive monitoring and GIS processing would support the implementation of wiser and more sustainable decisions (Taveira-Pinto, 2004). The solution should be based on a broad consensus that allows a long-term strategy to be adopted which goes beyond the time-scale characteristic of political cycles, thereby compromising all those involved in this process.

6. CONCLUSIONS

The awaking of the European community on coastal management with the first implementation of coastal policies in 1973 officially affirmed the understanding that Europe's coastline was at risk and that it was necessary to join forces to protect it. Throughout the 1970s, it became clear that the effective management of coastal areas required an inter-sectoral approach and therefore the term integrated was added. With the approval of several guidelines and policies, the basis was created for EU countries to start or better manage issues related to the coastal zones.

In Portugal, since the 1990s the development of Integrated Coastal Management (ICM) has stimulated a more integrative and participative approach to coastal management, with the government developing legislation for coastal zone protection, recovery, management, and governance. Laws and management tools link terrestrial, water, and maritime issues with coastal management. The path developed by Portuguese central, regional, and local entities will be important to minimise risk situations (for people and assets) and enhance the protection and sustainable development of coastal. Application of the national strategy has taken its first steps, but clarity and communication are key aspects for the future ICZM implementation. It is noteworthy, that the implementation of the management decisions/directives is taking very long not only due to the governmental system but to also the lack of knowledge and understanding among the general population that unpopular interventions like demolition of seaside buildings at risk are necessary.

The enormous difficulty of an integrated coastal management in Portugal is due to the large number of entities with jurisdiction on the coast creating an ineffective process. For instance, while one entity decides that metres of vegetation at the cliffs can be destroyed due to fire hazard and starts the cleaning process, another does not agree, because vegetation aids in the stability of the cliffs. Therefore, the intervention is cancelled until other entities decide what on the correct approach.

There is also the need to reinforce technical support mechanisms for the implementation of international agreements (*e.g.*, European Directives) by incorporating new monitoring techniques for coastal and ocean dynamics.

Furthermore, driven by climate change, reduced sediment supply, and mean sea level rise, the most significant coastal zone impacts include: often unbalanced or unsustainable development; coastal flooding and wetland and lowland displacement; accelerated coastal erosion; increased storm surges; and, estuary and lagoon encroachment with changes in tidal regime and sediments. Therefore, scientific knowledge should be developed to minimise risk and improve climate change adaptation.

ACKNOWLEDGMENTS

Sónia Oliveira was financially supported by the ERASMUS MUNDUS programme MACOMA SGA ERASMUS MUNDUS 2015-1626/001-001-EMJD and UNESCO UNITWIN Wicop. This work was also supported by the Portuguese Foundation for Science and Technology (FCT) through the grant UID/MAR/00350/2013 attributed to the Centre for Marine and Environmental Research (CIMA) of the University of Algarve.

REFERENCES

Alves, F.L., Sousa, L. P., Almodovar, M. and Phillips M. R. (2013) - Integrated Coastal Zone Management (ICZM): a review of progress in Portuguese implementation.

Antunes, C. and Taborda, R. (2009) - Sea level at Cascais tide gauge: data, analysis and results. Journal of Coastal Research, SI 56 (Proceedings of the 10th International Coastal Symposium), 218 – 222. Lisbon, Portugal, ISBN Available at : https://www.researchgate.net/publication/229038979_Sea_Level_at_Cascais_Tide_Gauge_Data_Analysis_and_Results accessed on Aug 20 2018.

APA- Agência Portuguesa do Ambiente. (2016) - Programa da Orla Costeira do Troço Odeceixe-Vilamoura Discussão Pública Parte 1-Programa Volume 3 relatório ambiental para consulta pública – resumo não técnico. Available at http://www.apambiente.pt/_zdata/Politicas/Agua/Ordenamento/POC/POC%20OV/Parte1-Vol-3-140084FOT01RA0.pdf on the 15/10/2017.

Auld, T.D. and Keith, D.A. (2009) - Dealing with threats: integrating science and management. Ecol. Manag. Restor. 10, 79e87.

Ballinger R. and Rhisiart M. (2011) - Integrating iczm and futures approaches in adapting to changing climates. Maritime Studies 2011, 10(1): 115-138.

Calado H, Ng K, Johnson D, Sousa L, Phillips M and Alves, F. (2010) - Marine spatial planning: lessons learned from the Portuguese debate. Mar Policy 34:1341–1349. doi:10.1016/j.marpol.2010.06.007.

Canaveira, P. and Papudo, R. (2013) - Relatório de Progresso da Estratégia Nacional de Adaptação às Alterações Climáticas Relatório Integrado. Available in Portuguese at https://www.apambiente.pt/_zdata/Politicas/AlteracoesClimaticas/Adaptacao/ENAAC/RelatProgresso/Relat_Progresso.pdf on the 16/01/2018.

Cicin-Sain, B. and Knecht, R. (1998) - Integrated Coastal and Ocean Management: Concepts and Practices. Washington, DC: Island Press.

Cicin-Sain, B. and Knecht, R. (2000) - The Future of U.S. Ocean Policy: Choices for the New Century. Washington, D.C.: Island Press.

Cicin-Sain, B., Knecht, R., and Fisk, G. (1995) - Growth in capacity for integrated coastal management since UNCED: an international perspective. Ocean & Coastal Management 29(1-3):93-123.

Cicin-Sain, B., Knecht, R., Vallega A., and Harakunarak, A. (2000) - Education and Training in Integrated Coastal Management: Lessons from the International Arena, Ocean & Coastal Management 43 (2000) 291-330 Doi:0964-5691/00/$ -

CIEO-Centro de Investigação sobre o Espaço e as Organizações. (2009) - Acompanhamento e Monitorização do PROT Algarve, 1º Relatório annual. Available in portuguese at http://www.prot.ccdr-alg.pt/Storage/pdfs/Relatorio_Avaliacao_2009.pdf on the 6/01/2018.

Cifuentes M, Mesquita C, Méndez J, Morales M, Aguilar N, Cancino D, Gallo M, Jolón M, Ramírez C, Ribeiro N, Sandoval E, Turcios M. (1999) - Capacidad de Carga Turística de las Áreas de Uso Público del Monumento Nacional Guayabo, Costa Rica. WWF Centroamérica. 75 p.

Collet, I. and Engelbert, A. (2013) - Coastal regions: people living along the coastline, integration of NUTS 2010 and latest population grid. *ISSN:2314-9647 Catalogue number:KS-SF-13-030-EN-N* available at https://publications.europa.eu/pt/publication-detail/-/publication/f1a5221a-98e6-4b1c-ac-43-c9ee6f479145 on the 27/06/2017.

Connolly, N., O'Mahony, C., Buchanan, C., Kay, D., Buckley, S. and Fewtrell, L. (2001) - Assessment of Human Activity in the Coastal Zone. Report on research project conducted by the Coastal Resources Centre, University College Cork and the Centre for Research into Environment and Health, University of Wales under the Maritime Ireland / Wales INTERREG II Programme.

Council of Europe, Committee of Ministers (1984) - Recommendation No. (84) 2 of the Committee of Ministers to Member States on The European Regional/Spatial Planning Charter available at https://wcd.coe.int/com.instranet.InstraServlet?command=com.instranet.lobGet&InstranetImage=974473&SecMode=1&DocId=681646&Usage=2 on the 5/01/2018.

Council of Europe. (2000) - Model Law on coastal protection and a code of conduct for coastal zones. Available at http://ec.europa.eu/environment/iczm/pdf/Model_Law.pdf on the 15/01/2018. French edition: Modèle de loi sur la gestion durable des zones côtières et Code de conduit européen des zones côtières. ISBN 92-871-4152-5.

Council of the European Union (2008) - ICZM Protocol on Integrated Coastal Zone Management in the Mediterranean. Official Journal of the European Union L 34/19. Available at http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:22009A0204(01) on the 15/01/2018.

Council of the European Union. (1992) - Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities No L 206/7. Available at http://eur-lex.europa.eu/legal--content/EN/TXT/PDF/?uri=CELEX:31992L0043&from=PT on the 15/01/2018.

Cummins, V., Mahony, C., and Connolly, N. (2003) - Review Of Integrated Coastal Zone Management & Principals Of Best Practice Prepared for the Heritage Council by the Coastal and Marine Resources Centre Environmental Research Institute University College Cork Ireland http://cmrc.ucc.ie.

DGPM- Direcção Geral de Politica do Mar. (2013) - Estratégia Nacional para o MAR 2013 – 2020. Available at https://www.portugal.gov.pt/media/1318016/Estrategia%20Nacional%20Mar.pdf on the 16/01/2018.

Ehler, CN. (2003) - Indicators to measure governance performance in integrated coastal management. Ocean & Coastal Management 46:335–345.

EU Monitor. (2020) - Legal instruments. Available at https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vh75mdhkg4s0 on the 20/04/2020.

European Commission (2007b) - Communication from the Commission - Report to the European Parliament and the Council: an evaluation of Integrated Coastal Zone Management (ICZM) in Europe/* COM/2007/0308 final */. Available in several languages at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52007DC0308 on the 16/01/2018.

European Commission (2013a) - Available at http://ec.europa.eu/environment/iczm/index_en.htm.

European Commission. (2000a) - Communication from the Commission to the Council and the European Parliament on integrated coastal zone management: a strategy for Europe /* COM/2000/0547 final */. Available in several languages at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52000DC0547 on the 15/01/2018.

European Commission. (2000b). Proposal for a European Parliament and Council recommendation concerning the implementation of integrated coastal zone management in Europe (COM/2000/545 of 8 September 2000) available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52000PC0545 on the 15/01/2018.

European Commission. (2007a) - Communication from the Commission to the European parliament, the Council, the European economic and social committee and the Committee of the Regions — An Integrated Maritime Policy for the European Union. Brussels COM (2007)575 final. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52007DC0308 on the 16/01/2018.

European Commission. (2013b) - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions an EU Strategy on Adaptation To Climate Change. Brussels, COM (2013) 216 final. 16.4.2013. Available at http://ec.europa.eu/transparency/regdoc/rep/1/2013/EN/1-2013-216-EN-F1-1.Pdf on the 16/01/2018.

European Commission. (2016) - Portugal - European Commission. Available at https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/portugal_climate_change_en.pdf).

European Parliament, Council of the European Union. (2002) - Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002D1600 on the 16/01/2018.

European Parliament, Council of the European Union. (2013) - Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC Text with EEA relevance.

European Parliament, Council of the European Union. (2000) - Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Available at http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32000L0060 on the 16/01/2018.

European Parliament, Council of the European Union. (2001). Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. Available at http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32001L0042 on the 16/01/2018.

FAO (2016) - The State of World Fisheries and Aquaculture 20016. Food and Agriculture Organization of the United Nations, Rome, 20016 Available at http://www.fao.org/3/a-i5555e.pdf at 27/06/2017

Ferreira, M., Silva, C., Fonseca, C., Pereira, M., Calado, H., Abreu, A., Andrade, F., Guerreiro, J., Gonçalves, E., Noronha, F., Lopes, C., Ribeiro, M., Stratoudakis, Y. and Vasconcelos, L. (2015) - Contributions towards maritime spatial planning (MSP) in Portugal – Conference report. Marine Policy. 59. doi:10.1016/j.marpol.2015.04.017.

Finkl, C. (2004) - Coastal Classification: Systematic Approaches to Consider in the Development of a Comprehensive Scheme. Journal of Coastal Research 20 1 166–213

GESAMP (2001) - Protecting the Ocean from Land-Based Activities. Reports and Studies 66. London: GESAMP. Available at http://www.jodc.go.jp/info/ioc_doc/GESAMP/report71.pdf at 27/06/2017.

Gonzalez, P., Neilson, R.P., Lenihan, J.M. and Drapek, R.J. (2010) - Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography, 19(6), 755-768

Governo de Portugal and APA. (2012ª) - Programa Nacional para o Uso Eficiente da Água Implementação 2012 – 2020. Available in Portuguese at https://www.apambiente.pt/_zdata/CONSULTA_PUBLICA/2012/PNUEA/Implementacao-PNUEA_2012-2020_JUNHO.pdf on the 16/01/2018.

Gregorić. (2014) - Pestel Analysis Of Tourism Destinations In The Perspective Of Business Tourism (Mice), Tourism and Hospitality Industry 2014, Congress Proceedings Trends in Tourism and Hospitality Industry.

GTL - Grupo de trabalho do litoral. (2014) - Gestão da Zona Costeira O Desafio da Mudança Relatório do Grupo de Trabalho do Litoral Dezembro de 2014. Available in Portuguese at http://www.apambiente.pt/_zdata/DESTAQUES/2015/GTL_Relatorio%20Final_20150416.pdf on the 16/01/2018.

Haines-Young, R. and Potschin M. (2011) - Integrated Coastal Zone Management and the Ecosystem Approach. Deliverable D2.1, PEGASO Grant agreement nº: 244170. CEM Working Paper No 7, 17pp.

Hartje, V., Klaphake, A. and Schliep, R. (2003) - The International Debate on the Ecosystem Approach: Critical Review, International Actors, Obstacles and Challenges. Bundesamt für Naturschutz, Bonn.

Inman, D.L. and Nordstrom, C.E. (1971). On the tectonic and morphologic classification of coasts. Journal of Geology, 79, 1–21.

IPCC. (2012) - Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

IPCC. (2013) - Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

IPCC. (2014) - Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Johnson, D.W. (1919) - Shore Processes and Shoreline Development. New York: Wiley, 584p.

Knecht, R. and J. Archer (1993) - “Integration” in the US coastal zone management program. Ocean & Coastal Management 21: 183– 199

Kristensen, P. (2004) - The DPSIR Framework. Paper presented at the 27-29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya.

Krockenberger, A.K., Kitching, R.L., Turton, S.M. (2003) - Environmental Crisis: Climate Change and Terrestrial Biodiversity in Queensland. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Rainforest CRC, Cairns.

Kwasi A. (2014) - Managing Shoreline Change Under Increasing Sea--Level Rise in Ghana, Coastal Management, 42:6, 555-567, DOI: 10.1080/08920753.2014.964820

Mayaka, M., and Prasad, H. (2011) - Tourism in Kenya: An analysis of strategic issues and challenges Elsevier, Tourism Management Perspectives.

McGarrigle, M. (1999). In Lee, J. (1999) - Securing a balance between competitive agriculture and environmental protection. Proceeding of the Agri-food Millennium Conference, 7 December 1999, Doyle Green isle Hotel, Dublin 22.

Millemann, B. (1995) - The US Coastal Zone Management Act: Politics and Partnerships for the Coast. Coast Alliance, Washington D.C., USA.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F. Ragoonaden, S. and Woodroffe, C.D. (2007) - Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.

Olsen SB, Olsen, E. and Schaefer, N. (2011) - Governance baselines as a basis for adaptive marine spatial planning. J Coast Conservat15:313–322. doi:10.1007/s11852-011-0151-6

Olsen, S., Lowry K., and Tobey, J., (1999) - A Manual for Assessing Progress in Coastal Management. Coastal Management Report. University of Rhode Island, Coastal Resources Centre. Narragansett, RI, USA. Available at http://www.commissionoceanindien.org/fileadmin/resources/RECOMAP%20Manuals/Manual%20for%20Assessing%20Progress%20in%20Coastal%20Management%202009.pdf.

Olsen, S., Tobey, J. and Hale, L. (1998) - A learning-based approach to coastal management. AMBIO A Journal of the Human Environment. 27. 611-619.

Olsen, S.B. and D. Nickerson. (2003) - The Governance of Coastal Ecosystems at the Regional Scale: An Analysis of the Strategies and Outcomes of Long-Term Programs. Coastal Management Report #2243. ISBN #1-885454-51-1. University of Rhode Island Coastal Resources Center. Narragansett, RI. Available at http://www.crc.uri.edu/download/GovLargeEcosystems_OlsenNickerson.pdf

Olsen, S.B., Sutinen, J.G., Juda, L., Hennessey, T.M. and Grigalunas, T.A. (2006) - A handbook on governance and socioeconomics of large marine ecosystems. Coastal Resources Center, University of Rhode Island, Narragansett

Portuguese Decree-Law Nº. 309 / 93. Available in portuguese in the Diário da República, 1.ª série A— N.º 206 — 2 de Setembro de 1993 at https://dre.pt/application/file/a/633060 on the 16/01/2018.

Portuguese Decree-Law Nº. 380/99 of 22 September available in Portuguese in the Diário da República, 1.ª série — N.º 222 — 22 de Setembro de 1999 at https://dre.pt/application/file/a/558952 on the 16/01/2018.

Portuguese Government and APA. (2012) - Plano de Ação de Proteção e Valorização do Litoral 2012-2015. Available in Portuguese at https://apambiente.pt/_zdata/Politicas/Agua/PlaneamentoeGestao/PAPVL/PAPVL_2012-2015-FEV-V18.pdf on the 16/01/2018.

Portuguese Law No. 31/2014 Law Nº. 31/2014 of 30 May. Lei de bases gerais da política pública de solos, de ordenamento do território e de urbanismo. Diário da República, 1.ª série — N.º 104 — 30 de maio de 2014. Available in Portuguese at https://dre.pt/application/file/a/25346138 on the 16/01/2018.

Portuguese Law No. 54/2007 Law Nº. 54/2007 of 31 August. Diário da República n.º 168/2007, Série I de 2007-08-31. Available in Portuguese at https://dre.pt/application/file/a/641063 on the 16/01/2018.

Portuguese Law No. 58/2007 Law Nº. 58/2007, of 4 September. Diário da República n.º 170/2007, Série I de 2007-09-04. Available in Portuguese at https://dre.pt/application/file/a/640048 on the 16/01/2018.

Qiu, W. and Jones P. (2013) - The emerging policy landscape for marine spatial planning in Europe. Marine Policy 39 (2013) 182–190. DOI: j.marpol.2012.10.010. Available at: https://www.sciencedirect.com/science/article/pii/S0308597X12002084 on the 20/04/2020.

Rabenold C. (2013) - Coastal Zone Management: Using No-Build Areas to Protect the Shorefront, Coastal Management, 41:3, 294-311, DOI: 10.1080/08920753.2013.784892

Resolution of Council of Ministers No. 33/99. Available at https://dre.pt/web/guest/pesquisa/-/search/531411/details/maximized.

Resolution of Council of Ministers Nº. 24/2010. Diário da República, 1.ª série — N.º 64 — 1 de Abril de 2010. Available in Portuguese at https://dre.pt/application/dir/pdf1sdip/2010/04/06400/0109001106.pdf on 19/12/2017.

Resolution of Council of Ministers Nº. 82/2009, of 8 September, Diário da República n.º 174/2009, Série I de 2009-09-08. Available at https://dre.pt/application/file/a/489302.

RIKZ- National Institute of Coastal and Marine Management of the Netherlands. (2004) - A guide to coastal erosion management practices in Europe. Service contract B4-3301/2001/329175/MAR/B3 "Coastal erosion – Evaluation of the needs for action" Directorate General Environment European Commission Available at http://webpages.fe.up.pt/ihrh/pdf/Shoreline_management_guide_jan04.pdf.

Robinson, N. (1992) - Agenda 21 and the UNCED Proceedings. New York: Oceana, 1992

Rummukainen, M. (2012) - Changes in climate and weather extremes in the 21st century. Wiley Interdiscip. Rev. Clim. Chang. 3, 115e129

Schmidt, L., Mourato, J., and Delicado, A. (2014) - Gestão Integrada da Zona Costeira - Policy Brief 2014. Available at: https://repositorio.ul.pt/bitstream/10451/24470/1/ICS_LSchmidt_JMourato_ADelicado_Gestao_PolicyBrief.pdf on the 20/04/2020.

Shepard, F.P. (1973) - Submarine Geology. New York: Harper and Row, 519p.

Sommer, J.H., Kreft, H., Kier, G., Jetz, W., Mutke, J. and Barthlott, W. (2010) - Projected impacts of climate change on regional capacities for global plant species richness. Proceedings of the Royal Society B, 277(1692), 2271-2280.

Suess, E. (1888) - The Face of the Earth (Das Anlitz der Erde), Volume 2. London: Oxford University Press (English translation 1906 by H.B. Sollas), 5 vols.

Tanner-McAllister, S.J., Rhodes, J., Hockings, M. (2017) - Managing for climate change on protected areas: An adaptive management decision making framework. Journal of Environmental Management 204 (2017) 510e518. DOI: http://dx.doi.org/10.1016/j.jenvman.2017.09.038

Taveira-Pinto, F. (2004) - The Practice of CZMP in Portugal, Journal of Coastal Conservation 10: 147-158, 2004.

Teixeira, S.B. (2014) - Coastal hazards from slope mass movement: Analysis and management approach on the barlavento coast, Algarve, Portugal. Ocean & Coastal management, 102, 285-293.

UNDP/UNDOALOS (1994) - Report on the Consultative Meeting on Training in Integrated Management of Coastal and Marine Areas for Sustainable Development, Sassari, Sardinia, Italy, 21-23 June 1993. United Nations Development Programme and Division for Ocean Affairs, United Nations, New York.

UNEP/MAP/PAP. (2001) - Good Practices Guidelines for Integrated Coastal Area Management in the Mediterranean. Split, Priority Actions Programme, 2001.

UNEP/MAP/PAP. (2008) - Protocol on Integrated Coastal Zone Management in the Mediterranean. Split, Priority Actions Programme, 2008.Available at http://www.pap-thecoastcentre.org/pdfs/Protocol_publikacija_May09.pdf on the 16/01/2018.

UNFCCC (2015) - Adoption of the Paris agreement – by the President – Draft decision -/CP.21 (PDF). 12 December 2015. Archived (PDF) from the original on 12 December 2015. Retrieved 2017-12-19.

Vallega, A (1996). In Cicin-Sain, B., Knecht, R., Vallega, A. and Harakunarak A. (2000) - Education and Training in Integrated Coastal Management: Lessons from the International Arena, Ocean & Coastal Management 43 (4-5):291-330.

Vallega, A. (1999) - Fundamentals of Integrated Coastal Management. The Geojournal Library Vol. 49, Kluwer Academic Publishers ISSN 0-7923-5875-9.

Yuan X., Wei, Y., Wang, B., Mi, Z. (2017) - Risk management of extreme events under climate change. Journal of Cleaner Production 166 (2017) 1169e1174. Doi: http://dx.doi.org/10.1016/j.jclepro.2017.07.209

Yuksel, I. (2012) - Developing a Multi-Criteria Decision-Making Model for PESTEL Analysis. International Journal of Business and Management; Vol. 7, No. 24; 2012 ISSN 1833-3850 E-ISSN 1833-8119 Published by Canadian Center of Science and Education.

Journal of Integrated Coastal Zone Management / Revista de Gestão Costeira Integrada 20(1):49-60 (2020)
http://www.aprh.pt/rgci/pdf/rgci-n257_Marengo.pdf | DOI:10.5894/rgci-n257

Revista de Gestão Costeira Integrada
Journal of Integrated Coastal Zone Management

Island-based Information Management System-GIS Data Centre as a key tool for spatial planning in the South Atlantic UK Overseas Territories

Ilaria Marengo[@] [1] , Amelie A. Augé[1,2], Letizia Campioni[3], Denise Blake[4], Samantha Cherrett[5], Andrew J. Richardson[6], Sam B. Weber[7]

[@] *Corresponding author: marengoila@gmail.com*
[1] *South Atlantic Environmental Research Institute, Stanley Cottage, Stanley, FIQQ 1ZZ, Falkland Islands. E-mail: marengoila@gmail.com*
[2] *Department of Conservation, Whangarei, New Zealand. E-mail: amelie.auge@gmail.com*
[3] *MARE – Marine and Environmental Sciences Center, ISPA - Instituto Universitário, Rua Jardim do Tabaco 34, 1149-041 Lisboa, Portugal. E-mail: letiziacampioni@hotmail.com*
[4] *Policy and Economic Development Unit, Falkland Islands Government, Thatcher drive, Stanley, FIQQ 1ZZ, Falkland Islands. E-mail: environmental.officer@sec.gov.fk*
[5] *Environmental Management Division, Saint Helena Government, Essex House, Jamestown, STHL 1ZZ, Saint Helena. E-mail: samantha.cherrett@fco.gov.uk*
[6] *Conservation Department, Ascension Island Government, Georgetown, ASCN 1ZZ, Ascension Island. E-mail: andy.james.richardson@gmail.com*
[7] *Centre for Ecology and Conservation, University of Exeter, Penryn Campus, Cornwall, TR10 9FE, UK. e-mail: sam.weber@exeter.ac.uk*

ABSTRACT: Environmental data require fit-for-purpose data management systems and related spatial applications to be used effectively for management. Geographic Information Systems (GIS) have become a key tool to analyse and visualise spatial data with their increasing volume and variety. Well-designed data centres that combine a data management system with GIS, reduce costs and improve efficiency for spatial planning processes. Small or remote territories and islands such as the South Atlantic UK Overseas Territories (SAUKOT), with limited financial resources and capacity, face many challenges to develop such centres. In 2013 an island-based Information Management System (IMS)-GIS Data Centre was established in the SAUKOT. Until then, governments did not have the ability to use spatial planning effectively to manage their environments. The IMS-GIS Data Centre has been operating as: 1) repository of high-quality reference datasets to support decision making, 2) interactive data visualisation to share maps and information with stakeholders and 3) data portals to assist data discovery and sharing. This paper describes i) how the SAUKOT have built their own IMS-GIS Data Centres ii), how these Data Centres have provided effective and manageable solutions to support terrestrial and marine spatial planning processes and iii) the challenges the Data Centres are still facing. Thanks to relatively simple data management concepts and the use of open-source programs, the IMS-GIS Data Centre is transferable to other contexts sharing similar challenges to those faced by the SAUKOT.

Keywords: Data management system, data centre, GIS, spatial planning, open-source, remote islands.

** Submission: 3 MAR 2019; Peer review: 8 SEP 2019; Revised: 5 MAR 2020; Accepted: 16 MAR 2020; Available on-line: 25 MAY 2020*

RESUMO: Os dados ambientais exigem uma adequação dos sistemas de gestão de dados e respetivas aplicações geográficas para que sejam utilizados eficazmente na gestão. Os Sistemas de Informação Geográfica (SIG) tornaram-se uma ferramenta essencial para analisar e visualizar dados espaciais com seu volume e variedade crescentes. Os Data centers bem projetados, que combinam um sistema de gestão de dados com SIG, reduzem custos e melhoram a eficiência dos processos de planeamento espacial. Os territórios e ilhas pequenas ou remotas, como os Territórios Ultramarinos do Atlântico Sul do Reino Unido (SAUKOT), com recursos e capacidade financeira limitados, enfrentam muitos desafios para desenvolver esses centros. Em 2013, um centro de dados do Sistema de Gestão de Informações em Ilhas (IMS) foi estabelecido no SAUKOT. Até então, os governos não tinham a capacidade de usar o planeamento espacial efetivamente para gerir os seus ambientes. O IMS-GIS Data Center opera como: 1) repositório de conjuntos de dados de referência de alta qualidade para apoiar a tomada de decisão, 2) visualização interativa de dados para compartilhar mapas e informações com as partes interessadas e 3) portais de dados para auxiliar na descoberta e compartilhamento de dados. Este artigo descreve i) como os SAUKOT construíram os seus próprios Data Centers IMS-GIS; ii) como esses Data Centers forneceram soluções eficazes e geríveis para apoiar os processos de planeamento espacial terrestre e marinho; e iii) os desafios que os Data Centers ainda enfrentam. Graças a conceitos de gestão de dados relativamente simples e o uso de programas de código aberto, o IMS-GIS Data Center é transferível para outros contextos que compartilham desafios semelhantes aos enfrentados pelo SAUKOT.

Palavras-chave: Sistema de gestão de dados, data center, GIS, planeamento espacial, código aberto, ilhas remotas.

1. INTRODUCTION

Spatial data are data that can be visualised on a map because they are linked to a site or a particular location with the use of geographical coordinates based, most often, on latitude and longitude. Geographic Information Systems (GIS) are well-established computer-based tools for spatial data manipulation, analysis and visualisation that are now extensively included in environmental spatial planning and policy-making (O'Shea, 2006).

Spatial planning is a strategic and integrated process that spatially allocates different human-use functions and activities across a landscape as efficiently and effectively as possible to maximise the benefits and ensure environmental sustainability in the long-term. The process initially requires spatial data on abiotic (*e.g.* Geology, Climatology, Hydrology) and biotic (*e.g.* flora, fauna) ecosystem components and on human activities (*e.g.* land use, shipping traffic) and values (*e.g.* economic, cultural) (Wit *et al.*, 2009). These data first allow spatial planners to identify and describe the environmental and socio-economic context that affects the communities and their environment. This information can then be used during the planning and policy-making process for understanding the spatial context in which people and nature coexist and for defining the allocation of space that balances the value of people and nature, to ensure sustainable development and environmental integrity of ecosystems (Wit *et al.*, 2009). Geo-processing functions such as map overlay, connectivity measurement, cost/benefit evaluation, suitability assessment, buffering (Longley *et al.*, 2010), photogrammetry from UAV surveys (Scarelli *et al.*, 2016 ane Scarelli *et al.*, 2017) and interactive mapping (webGIS) are some of the GIS analytical and mapping tools used by spatial planners. Thus, spatial planning processes and GIS are interlinked from the initial definition and analysis of the present situation and stakeholder engagement, to the final mapping of possible future scenarios and decision making. However, the best spatial data and GIS functionalities are not sufficient to enhance the workflow of the spatial planning process for achieving efficiency in its performance and application.

The spatial planning process needs a long-term data management system that provides continuous and structured data management and that takes care of how data are collected, documented, analysed, publicised, stored and ultimately archived (Zwirowicz-Rutkowska and Michalik, 2016; USGS, 2018). For example, without a data management system in place, data sources can be disparate and data availability remains uncertain. The time and resources needed by the spatial planners to compile and map the data can also be significantly longer, even if data have been used in the past for a different process or planning. The spatial planning process becomes expensive and it slows down with a negative impact on keeping the scheduled deliverables on time and the quality of the planning outcomes acceptable. Furthermore, if spatial planners do not have a clear knowledge of who, when and how data have been generated because an accurate documentation is absent, the risk of introducing low quality data in the analytical process increases. From a spatial planner perspective, saving time in collecting and collating spatially-explicitly data results in speeding up the initial phase of the spatial planning process. Similarly, having access to official, documented and referenced datasets ensures reliable outcomes at its end.

The data management system also needs to support standard best practices for data collection and policies including plans for data security and the protection of copyright and intellectual property rights. This offers credibility and reliability to those who provide or own data that are used in planning processes. As a result, the likelihood that data are delivered according to standards shared or made more accessible to spatial planners and other potential data users increases.

A data management system does not stand in isolation. It requires the presence of a data centre and a dedicated data manager or a team of data managers depending on its scale. All around the world, there are organisations, institutions and data centres that look at finding solutions that satisfy the requests of services that facilitate data discovery, access, manipulation, analyses and visualisation. Online data portals, data repositories, metadata catalogues online, and web mapping platforms are designed and built to allow data users to easily source data, verify their quality and validity, and disseminate information. For example, BirdLife International (http://www.seabirdtracking.org/mapper/index.php) and Movebank (https://www.movebank.org/) provide the infrastructure and the data managers to maintain and manage some of the largest databases on animal tracking data. Similarly, the London-based Natural History Museum (NHM) (http://data.nhm.ac.uk/) and Kew Gardens (https://www.kew.org/science/data-and-resources/data) make available more than 80 million specimens from one of the world's most important natural history and plant/fungal collections. The UK Polar Data Centre (https://www.bas.ac.uk/data/uk-pdc/) managed by the British Antarctic Survey (BAS) is the focal point for Arctic and Antarctic environmental data management in the UK. This data centre offers services to explore and discover the data, but also support researchers in complying with national and international data legislation and policies.

The organisations and institutions given as examples of data centres with *ad hoc* data management systems have the human and financial resources to sustain the management of data coming in large volume and frequency and various formats. However, in remote islands and territories, spatial planners and data managers face several challenges due to the physical isolation (Figure 1 and Table 1), the lack of existing data policies, the access to basic information technology, the financial constraints and the narrow pool of skills and technical expertise in spatial analytical tools.

Here, we show how the development of the Information Management System-GIS (IMS-GIS) Data Centre in the South Atlantic UK Overseas Territories (SAUKOT) has taken place and how challenges were overcome. This paper describes 1) how the SAUKOT have built their own data management system under the standards provided by the IMS-GIS Data Centre 2) how these Data Centres have provided effective and manageable solutions to support terrestrial and marine spatial planning processes and 3) the challenges the Data Centres are facing.

2. THE ROLE OF THE IMS-GIS DATA CENTRE AS SUPPORT TOOL FOR SPATIAL PLANNING PROCESSES

The SAUKOT are a set of remote islands found from the equator down to the Antarctic (Figure 2). Due to their remoteness, marine and terrestrial ecosystems are unique and comprise of many endemic species that are irreplaceable and valuable assets not only for the islands (FIG-EPD, 2016; Otley *et al.*, 2008; SHG-EMD, 2012; Taylor *et al.*, 2016) but also for the UK, since it has been estimated that approximately 90% of the UK's biodiversity resides in the overseas territories (Wentworth, 2013). The islands have their own governments that oversee the management of the marine and terrestrial areas.

Research grants and conservation programmes provided by the Foreign Commonwealth Office (FCO), the UK Department for Environment, Food and Rural Affairs (The Darwin Initiative and the Darwin Plus grant schemes), the UK Department for International Development (DFID) or the European Union (*e.g.*, EU BEST programs) have assisted the local governments to sustain the effort and the costs of data collection. However, these types of funding had never included support for the establishment of island-based Data Centres where governmental data management systems and plans could ensure the availability of data for spatial planning and decision-making processes for the islands.

Without direct governmental control over the collected data from the islands and their marine areas, poor data documentation and taking data back to overseas academic institutions without providing copies to local government became widespread habits among the researchers and data collectors working in the islands. As a consequence, data were lost, and others were duplicated in the attempt of recovering the data that went missed. Overall, the work of local spatial planners, conservation Non-Governmental Organisations (NGOs) and government officers was affected as the accessibility to the data was compromised. Time, effort and resources instead of being invested in understanding and learning something new about the local environment, were targeted to fill gaps and chase datasets around the world due to the lack of a functioning data management.

In order to remedy the lack of data management in the SAUKOT, in late 2013, the Foreign Commonwealth

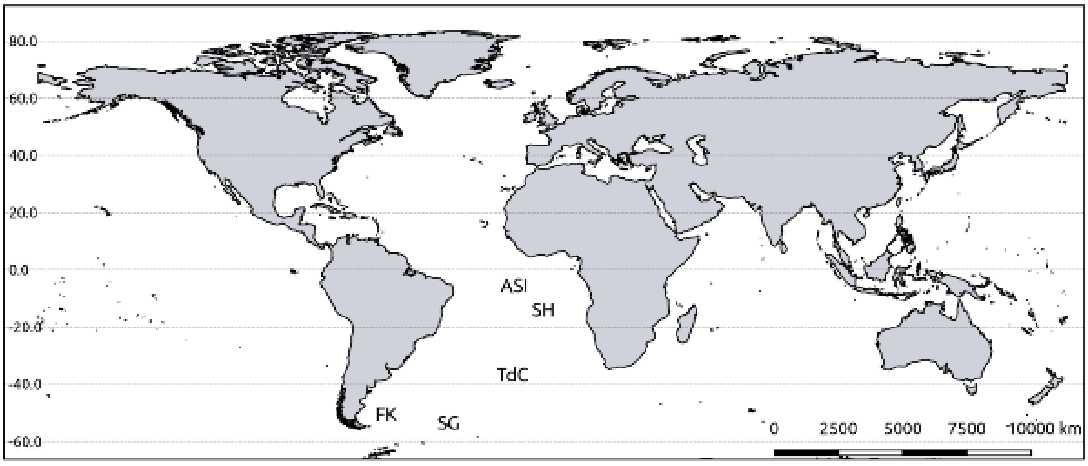


Figure 1. Locations of the South Atlantic UK Overseas Territories: Ascension Island (ASI), Saint Helena (SH), Tristan da Cunha (TdC), Falkland Islands (FK), South Georgia (SG). Datasource: https://www.naturalearthdata.com/downloads/50m-physical-vectors/

Table 1. The table describes the remoteness of the territories by providing journey time, type and frequency of connection (update 2018) from each territory to the main overseas land. It is worth noting that for Tristan, due to the reduced number of berths in the vessel, the priority is given to islanders. For South Georgia, the vessel main function is patrolling the Maritime Zone from illegal fishing practices and it is used to provide access to the island to the Government officers and their family.

Territory	Transport	Number of connections	Time
Falkland Islands	plane	3 flights/Wk.	18 hrs from the UK 1.5 hrs from Punta Arenas
Saint Helena	plane	1 flight/Wk. 2 flights/Wk. (Dec-Apr)	6 hrs from Johannesburg
Ascension Island	plane	1 flight/m. to Saint Helena	1.5 hrs from Saint Helena
Tristan da Cunha	vessel	10 ships/Yrs. (max 12 passengers)	5-8 d. (weather dependent) from Cape Town
South Georgia	vessel	Sporadic governmental vessel (max 12 berths); Cruise ships in summer	2-6 d. (weather dependent) from Stanley-Falkland Islands

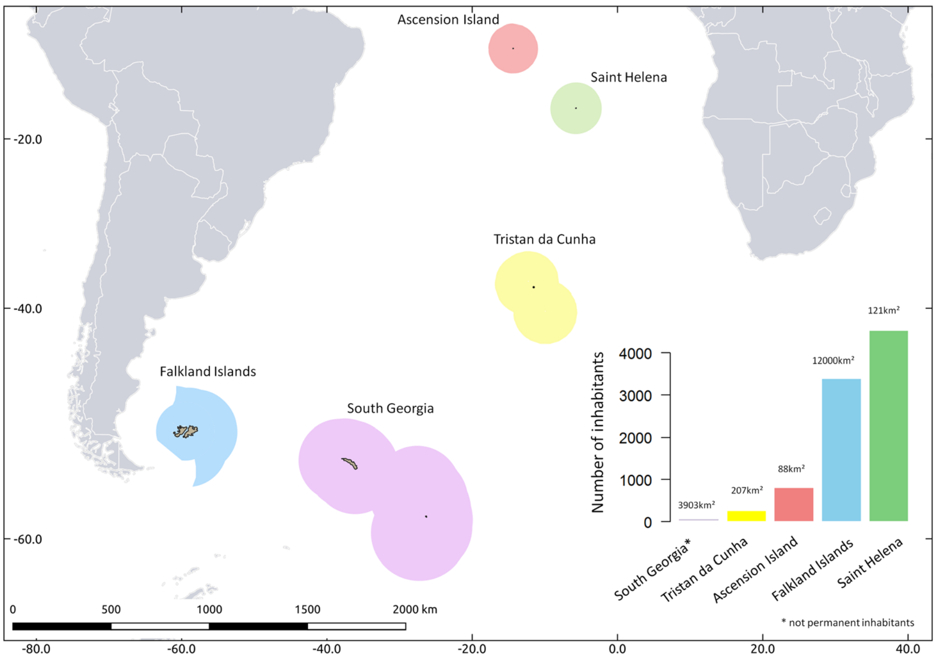


Figure 2. Areas managed by the South Atlantic UK Overseas Territories, including their Exclusive Economic Zones (EEZ) and histogram of the number of inhabitants with the land area (in km^2) indicated above each bar(right down corner).
Datasource: https://www.naturalearthdata.com/downloads/50m-physical-vectors/

Office, via the Joint Nature Conservation Committee (JNCC), sponsored the development of the IMS-GIS Data Centre in the Falkland Islands and Saint Helena (https://www.south-atlantic-research.org/research/data-science/). The management and oversight of the project was given to the JNCC (JNCC, 2016), whereas the newly-born South Atlantic Environmental Research Institute (SAERI) created in 2012, based in the Falkland Islands, had the responsibility of designing the architecture of the island-based central data repository for the environmental data collected in each SAUKOT (South Georgia and the South Sandwich Islands were not included as their Government contract British Antarctic Survey to do their data management). During the two-year project, SAERI's main tasks were to develop and implement tools for a long term, sustainable and practical data management system. Initially two GIS specialists and data manager posts were created in the Falkland Islands (2013) and in Saint Helena (2014), followed up by a part-time data manager post in Ascension Island (2015). On island data managers were fundamental to the efficiency and success of the South Atlantic wide IMS-GIS Data Centre.

One of the advantages of starting a data centre from scratch was the opportunity to create an architecture that fits the geographical and socio-economic characteristics of the SAUKOT, and that accommodates the ambitions and requirements of its users on the islands. Another advantage of starting a new process was the abundance of models and best practices that could be used as a guide during the design and development phase. Thus, the IMS-GIS Data Centre was created through a participatory, open and inclusive process, where local stakeholders, ranging from government offices and representatives of local and international NGOs, and overseas researchers helped prioritising the data services and identifying where international standards (AGI, 2012) and existing data policies (NERC, 2018; Van den Eynden *et al.*, 2011) needed simplified and turned into tools for data management.

The main objective of the IMS-GIS Data Centre was to provide the small territories with a data management system that would be standard across the territories, and could be understood by the users and maintained locally in the long term. A system architecture that could take into consideration these points was designed and implemented (Figure 3). Open-access software was used for all components of the system (QGIS, 2018; PostgreSQL, 2018; PostGIS, 2018).

A simple searchable online catalogue was designed as first solution for the retrieval of the metadata harvested by the IMS-GIS Data Centre in the various SAUKOT. Many metadata had their corresponding data stored locally on dedicated servers and the data were made accessible to data requestor via a data request form (https://www.south-atlantic-research.org/research/data-science/data-services-metadata-catalogue/). This elementary system has been upgraded between 2018 and 2019 thanks to a collaboration with the Satellite Receiving Station at the University of Dundee. A more complex data portal based on CKAN (https://ckan.org/) was built only for the Falkland Islands Government. The improved data service has the main advantage to discover metadata and data with the same online search. If the data are classified as "open access", then the resource can be downloaded directly from the portal. Otherwise, the data requestor has to fill an online form and receive the authorisation for the data download via email (http://dataportal.saeri.org).

Although the IMS-GIS data centre system architecture reflects the standard life cycle of data, it was revolutionary for the SAUKOT, because it introduced concepts new to the majority of the stakeholders and kept the tools used for its implementation simple (*e.g.*, an excel file for the metadata form and a word document for the data request, in the case of the former metadata catalogue) and without a licence fee. Furthermore, the change of habit requested by the data management system was fully supported by free training courses on how to use and apply GIS, how to fill in metadata records, and assisted by guidelines and explanations on why data curation impacts on spatial planning and decision-making processes. Aims, objectives and solutions identified for the realisation of the IMS-GIS Data Centre reflect the attention dedicated to the end-users and the intention of delivering a practical and sustainable data management system (Table 2). A series of case studies are presented to describe how and in which terms the solution proposed by the IMS-GIS Data Centre became practical and useful services for spatial planners and how the existence of the IMS-GIS Data Centre impacted positively on small islands spatial planning processes.

3. CASE STUDIES

3.1 Marine Spatial Planning for the Falkland Islands

In 2014, at the same time as the IMS-GIS Data Centre was being developed, the Falkland Islands Government with the UK Government support (via the Darwin Plus Programme) started a project to initiate Marine Spatial Planning (MSP) (https://www.south-atlantic-research.org/research/completed-research-projects/marine-spatial-planning-for-the-falkland-islands/). One of the goals of this project was to gather data relevant for spatial planning (environmental, anthropogenic and biological)

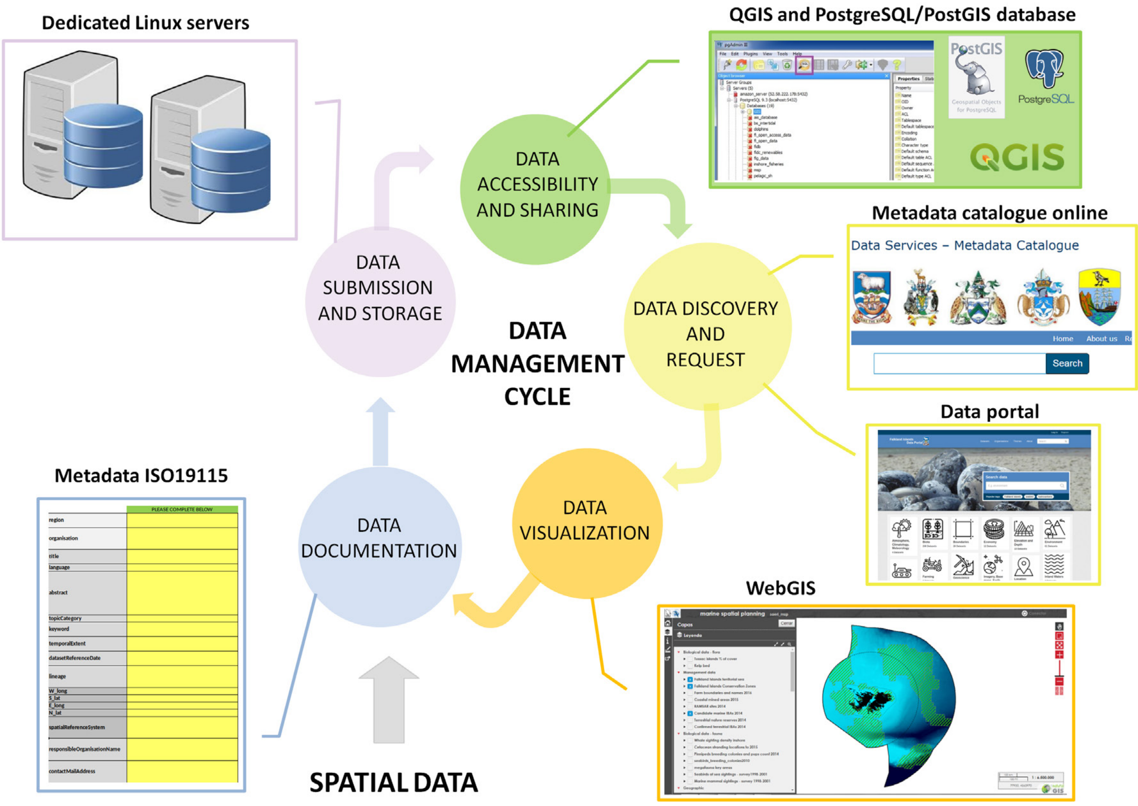


Figure 3. System architecture of the South Atlantic UK Overseas Territories Information Management System-GIS Data Centre. For each phase, the main component and type of service provided are highlighted.

Table 2. Summary of the aims, objectives, and solutions identified and implemented by the IMS-GIS Data Centre in its years of activity (2013-2019).

AIMS	OBJECTIVES	SOLUTIONS
Design a simple and manageable metadata harvesting process that would ensure data documentation	Adopt a metadata standard form. Include the metadata form as part of the Research Permit Application. Meet overseas researchers either before or after data collection. Provide training and explanation on how to fill the metadata form correctly. Collect metadata at short distance from data collection. Include metadata into the metadata catalogue Publish metadata regularly	Metadata catalogue online for SAUKOT except the Falkland Islands https://www.south-atlantic-research.org/research/data-science/data-services-metadata-catalogue/ CKAN-based Data portal for the Falkland Islands http://dataportal.saeri.org
Ensure that a copy of the data collected by overseas researchers is also kept and stored in a server on the island	Invest in hardware. Set up two secure servers: one acting as a data bank and the other working as an off-site back-up. Ensure the level of security for both servers	Central data repository based on the island
Allow as many people as possible to familiarise with and learn how to use analytical and mapping tools such as GIS	Organise training courses in GIS and data management to cover basic, intermediate and advanced level. Adopt QGIS as a GIS tool. Adopt PostgreSQL and PostGIS as spatial database	Embrace open source movement and use open source software https://www.south-atlantic-research.org/news/
Consolidate data management and use of standards among data owners and users	Engage with local stakeholders to identify solutions that can fit with the islands. Do not reinvent the wheel, but take data policies from other countries as models and re-frame them to reflect stakeholders inputs. Design a data management system that is simple, manageable and sustainable in the long term	Publications, through a dedicated web portal, of local data polices and standard guideline for best practice in data management https://www.south-atlantic-research.org/research/data-science/guidelines-and-data-policies/
Facilitate access to data and information within the islands and between the islands and the rest of the world	Work with governmental IT and telecommunication provider to ensure that locals can access the services at minimum cost. Adopt interoperability schema for ensuring data sharing within the island. Design, develop and implement webGIS and other web application to make data and information widely accessible	System based on interoperability. webGIS projects https://www.south-atlantic-research.org/research/data-science/managing-data/webgis-projects/

to understand where issues already existed, to identify key knowledge gaps and for analysing tracking and sighting data and identify key areas for marine megafauna (Augé *et al.*, 2018b). Another goal of the project was to start educating and engaging stakeholders and the local community in MSP so they would understand the benefits of the process.

The IMS-GIS Data Centre provided some initial baseline spatial data and then was used as the repository for all the data gathered or created during the project so that any further projects and spatial planning analyses would benefit from the effort put in gathering that data. In total, 35 datasets were added to the IMS-GIS Data Centre metadata catalogue during the project. Data ranged from existing data that were available but not catalogued publicly (*e.g.*, fisheries management areas), data that were digitised and formatted as part of the project (*e.g.*, cetacean stranding data, Augé *et al.*, 2018a), to new data created during the project from research (*e.g.*, cultural coastal values, Blake *et al.*, 2017).

The IMS-GIS Data Centre also allowed storing and recording raw data, not directly useful for MSP, but that was used for analyses that provided the layers required for spatial planning. For instance, a study part of the MSP project gathered all available information on historical whale sightings in the Falkland Islands to understand better their status and current distribution to feed into spatial planning (Frans and Augé, 2018). Many raw data were acquired and digitised (*e.g.*, local ecological knowledge, commercial whaling catch data). While the data relevant for marine spatial planning was the output layer of this study (*i.e.*, distribution of whales), the raw data were essential and needed to be recorded and stored because they could be used for further studies, in particular as the study was published and future researchers may want to analyse the data when new data become available in the future. The IMS-GIS Data Centre was essential in the ability to store these data and make it available for future studies.

The GIS training courses promoted by the IMS-GIS Data Centre and the adoption of open source GIS and spatial database solutions allowed for a successful collaboration to make the data collected and derived through the MSP project available to stakeholders, independently of their GIS skills. If in the past, a single licence use of GIS software determined that only one person could be in charge of analysing and mapping spatial data, the use of licence-free tools, gave many people the opportunity to learn new skills. Free spatial database solutions facilitated data sharing across data users within and between organisations. For instance, data from the MSP process were accessed and viewed by GIS users at various government departments and research institutions locally and overseas. Where learning and understanding GIS was not a necessity and priority, webGIS services came to a hand as useful tools for understanding the value of spatial planning. The wider public and the majority of stakeholders could access and visualise the MSP data from a dedicated webGIS (https://data.saeri.org/saeri_webgis/lizmap/www/index.php/view/map/?repository=04f&project=webGIS20170717). The webGIS provided by the IMS-GIS Data Centre was a key element of successful stakeholder engagement and they repeatedly expressed how useful this tool was for them to be able to understand the value of MSP, and for consultation. The webGIS was also useful for running workshops and public meetings.

3.2 Spatial Planning for the Common of Stanley, Falkland Islands

In 2018, a web-based public participation GIS (PPGIS) approach together with the integration of spatial data from the IMS-GIS Data Centre was used by the Falkland Islands Government (FIG) to support the creation of a management plan for the public area known as Stanley Common. The area was prone to usage conflicts arising from a large variety of stakeholders and stakeholder interests. The use of PPGIS to identify activity use as well as data gathered on artefacts, infrastructure, and natural features was facilitated by the data repository provided by the IMS-GIS Data Centre. The IMS-GIS Data Centre served as an easy-to-use tool to quickly gather all the relevant spatial data available for the area known as Stanley Common. This included spatial data on public infrastructure as well as natural features. Where in some instances the data were not yet in the Data Centre, they were gathered and were entered in the Data Centre and its metadata catalogue for later analyses, policy making, research studies and for avoiding repetition of effort in the future. The use of spatial data facilitated mapping conflicts and enabled practitioners to better understand where management efforts can help achieve resolution and clarity.

3.3 Management of environmental research permits in the Falkland Islands

Research permits issued by the FIG are required by anyone undertaking environmental research in the Falkland Islands. These permits allow FIG to document the on-going environmental research in the Falkland Islands and establish where new sources of data are created. The IMS-GIS Data Centre data manager worked with the environmental officer to create a data management policy for the Data Centre and to ensure that permit applications now include a close where researchers must provide a copy of their raw data to FIG via the Data Centre metadata catalogue. Data are stored in the Data Centre and can be used for environmental management decision purposes of the islands (with appropriate acknowledgements). This metadata is available through the centre where it can be used to inform on data available and data ownership and access. It became a key tool for researchers intending to undertake research in the Falkland Islands as they can identify the data gaps or where research activities would be a duplication of effort. The Centre has also developed guidelines for data management and permit applications for researchers with a "checklist before arriving in the Falklands" (https://www.south-atlantic-research.org/research/data-science/check-list-before-arriving-to-the-falklands/). It also enables researchers to synergise their efforts where research overlaps exist.

3.4 Mapping Natural Capital in the SAUKOT

The UK Government, through the FCO managed Conflict, Stability and Security Fund (CSSF), is supporting a suite of natural capital projects across the UK's South Atlantic and Caribbean Overseas Territories. This work is designed to improve economic stability in the Territories through enhanced environmental resilience as part of a programme led by the UK's Department for Environment and Rural Affairs (Defra). The natural capital project began in September 2016 and will be completed by March 2019 with the JNCC as the Implementing Body. In the South Atlantic, the natural capital project work is being undertaken by SAERI under a Memorandum of Agreement with the JNCC (https://www.south-atlantic-research.org/research/terrestrial-science/natural-capital-assessment/).

This project assists the territories in assessing and mapping natural capital, valued priority assets, and deploys decisions support tools to secure long-term economic benefits from the sustainable management of their natural assets. The outcome will be a framework for the SAUKOT to assess the value of the environmental goods and services available and integrate this information into marine and terrestrial spatial planning, economic planning and environmental protection. The natural capital project focuses on:

- mapping spatial data on the distribution of selected natural capital assets, both marine and terrestrial, derived from satellite imagery and other existing resources, as relevant to each Territory;
- valuating of priority natural capital assets (value mapping integrated into national GIS) and assessing the economic and societal benefits arising from them;
- applying analytical tools that will support decision making in the context of environmental management and economic development (*e.g.*, scenarios); and
- identifying methods for monitoring changes to priority natural capital over time using appropriate attributes (*e.g.*, indicators).

To achieve the deliverables, the project utilises extensively the IMS-GIS Data Centre's metadata catalogue online and open source GIS tools for the development and collation of spatial evidence, and the technical expertise of the local data managers for promoting knowledge exchange and capacity building within the territories in the region.

For instance, in Saint Helena, the project supported a cost-benefit analysis (CBA) to explore different waste management options for the island, including improved recycling to extend the life of the existing landfill site. One option within the CBA included developing a new landfill site, and identifying a suitable site was part of the analysis. With flat land at an absolute premium on the island, identifying suitable locations was going to be a challenge. The use of GIS spatial analytical techniques proved an ideal solution (Marengo *et al.*, 2018). The recently completed Darwin Plus project 'Mapping St Helena's Biodiversity and Natural Environment' (Pike *et al.*, 2018), provided the majority of the baseline data for the analysis through the IMS-GIS Data Centre's data catalogue and database. Thanks to the GIS specialist and GIS data manager based on St Helena, the suitability assessment was run locally, without having to pay for an overseas consultant. This case study highlighted another main achievement of the IMS-GIS Data Centre in the context of a spatial planning and decision-making process. Not only data have been retained and managed locally, but also the technical expertise and knowledge on how to use the data and turn them into information came directly from the island. In this way, the IMS-GIS Data Centre proved that it has a positive long-term impact on the territories by favouring and enabling local people to learn about a multidisciplinary tool, build technical capacity and seize work opportunities, which in the past would have been given to overseas professionals.

4. MAIN RESULTS AND CHALLENGES TO BE ADDRESSED

The data management system introduced by the IMS-GIS Data Centre has showed that island-based data centres are a suitable and efficient support tool to spatial planning and decision-making processes. The examples of spatial planning support by the Centre have demonstrated that the direct participation and involvement of the stakeholders and spatial planners and the establishment of a "one to one" communication line between data users and data centre are fundamental for the success of the data services. A full-time data manager, and where is possible a team of data managers, is an essential element of the IMS-GIS Data Centre. Once contact with the data users is created, maintaining the data management system and the data services continuously can only be achieved by the full dedication of the data manager. For instance, a time-consuming task is gaining the trust from the practitioners and data users. Generally, people show resistance in two main areas: willingness to share data and fear of losing ownership of the data. A considerable amount of time in the initial phase of the development of the Data Centre was spent in providing data users and data collectors with evidence on how it would be advantageous and improve their way of working with and managing spatial data. Pilot projects worked out examples and one-to-one meetings with the stakeholders turned out to be useful solutions to demonstrate how the Data Centre operates for safeguarding ownership and intellectual property rights, for securing data with off-site back-ups and for enabling the access to data only through the data owners' authorisation. However, gaining stakeholders trust is a constant task because of the high turn-over of specialised workers on the islands and visitor researchers, which is typical of the SAUKOT. Therefore, there is a continuous need to introduce and train the new stakeholders to the local data management system.

Peoples' needs and aspirations in terms of use of data have been central to the development of the services. Designing the IMS-GIS Data Centre on open source software and the principle of simplicity was powerful. The data management system and its architecture have already been transferred to other territories outside the South Atlantic region, which present similar technical and socio-economic constraints. In 2018, thanks to a "Territory to Territory" project delivered in partnership with the JNCC, the system for harvesting and publishing metadata has been exported to Montserrat, where the Ministry of Agriculture, Trade, Housing, Land and Environment (MATHLE) requested a tool to discover its data, their availability, and accessibility. On top of these requirements, the tool needed to be managed locally, developed and implemented quickly, and had to ensure its long-term sustainability. Hence, the online metadata catalogue developed by the IMS-GIS Data Centre turned out to be a good solution. Training on how to set up and maintain the metadata catalogue were delivered in the Falkland Islands, where representatives of MATHLE were hosted for a week and in Montserrat, where the launch of the metadata catalogue online occurred shortly after (http://landinfo.gov.ms/Metadata.aspx). In 2019, the IMS-GIS data centre, thanks to the work in collaboration with the University of Dundee (Satellite Receiving Station) was commissioned by the JNCC to upgrade the metadata catalogue online to a full data portal (https://gisdataportal.gov.ms/).

The metadata catalogue has had a strong impact not only on data discovery but also on highlighting where data gaps exist. Therefore, the service can be used by the local governments to target their budgets and/or their support to projects that allow filling critical knowledge and data deficient areas. Not only the metadata catalogue allows a more thoughtful financial investment strategy, but it also enables researchers to write proposals for projects with a more practical and immediate application, above all in the spatial planning process. For example, overseas researchers were assisted in discovering information on target wildlife and locations which was used in support of the development of their research activity and related results (*e.g.*, Campioni *et al.*, 2017, Granadeiro *et al.*, 2018). At the same time, by speeding up the access to historic data, which used to be difficult to source, the metadata tool promoted the development of research projects focused on understanding the long-term effect of human-related activities on wildlife populations (*e.g.*, Clark *et al.*, 2019). It also helped fostering new networks of research collaborations amongst local partners and overseas researchers.

The IMS-GIS Data Centre, since it acts as a hub for the local data and promotes the concepts of data sharing and openness, has proven to facilitate the access to and visualisation of the data. As highlighted by the case studies, the data are now made open and available therefore, the sprout and growth of new spatial planning processes are facilitated. For instance, the data collected and derived through the Darwin Plus project in Saint Helena (Pike *et al.*, 2018) found immediate use in the assessment of suitable sites for a new landfill. Similarly, the data created during the Falkland Islands Marine Spatial Planning project were used as a baseline to develop a series of case studies on fisheries closure areas and now for a new Darwin Plus funded project to implement Marine Management Areas.

Although the IMS-GIS Data Centre has achieved considerable results, it continues to face challenges that have not yet been resolved. The information and technology facilities available on the islands determine how far the services can be provided locally. As it emerged from the case studies, the majority of the publicly-funded projects have been published online through the Lizmap web mapping application (Lizmap, 2018). However, due to the high cost of data usage via the Falkland Islands' local internet network and the satellite connection, and limited capital investment, all the webGIS projects have been published from servers remote to the islands. If this solution offers a good service for overseas researchers and potential data users, it is less convenient for those based on the islands as the internet costs are large. If data could be hosted locally, then a local network could be created free of charge in agreement whit the local internet provider. Only future changes in the local network design and improvements in the international internet connection will allow the development of local webGIS services, which would offer a cheaper and faster service for the islanders.

Long-term resourcing is a key challenge for the data centres on small islands. There are short-to-medium term grant schemes available to the small territories but it is rare to find funding resources or sponsors that will fund costs of a data management system specifically. Currently, in the Falkland Islands the approach adopted by the IMS-GIS Data Centre is to dedicate part of the budget of each SAERI-led research project benefiting data services to contribute to the running costs of the Data Centre and apply other fees for commercial works commissioned by the private sector. In other islands, such as Saint Helena, resourcing for the data centre is done by the way the local Government charges their internal departments for services. A solution to this challenge would be to see local governments, research institutions, and UK Government bodies to work more in synergy and to share a common data management funding strategy for the SAUKOT. Another solution would be to commercialise the provision of data services, above all when these are delivered to the private sector. However, this has so far only been pursued in the Falkland Islands (which has benefited from the presence of the hydrocarbons and commercial fishing industries) due to a lack of large private investors elsewhere. In conclusion, it emerges that identifying a budget that can pay for the long-term support of the IMS-GIS Data Centre has not been resolved yet and more work needs to be conducted for resourcing for its long-term sustainability.

Hiring a person for a full-time role of data manager is also challenging due to the combination of limited availability of financial resources and the physical remoteness of territories, such as the SAUKOT. Apart from the Falkland Islands, all the other territories have data managers that also cover other roles. As a result, the services are provided less continuously and are prioritised according to the rest of the tasks that the data manager has to accomplish. Appropriate resourcing is vital for the survival of any Data Centre. We recommend that for any Data Centre in small islands or territories, this should include adequate long-term provisions for not only the financial aspects of running a Centre but also other resources needed. Future-proofing a Centre in terms of technical requirements as well as staffing requirements is key to the long-term survival of any Data Centre.

As described in the case studies, webGIS applications have proven to be one of the best solutions for interacting with and informing stakeholders and the wider public since people can access data and information without having particular skills and abilities in using spatial tools, such as GIS. However, spatial planners have started requesting "*living maps*" since real-time data have become more common and are frequently available. Contrary to webGIS, that offers snapshots of reality, living maps are fed by a continuous stream of data coming either from remote devices or from computational systems that are set up to process data as soon as new ones are input. Similarly, the increase in the collection of data from remotely sensed devices, drones and "go-pro" above all, and the endless recording of photos and videos in many fieldworks, has prompted the need for a data management system specific to media files. Currently, living maps and dealing with media files are ambitious projects and challenges for a second phase of the IMS-GIS Data Centre.

5. CONCLUSIONS

The case studies brought as examples in this paper have demonstrated how the SAUKOT's IMS-GIS Data Centre has helped to support marine and terrestrial spatial planning processes, along with a range of research projects that fed data into planning activities.

Thanks to its integration with the local community, the Data Centre has provided the governments with the option to become less dependent on costly overseas consultants and to rely more on the data services offered "in house", with the result of investing in the development of government personnel's skills.

Similarly, because the Data Centre has been designed and built to be operational in remote islands of the South Atlantic Ocean, facing technological and financial limitations, then the simple data management concepts used to sustain the data management system have found their applicability to other realities sharing similar geographical and resource constraints. The case of Montserrat is an example of how another island has adopted and implemented the IMS-GIS Data Centre tools according to its necessities and capabilities.

Overall this paper has highlighted that spatial data management is crucial for both marine and terrestrial spatial planning processes especially for small territories or islands that must manage carefully the environment they rely on in the face of significant future changes ahead. Hence, the role and the utilisation of a data centre, once established, cannot be marginal or one-off, rather it should be integrated and become part of the baseline services that governments provide to their communities. It is recognised that resourcing for the long-term sustainability of the data centre is the main challenge that remote islands will face. Therefore, ahead of creating a data centre it is important to have a strategy that helps identifying and planning the sources of funding. The solution suggested here is an approach based on targeting multiple sponsors. Considering the size of the islands it is unlikely that the small governments can take the entire accountability of a data centre, hence partnerships with local or external research institutes, universities, NGOs and private/public bodies should be built. The investment from the engaged partners will be returned for example, in data services provided by the data centre.

The role and activities of the SAUKOT's IMS-GIS Data Centre presented here should therefore prove to be a useful example from which take further ideas and inspiration.

ACKNOWLEDGEMENTS

We acknowledge SAERI for its continuous support and investment, the JNCC for managing the initial FCO funding and for involving the Data Centre in the "Territory to Territory" partnerships and the University of Dundee (Satellite Receiving Station and Centre for Remote Environment) for enabling the realisation of the new data portal. We are grateful to the Governments of the Falkland Islands, Saint Helena, Ascension Island and Tristan da Cunha and their officers, especially D. Yon and M. Henry, for investing resources and time on the development and implementation of the IMS-GIS Data Centre in Saint Helena. A special thank to N. Rendell, former senior Environmental Officer at FIG, and J. Glass, director at the Fisheries Department at TdC, for their enthusiasm and for facilitating the Data Centre activities. We thank the two anonymous reviewers for their suggestions and comments. Finally, sincere thanks to Ness Smith, manager of the South Atlantic Natural Capital Assessment project, all the local and overseas researchers and NGO officers who collaborated and participated to this project and are still supporting it. The work by L.C. was funded by the post-doctoral research fellowship FCT-SFRH/BPD/89904/2012.

REFERENCES

Association for Geographic Information (AGI), (2012) - *UK GEMINI Specification for discovery metadata for geospatial data v.2.2*. In: https://www.agi.org.uk/agi-groups/standards-committee/uk-gemini/40-gemini/1051-uk-gemini-v2-2-specification-for-discovery-metadata-for-geospatial-resources

Augé, A.A.; Otley, H.; Rendell, N.; Frans, V.F. (2018a) - Spatial distribution of cetacean strandings in the Falkland Islands to define monitoring opportunities. *Journal of Cetacean Research and Management* (ISSN: 1562-0713), 19: 1-7. Available on-line at https://archive.iwc.int/pages/search.php?search=%21collection15&k

Augé, A.A.; Dias, M.P.; Lascelles, B.; Baylis, A.M.M.; Black, A.; Dee Boersma, P.; Catry, P.; Crofts, S.; Galimberti, F.; Granadeiro, J.P.; Hedd, A.; Ludynia, K.; Masello, J.F.; Montevecchi, W.; Phillips, R.A.; Pütz, K.; Quillfeldt, P.; Rebstock, G.; Sanvito, S.; Staniland, I.J.; Stanworth, A.; Thompson, D.; Tierney, M.; Trathan, P.N.; Croxall, J.P. (2018b) - Framework for mapping key areas for marine megafauna key areas to inform Marine Spatial Planning: Falkland Islands as a case study. *Marine Policy,* 92:61-72. DOI: https://doi.org/10.1016/j.marpol.2018.02.017

Blake, D.; Augé, A.A.; Sherren, K. (2017) - Participatory mapping to elicit cultural coastal values for marine spatial planning in a remote archipelago. *Ocean & Coastal Management*, 148: 195-203. DOI: https://doi.org/10.1016/j.ocecoaman.2017.08.010

Campioni, L.; Granadeiro, J.P.; Catry, P. (2017) - Albatrosses prospect before choosing a home: intrinsic and extrinsic sources of variability in visit rates. *Animal Behaviour*, 128: 85-93. DOI: https://doi.org/10.1016/j.anbehav.2017.04.008

Clark, T.J.; Bonnet-Lebrun, A-S.; Campioni, L.; Catry, P.; Wakefield, E. (2019) - The depth of Sooty Shearwater *Ardenna grisea* burrows varies with habitat and increases with competition for space. *Ibis,*161(1):192-197.DOI: https://doi.org/10.1111/ibi.12631

Falkland Islands Government-Environmental Planning Department (FIG-EPD), (2016) - *Falkland Islands Biodiversity Framework 216-2030.* In: http://www.fig.gov.fk/epd/environment/biodiversity-framework

Frans, V.F.; Augé, A.A.; Edelhoff, H.; Erasmi, S.; Balkenhol, N.; Engler, J. (2018) - Quantifying apart what belongs together: a multi-state species distribution modeling framework for species using distinct habitats. *Methods in Ecology and Evolution,* 9(1), 98-108. DOI:https://doi.org/10.1111/2041-210X.12847

Granadeiro, J.P.; Campioni, L.; Catry, P. (2018) - Albatrosses bathe before departing on a foraging trip: implications for risk assessments and marine spatial planning. *Bird Conservation International*, 28(2), 208-215. DOI: https://doi.org/10.1017/S0959270916000459

JNCC, (2016) - *Report from the South Atlantic Information Management Centre project - Information Management System / GIS Data Centre for the South Atlantic region. Project Report*. Joint Nature Conservation Committee, Peterborough. http://jncc.defra.gov.uk/pdf/southatlanticims_finalreport_v05(webready).pdf

Longley, P.A.; Goodchild, M.F.; Maguire, D.J.; Rhind, D.W. (2010) - *Geographic Information Systems and Science (3rd ed)*. 560p., John Wiley & Sons. ISBN:9780470721445

Lizmap, (2018). Lizmap Version: 3.1. URL: https://www.3liz.com/lizmap.html

Marengo, I.; Cherret, S.; Smith, N. (2018) - *South Atlantic Overseas Territories Natural Capital Assessment: Constraints mapping to identify suitable land-fill sites on St Helena.* Joint Nature Conservation Committee, Peterborough, UK. Unpublished

NERC, (2018)- *UK Natural Environment Research Council webpage: Data policy.* In: https://nerc.ukri.org/research/sites/data/policy/

O'Shea C.J., (2006) - GIS and spatial data management: a tool to planning in the Highlands and Islands of Scotland, *The International Journal of Biodiversity Science and Management*, 2:3, 178-181. DOI: https://doi.org/10.1080/17451590609618119

Otley, H.; Munro, G.; Clausen, A.; Ingham, B. (2008) - *Falkland Islands State of the Environment report*. Falkland Islands Government, Stanley, Falkland Islands In: https://www.fig.gov.fk/epd/component/jdownloads/send/6-environment/574-state-of-environment-report-2008?option=com_jdownloads

Pike, S.; Medcalf, K.; Naumann, E.K.; Scullion, J.; Detheridge, A.P. (2018) - *DPLUS052: Mapping St Helena's Biodiversity and Natural Environment. Remote sensing, monitoring and ecosystem service mapping.* Saint Helena Government, Jamestown, Saint Helena. http://www.sainthelena.gov.sh/wp-content/uploads/2018/08/DPLUS_052_FinalReport_20180723.pdf

PostgreSQL, (2018). PostgreSQL Global Development Group. Version 10. URL: https://www.postgresql.org/

PostGIS, (2018). PostGIS PSC Version: 2.2 URL: https://postgis.net/

QGIS, (2018). QGIS Development Group. Version: 2.18. URL: https://qgis.org/en/site/

Scarelli, F.M.; Cantelli, L.; Barboza, *E.g.*; Rosa, M.L.C.C.; Gabbianelli, G., (2016) - *Natural and Anthropogenic coastal system comparison using DSM from a low cost UAV survey (Capão Novo, RS/Brazil).* In: Vila-Concejo, A.; Bruce, E.; Kennedy, D.M., and McCarroll, R.J. (eds.), Proceedings of the 14th International Coastal Symposium (Sydney, Australia). Journal of Coastal Research, Special Issue, No. 75, pp. 1232 - 1236, ISSN 0749-0208. DOI: https://doi.org/10.2112/SI75-247.1

Scarelli, F.M.; Sistilli, F.; Fabbri, S.; Cantelli, L.; Barboza, *E.g.*; Gabbianelli, G. (2017) - *Seasonal dune and beach monitoring using photogrammetry from UAV surveys to apply in the ICZM on the Ravenna coast (Emilia-Romagna, Italy), Remote Sensing Applications: Society and Environment, 7, 27-39. DOI: https://doi.org/10.1016/j.rsase.2017.06.003*

St. Helena Government - Environmental Management Directorate (SHG-EMD), (2012) - *St. Helena Island National Environmental Management Plan 2012-2022.* http://www.sainthelena.gov.sh/wp-content/uploads/2012/08/St.-Helena-National-Environmental-Management-Plan-2012_2022-FINAL-070912.pdf

Taylor, M.; Brickle, P.; Pelembe, T. (2016) - *Regional ecosystem profile – South Atlantic Region. Biodiversity and Ecosystem Services in Territories of European Overseas (EU-BEST). European Commission.* http://ec.europa.eu/environment/nature/biodiversity/best/pdf/best-ecosystem_profile_south_atlantic_2016.pdf

USGS, (2018) - *Overview of Data Management*. Available on-line at https://www.usgs.gov/products/data-and-tools/data-management/overview-data-management

Van den Eynden, V.; Corti, L.; Woollard, M.; Bishop, L.; Horton, L. (2011) - *Best practice for researchers*, UK Data Archive, University of Essex, UK. https://ukdataservice.ac.uk/media/622417/managingsharing.pdf

Wentworth, J. (2013) - Biodiversity in the UK Overseas Territories, POSTnote 427, Houses of Parliament, Parliamentary Office of Science and Technology. London, UK. In: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-427#fullreport

de Wit, A.; van de Brink, A.; Bregt, A.K.; van de Velde, R. (2009) - Spatial Planning and Geo-ICT: How spatial planners invented GIS and are still learning how to use it. In: H.J. Scholten; R.van. de Velde; N. Manen (Eds.), *Geospatial Technology and the Role of Location in Science,* pp. 163 – 185,Springer, New York, US. ISBN:978-90-481-2620-0

Zwirowicz-Rythowska, A.; Michalik, A. (2016) - The use of spatial data infrastructure in Environmental Management: an example from the Spatial Planning Practice in Poland. *Environmental Management*, 58(4), 619-635. DOI: https://link.springer.com/article/10.1007%2Fs00267-016-0732-0.

Journal of Integrated Coastal Zone Management / Revista de Gestão Costeira Integrada 20(1):61-78 (2020)
http://www.aprh.pt/rgci/pdf/rgci-n281_Ceregeiro.pdf | DOI:10.5894/rgci-n281

Revista de Gestão Costeira Integrada
Journal of Integrated Coastal Zone Management

Tidal Farm Electric Energy Production in the Tagus Estuary

José Maria Ceregeiro[@,1], Manuel Duarte Pinheiro[2], Francisco Javier Campuzano[3]

[@] *Corresponding author: jmsasceregeiro@gmail.com*
[1] *Instituto Superior Técnico.*
[2] *Instituto Superior Técnico. Email: manuel.pinheiro@tecnico.ulisboa.pt*
[3] *Instituto Superior Técnico. Email: campuzanofj.maretec@tecnico.ulisboa.pt*

ABSTRACT: The exponential population growth and increasing world energy consumption has prompted the World to search for new forms of renewable energy that could curb our dependence on fossil fuels, in order to safeguard the world's environment from the looming threat of climate change. Tidal energy is arguably one of the most promising renewable solutions to replace and diversify part of the energy supply. This is due to the tide's high predictability and technological maturity when compared to other renewable sources, as it is an untapped market with room for development. The main goal of this work is to explore the viability of powering the river-side urban areas, namely Oeiras and Lisbon, through the Tagus' tidal energy. Such is accomplished by modelling the Tagus estuary's hydrodynamics through MOHID – a water modelling software developed by MARETEC, at the Instituto Superior Técnico. Different simulations were made, for different river water discharges throughout the year, so as to determine the behavior of said tidal farm over the course of one year. To simulate the energy production that this solution would generate, two calculation modes were used – one through the use of theoretical equations to predict the energy production of a tidal farm, and the other through the use of MOHID's built-in tool to assess a tidal turbine's energy production. In the end, an economic assessment of such a solution is presented, based on current tidal energy costs.

Keywords: Tidal Energy; Tidal Energy Converter (TEC); Levelized Cost of Energy (LCOE); MOHID; Tidal turbine; Simulation.

RESUMO: O crescimento populacional e o consequente aumento do consumo de energia mundial originou a procura de novas formas de energias renováveis que pudessem reduzir a nossa dependência em combustíveis fósseis, de forma a salvaguardar o Ambiente da ameaça iminente das alterações climáticas. A energia das marés é uma das possíveis soluções para substituir e diversificar parte do fornecimento de energia. Isto deve-se à elevada previsibilidade das marés e da maturidade das soluções tecnológicas existentes quando comparadas com outras fontes de energia renovável, dado que se trata de um mercado inexplorado com espaço para desenvolvimento. O objetivo principal deste trabalho é explorar a viabilidade de alimentação das zonas urbanas ribeirinhas, nomeadamente Oeiras e Lisboa, através da energia das marés do estuário do Tejo, através da modelação do estuário do rio Tejo com o

** Submission: 25 AGO 2019; Peer review: 8 SEP 2019; Revised: 16 MAR 2020; Accepted: 16 MAR 2020; Available on-line:25 MAY 2020*

MOHID, um software de modelação hidrodinâmica desenvolvido pelo MARETEC, no Instituto Superior Técnico. Diferentes simulações foram feitas, para diferentes descargas do rio, para determinar o comportamento de um hipotético parque de turbinas ao longo de um ano. Foram usados dois modos de cálculo para estimar a energia que esta solução produziria – um através do uso de equações teóricas para prever a produção de energia de um campo de aproveitamento de energia das marés, e outro através do uso de uma ferramenta incorporada no MOHID para determinar a produção de energia de uma turbina. No fim, é apresentada uma avaliação económica dessa solução com base nos custos atuais de energia das correntes de marés.

Palavras-chave: Energia das marés; Conversor da Energia das Marés (TEC); Custo Nivelado de Energia (LCOE); MOHID; Turbina de marés; Simulação.

1. INTRODUCTION

The growing human population is putting an increasingly bigger strain on the world's resources, specifically on the amount of fossil fuel that is burned to power our ever-increasing energy needs. This is hailed as being one of the world's most important problems: to generate enough clean energy to guarantee human consumption without harming the environment (Castro-Santos *et al.*, 2015).

The looming threat of climate change has prompted policy makers such as the European Union to adopt targets to limit carbon dioxide emissions and utilize energy from renewable sources in order to curb the environmental impact of our energy needs. However, traditional renewable energy sources such as solar and wind power may not always be available, as they are highly influenced by weather patterns. It is therefore necessary to expand the sources of renewable energies, so as to diversify their origin and thus rely less on fossil fuels to power our energy needs.

By having most of its population within 50 km of the sea, Portugal has a great potential to power urban areas through ocean energy. Tidal power is a largely untapped energy source that is, for the most part, uninfluenced by weather patterns.

Tidal energy can be harvested through tidal stream energy or tidal barriers. This work will mainly focus on the potential of tidal stream energy to power coastal urban areas near the Tagus estuary, since the country's low tidal range of roughly 3 m (Antunes, 2013) renders the application of tidal barrier solutions purposeless (U.S. Energy Information Administration (EIA), n.d.).

Although it is in its infancy, tidal energy has the potential to be a significant renewable energy contributor, as studies indicate that the global theoretical resource is approximately 3 TW, of which 1 TW is harvestable in coastal areas (Kempener and Neumann, 2014).

By having a channel that acts like a choking point, the Tagus estuary has a large potential for the application of tidal current energy solutions, as the water is forced to undergo a converging effect much like the Venturi effect as it goes in-and-out of the estuary due to tidal action, thus generating powerful currents that are capable of electric energy production.

2. TIDAL ENERGY

Tidal energy is a form of hydropower that converts the energy from the natural rise and fall of the tides into electricity. This phenomenon is caused by the combined effects of the gravitational forces exerted by the Moon, the Sun and the rotation of the Earth. This cyclical vertical movement of the sea levels is also accompanied by variable horizontal movements, designated by tidal currents (Owen, 2008).

This pulling effect from both the Moon and the Sun, however, can work in accordance or in opposition to one another, thus resulting in spring tides and neap tides, respectively. The tide's range is at its maximum when all three celestial bodies line up with each other, culminating in higher high tides and lower low tides. Neap tides on the other hand happen when the celestial bodies' gravitational pull alienates each other, causing less extreme tidal variation (Hammons, 2011).

In general, tides are influenced by the Moon's behavior, where the tidal amplitude is influenced by the lunar cycle (29.5 days), while the tidal frequency is influenced by the lunar day (24h50min) and geographical characteristics. Depending on the location of the planet, there can be three main types of tides when it comes to their daily frequency: semidiurnal, mixed and diurnal tides. The tides experienced on the Portuguese coastline (as is for most of the world) are of semidiurnal nature. Semidiurnal tides are characterized by having a tide period of 12h25min, meaning that there are two high-tides and two low-tides every lunar day, as is shown in Figure 1. Tides can also be diurnal, meaning there's only one high-tide and one low-tide per lunar day, or mixed, where high-tides and low-tides have different heights between each other (O Rourke *et al.*, 2010).

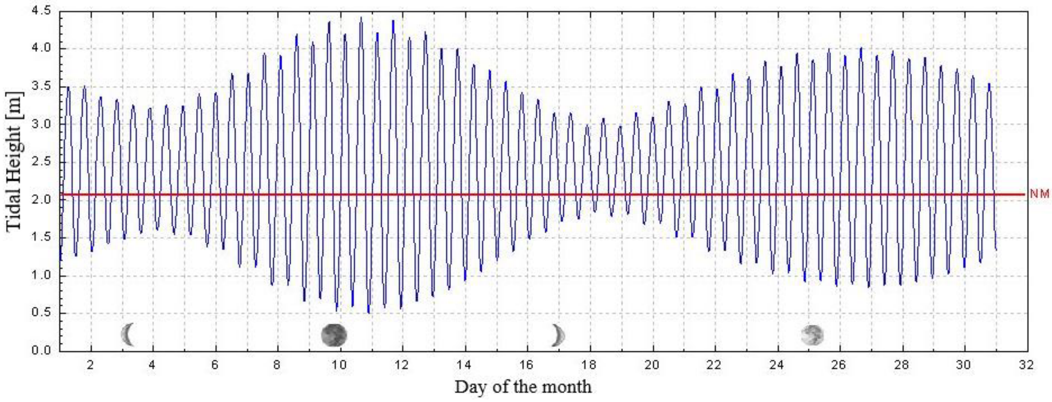


Figure 1. Tidal profile in Lisbon, September 2018 (FCUL, n.d.).

2.1 Technologies

Tidal energy consists of potential and kinetic components, thanks to the elevation in the water level and the resulting currents, respectively. Hence, tidal power technologies can be categorized into two main types: tidal range and tidal current technologies, which take advantage of a tide's potential and kinetic energy, respectively (O Rourke *et al.*, 2010).

2.1.1 Tidal range

Tidal technologies take advantage of the potential energy created by the difference in water levels through the use of tidal barrages. The principles of energy production of a tidal barrage are similar to a dam, except that a tidal barrage is built across a bay or estuary and that tidal currents flow in both directions (O Rourke *et al.*, 2010).

Tidal barrages work primarily by closing its valves once the tide reaches its maximum height, so as to trap the water inside the basin, or estuary. As the tide recedes and it reaches its minimum height, the valves are opened, letting the water flow through hydropower turbines, which keep generating electricity for as long as the hydrostatic head is higher than the minimum level at which the turbines can operate efficiently (Kempener and Neumann, 2014; Prandle, 1984).

However, given that the conventional tidal difference between high-tide and low-tide for the use of tidal barrages is 5-10 m, this renders the application of this solution in Portugal purposeless, as the average tidal difference in Portugal is roughly 3 m (Antunes, 2013). For this reason, this work focuses only on the tidal current potential of the Tagus estuary.

2.1.2 Tidal current

Unlike tidal range technologies, tidal current or tidal stream technologies make use of the tide's kinetic energy, converting it into electricity, in a manner similar to how wind turbines work (O Rourke *et al.*, 2010). The available tidal power [W] of a tidal current is given by the following equation:

$$P = \frac{1}{2}ApU^3 \quad (1)$$

where U is the velocity of the water flow [m/s] through the specific area A [m^2], and ρ is the water density [kg/m^3].

Considering that water is 832 times denser than air, a tidal rotor can be smaller and turn more slowly than a wind turbine, while still delivering a significant amount of power (O Rourke *et al.*, 2010).

Unlike photovoltaic panels or wind turbines, tidal turbines are hardly influenced by weather conditions, which grants them a high predictability. However, there is not one device technology design that trumps above the others as the overall consensual design of what a tidal turbine should look like. As such, TEC devices fall into four main categories.

Horizontal-axis turbines work similarly to wind energy converters, in the way that they exploit the lift that the fluid flow exerts on the blade, forcing the rotation of the turbine that is mounted on a horizontal axis (parallel to the direction of the water flow), which in turn is connected to a generator, converting mechanical energy into electrical energy (World Energy Council, 2016).

Despite resembling wind turbine generators, marine rotor designs must also consider factors such as reversing flows, cavitation and a harsher environment like salt-water corrosion, debris and having to endure greater forces due to the water's higher density (Lewis *et al.*, 2011).

The working principle of Vertical Axis Turbines is similar to the one described above, except that the turbines are mounted on a vertical axis (perpendicular to the direction of the water flow).

Enclosed tips turbines are essentially horizontal-axis turbines that are encased in a Venturi tube type duct. This is made in order to accelerate and concentrate the fluid flow that goes through the turbines, taking advantage of the Venturi effect (World Energy Council, 2016).

Oscillating hydrofoils consist of a blade called a hydrofoil (shaped like an airplane wing) located at the end of a swing arm, which moves up-and-down. This pitching motion is used to pump hydraulic fluid through a motor, which in turn is converted to electricity through a generator (World Energy Council, 2016).

2.2 Tidal Energy Challenges

The deployment of TEC devices can have a wide array of benefits. However, they do not come without drawbacks, and being a relatively new technology means that they have a lot of uncertainties related to them. As such, tidal energy devices need to overcome several challenges in order to become commercially competitive in the global energy market.

The barriers to the development of these technologies can be categorized in: (1) technical barriers, that are inherent to the characteristics of the environment in which the devices are inserted, as the fact that being in water makes them more difficult to maintain, or the fact that salt water has a corrosive effect on materials; (2) environmental issues that can arise from the deployment of TEC devices, such as posing a navigation hazard for vessels; (3) financial, economic and market barriers – since tidal energy is a fairly new technology when compared to more mature technologies such as wind and solar power, funding is proving to be one of the most difficult challenges to overcome, since investors are not interested in high-risk demonstration projects that lack sufficient grid infrastructure, whose primary benefits lie in learning and experience rather than financial returns; (4) political and social barriers, such as public acceptability from coastal communities that tend to be suspicious of new sea-related activities, as they could pose conflicts of interests (Kempener and Neumann, 2014).

Given how horizontal-axis tidal turbines receive 76% of all R&D funding (Corsatea and Magagna, 2014), this work focuses only on the hypothetical deployment of a tidal farm solution composed of said turbines.

Given the wide range of existing energy conversion technologies, it is necessary to develop a standard by which the various technologies can be compared to one another, in order to properly assess the cost of a specific technology. One such standard is the levelized cost of energy, or LCOE.

The LCOE of a given technology is the ratio of total lifetime expenditure over the total lifetime output, or electricity generation, reflecting the average cost of capital. This means that an electricity price above this value yields a greater return on capital, while a price below it would yield a loss on capital (Corsatea and Magagna, 2014; U.S. Energy Information Administration, 2018). The LCOE is therefore given by Eq. (2).

$$LCOE = \frac{Life\ time\ cost\ (€)}{Life\ time\ energy\ production\ (kWh)} \qquad (2)$$

A project's lifetime cost can be grouped into two main generic categories: *Capex* (capital expenditures), that include the initial upfront expenses, and *Opex* (operational expenditures), which are the operation and maintenance costs (O&M) (IEA, 2016). It can be stated that CAPEX costs represent 60% of a tidal farm deployment expenditure, while OPEX costs represent the other 40%, both of which can be broken down by cost category, as is shown in Table 1:

Table 1. Tidal LCOE breakdown by cost category (IEA, 2016; Ocean Energy Systems, 2015).

CAPEX (60%)	%	OPEX (40%)	%
Project development	4	Material costs	7
Grid connection	7	Transport costs	32
Device	29	Labour costs	2
Mooring and Foundation	10	Production losses costs	2
Installation	9	Fixed expenses	57

An early assessment of tidal energy's LCOE (Kempener and Neumann, 2014) placed at-the-time demonstration projects to be in the range of 0.25-0.47 €/kWh, while estimating that this value should be between 0.17-0.23 €/kWh by 2020. A more recent study in tidal energy LCOE, however, forecasts an LCOE of 0.17 €/kWh for a tidal farm deployment of 100 MW, 0.15 €/kWh if it's 200MW and 0.10 €/kWh if it's 1GW, in 2018 (Smart and Noonan, 2018).

This evidence is corroborated by Segura *et al.* (2017) who place an LCOE for a tidal energy project in a non-commercial stage (meaning higher risks and uncertainties) and for current TEC technology at 0.15 €/kWh, with values between 0.12-0.15 €/kWh being predicted.

As such, an LCOE value of 0.15 €/kWh for a tidal farm deployment is assumed for the remainder of this work, for a considered service life of the tidal farm of 20 years, similarly to that of an offshore wind farm (Det Norske Veritas, 2014).

3. MOHID SOFTWARE

MOHID is an open source, three-dimensional water modelling system, developed continuously since 1985 by MARETEC, mainly at the Instituto Superior Técnico (IST) from the Universidade de Lisboa, Portugal.

It is a modular system based on finite-volumes where each module is responsible for the management of a certain kind of information, which in turn will be communicated to other modules and the system will run under a single executable program. At its core is a fully 3D hydrodynamics model which is coupled to modules that handle, among others, water quality, discharges, oil dispersion, atmosphere processes. An important feature is MOHID's ability to run nested models, which enables the study of local areas, by obtaining the boundary conditions from the "father" model. Every model can have one or more nested "child" models, and the number of nested models that a simulation can have is only limited by the amount of the available computing power (MARETEC, n.d.).

The versatility of the modular structure allows for the model to be used in virtually any free surface flow water mass. The MOHID Water model has been applied to many coastal and estuarine areas worldwide and has shown its ability to simulate successfully very different spatial scales from large coastal areas to coastal structures (Campuzano *et al.*, 2017).

The Tagus river Mouth operational model runs the MOHID numerical model in full 3D baroclinic mode with a variable horizontal grid cell resolution of 120x145, ranging from 2 km on the ocean boundary to 300 m around the estuary mouth. The model's vertical discretization consists of a mixed vertical geometry, composed of a 50-layer domain. The first 7 layers from the water surface until 8.68 m deep are of a sigma domain, which are on top of a cartesian domain of 43 layers, with their thickness increasing towards the bottom (Campuzano *et al.*, 2017).

The model's horizontal domain is defined by its bathymetry, where a value is attributed to each one of the grid cells mentioned above. This is arguably the most essential information needed to run any MOHID Water simulation.

As for the remaining boundary conditions, the Tagus river Mouth model has an open boundary on the ocean side, receiving hydrodynamic and ecological forcing from the 3D model PCOMS (Portuguese Coast Operational Model System). On the landward side, the Tagus estuary is forced by the river flow, namely the water discharge of the Tagus, Sorraia and Trancão rivers (Campuzano *et al.*, 2017). Figure 2 highlights the aforementioned domains.

In the atmospheric interface, the model is forced by atmospheric results obtained from a 3 km resolution WRF model application performed by the IST Meteorological team (Campuzano *et al.*, 2017).

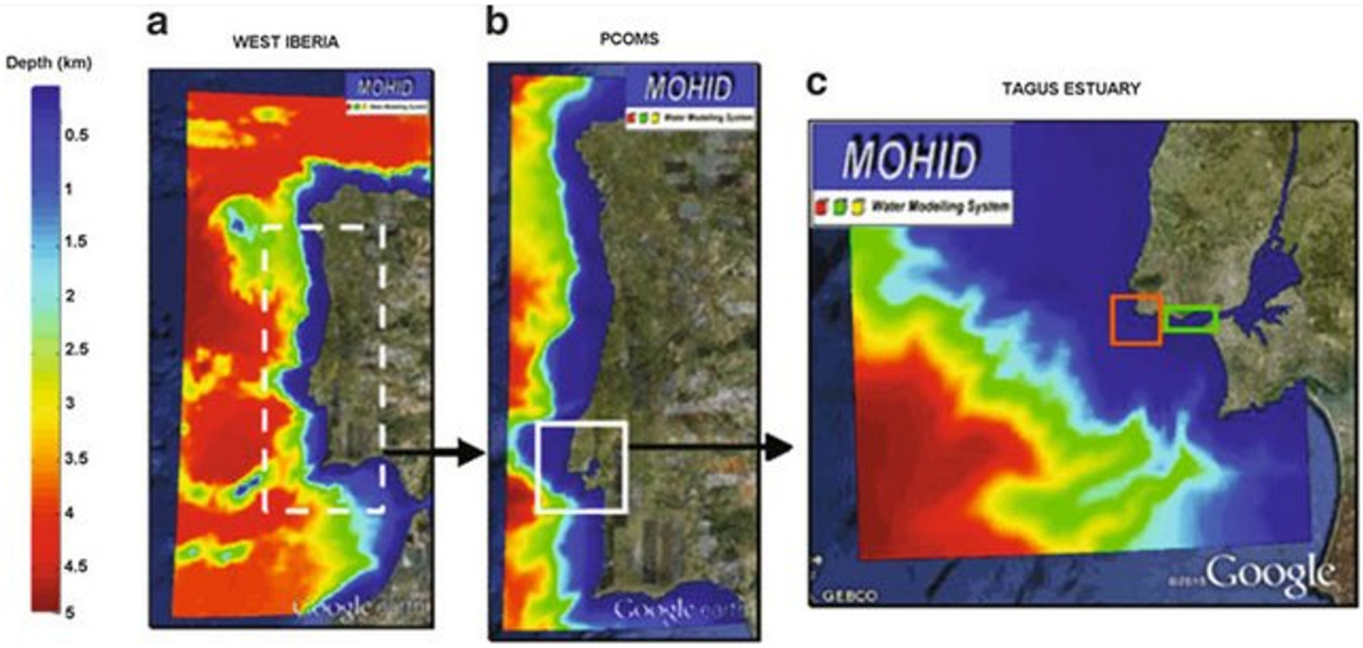


Figure 2. Nested domains used to implement the Tagus model. The domain on the left (a) provides tidal boundary conditions to the PCOMS model (b), which supplies hydrodynamic and bio-geochemical boundary conditions to the Tagus model (c) (Campuzano *et al.*, 2017).

4. CASE STUDY: TAGUS ESTUARY

The Tagus is the longest river in the Iberian Peninsula. Its 1.100 km drain the peninsula's third largest watershed into the Atlantic Ocean, through the Tagus estuary, which is the transition zone between the two (ARH Tejo, 2011).

Morphologically, the Tagus estuary can be divided into four main sections (Portela, 1996), all of which can be visualized in Figure 3. The *fluvial section* is correspondent to the river section that is still influenced by tides, going 30 km inland, with an average width of 600 m; The *upper section* part of the estuary is composed mainly of mudflats, salt marshes and shallow channels that cover 1/3 of the estuary's total area; The *middle section* (or "Mar de Palha") has an average water depth of 5 m; Lastly, the *lower section* is correspondent to a straight and narrow seawater inlet channel about 15 km long and 2 km wide, reaching maximum depths around 45 m. Its narrow nature allows tidal water to undergo a convergence effect similar to the Venturi effect, creating water velocities that make it possible for energy to be extracted, thus making it this work' case study area.

There are two main sources of water inputs into the estuary: fresh water from the rivers and salt water from the tides. The main source of fresh water comes from the Tagus river, which has a mean annual water flow rate of roughly 350 m^3/s, varying seasonally throughout the year with rates typically between 100 and 650 m^3/s (Macedo, 2006). As for other fresh water contributors, Portela (1996) estimates that the Sorraia river's mean annual flow rate is equivalent to around 8.5% of the Tagus' discharge, whereas the remaining effluents have a near negligible flow rate. Figure 4 illustrates the Tagus river average monthly flow rate.

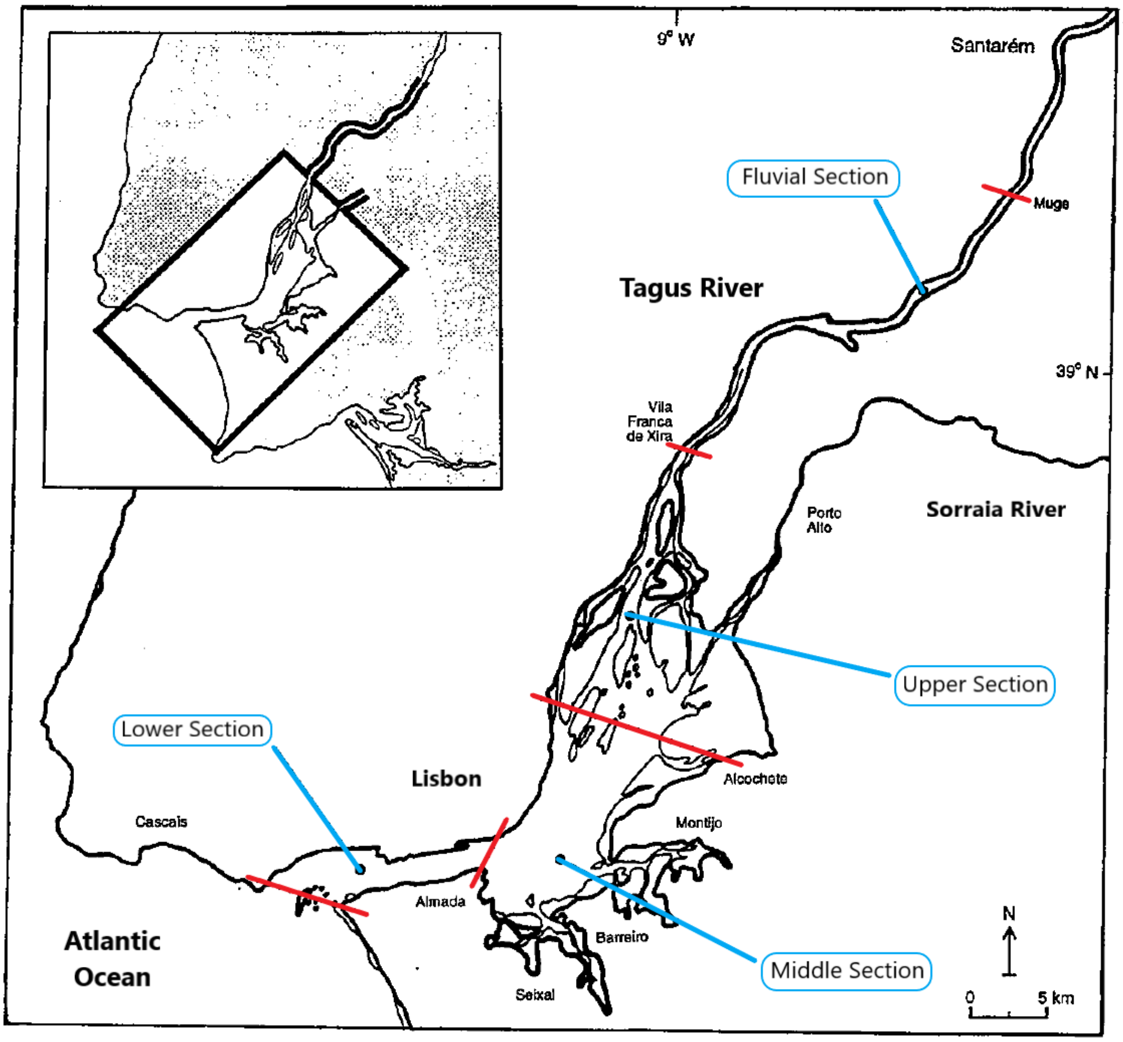


Figure 3. Tagus Estuary (Portela, 1996).

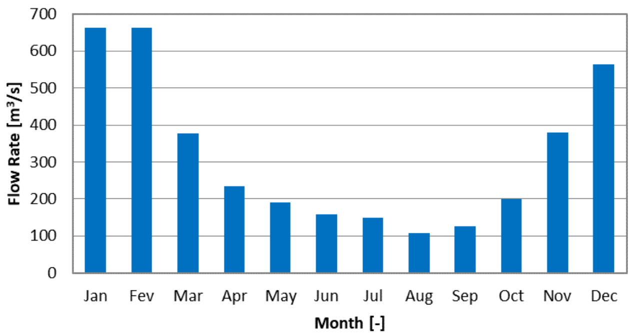


Figure 4. Tagus river average monthly flow rate (1973-2010) (SNIRH, n.d.)

However, the main factor that determines the characteristics of the estuary's hydrodynamic regime is the salt water from the tides. The reason for this is because the average tidal water volume is immense when compared to the estuary's water volume at low tide.

Table 2. Average values for the different tidal reference levels in Lisbon (2010-2018) (Instituto Hidrográfico, n.d.).

Tide		Level (CD) [m]
HAT	Highest Astronomical Tide	4.28
MHWS	Mean High Water Springs	3.86
MHW	Mean High Water	3.43
MHWN	Mean High Water Neap	3.00
MSL	Mean Sea Level	2.20
MLWN	Mean Low Water Neap	1.42
MLW	Mean Low Water	0.98
MLWS	Mean Low Water Springs	0.54
LAT	Lowest Astronomical Tide	0.17

The estuary's water volume at low tide is 1 900 x 10^6 m^3 (ICNF, n.d.). Given that the mean tidal range is roughly 2.45 m, as is shown in Table 2, this means that an additional 600 x 10^6 m^3 of water is added to the estuary during an average high tide (ICNF, n.d.). This makes up to roughly 26 850 m^3/s between tides, which is the reason behind the powerful tidal currents that are generated.

While the monthly variation of tidal amplitudes are fairly constant throughout the year, the same cannot be said about river discharges, with there being much more water flow during the Winter months than the Summer months.

As such, in order to have a general idea of the amount of energy a tidal farm can generate throughout the year, this work contemplates 3 different simulation scenarios:

- Energy production during a Summer month;
- Energy production during an average month;
- Energy production during a Winter month.

Furthermore, the tidal farm energy resource will be assessed in one of two different ways: according to data processing in the Excel, and through the use of a MOHID Module, named TURBINE Module. This comparison will be made so as to determine whether the TURBINE Module that was coded into the MOHID software is a good enough approximation to the industry's guidelines on how to assess tidal turbines energy potential, or not.

4.1 Modelling the MOHID solution

4.1.1 River discharges

The information regarding the Tagus water flow throughout the year can be accessed in the *Sistema Nacional de Informação de Recursos Hídricos* (SNIRH). It shows that the river has a great seasonal variability, which is why three different scenarios of monthly water discharges were adopted, in an effort to simplify the number of simulations to model: the first simulation will consider a continuous water flux of 110 m^3/s, while the second and third simulations contemplate a continuous monthly discharge of 350 m^3/s and 660 m^3/s, respectively. These values are comparable with the river's average Summer month, average month and average Winter month water discharges.

In Figure 5, both the river's average monthly discharge (in blue) and assumed monthly water discharge for simulation purposes (orange) are displayed.

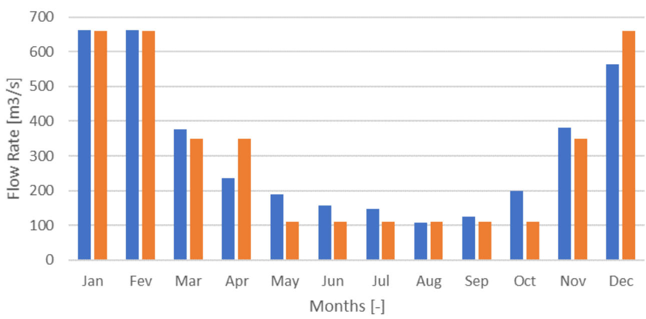


Figure 5. Average Tagus monthly flow rate, 1973-2010.

As for the other freshwater contributors, the Sorraia river's flow rate is adjusted accordingly for each simulation, while other water inputs are considered to be negligible.

4.1.2 Tidal influence

The tidal range found in the area has been obtained from data collected by the tidal gauge located in Cascais. This was done in order to have an overview of the tidal behavior so that it can be modelled as a boundary condition in the MOHID simulation model. As such, one year-long time series was used to investigate the seasonal variability (displayed in Figure 6), as well as the spring-neap tidal cycles in the area.

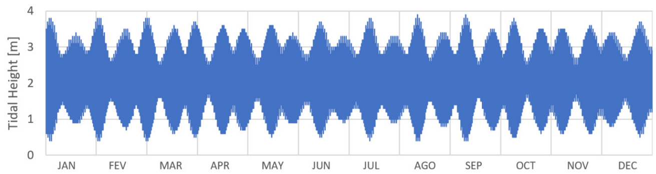


Figure 6 - Tidal height in Cascais during 2018
(Instituto Hidrográfico, n.d.)

Given how the tidal heights caused by the spring/neap cycles remain fairly consistent throughout the year, only the month that is representative of the average tidal range will be considered when modeling the MOHID solution. Table 3 shows each month's average tidal range value.

Table 3 - Tidal range monthly mean values at Cascais.

Month	Mean value (m)	Month	Mean value (m)
January	2.1683	July	2.0817
February	2.1019	August	2.1200
March	2.2217	September	2.1466
April	2.1569	October	2.1196
May	2.1000	November	2.1155
June	2.0621	December	2.0900
Average		**2.1237**	

Monthly tidal range averages show that the month that is representative on the average annual tidal range is August, meaning it will be the one to be used to estimate the average power density during the year. The tidal level profile for the month of August is shown in Figure 7.

The maximum water level variability takes place between the 11th and the 13th, so it is expected for the maximum tidal velocities (and thus the maximum power output) to be reached around those days. Part of this work's analysis will contemplate the differences in a tidal farm's power output throughout the course of one day, for all the different days in one month so as to allow for the prediction of electricity generation in any given moment.

4.1.3 Tidal turbines

Given that no single tidal current technology is currently the 'standard' technology, Legrand (2009) states that a turbine with generic characteristics ought to be used in order to assess the available resources.

When considering the TECs' characteristics, they should follow the following rules (Legrand, 2009):

- A maximum diameter of 20-25m, as that is currently the technological limit of a horizontal axis turbine;
- A minimum top clearance of 5m below the lowest astronomical tide, so as to allow for recreational activities and minimize turbulence and wave loading effects on the TECs, as well as damage from floating materials;
- A minimum bottom clearance of either 5m, or 25% of the water depth (whichever is the greater), to minimize turbulence and shear loading from the bottom boundary layer;
- As for device spacing, the lateral spacing between devices ought to be 2.5 times the rotor diameter (2.5d), whereas downstream spacing should be 10d. The devices should also be positioned in an alternating downstream arrangement.

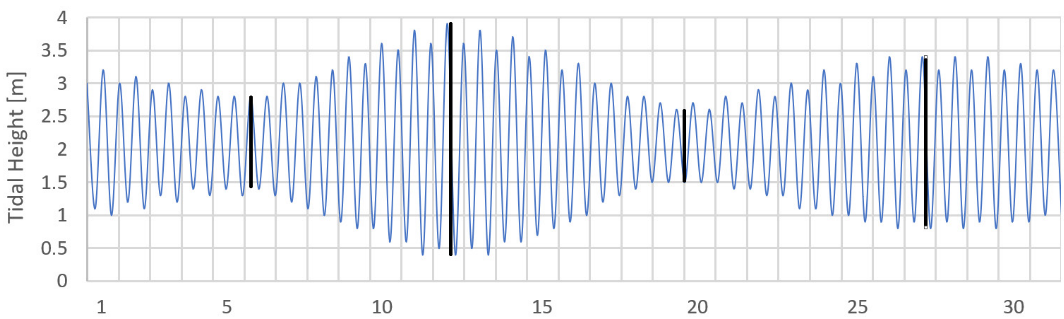


Figure 7. Tidal height in Cascais, during August 2018.

The available kinetic energy of a tidal current was given in Equation (1). However, not all the current's power is susceptible of being transferred to the TEC and transformed in electric energy, as one has to take into account the efficiency of all the mechanisms implicated in that transfer. As such, the power generated by a TEC can be defined as the following:

$$P = \frac{1}{2} A \rho C_P \eta_{PT} U^3 \qquad (3)$$

Where η_{PT} is the powertrain efficiency (generator power/rotor power) and C_p is the rotor power coefficient.

The rotor power coefficient represents the ratio of actual electric power produced by a turbine divided by the total water current power flowing through the turbine at any given current speed. The theoretical maximum rotor power coefficient is given by the Betz's Law. It states that no turbine can convert more than 16/27 (0.593) of the kinetic energy of the current into mechanical energy by turning a rotor (Manwell *et al.*, 2009).

According to Legrand (2009), the rotor power coefficient can be considered to rise linearly from 0.38 at cut-in velocity to 0.45 at the rated velocity. While the former is the minimum velocity required for device operation (necessary to produce the torque needed to rotate the rotor), the latter is the current velocity at which the power output reaches the limit that the electrical generator is capable of.

As for the turbine's powertrain efficiency, it is the efficiency at which a turbine converts mechanical energy into electrical energy, and it is determined by the rotor efficiency, the generator efficiency and the electrical grid efficiency. All in all, the average powertrain efficiency can be considered to be 90% (Legrand, 2009).

4.2 Data analysis

The first thing to consider when determining the best suited areas for implementing a tidal farm is assessing where the greatest energy potential is. In order to do so, the modelled simulation of the estuary with all the parameters mentioned beforehand was run for the three different scenarios of water flow, displayed in Figures 8 to 10.

In order to assess the locations with the highest energy potential, the fifty areas (model cells) with the highest energy density were highlighted, as shown in Figure 11.

The highlighted points remain largely unchanged for the other two simulations (Summer and Winter river discharges). Thus, there is a general trend between the three simulations that the locations with the highest energy potential are located within the regions of Oeiras, Belém and Cais do Sodré.

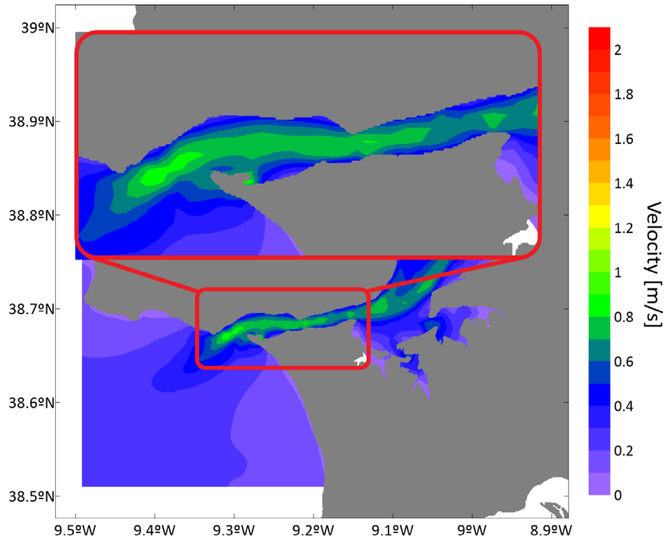


Figure 8. Average water velocity for Summer flow rate simulation.

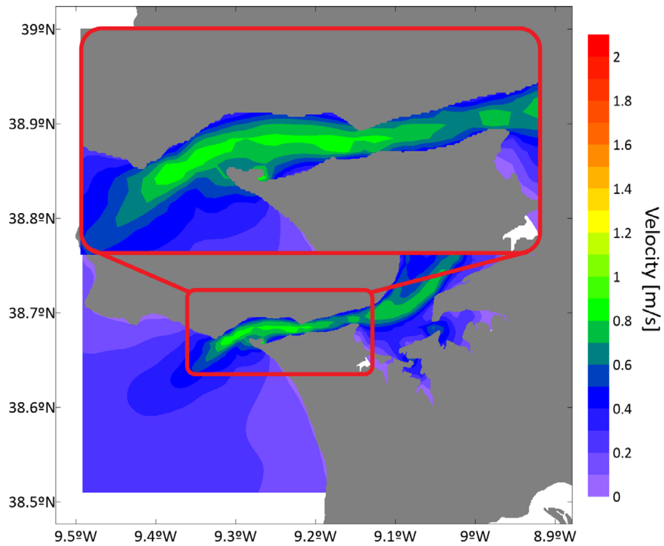


Figure 9. Average water velocity for average flow rate simulation.

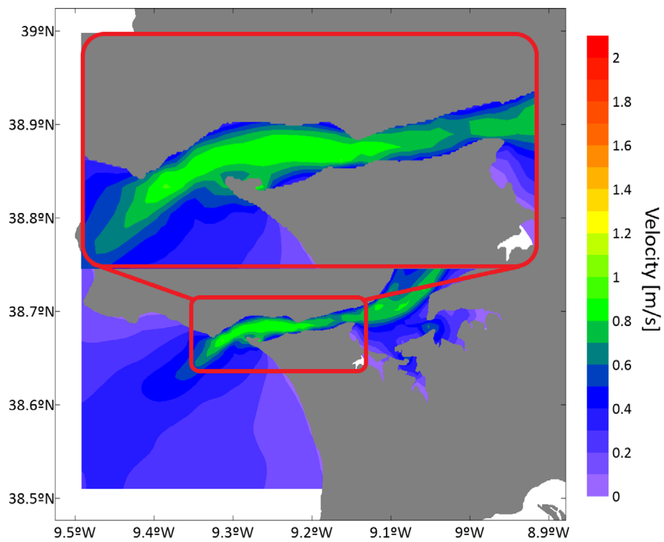


Figure 10. Average water velocity for Winter flow rate simulation.

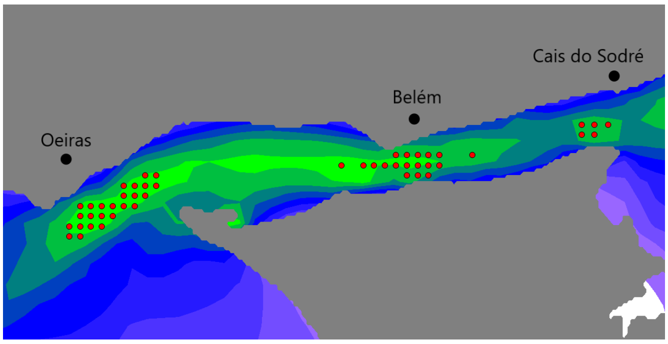


Figure 11. Fifty areas (model cells) with the highest energy density during the average monthly flow rate simulation.

It is worth mentioning that the water channel that connects the Atlantic Ocean to the Tagus estuary is a vital waterway with a large economic importance to the city of Lisbon, as it allows the access of vessels such as cruise ships and cargo ships, which dock in Lisbon's Port. As such, a mandatory approach channel that is 250 m wide (to allow for two-way vessel traffic) has been set, as shown in Figure 12.

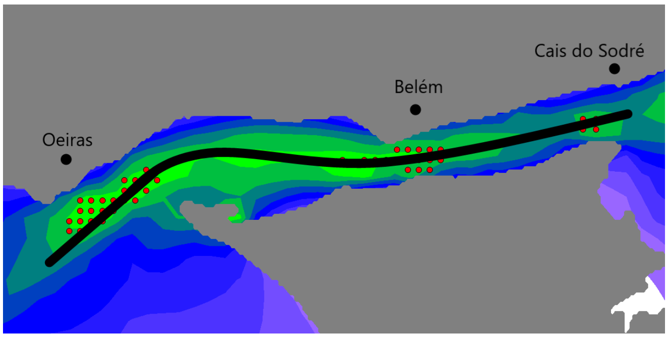


Figure 12. Port of Lisbon's approach navigation channel.

Given the turbines' necessary top clearance of 5 m, other minor vessels such as traffic passenger ships, water-taxis, yachts and recreational ships don't pose a threat to a potential tidal farm, as their draught is usually well below 5 m. Therefore, two energy-production assessments will be made:

- Assuming there are no limits within the estuary channel where a tidal farm could be placed;
- An exclusion zone made of the port's approach channel is taken into account, where a tidal farm cannot be built due to the movement of ships, which rules out several potential sites for implementing a tidal farm.

The comparison between these two assessments is done in order to compare the maximum theoretical energy that a turbine placed in the channel would produce, with the energy produced by a turbine placed in an area that does not interfere with the port's activity. In both assessments, the area used to calculate the energy produced by a turbine is the one with the highest energy potential available in each of the three regions. The selected areas are presented in Figure 13, where the points highlighted in red represent the areas with the maximum theoretical energy potential, and the ones in blue represent the areas with maximum energy potential when taking into account an exclusion zone brought by the port's approach channel.

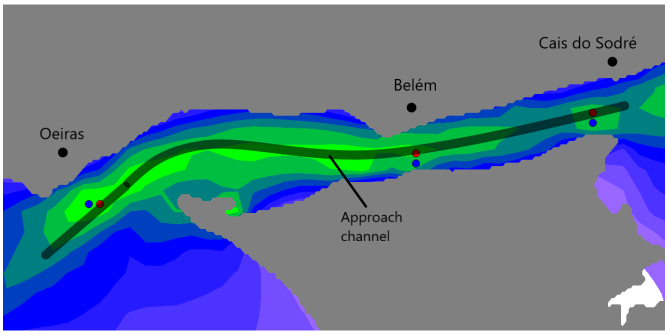


Figure 13. Assessment areas.

4.2.1. *Placement of the turbines*

Thanks to the boundary shear stress caused by the bottom friction of an open channel, the water velocities will differ over the water depth of each specific area. Considering that tidal turbines are submerged devices, this makes it necessary to determine the vertical distribution of the water velocity on the highlighted areas of interest.

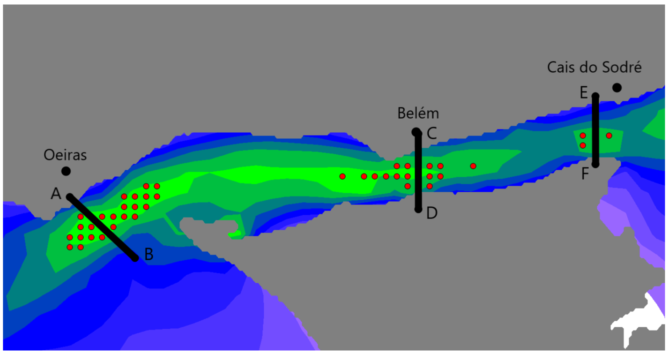


Figure 14. Cross-sections of the regions of interest.

Consequently, three cross sections of the channel were made, in order to visualize the spatial distribution of the average power density per square meter in the regions of interest, for the average flow rate simulation, as shown in Figure 14. This was achieved by inputting the water velocity field values in Equation (1). The results are shown in Figures 15, 16 and 17.

It is easily discernable that there is an area roughly 8-12 m below the sea-level with a high power density, in all three regions of interest. As such, this is seen as the optimal depth at which to place the turbine axis, in order for the turbine to harness the largest amount of energy possible.

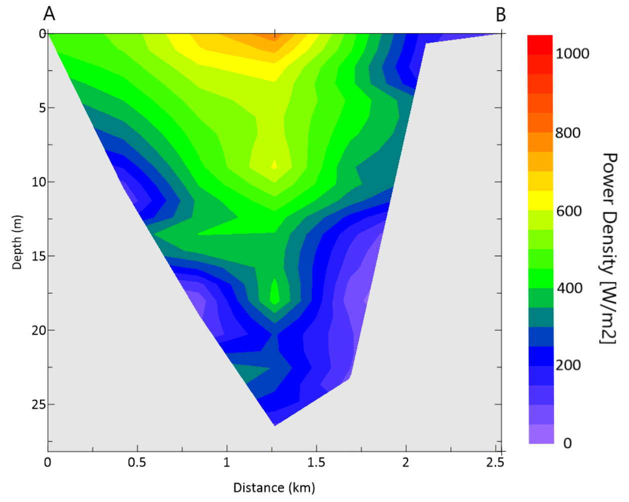


Figure 15. Variation of power density per square meter in Oeiras region.

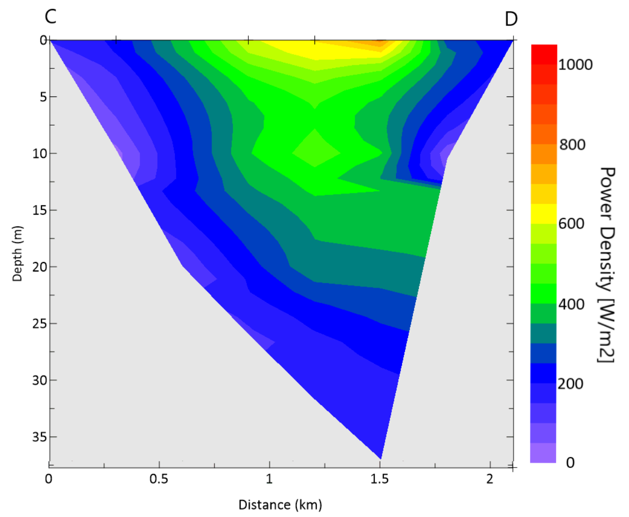


Figure 16. Variation of power density per square meter in Belém region.

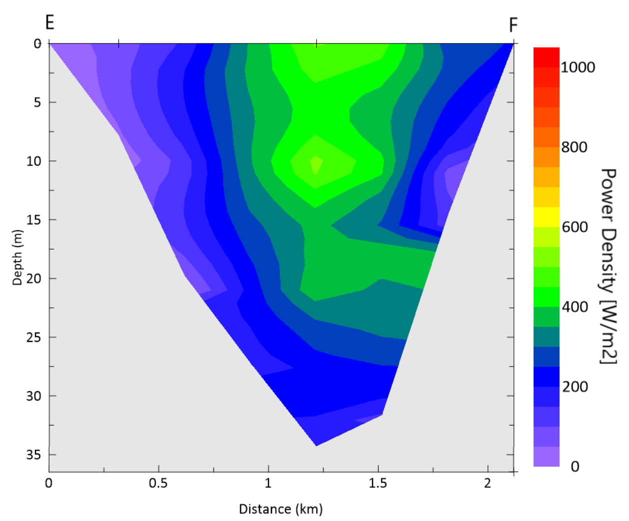


Figure 17. Variation of power density per square meter in Cais do Sodré.

4.2.2. Assessment of the rotors' dimensions

It has already been established, in subchapter 4.1.3, that the diameter of current tidal turbines is limited to 20-25 m, and that they require a 5-meter top clearance and a bottom clearance of 25% of the water depth (or of 5 m, depending on which value is larger).

Table 4 defines the maximum theoretical diameter that a turbine could have in each of the different areas of interest, based on the limitations mentioned above.

Table 4. Maximum theoretical rotor diameter [m] for each area.

	Without Channel	**With Channel**
Oeiras [m]	**14.87**	**11.87**
Water depth [m]	26.50	22.50
Bottom clearance [m]	6.63	5.63
Belém [m]	**18.77**	**22.75**
Water depth [m]	31.70	37.00
Bottom clearance [m]	7.93	9.25
Cais do Sodré [m]	**20.72**	**18.70**
Water depth [m]	34.30	31.60
Bottom clearance [m]	8.58	7.90

Although the different locations have different sized turbines, this isn't necessarily a desirable solution, because rotors could start reaching into velocity fields that aren't necessarily relevant, energy density wise. Another argument against having a different-sized turbines solution is the fact that economies of scale would be lost, adding to the complexity and cost of implementation of such a solution, not only in terms of acquisition of the devices, but also in terms of their maintenance.

As such, this work considers a 15-meter wide tidal turbine for most assessments, except for the Oeiras zone assessment with an exclusion zone. For this case in particular, a 10-meter wide tidal turbine will be considered, due to water depth limitations.

4.2.3. Assessment of velocity fields encompassed by the turbines

Considering the dimensions of the turbines, it is easy to see that the rotors will be subject to various different current velocities, from various different layers in the modelling simulation.

It was previously mentioned in subchapter 3.1 that the model's vertical discretization consists of a mixed vertical geometry, composed of a 50-layer domain. The first 7 layers from the water surface until 8.68 m deep are of a sigma domain, which are on top of a cartesian domain of 43 layers, with their thickness increasing towards the bottom.

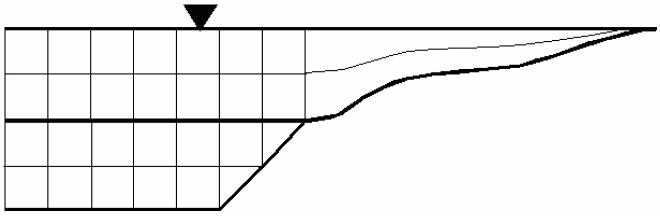


Figure 18. Example of the subdivision of the water column in a Sigma domain (upper 2 layers) and a Cartesian domain (bottom 2 layers).

Given the turbine placement's upper and lower restrictions, their horizontal axis is to be placed at a depth of 12.5 m and 10 m, for the 15 m and 10 m diameter turbines, respectively. This is done so in order to allow for a top clearance of 5 m and in order for the turbines to encompass the layers with the highest velocity fields, as determined in 4.2.1.

Knowing the depth at which to place the turbines and the rotor's diameter, one can assess a turbine's swept area in each model layer by using the following equation,

$$A_{Tk} = \frac{r^2}{2}\,\theta - r\ .\ \sin\frac{\theta}{2}\ .\ d - \sum_{k=1}^{k} A_{Tk-1} \tag{4}$$

where A_{Tk} represents the turbine's swept area in layer *k*. As such, the values for *U* in equation (3) are calculated as:

$$U_{AV} = \frac{\sum_k A_{Tk}\ .\ U_k}{\sum_k A_{Tk}} \tag{5}$$

where U_{AV} is the average modulus velocity [m/s] of the *k* layers in the cell of (i,j) coordinates that contains the turbine.

In order to determine the mean annual electrical power produced by a tidal turbine, a histogram analysis for the tidal current speed going through a turbine was carried out. The analysis has been performed by using an interval of 1 hour and a bin size of 0.1 m/s, so as to obtain the percentage of time at which the velocity falls within each bin. The results are shown in Figures 20, 21 and 22.

5. ANALYSIS AND DISCUSSION OF RESULTS

5.1. Annual Energy Production (AEP)

Once the velocity distribution in the area of interest has been estimated, it can be applied to a TEC's power curve, in order to calculate its annual energy output. Since no specific TEC device has been chosen, a generic device will be used for this purpose.

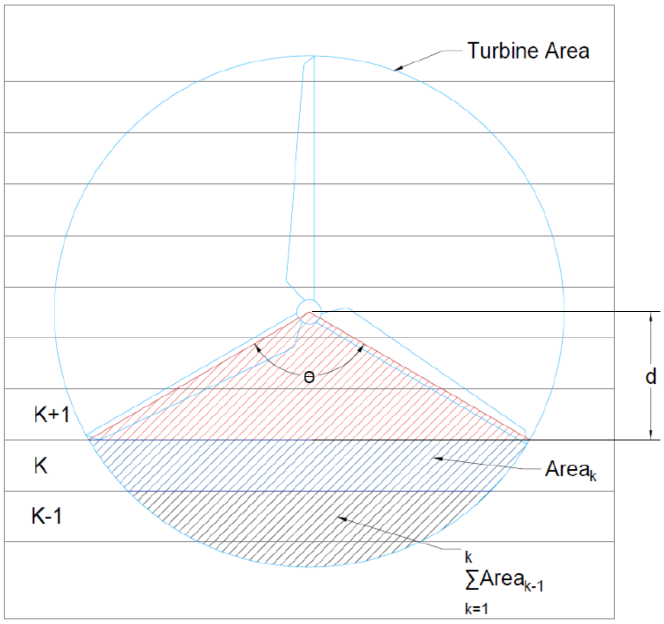


Figure 19. Vertical discretization of the turbine area (Balsells Badia, 2017).

It's already been established that a turbine's rotor power coefficient rises linearly from 0.38 at cut-in-velocity to 0.45 at rated velocity. According to Legrand (2009), a turbine's cut-in-velocity can be considered 0.5 m/s, while its rated velocity (current velocity at which the power output reaches the limit that the electrical generator is capable of) can be taken as 71% of the Mean Spring Peak Velocity (V_{msp}), which is the peak tidal velocity observed at a mean spring tide. Table 5 illustrates each assessment area's rated velocity.

Table 5. Regions' rated velocities (RV) in both assessments.

	Oeiras		Belém		Cais do Sodré	
	without channel	**with channel**	**without channel**	**with channel**	**without channel**	**with channel**
[m/s]	2.2	2.2	1.9	2.0	2.0	1.8
RV [m/s]	1.56	1.56	1.35	1.42	1.42	1.28

All the parameters necessary to assess the electrical power generated by a tidal turbine over the course of one year have now been determined. Table 6 presents the calculation of the electrical power and of the mean annual electrical power (AEP) for each velocity bin used in the velocity distributions computation for the Oeiras region without considering an approach channel. The rotor diameter considered here is of 15 m, meaning the turbine has a swept area of 177 m^2.

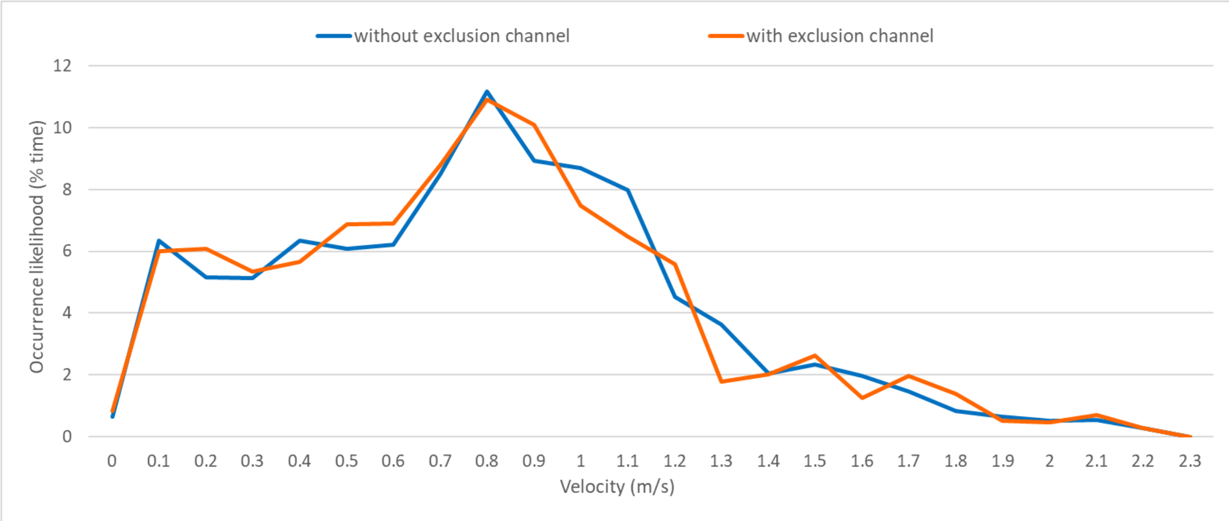


Figure 20. Water velocity distribution in Oeiras turbines.

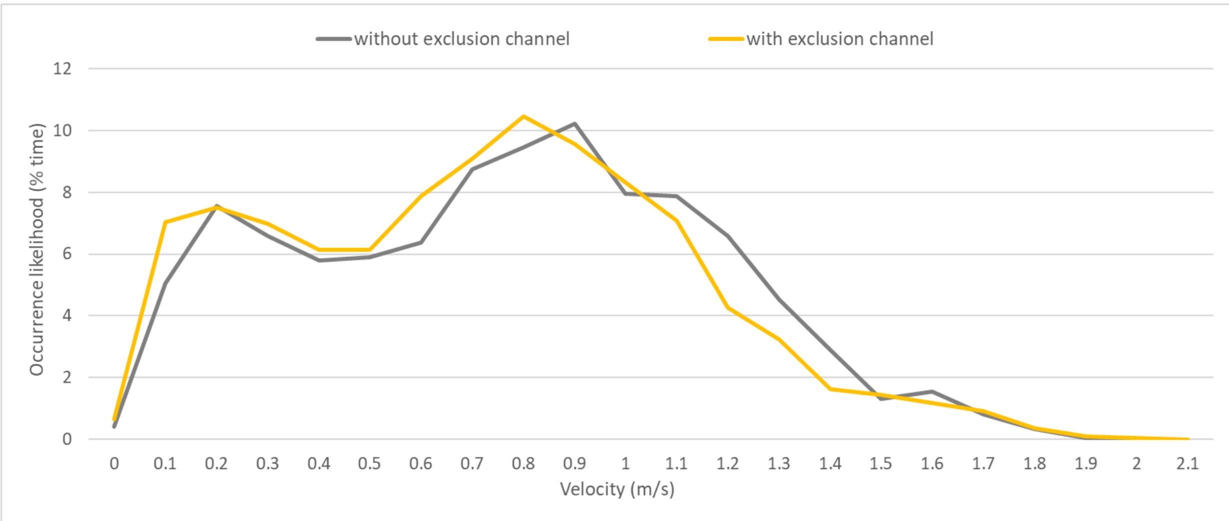


Figure 21. Water velocity distribution in Belém turbines.

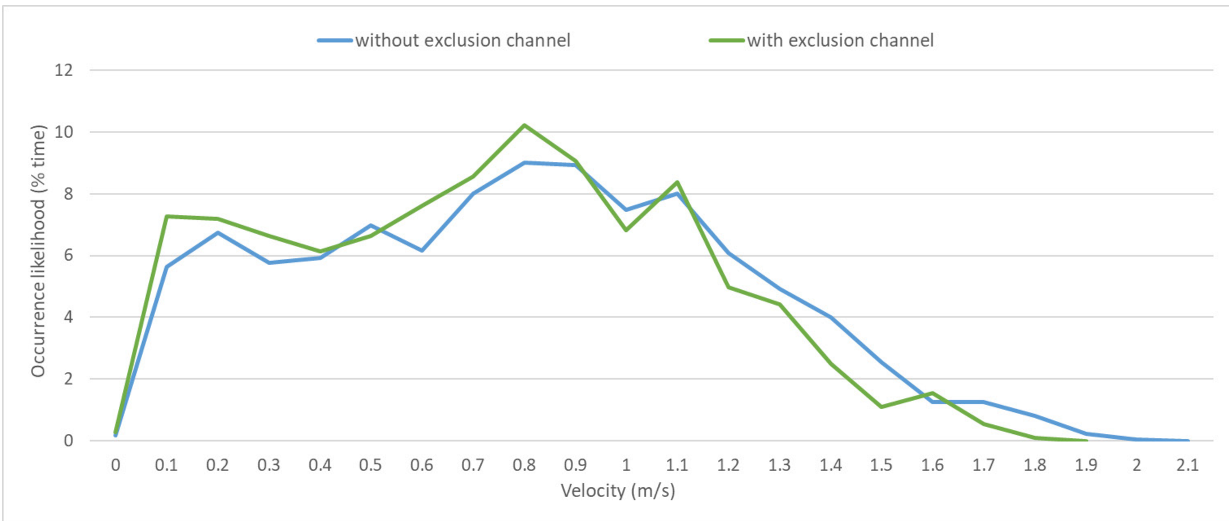


Figure 22. Water velocity distribution in Cais-Sodré turbines.

Table 6. Mean AEP [kW] for Oeiras, without approach channel.

Velocity bin	Occurrence likelihood	Available power	Rotor power coefficient	Electrical power per bin	Mean AEP/bin
[m/s]	[%]	[kW]	[-]	[kW]	[kW]
0	0.64	0.00	0	0.00	0.00
0.1	6.34	0.09	0	0.00	0.00
0.2	5.17	0.72	0	0.00	0.00
0.3	5.13	2.45	0	0.00	0.00
0.4	6.34	5.80	0	0.00	0.00
0.5	6.07	11.32	38	4.30	0.26
0.6	6.21	19.56	39	7.56	0.47
0.7	8.52	31.06	39	12.21	1.04
0.8	11.17	46.37	40	18.54	2.07
0.9	8.93	66.02	41	26.83	2.39
1.0	8.69	90.57	41	37.40	3.25
1.1	7.99	120.54	42	50.57	4.04
1.2	4.53	156.50	43	66.69	3.02
1.3	3.62	198.97	43	86.10	3.12
1.4	2.05	248.51	44	109.18	2.23
1.5	2.35	305.66	45	136.30	3.20
1.6	1.98	370.96	45	155.32	3.08
1.7	1.48	444.95	X	155.32	2.29
1.8	0.84	528.18	X	155.32	1.30
1.9	0.64	621.19	X	155.32	0.99
2.0	0.50	724.53	X	155.32	0.78
2.1	0.54	838.73	X	155.32	0.83
2.2	0.27	964.35	X	155.32	0.42
					34.80 kW

As such, a 15m diameter turbine placed in the highest energy density area of the Oeiras region has a mean annual electrical power of 34.80 kW. As for the annual energy production (AEP) of said turbine, it can be obtained by multiplying the P_{mean} computed above by the available hours per year and the powertrain efficiency, as follows:

$$AEP = 8760 \cdot \eta_{PT} \cdot P_{mean} \tag{6}$$

Considering a powertrain efficiency of 90% and that a year has 8760 hours, the turbine's AEP is roughly 274.4 MWh.

The same assessment was done for all other areas of interest, and the results for their AEP are presented in Table 7.

5.2. Monthly Energy Production (MEP)

Although knowing a turbine's AEP is important, it is also relevant to know how this electric energy is produced throughout one month. As such, instead of grouping the velocity data into different velocity bins, the water velocity values were used directly in Equation (3).

Table 7. AEP for a single turbine in the different areas.

	Oeiras		Belém		Cais do Sodré	
	without channel	with channel	without channel	with channel	without channel	with channel
Rotor ø [m]	15	10	15	15	15	15
[kW]	34.80	15.06	28.94	25.52	32.83	25.48
AEP [MWh]	274.37	118.69	228.18	201.20	258.83	200.84

Figure 23 shows the variation in the current velocity through the turbine in the area with the highest energy in the Oeiras region, for the different simulated months:

It is easily discernable that the different river discharges have very little impact on the current velocities that occur during the spring tides, as they pale in comparison to the water input from the tidal action. The same cannot be said during neap tides, as river discharges have a greater ponderosity in the water that builds up in the estuary, meaning higher current velocities during the Winter months.

When putting these values through Equation (3), and attending to the resulting rotor power coefficient, one can assess the turbine's power generation at any given instance during the month, resulting in Figure 24.

It can be concluded that the only instances where the turbine reaches its rated velocity is during the spring tides, as there is a limit to how much power a turbine can produce. It is also easily discernable from this figure that the amount of energy produced by a turbine in the Tagus estuary remains largely unchanged over the course of the year, as a Winter month doesn't produce that much more energy than a Summer month. Cumulatively, this amounts to roughly 22.93 MWh during a Summer month, 23.26 MWh during an average month, and 23.97 MWh during a Winter month. By assuming that a year is composed of 6 Summer months, 3 average months and 3 Winter months, one can also estimate the turbine's AEP, with the results shown in Table 8.

The reason why the AEP values are slightly more conservative than the one's determined in 5.1, is that in that assessment, the current velocities were grouped into velocity bins which can give rise to inaccuracies due to rounding.

5.3. AEP comparison with Module Turbine

In order to determine if MOHID's recently coded module, named Module Turbine, is a good approximation to the industry's guidelines way of assessing a tidal turbine's energy production, a 4th simulation was also computed.

The differences reside with the fact that this Module: (1) considers a constant rotor power coefficient, instead of

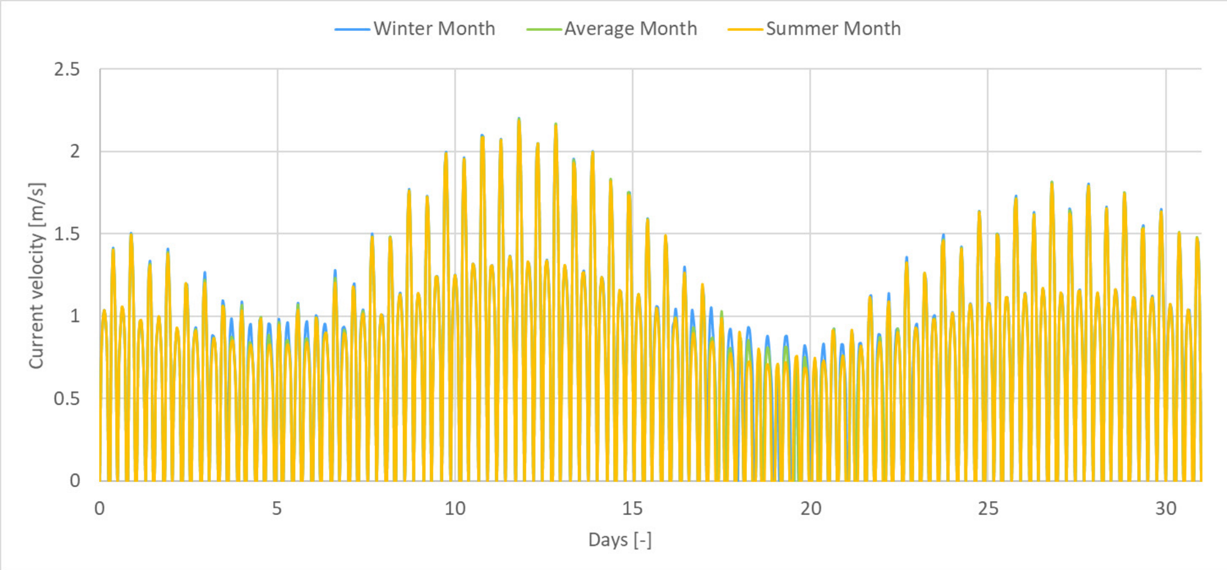


Figure 23. Water velocity through the turbine in the highest energy dense region in Oeiras.

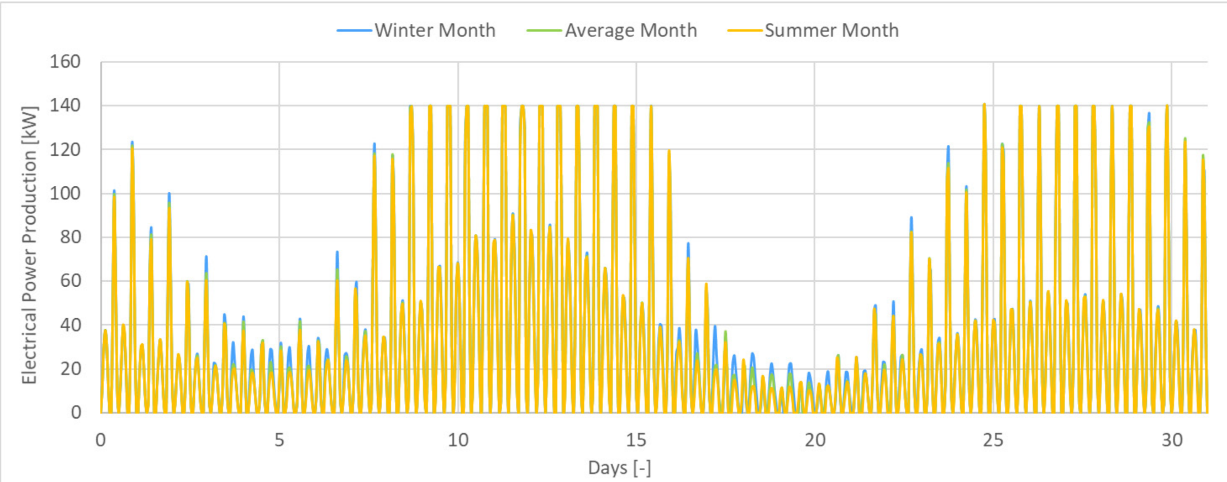


Figure 24. Turbine's energy output throughout the month.

having it rise linearly; (2) it assumes a security factor of 15% of the cut-in-speed (meaning once the rotor is spinning, it will only stop once the current velocity falls below 0.85 times the cut-in-speed); and (3) doesn't take into account the turbine's powertrain efficiency.

This simulation had the exact same specifications as the one for the month with the average river discharge, so as to offer a point of comparison between the two. The difference here is that 6 turbines were placed in the simulation model: one for each of the areas of interest. All of them have the exact same specifications as the ones in the turbines determined above, in terms of location, diameter, cut-in speed, rated velocity and depth at which they are placed.

The sole difference in the turbine's characteristics, is that they were set to have a constant rotor power coefficient of 0.40 from the cut-in speed, to the rated velocity.

Given that only an average water discharge month was simulated this time, the turbine's AEP was calculated considering that one year consists of 12 average water discharge months, instead of the previous assumption of it being composed of 6 Summer months, 3 average months and 3 Winter months. Table 9 compares the results obtained in both methods.

It is clear that the Module Turbine that was coded into MOHID offers, for most situations, a good approximation to a turbine's electrical energy production, even without taking into account the powertrain efficiency. Where it falls short is when the assessment is made in less energy dense locations. One possible explanation for this is the fact that the turbine's electrical output is stifled by the imposition of a fixed value for the rotor power coefficient, whereas this value varies from 0.38 to 0.45, according to the previous assessment.

Table 8. MEP for one turbine in different assessment areas.

Region	Assessment (Turbine ø)	Simulation	MEP [MWh]	AEP [MWh]
Oeiras	without channel (15m)	Summer	22.93	279.30
		Average	23.26	
		Winter	23.97	
	with channel (10m)	Summer	9.86	120.64
		Average	10.10	
		Winter	10.39	
Belém	without channel (15m)	Summer	18.49	232.54
		Average	19.71	
		Winter	20.82	
	with channel (15m)	Summer	16.41	204.26
		Average	17.30	
		Winter	17.97	
Cais do Sodré	without channel (15m)	Summer	21.18	261.86
		Average	22.19	
		Winter	22.75	
	with channel (15m)	Summer	16.64	203.45
		Average	17.08	
		Winter	17.46	

Table 9. Comparison of the AEP assessed for both methods.

	Oeiras		Belém		Cais do Sodré	
	without channel	with channel	without channel	with channel	without channel	with channel
AEP [MWh]	274.95	111.08	239.18	137.91	255.28	173.88
AEP (5.2)	279.11	121.18	236.50	207.64	266.24	205.00
%	98.51	91.66	101.13	66.42	95.88	84.82

5.4. AEP of a potential tidal farm

When considering the fact that the grid cell size on the simulation model is roughly 300x300m, one can determine how many tidal turbines can be fit in such an area, when looking at the turbines' characteristics, described in 4.1.3. Table 10 shows the number of turbines that can be placed in each area, as well as their cumulative energy production.

Table 10. Tidal farm AEP.

	Oeiras		Belém		Cais do Sodré	
	without channel	with channel	without channel	with channel	without channel	with channel
Turbine ø [m]	15	10	15	15	15	15
Cell size [mxm]	300x300	300x300	300x300	300x300	300x300	300x300
Number of turbines	24	48	24	24	24	24
AEP [GWh]	6.58	5.70	5.48	4.83	6.21	4.82

When considering a tidal farm solution that does not interfere with the Port of Lisbon's activity, one can conclude that a 48-turbine tidal farm solution placed in Oeiras can meet 44% of the county's entire electricity use in order to power the streetlights, as the total consumption sits at 13.11 GWh annually (PORDATA, n.d.-a). As for the city of Lisbon, the other two tidal farms (placed where the Lisbon Port's activities aren't interfered with) can meet 15% of the city's 66.09 GWh electric energy use to power the streetlights (PORDATA, n.d.-a). Alternatively, these solutions would power roughly 2600 and 4300 houses annually, respectively.

5.5 Tidal farm economic analysis

When considering the LCOE value of 0.15 €/kWh determined beforehand, it would cost roughly €16.8 million over the course of 20 years in order to implement the average considered tidal farm in the Tagus estuary (24-turbine tidal farm array with d=15m producing 5.6 GWh/annually). This cost can be further broken into CAPEX and OPEX costs, based on what was said in 2.2.1. which are highlighted in Table 11.

Table 11. LCOE breakdown of average tidal farm in Tagus.

Cost Category	Total Cost
CAPEX [€]	10.080.000
Project development [€]	672.000
Grid connection [€]	1.176.000
Devices [€]	4.872.000 (€203.000/turbine)
Moorings and foundation [€]	1.680.000
Installation [€]	1.512.000
OPEX [€]	6.720.000
Material costs [€/year]	23.520
Transport costs [€/year]	215.040
Labour costs [€/year]	6.720
Production losses costs [€/year]	6.720
Insurance/Fixed expenses [€/year]	191.520

Considering the fact that Portugal's energy supply cost sits at 0.22 €/kWh (PORDATA, n.d.-b), this makes the tidal farm solution in the Tagus estuary (with its LCOE of 0.15 €/kWh) to have an expected breakeven point after 11.25

years, making it a legitimate alternative to power a good part of a nearby county's electricity consumption in order to illuminate the public streets. At the end of the project's life cycle, it would amount to a €7.84 million profit.

6. CONCLUSIONS

It is now more important than ever to diversify our energy sources, since humanity depends too much on fossil fuels to power its needs, and solutions like wind and solar power are dependent on the weather. Tidal power, however, is cyclical and can be predicted to a degree of months in advance.

It has been shown that a small tidal farm composed of only 24 turbines over an area 300x300 m in one of Tagus' river most energy density areas (while considering a vessel approach channel) is able to power on average 2 400 homes for a period of 20 years. Such a project is predicted to cost €16.8 million and it would remove the equivalent of 29 thousand tons of CO_2 emissions from the atmosphere.

Being in close proximity to the power grid and to several ports that can be used to aid in O&M services makes the Tagus estuary an ideal location to implement a tidal farm, as these would imply lesser costs and logistics in order to maintain such an infrastructure. Its close proximity to the power grid also translates into a less extensive underwater power cable, further reducing the tidal farm's CAPEX costs.

It has also been shown that the Module Turbine that was coded into the MOHID software is a good approximation to the industry's guidelines of a tidal turbine's electrical energy output, based on a location's hydrodynamic characteristics, namely the water current speed. This proves that using it in a MOHID simulation model for assessing any area of interest's energy potential will provide with a good estimate of the amount of electrical energy that a tidal farm would generate, if it were placed there.

This study doesn't come without its limitations, however, such as the fact that it doesn't consider the energy output of a specific tidal turbine, but rather a generic, bi-directional one, meaning it may not be entirely representative of the estuary's potential. Another limitation comes in the form of the simulation model itself, both in terms of its resolution (300x300 m) and also the output data time (one hour), as these aren't entirely representative of the estuary's resources. Another thing that was lacking was the consideration of multiple turbines in the simulation for a single cell. This stems from the fact that the way the Turbine Module was computed means that there can only be one turbine per cell.

Following the study carried out, some opportunities and suggestions for the making of future works are presented, in order to complement and develop upon the results obtained in this study.

With respect to the simulation model itself, it would benefit from having not only a higher grid cell resolution, but also from outputting data in more instances, in order to have a clearer picture of a site's hydrodynamics and energy potential. This can be easily solved through the use of a higher-resolution nested model in the simulation model used and by setting a lower output time so as to get more time instances from the simulation model. The assessment made would also benefit from determining the dynamics of multiple tidal turbines together, so as to see the influence they have on each other's energy production. Another interesting variation would be the use of a specific tidal turbine technology – hopefully one that has already been developed and is higher up on the readiness scale. That could add to the validation of a feasibility of the implementation of such a technology in settings beside urban environments, such as the Tagus estuary is to the city of Lisbon.

Finally, the Module Turbine that was coded into the MOHID software can be perfected into mimicking better a tidal turbine's reaction to a water current, namely taking into account the powertrain efficiency and considering a variating rotor power coefficient, based on the water current velocity. Such improvements would likely result in a more trustworthy result for a tidal turbine's electric energy output potential, on a specific assessment site.

REFERENCES

Antunes, C. (2013). *Caracterização do regime de marés* (p. 18). Faculdade de Ciências da Universidade de Lisboa (FCUL). https://sniambgeoviewer.apambiente.pt/Geodocs/geoportaldocs/Politicas/Agua/Ordenamento/SistemasMonitorizacaoLitoral/E_1.1.3.a_Regime_mares.pdf

ARH Tejo. (2011). *Plano de Gestão da Região Hidrográfica do Tejo* (p. 493). Ministério da Agricultura, Mar, Ambiente e Ordenamento do Território. https://www.apambiente.pt/_zdata/Politicas/Agua/ParticipacaoPublica/Documentos/ARHTejo/PGRH/2_PGRHTejo_versoextensa.pdf

Balsells Badia, Ó. (2017). *Implementation of the effect of turbines on water currents in MOHID Modelling System* [Instituto Superior Técnico]. https://upcommons.upc.edu/handle/2117/112828

Campuzano, F. J., Juliano, M., Sobrinho, J., dePablo, H., Brito, D., Fernandes, R., and Neves, R. (2017). Coupling Watersheds, Estuaries and Regional Oceanography through Numerical Modelling in the Western Iberia: Thermohaline Flux Variability at the Ocean-Estuary Interface. *Estuary*. https://doi.org/10.5772/intechopen.72162

Castro-Santos, L., Garcia, G. P., Estanqueiro, A., and Justino, P. A. P. S. (2015). The Levelized Cost of Energy (LCOE) of wave energy using GIS based analysis: The case study of Portugal.

International Journal of Electrical Power & Energy Systems, *65*, 21–25. https://doi.org/10.1016/j.ijepes.2014.09.022

Corsatea, T. D., and Magagna, D. (2014). *Overview of European Innovation Activities in Marine Energy Technology* (p. 60). Joint Research Centre - Institute for Energy and Transport. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC90901/jrc-14-marinereport-online-dm.pdf

Det Norske Veritas. (2014). *Design of Offshore Wind Turbine Structures* (p. 238). DNV. https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2014-05/Os-J101.pdf

FCUL. (n.d.). *Previsão de Marés dos Portos Principais de Portugal*. Retrieved 5 September 2018, from http://webpages.fc.ul.pt/~cmantunes/hidrografia/hidro_mares.html

Hammons, T. J. (2011). Tidal Power in the UK and Worldwide to Reduce Greenhouse Gas Emissions. *International Journal of Engineering Business Management*, *3*(2), 16–28.

ICNF. (n.d.). *Geologia | Hidrologia | Clima* [Página]. Geologia, hidrologia e clima da Reserva Natural do Estuário do Tejo. Retrieved 19 September 2018, from http://www2.icnf.pt/portal/ap/r-nat/rnet/geo

IEA. (2016). *World Energy Outlook 2016*. International Energy Agency. https://www.iea.org/reports/world-energy-outlook-2016

Instituto Hidrográfico. (n.d.). *Tabela de Marés*. Tabela de Marés. Retrieved 27 December 2018, from http://www.hidrografico.pt/tabelamares

Kempener, R., and Neumann, F. (2014). *Tidal Energy - Technology Brief* (p. 36). International Renewable Energy Agency (IRENA). http://www.irena.org/DocumentDownloads/Publications/Tidal_Energy_V4_WEB.pdf

Legrand, C. (2009). *Assessment of Tidal Energy Resource - Marine Renewable Energy Guides* (p. 60). European Marine Energy Centre Ltd (EMEC). http://www.emec.org.uk/assessment-of-tidal-energy-resource/

Lewis, A., Estefen, S., Huckerby, J., Musical, W., Pontes, T., and Torres-Martinez, J. (2011). *Ocean Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press. http://www.ipcc-wg3.de/report/IPCC_SRREN_Ch06.pdf

Macedo, M. E. (2006). *Caracterização de Caudais do Rio Tejo* (p. 30). Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional. http://www.ccdr-lvt.pt/files/fab372a0a4525eddaf1c20e1ab852a25.pdf

Manwell, J. F., McGowan, J. G., and Rogers, A. L. (2009). *Wind Energy Explained - Theory, Design and Application* (p. 705). http://ee.tlu.edu.vn/Portals/0/2018/NLG/Sach_Tieng_Anh.pdf

MARETEC. (n.d.). *MOHID Description: Description of the 3D water modelling system* (p. 112). MARETEC. http://www.mohid.com/PublicData/Products/Manuals/Mohid_Description.pdf

O Rourke, F., Boyle, F., and Reynolds, A. (2010). Tidal energy update 2009. *Applied Energy*, *87*(2), 398–409. https://doi.org/10.1016/j.apenergy.2009.08.014

Ocean Energy Systems. (2015). *International Levelised Cost Of Energy for Ocean Energy Technologies* (p. 48). International Energy Agency. https://www.ocean-energy-systems.org/news/international-lcoe-for-ocean-energy-technology/

Owen, A. (2008). Chapter 7 - Tidal Current Energy: Origins and Challenges. In T. M. Letcher (Ed.), *Future Energy* (pp. 111–128). Elsevier. https://doi.org/10.1016/B978-0-08-054808-1.00007-7

PORDATA. (n.d.-a). *Consumo de energia eléctrica: total e por tipo de consumo*. Retrieved 27 March 2019, from https://www.pordata.pt/Municipios/Consumo+de+energia+el%c3%a9ctrica+total+e+por+tipo+de+consumo-25-123

PORDATA. (n.d.-b). *Preços da electricidade para utilizadores domésticos e industriais (Euro/ECU)*. Retrieved 14 March 2020, from https://www.pordata.pt/Europa/Pre%C3%A7os+da+electricidade+para+utilizadores+dom%C3%A9sticos+e+industriais+(Euro+ECU)-1477

Portela, L. (1996). *Modelação matemática de processos hidrodinâmicos e da qualidade da água no estuário do Tejo* [Instituto Superior Técnico]. http://repositorio.lnec.pt:8080/xmlui/handle/123456789/8737

Prandle, D. (1984). Simple theory for designing tidal power schemes. *Advances in Water Resources*, *7*(1), 21–27. https://doi.org/10.1016/0309-1708(84)90026-5

Segura, E., Morales, R., and Somolinos, J. A. (2017). Cost Assessment Methodology and Economic Viability of Tidal Energy Projects. *Energies*, *10*(11), 1806. https://doi.org/10.3390/en10111806

Smart, G., and Noonan, M. (2018). *Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit* (p. 21). Offshore Renewable Energy Catapult. https://www.marineenergywales.co.uk/wp-content/uploads/2018/05/ORE-Catapult-Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf

SNIRH. (n.d.). *SNIRH :: Sistema Nacional de Informação de Recursos Hídricos*. Retrieved 14 March 2020, from https://snirh.apambiente.pt/index.php?idMain=

U.S. Energy Information Administration. (2018). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2018* (p. 20). U.S. Energy Information Administration. https://www.eia.gov/outlooks/archive/aeo18/pdf/electricity_generation.pdf

U.S. Energy Information Administration (EIA). (n.d.). *Tidal power*. Retrieved 14 March 2020, from https://www.eia.gov/energyexplained/hydropower/tidal-power.php

World Energy Council. (2016). *World Energy Resources - Marine Energy* (p. 79). World Energy Council. http://large.stanford.edu/courses/2018/ph240/rogers2/docs/wec-2016.pdf

Revista de Gestão Costeira Integrada

Journal of Integrated Coastal Zone Management