Blue Carbon

CALOUSTE GULBENKIAN FOUNDATION

SCIENTIFIC REPORT II

The 10 main blue carbon ecosystems in mainland Portugal

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The 10 main blue carbon ecosystems in mainland Portugal

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CCMAR
Centro de Ciências do Mar

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I. Introduction

The second volume of the scientific report of the Gulbenkian Blue Carbon project – Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal – complements and supports the first volume, Scientific Report I: Assessment of blue carbon ecosystems in mainland Portugal, by presenting detailed information, in theform of technical sheets, for each of the ecosystems studied.

The technical sheets include the geographical location, the types of habitats and the area they occupy, the protection statuses in which they are included, estimates of stocks and sequestration rates, environmental quality, the threats to which they are exposed, and conservation interventions implemented in the past, underway or proposed for the future. Each sheet concludes with a survey of local stakeholders so that conservation and restoration processes can be set in motion for the systems being analysed.

II. Saltmarsh and seagrass species of the systems studied

List of saltmarsh and seagrass species described in the systems. The following list shows their current names according to the *Plants of the World Online* (POWO) database of the Royal Botanic Garden, Kew (https://powo.science.kew.org) and the scientific names used in the bibliography consulted for the compilation of the relevant data for the report.

Seagrasses

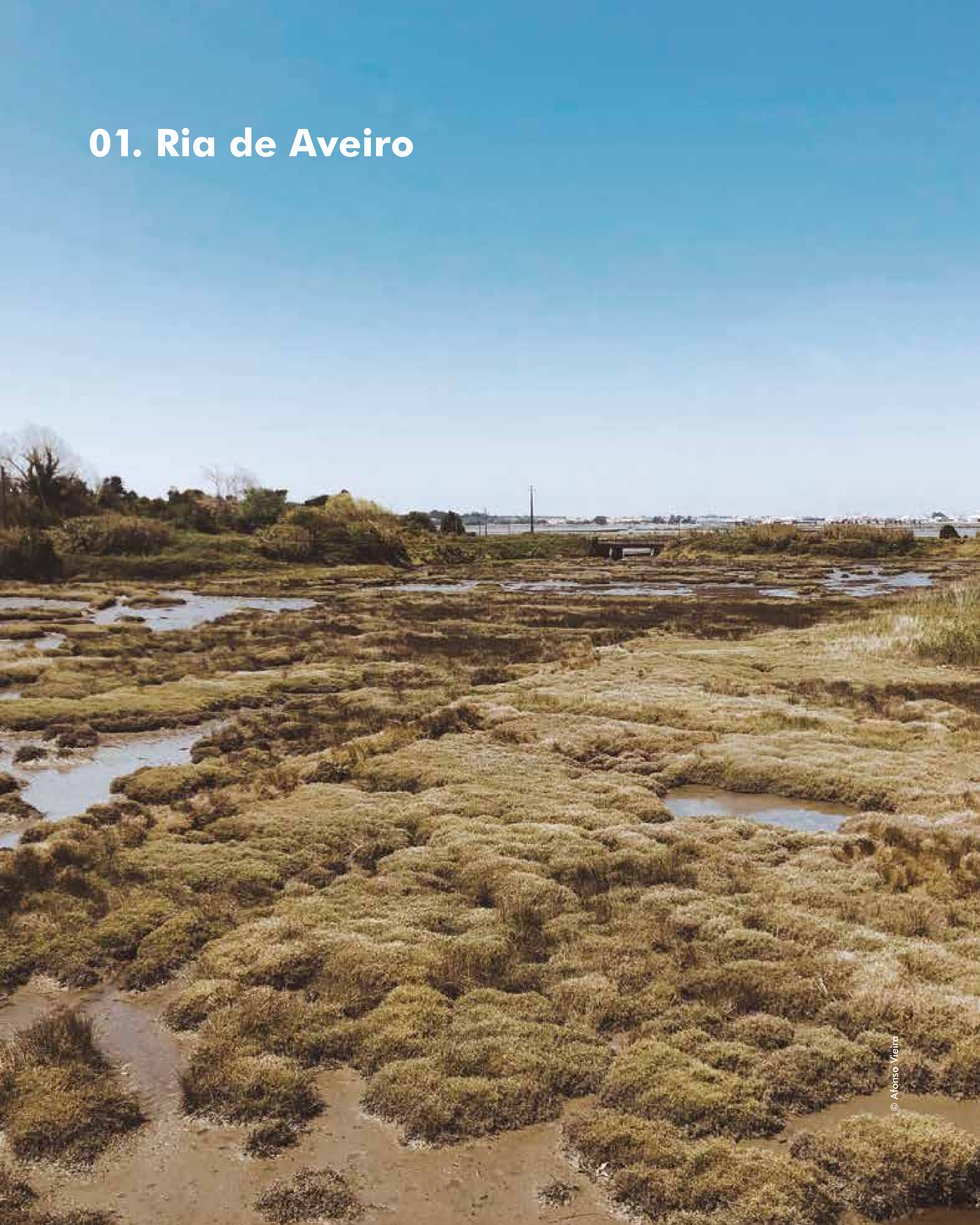
Current name	Previous names
Cymodocea nodosa (Ucria) Asch.	-
Zostera marina L.	-
Zostera noltei Hornem.	*Zostera noltii* Hornem.

Saltmarsh plants

Current name	Previous names
Arthrocaulon macrostachyum (Moric.) Piirainen & G.Kadereit	*Arthrocnemum macrostachyum* (Moric.) K.Koch *Arthrocnemum glaucum* (Moq.) Ung.-Sternb.
Atriplex glauca L.	
Atriplex portulacoides L.	*Halimione portulacoides* (L.) Aellen
Bolboschoenus maritimus (L.) Palla	*Scirpus maritimus* L.
Caroxylon vermiculatum (L.) Akhani & Roalson	*Salsola vermiculata* L.
Cistanche phelypaea (L.) Cout.	-
Juncus maritimus Lam.	-
Limbarda crithmoides (L.) Dumort.	*Inula crithmoides* L.
Limoniastrum monopetalum (L.) Boiss.	-
Limonium algarvense Erben	-
Limonium ferulaceum (L.) Chaz.	-
Limonium lanceolatum (Hoffmanns. & Link) Franco	-
Limonium vulgare Mill.	-
Myriolimon diffusum (Pourr.) Lledó, Erben & M.B.Crespo	*Limonium diffusum* (Pourr.) Kuntze
Phragmites australis (Cav.) Trin. ex Steud.	-
Puccinellia foucaudii (Hack.) Holmb.	-
Puccinellia maritima (Huds.) Parl.	-
Salicornia europaea L.	*Salicornia ramosissima* (Hook.f.) J. Woods ex W.A.Clarke & E.S.Marshall
Salicornia fruticosa (L.) L.	*Sarcocornia fruticosa* (L.) A.J.Scott *Arthrocnemum fruticosum* (L.) Moq.
Salicornia nitens P.W.Ball & Tutin	-
Salicornia perennans subsp. perennans	*Salicornia patula* Duval-Jouve
Salicornia perennis Mill.	*Sarcocornia perennis* (Mill.) A.J.Scott *Arthrocnemum perenne* (Mill.) Fourc.
Salicornia pruinosa (Fuente, Rufo & Sánchez Mata)	*Sarcocornia pruinosa* Fuente, Rufo & Sánchez Mata
Sporobolus maritimus (Curtis) P.M.Peterson & Saarela	*Spartina maritima* (Curtis) Fernald
Sporobolus montevidensis (Arechav.) P.M.Peterson & Saarela	*Spartina densiflora* Brongn.
Sporobolus pumilus (Roth) P.M.Peterson & Saarela	*Spartina patens* (Aiton) Muhl.
Sporobolus versicolor (E.Fabre) P.M.Peterson & Saarela	*Spartina versicolor* E.Fabre
Suaeda maritima (L.) Dumort.	-
Suaeda vera Forssk. ex J.F.Gmel.	-
Triglochin maritima L.	-
Tripolium pannonicum (Jacq.) Dobrocz.	*Aster tripolium* L.

III. The 10 main blue carbon ecosystems in mainland Portugal

01. Ria de Aveiro



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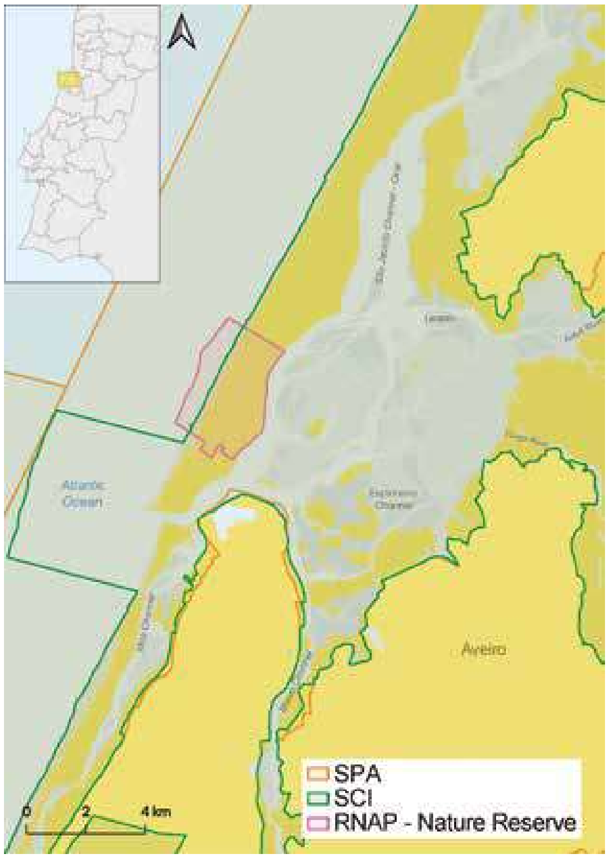
1.1 Geographical location

The Ria de Aveiro is a lagoon located in the districts of Aveiro and Coimbra on the west coast of northern Portugal, and it is integrated into the municipalities of Aveiro, Estarreja, Ílhavo, Mira, Murtosa, Ovar, and Vagos. It is separated from the sea by a sand barrier and connected to the Atlantic Ocean by an artificial inlet (**Figure 1.1**). The average depth is 10 m. Its complex system includes several arms, internal basins, tidal flats, and islands, forming four main channels: Mira, Ílhavo, Espinheiro, and São Jacinto-Ovar. Tides dominate the hydrodynamics of the lagoon, and the Vouga River, which flows through the Espinheiro Channel, is the most important freshwater input.

Figure 1.1 Location of the Ria de Aveiro in the districts of Aveiro and Coimbra and the area covered by the protection regimes SCI (Site of Community Importance, Natura 2000 network), SPA (Special Protection Area, Natura 2000 network), and Nature Reserve in the National Network of Protected Areas (RNAP). Elements of the base map: Geographical information supplied by the Directorate-General for Territorial Development.



1.2 Types of habitats

The Ria de Aveiro features *Zostera noltei* seagrass meadows (Cunha et al., 2013), mostly intertidal, and some patches of the species *Z. marina* (Guerrero-Meseguer et al., 2021). Seagrasses are mainly found in the Mira Channel, which is about 25 km long and has an average depth of 1 m.

The main saltmarsh areas in the Ria de Aveiro are found in the northern and central parts of the estuary. In the Laranjo area, the dominant species are *Bolboschoenus maritimus* and *Juncus maritimus* (Cleary et al., 2012; Válega et al., 2008). Verdemilho saltmarsh is dominated by the species *Atriplex portulacoides*, *Salicornia perennis*, and *Puccinellia maritima*, while Barra saltmarsh is mainly colonised by the species *A. portulacoides*, *S. perennis*, *J. maritimus*, and *Sporobolus maritimus* (Duarte et al., 2018). Other species that may be found there are *Salicornia europaea*, *Phragmites australis*, and *Limonium vulgare* (Silva et al., 2004; Sousa et al., 2017). The low saltmarsh is dominated by the *S. maritimus* and *S. europaea* species, while the medium and high saltmarsh is dominated by the species *A. portulacoides*, *S. perennis*, *J. maritimus*, and *Phragmites australis* (Silva et al., 2004; Sousa et al., 2017).

1.3 Protection regimes

The Ria de Aveiro is within the boundaries of the areas designated as a Site of Community Importance (SCI) and Special Protection Area (SPA) under the Habitats and Birds Directives, respectively (**Figure 1.1**, **Table 1.1**). A small part of the system, Dunas de São Jacinto, is a Nature Reserve included in the National Network of Protected Areas (RNAP) (Decree-Law No. 41/79 of 6 March). This protected area does not include the adjacent Ria de Aveiro wetlands (**Figure 1.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06). In the Red List of the Vascular Flora of Mainland Portugal (Carapeto et al., 2020), the species *Zostera marina* is classified as *Vulnerable* (VU).

Table 1.1 Summary of protection regimes in the Ria de Aveiro. RNAP: National Network of Protected Areas.

Regime	**Reference**	**Year of designation**	**Area** (ha)
Site of Community Importance (Natura 2000 Network)	PTCON0061	2014	33 127
Special Protection Area (Natura 2000 network)	PTZPE0004	1988	51 446
Dunas de São Jacinto Nature Reserve (RNAP)	Decree-Law n.º 41/79	1979	996

1.4 Total area of each habitat

1.4.1 Seagrasses

Overall, seagrass meadows in the Ria de Aveiro declined during the 20th century (Azevedo et al., 2013; Cunha et al., 2013; Silva & Duck, 2001; Silva et al., 2004). However, a temporal analysis of intertidal areas occupied by the species *Zostera noltei* showed a recovery from 2005 to 2014 as the area increased from 106 ha to 226 ha due to a reduction in anthropogenic impacts (Sousa et al., 2019; **Table 1.2**, **Figure 1.2**). Neto et al. (2018) estimated that the area occupied by intertidal seagrasses was 33 ha in 2010. In a study published in 2019, Lopes et al. (2019) present a map in which seagrasses occupy about 188 ha. However, the source of these data and the date they were obtained are unknown (**Table 1.2**, **Figure 1.2**).

The species *Zostera marina* was once very abundant in the Ria de Aveiro, but it has declined since the 1930s (Cunha et al., 2013). In 2009, only a single patch of this species was observed in the Ovar Channel and ten small patches in the Mira Channel, but they disappeared in 2010 due to strong storms (Cunha et al., 2013). A decade later, in 2019, Guerrero-Meseguer et al. (2021) reported the presence of nine patches of *Z. marina* in the Mira Channel with a total estimated area of 0.027 ha, which indicates a slight recovery of the species in this system.

Since the last survey by Sousa et al. (2019), no data have been available on the area covered by the intertidal seagrass *Zostera noltei*. For the blue carbon estimates of this species, an area of 226 ha reported for 2014 (Sousa et al., 2019) was considered. These data were assigned a *Cat 2* quality category as they were not up to date. Although data for *Z. marina* are up to date, these were not considered in the blue carbon estimates as they represent a very small fraction of the total.

Table 1.2 Estimates of seagrass meadow areas in the Ria de Aveiro over time. The data were exclusively collected from studies that included a full survey of seagrasses in the estuary.

Habitat	**Year**	**Area** (ha)	**Source**
Intertidal seagrasses	2005	106	Sousa et al. (2019)
Intertidal seagrasses	2010	32,70	Neto et al. (2018)
Intertidal seagrasses	2014	26	Sousa et al. (2019)
Seagrasses (total)	2019*	188	Lopes et al. (2019)
Subtidal seagrasses**	2019	0,027	Guerrero-Meseguer et al. (2021)

* Year of publication, year of observation not reported.

** *Zostera marina*.

Figure 1.2 Location of seagrass meadow areas reported in 2005 and 2014 by Sousa et al. (2019) and in 2019 by Lopes et al. (2019). Base image: geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

1.4.2 Saltmarsh

The only available information on the saltmarsh area in the Ria de Aveiro is from the global saltmarsh distribution database (Mcowen et al., 2017; **Table 1.3**, **Figure 1.3**), which indicates that the occupied area was 6 343 ha in 2006 and 3 455 ha in 2010. However, the 2006 data include areas occupied by seagrasses, indicating that this saltmarsh area is overestimated. The loss of saltmarsh in the Ria de Aveiro in this period was approximately 50%.

There are no available data on the saltmarsh area of this system from 2010 onwards. For the blue carbon estimates, an area of 3 455 ha estimated in 2010 by Mcowen et al. (2017) was considered. These data were assigned a *Cat 2* quality category as they are not up to date.

Table 1.3 Estimates of saltmarsh areas in the Ria de Aveiro over time.

Habitat	Year	Area (ha)	Source
Saltmarsh (total)	2006	6 343,47	Mcowen et al. (2017)
Saltmarsh (total)	2010	3 454,67	Mcowen et al. (2017)

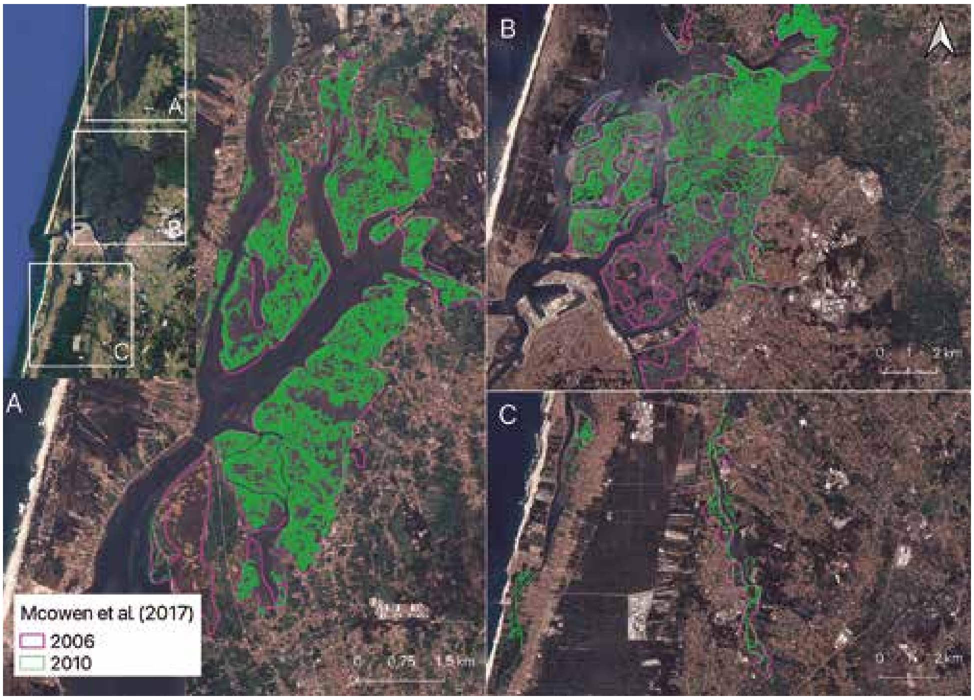


Figure 1.3 Location of saltmarsh areas in the Ria de Aveiro in 2006 and 2010. Adapted from Mcowen et al. (2017). Base image: Geographical information provided by Directorate-General for Territorial Development (image date 22-05-2018).

1.5 Estimates of carbon stocks and sequestration rates

1.5.1 Data compilation

Zostera noltei biomass data in the Ria de Aveiro measured between 2003 and 2021 are available (Costa et al., 2021, 2022; Silva et al., 2004, 2009; Sousa et al., 2019; **Table 1.4**), but not carbon content data. Carbon stock in *Z. noltei* biomass was estimated to be 0.64 ± 0.10 Mg C ha^{-1} (Sousa et al., 2019). Likewise, biomass data are available for the main saltmarsh species in the Ria de Aveiro (Cleary et al., 2012; Duarte et al., 2014, 2018; Figueira et al., 2012; Santos et al., 2007; Sousa et al., 2017; **Table 1.4**). Sousa et al. (2017) report the existing carbon stock in the saltmarsh biomass of the entire Ria de Aveiro (**Table 1.4**).

Regarding the carbon stock in sediments, there are data available for seagrasses (Sousa et al., 2019) and saltmarshes (Sousa et al., 2017), but only for the uppermost sediment layer (10 cm for seagrasses and 25 cm for saltmarshes; **Table 1.4**).

A *Cat 3* quality category was assigned to seagrass and saltmarsh vegetation data, and a *Cat 2* quality category to the sediment data of the two types of habitats, as they were incomplete, representing only the surface layer (**Table 1.5**).

Table 1.4 Compilation of the values used for calculating carbon stocks in the Ria de Aveiro after the necessary conversions for data standardisation. There are no data for the calculations of carbon sequestration rates.

Variable	Seagrasses (ZN)	Saltmarsh (AP)	Saltmarsh (BM)	Saltmarsh (JM)	Saltmarsh (SP)	Saltmarsh (SM)
Area (ha)	226	3 454,67				
Epigean biomass (g DW m^{-2})	87,1 ± 25,8	596 ± 678	421 ± 417	1 088 ± 541	107 ± 21	370 ± 96
Hypogean biomass (g DW m^{-2})	68,3 ± 14,3	2 994 ± 2 540	245 ± 34	1 642 ± 956	13 ± 3	1 963 ± 2 439
Biomass stock by area (Mg DW ha^{-1})	-	-	-	-	-	-
Total biomass stock (Mg DW)	-	-	-	-	-	-
Carbon stock in total biomass (Mg C ha^{-1})	0,64 ± 0,10	-	-	-	-	-
Carbon stock in the total biomass in the system (Mg C)		13 118§	948§	17 368§	1 946§	2 326§
Carbon content (epigean biomass) (% DW)	-	35,9 ± 1,7	-	43,3 ± 0,4	36,6 ± 1,3	40,9 ± 3,3
Carbon content (epigean biomass) (% DW)	-	43,4 ± 1,0	-	-	43,5 ± 1,1	-
Organic carbon content (sediment) (% DW)	-	-	-	-	-	-
Organic matter content (sediment) (% DW)	-	-	-	-	-	-
Carbon stock in sediment (Mg OC ha^{-1})	1,63 ± 0,11*	-	-	-	-	-
Carbon stock in sediment in the system (Mg OC)	-	104 102**§	6 461**§	69 017**§	16 524**§	22 188**§
Sediment accumulation rate (mm year^{-1})	-	-	-	-	-	-
Carbon sequestration rate in sediment (g OC m^{-2} year^{-1})	-	-	-	-	-	-

DW: dry weight. **OM**: organic matter. Species code: **ZN**, *Zostera noltei*; **AP**, *Atriplex portulacoides*; **BM**, *Bolboschoenus maritimus*; **JM**, *Juncus maritimus*; **SP**, *Salicornia perennis*, **SM**, *Sporobolus maritimus*. * For the upper 10 cm sediment layer (Sousa et al., 2019). ** For the upper 25 cm sediment layer (Sousa et al., 2017). § For a total saltmarsh area of 4 400 ha (Sousa et al., 2017).

Table 1.5 Data quality for the calculations of carbon stocks in the Ria de Aveiro. There are no data for the calculations of carbon sequestration rates.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 3	Cat 3
Level 3: Sediment	Cat 1	Cat 1

Quality categories for each level: *Cat 0* (no data), *Cat 1* (incomplete data), *Cat 2* (complete but non-representative or outdated data, i.e., < 2018), *Cat 3* (data is complete, representative, and up to date, i.e., ≥ 2018).

1.5.2 Estimates

It is estimated that blue carbon habitats in the Ria de Aveiro have a total stock (sediment and biomass) of 252 558 Mg OC and that they sequester an annual total of 1 136 Mg OC year^{-1}, with seagrasses contributing 0.2% and 11%, respectively (**Table 1.6**). These estimates of total stock were obtained with data published by Sousa et al. (2017) and Sousa et al. (2019) for the uppermost sediment layer (10 cm for seagrasses and 25 cm for saltmarshes). The shortcomings in the data available for sequestration rates were filled using the values available for the Ria Formos a. Therefore, these values are underestimated compared to those obtained for the other systems.

Table 1.6 Estimates of blue carbon stocks and sequestration rates in the Ria de Aveiro.

Variable	Seagrasses (ZN)	Saltmarsh (AP)	Saltmarsh (BM)	Saltmarsh (JM)	Saltmarsh (SP)	Saltmarsh (SM)	TOTAL
Total OC stock in biomass (Mg OC)	145	13 118	948	17 368	1 946	2 326	**35 851**
Total OC stock in sediment (Mg OC)	362	104 102	6 461	69 017	14 578	22 188	**216 708**
Total stock (Mg OC)	506	117 220	7 409	86 385	16 524	24 514	**252 558**
Annual sequestration rate (Mg C year^{-1})	127	202	202	202	202	202	**1 136**

OC: organic carbon. Species code: **ZN**, *Zostera noltei*; **AP**, *Atriplex portulacoides*;
BM, *Bolboschoenus maritimus*; **JM**, *Juncus maritimus*; **SP**, *Salicornia perennis*, **SM**, *Sporobolus maritimus*.

1.6 Environmental quality and threat

The Ria de Aveiro is in a densely urbanised and industrialised region where the Port of Aveiro is located. Urban and industrial pressure, as well as the historical land claim of saltmarsh areas for agriculture, are responsible for the high artificialisation and alteration of the morphology of riverbanks. The deepening and alteration of the riverbed due to dredging carried out for the maintenance of navigation channels and access to the Port of Aveiro and other infrastructures, the dams and the piers have altered the hydrological regime, the transport of solids and the tidal regime (APA, 2022). It should be highlighted that an alkaline-chlorinated products factory located in the industrial complex in the vicinity of the Ria de Aveiro discharged an effluent rich in mercury into a channel that ends at Laranjo Bay for many years. Mercury discharge has decreased considerably since 1994, but mercury concentration in the uppermost sediments of the bay is still much higher than pre-industrial levels (Figueira et al., 2012).

According to the latest characterisation and diagnosis of the River Basin Management Plan of Vouga, the Mondego and the Lis (RH4A), carried out in 2019, the Ria de Aveiro transitional waters (PT04VOU0552, PT04VOU0547, PT04VOU0550, PT04VOU0536, PT04VOU0514) presented an ecological status of *Good*, *Moderate* or *Poor* (APA, 2022). The results below *Good* are due to the poor condition of biological elements, namely marshes, benthic macroinvertebrates, and fish fauna (APA, 2022).

Among the most important threats to blue carbon habitats are coastal and tourism development, port activities, the physical impact caused by destructive fishing, aquaculture (bivalve mollusc production) and shellfish harvesting (APA, 2022). The presence of two invasive species of polychaetes (*Arenicola defodiens* and *A. marina*) and channel dredging activities may cause problems in the recovery of the *Zostera noltei* meadows (Costa et al., 2022; Sousa et al., 2019).

1.7 Conservation interventions

1.7.1 Past and ongoing interventions

In 2021, the Environment, Energy and Spatial Planning Parliamentary Committee of the Assembly of the Republic received a proposal for the creation of the Aveiro Natural Park, which integrates the National Network of Protected Areas and covers land, river, lagoon, and marine territories (Draft Resolution No. 1372/XIV/2, 2021) The proposal was approved in October of that year (Resolution No. 266/2021, 21 October 2021). The creation of this park aimed at allowing "the common, coherent and integrated management of seven classified and protected areas of high ecological, aesthetic and landscape value, and of great interest for the conservation of biodiversity, as well as for the mitigation of and adaptation to the effects of the climate crisis". The SCI and SPA of the Ria de Aveiro were included. The Resolution of the Assembly of the Republic only constituted a recommendation to the government, and intentions to implement it are unknown.

In the report of the 3rd Cycle of the River Basin Management Plan, the APA proposes to eliminate or reduce wastewater not connected to the drainage network in order to improve water quality in the estuary (APA, 2022). If implemented, this measure could result in the improvement of environmental quality in blue carbon ecosystems.

The "BioPradaRia – Restoration, management and conservation of marine meadows of the Ria de Aveiro" project (https://biopradaria.weebly.com/), which was developed between 2018 and 2022, aimed to contribute towards and promote the conservation and restoration of seagrass ecosystems and aquatic biodiversity within the framework of sustainable fishing activities, particularly a better marine biological resource management and conservation. This project was coordinated by researchers from the Centre for Environmental and Marine Studies (CESAM) of the University of Aveiro and funded by the MAR2020 operational programme. In a study published recently within this project, researchers presented a three-step approach to improve the resilience of *Zostera noltei* in order to facilitate the success of restoration plans for this species (Costa et al., 2022), namely 1) to characterise the donor population, 2) to identify constraints and implement measures to avoid them, and 3) to widen the restoration plan.

The "Remidigrass – Seagrasses as tools in the rehabilitation of degraded ecosystems" project (https://remedigrass.web.ua.pt/) is another project being developed in the Ria de Aveiro (2018-2022), which aims to create a methodological toolbox (site assessment, methodologies, contingency plans, cost-benefit ratio) to rehabilitate degraded estuarine ecosystems. The project includes the following tasks: 1) to determine the most favourable conditions for the survival of *Zostera noltei* transplants through laboratory growth experiments; 2) to conduct a pilot experiment of *Zostera noltei* transplantation in the Largo do Laranjo in the Ria de Aveiro; 3) to evaluate the effect of seagrass meadows on the geochemistry of contaminants; and 4) to evaluate the effect of transplantation on biodiversity and annual production of macrobenthic communities. This project is coordinated by researchers from the Centre for Environmental and Marine Studies (CESAM) of the University of Aveiro and is funded by the Foundation for Science and Technology and the COMPETE2020 operational programme.

1.7.2 Proposed interventions

a) Monitoring
An update of the saltmarsh mapping in the Ria de Aveiro is recommended, as well as the evaluation of seagrass and saltmarsh sedimentary stocks down to a depth of 1 m and blue carbon sequestration rates.

b) Protection
Support for the proposal to create the Aveiro Natural Park is recommended (Draft Resolution No. 1372/XIV/2ª, 2021), which includes specific measures for assessing and protecting seagrass ecosystems (**Figure 1.4**).

c) Restoration
The blue carbon ecosystems of the Ria de Aveiro have historically been subjected to great anthropogenic pressures that resulted in the reclamation of large natural areas for several other uses, such as agriculture, urban and port development, aquaculture, salt production, etc. The extensive drainage of marshes and the opening of estuaries by dredging of small channels have significantly altered the distribution and morphology of saltmarshes in the Ria de Aveiro. Currently, there is no mapping of the inactive, artificialized areas of the Ria de Aveiro, which could be used to restore the original saltmarsh and seagrass habitats. It will be necessary to conduct such a survey to assess the areas that are best suited for large-scale blue carbon ecosystem restoration in this system.

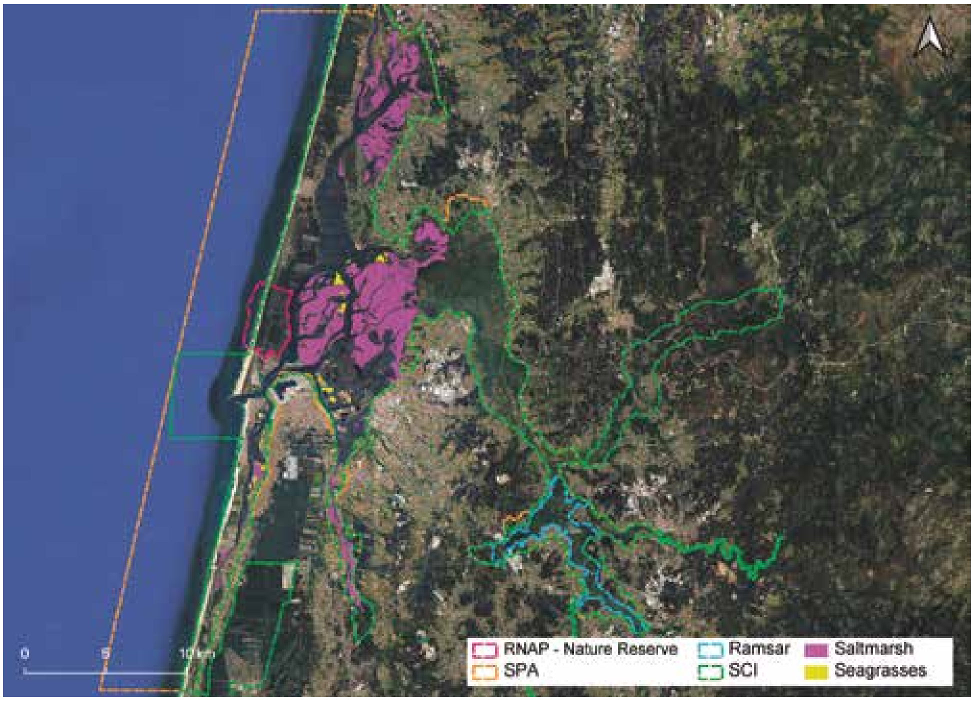


Figure 1.4 Location of saltmarsh and seagrass areas in the Ria de Aveiro and the boundaries of current protection regimes. Base image: Geographical information provided by Directorate-General for Territorial Development (image date 22-05-2018).

1.8 Local stakeholders

Municipality of Aveiro
Municipality of Estarreja
Municipality of Ílhavo
Municipality of Mira
Municipality of Murtosa
Municipality of Ovar
Municipality of Vagos
Centre for Environmental and Marine Studies – University of Aveiro (CESAM – UA)
Associação de Pesca Artesanal da Região de Aveiro *[Artisanal Fisheries Association of the Aveiro Region]*
Associação dos Amigos da Ria e do Barco Moliceiro *[The Ria and the Moliceiro Boat Friends Association]*
Associação Comercial e Empresarial do Distrito de Aveiro *[Municipality of Aveiro Commercial and Business Association]*
Association of Companies for an Innovation Network in Aveiro (Inova-Ria)
Port of Aveiro
Ciência Viva Centre, Aveiro

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02. Mondego Estuary

2.1 Geographical location

The Mondego Estuary is located in the municipality of Figueira da Foz (district of Coimbra) in the centre of Portugal (**Figure 2.1**). It is 7 km long, 2-3 km wide at its widest part, and it consists of two arms (northern and southern) with distinct characteristics, separated by Morraceira Island. The northern arm is deeper (4-8 m on the high tide), more hydrodynamic, and is the main navigation channel. The southern arm is shallower (2-4 m during high tide) and is also characterised by low hydrodynamics and large, exposed intertidal areas during low tide.

Figure 2.1 Location of the Mondego Estuary in the municipality of Figueira da Foz and the area under the protection regimes SCI (Site of Community Importance, Natura 2000 network), SPA (Special Protection Area, Natura 2000 network), and the Ramsar Convention. Elements of the base map: Geographical information provided by the Directorate-General for Territorial Development.

2.2 Types of habitats

The Mondego Estuary presents intertidal seagrass meadows and saltmarsh areas. The intertidal seagrass meadows are composed of *Zostera noltei*, which is concentrated in the southern arm of the estuary (Cardoso et al., 2004; Cunha et al., 2013; Lillebø et al., 2004; Marques et al., 2013). The saltmarsh areas are distributed mainly along the southern arm, where there are two main areas – one in the outer part of the estuary (Gala) and another in the inner part (Justante or Esteiro dos Armazéns) (Lillebø et al., 2004; Mcowen et al., 2017; Sousa et al., 2008, 2010a, 2010b). The saltmarsh is mainly composed of the species *Bolboschoenus maritimus* and *Sporobolus maritimus* (Couto et al., 2013; Lillebø et al. 2003, 2004; Sousa et al., 2008).

2.3 Protection regimes

The Mondego Estuary has been recognised internationally as a Ramsar site by the International Convention on Wetlands since 2005 (**Figure 2.1**, **Table 2.1**). However, the estuary is not included within the boundaries of the areas designated as a Site of Community Importance (SCI) or Special Protection Area (SPA) under the Habitats and Birds Directives, respectively (**Figure 2.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06).

Table 2.1 Summary of protection regimes in the Mondego Estuary.

Regime	Reference	Year of designation	Area (ha)
Ramsar site	No 1617	2005	1 518

2.4 Total area of each habitat

2.4.1 Seagrasses

In the 1980s, *Zostera noltei* meadows occupied approximately 15 ha of the southern arm of the estuary (Cardoso et al., 2004; **Table 2.2**, **Figure 2.2**). However, in the early 1990s, anthropogenic activities (e.g., riverbank alignment with stones and deepening of the northern arm) interrupted the communication between the northern and southern arms. That interruption had an impact on the hydrodynamic regime of the system: the water circulation in the southern arm became dependent on tides and the small freshwater runoff from the Pranto River, which is a strong source of nutrients from agricultural areas (Cardoso et al., 2004; Marques et al., 2013; Neto et al., 2013). These changes resulted in high eutrophication of the southern arm, inducing a proliferation of opportunistic green algae and a decrease in seagrasses, which came to occupy about 0.02 ha in 1996 – a reduction in the area of approximately 99% (Cardoso et al., 2004; **Table 2.2**, **Figure 2.2**). In 1998, mitigation measures were implemented, and the connection between the two arms was re-established. Lillebø et al. (2004) estimated that the area occupied by meadows increased to 1.76 ha (**Table 2.2**, **Figure 2.2**). The connection between both arms of the estuary was further extended in 2006 by the Water Institute (INAG) so that water could flow easily between the two arms during the full tidal cycle (Neto et al., 2013). In 2009, seagrass meadows occupied 4.4 ha (Cunha et al., 2013) and 15.14 ha in 2010 (Neto et al., 2018; **Table 2.2**).

Since the last survey by Neto et al. (2018) in 2010, no data have been available on seagrass meadow areas in this system. Regarding blue carbon estimates in seagrass meadows, the most recent (2010) area of 15 ha was considered (Neto et al., 2018). A *Cat 2* category was assigned to the area data since those are not up to date.

Table 2.2 Estimates of seagrass meadow areas in the Mondego Estuary over time.

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	1986	15,00	Cardoso et al. (2004)
Intertidal seagrasses	1996	0,02	Cardoso et al. (2004)
Intertidal seagrasses	2004*	1,76	Lillebø et al. (2004)
Intertidal seagrasses	2009	4,4	Cunha et al. (2013)
Intertidal seagrasses	2010	15,14	Neto et al. (2018)

* Year of publication, not of observation.

Figure 2.2 Location of seagrass meadow areas in the Mondego Estuary in 1986, 1996, and from a study published in 2004. Adapted from Cardoso et al. (2004) and Lillebø et al. (2004). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

2.4.2 Saltmarsh

Lillebø et al. (2004) estimate that the saltmarsh area occupied 66 ha (**Table 2.3**, **Figure 2.3**), with the species *Sporobolus maritimus* and *Bolboschoenus maritimus* being the most abundant (19.35 ha and 46.88 ha, respectively). Information available on the global saltmarsh distribution database (Mcowen et al., 2017) shows an area of 89 ha in 2006 and 54 ha in 2010 (**Table 2.3**, **Figure 2.3**).

No data on the marsh area in this system have been available since the last survey conducted by Mcowen et al. (2017) in 2010. For the blue carbon estimates in the Mondego Estuary saltmarsh areas, the most recent (2010) area of 53.7 ha was considered. These data were assigned a *Cat 2* quality category as they are not up to date.

Table 2.3 Estimates of saltmarsh areas in the Mondego Estuary over time.

Habitat	**Year**	**Area** (ha)	**Source**
Saltmarsh (total)	2004*	66,23	Lillebø et al. (2004)
Saltmarsh (total)	2006	89,19	Mcowen et al. (2017)
Saltmarsh (total)	2010	53,70	Mcowen et al. (2017)

* Year of publication, not of observation.

Figure 2.3 Location of saltmarsh areas in the Mondego Estuary in 2006, 2010, and from a study published in 2004. Adapted from Mcowen et al. (2017) and Lillebø et al. (2004). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

2.5 Estimates of carbon stocks and sequestration rates

2.5.1 Data compilation

Biomass and carbon content data were compiled for the species *Zostera nolte*i (Baeta et al., 2011; Bordalo et al., 2011; Couto et al., 2013; Pardal et al., 2000) and the two main saltmarsh species (Couto et al., 2013; Lillebø et al., 2003; Sousa et al., 2008) (**Table 2.4**). Regarding sediment, data was found on organic matter for seagrasses (depth down to 3 or 25 cm; Cardoso et al., 2007; Lillebø et al., 2004; Marques et al., 2013), and for each of the saltmarsh species (Lillebø et al., 2004; Sousa et al., 2008). Although some data are available for the total carbon content in the sediment (Duarte et al., 2013) and the total carbon deposition rate (Couto et al., 2013; Sousa et al., 2010), these data were not considered due to inexistent estimates on the fraction of organic carbon (**Table 2.4**).

Seagrass and saltmarsh vegetation data were assigned a *Cat 2* quality category as they were not up to date, and sediment data a *Cat 1* quality category for both types of habitats (**Table 2.5**).

Table 2.4. Values compiled for the calculations of carbon stocks and sequestration rates in the Mondego Estuary after making the necessary conversions for data standardisation and statistical analyses.

Variable	Intertidal seagrasses (ZN)	Saltmarsh (BM)	Saltmarsh (SM)
Area (ha)	15,14	53,7	
Epigean biomass (g DW m^{-2})	203 ± 117	280 ± 268	1 474 ± 1 349
Hypogean biomass (g DW m^{-2})	152 ± 65	887 ± 283	1 675 ± 1 103
Biomass stock per area (Mg DW ha^{-1})	-	-	-
Total biomass stock (Mg DW)	-	-	-
Carbon content (epigean biomass) (% DW)	36,7 ± 2,1	32,8 ± 3,4	37,5 ± 1,1
Carbon content (epigean biomass) (% DW)	31,3 ± 0,3	37,8 ± 2,3	32 ± 4,3
Organic carbon content (sediment) (% DW)	2,79*	2,33*	3,04*
Organic matter (sediment) content (% DW)	5,1 ± 1,7	7,3 ± 1,7	10,7 ± 3,8
Carbon stock in sediment (Mg OC ha^{-1})	-	-	-
Sediment accumulation rate (mm $year^{-1}$)	-	7	-
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	353*	45*	196*

* Total carbon value (not used in the estimates)

DW: dry weight. **OM**: organic matter. Species code: **ZN**, *Zostera noltei*; **AP**, *Atriplex portulacoides*; **BM**, *Bolboschoenus maritimus*;**SM**, *Sporobolus maritimus*.

Table 2.5 Data quality for calculating carbon stocks and sequestration rates in the Mondego Estuary.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 2	Cat 2
Level 3: Sediment	Cat 1	Cat 1

Quality categories for each level: Cat 0 (no data), Cat 1 (incomplete data), Cat 2 (complete but non-representative or outdated data, i.e., < 2018), Cat 3 (data is complete, representative, and up to date, i.e., ≥ 2018).

2.5.2 Estimates

Blue carbon habitats in the Mondego Estuary are estimated to contain a total stock (sediment and biomass) of 3 348 Mg OC and to sequester an annual total of 24.2 Mg OC year^{-1}, with intertidal seagrasses contributing 35% and 41% to these values (**Table 2.6**). The lack of data for these calculations was remedied using the values available for the Ria Formosa. Therefore, the estimates of blue carbon stocks and sequestration rates in the Mondego Estuary are very imprecise.

Table 2.6 Estimates of blue carbon stocks and sequestration rates in the Mondego Estuary.

Variable	Seagrasses (intertidal)	Saltmarsh (BM)	Saltmarsh (SM)	TOTAL
Total OC stock in biomass (Mg OC)	18	162	171	**352**
Total OC stock OC sediment (Mg OC)	1 363	711	923	**2 996**
Total stock (Mg OC)	1 381	873	1 093	**3 348**
Annual sequestration rate (Mg C year^{-1})	8,5	11,1	4,6	**24,2**

OC: organic carbon. Species code: BM, *Bolboschoenus maritimus*; SM, *Sporobolus maritimus*.

2.6 Environmental quality and threats

The Mondego River is an artificial system with major geomorphological and hydrological changes for hydroelectric use, for public, industrial, and agricultural (irrigation) supply, and for flood protection purposes. Its riverbanks are heavily urbanised and equipped with port infrastructure (fishing and commercial port). The river flow is controlled upstream by dams, and channel maintenance is done by dredging (APA, 2022). Historically, the downstream area of the river has been heavily polluted (Ferreira et al., 2004). According to the latest characterisation and diagnosis of the River Basin Management Plan for the Vouga, the Mondego, and the Lis (RH4A), carried out in 2019 (APA, 2022), the ecological status of the Mondego waters is either *Poor* (PT04MON0685) or *Moderate* (PT04MON0681, PT04MON0688) based on several biological indicators. Among the greatest pressures on the saltmarshes and seagrasses in the Mondego Estuary are tourism, urban and industrial development, coastal engineering, dredging of navigation channels and macroinvertebrate harvesting (APA, 2022; Cunha et al., 2013).

2.7 Conservation interventions

2.7.1 Past and ongoing interventions

In 1998, a project was implemented to restore the natural seagrass habitat that had suffered a dramatic decline due to eutrophication (Cardoso et al., 2004, 2005; Martins et al., 2015; Pardal et al., 2000). The project included several restoration and environmental management measures, including the protection of existing seagrass patches and the improvement of hydrodynamic conditions by modifying sluice gate opening regimes, thereby reducing nutrient loading in the southern arm of the estuary. A project was also carried out to restore *Zostera noltei* by transplantation (Martins et al., 2005), as well as environmental education activities among stakeholders to raise awareness of the ecological importance of the estuary. The project was carried out by IMAR (Institute of Marine Research) in partnership with the Ministry for the Environment and in collaboration with other stakeholders (farmers, fishermen, etc.). The project resulted in improved water quality in the estuary, and seagrass meadow recovery from 0.02 ha to 15 ha, between 1996 and 2010 (Cardoso et al., 2007, 2010; Lillebø et al., 2005; Neto et al., 2018; Verdelhos et al., 2005).

Currently, the "ReSEt – Restoration of Estuarine Saltmarshes with a view to Sustainability" project (https://resetproject.pt/), which began in 2019, aims to improve saltmarsh protection and restoration in the Mondego Estuary and its biodiversity from the standpoint of preservation and sustainable use of resources and enhancement of the services provided by these ecosystems. This project brings together 15 researchers from the Marine and Environmental Sciences Centres of the Universities of Coimbra (MARE-UC) and Lisbon (MARE-UL), the Institute for Sustainability and Innovation in Structural Engineering (ISISE) and the Department of Earth Sciences of the Faculty of Science and Technology of the University of Coimbra. Various eco-engineering techniques are being tested to avoid the risk of saltmarsh loss due to climate change.

The APA has presented a series of measures for the Mondego hydrographic region in the River Basin Management Plan – 3rd Cycle (RH4A – Vouga, Mondego e Lis, APA, 2022) that could improve the conservation of blue carbon habitats in the estuary:

- Construction and rehabilitation of the sewerage systems (transport and treatment) of Torres do Mondego and Carvalhosas in the municipality of Coimbra (PTE1P01M05_SUP_RH4).
- Drawing up the Special Programme for the Planning of the Mondego River Estuary (PTE9P07M02_SUP_RH4_3Ciclo).
- Requalification of the Mondego River between Portela Bridge and Palheiros weir in the Coimbra municipality (PTE3P02M02_SUP_RH4_3Ciclo).

2.7.2 Proposed interventions

a) Monitoring
A mapping update of seagrass and saltmarsh meadows in the Mondego Estuary and the assessment of blue carbon stocks and sequestration rates are recommended.

b) Protection
The saltmarsh and seagrass areas of the Mondego Estuary are recognised by the Ramsar Convention but are not covered by any protection regime at the national or European level (**Figure 2.4**).

c) Restoration
It is not possible to recommend specific areas for passive or active restoration with the available spatial data. It will be necessary to identify inactive, artificialized areas in the Mondego Estuary that could be used to restore original saltmarsh and seagrass habitats. This survey will need to be carried out so that the best areas for large-scale restoration of the blue carbon ecosystems in the Mondego Estuary can be assessed later.

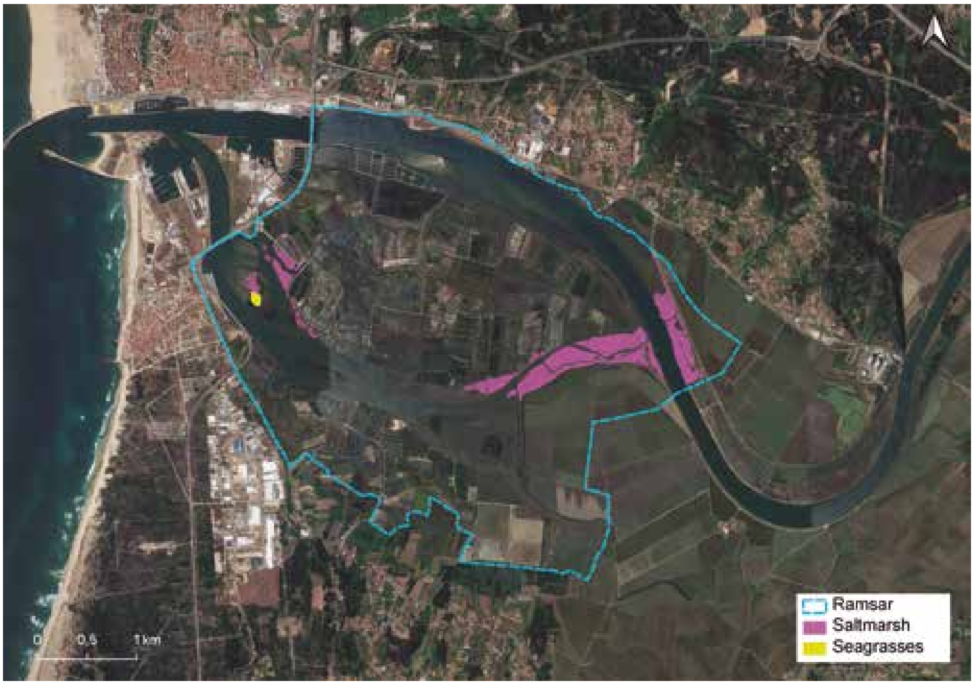

Figure 2.4 Location of saltmarsh and seagrass areas in the Mondego Estuary and the boundaries of current protection regimes. Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

2.8 Local stakeholders

Municipality of Figueira da Foz
Municipality of Coimbra
Regional Coordination and Development Commission – Centro Region (CCDRC)
Marine and Environmental Sciences Centre – University of Coimbra (MARE-UC)
Institute for Sustainability and Innovation in Structural Engineering (ISISE) – University of Coimbra and University of Minho
Professional fishermen (no association found)
Águas do Centro Litoral *[Centro Litoral Water Services]*
Port of Figueira da Foz

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03. Óbidos Lagoon

3.1 Geographical location

The Óbidos Lagoon is located in the municipalities of Caldas da Rainha and Óbidos (district of Leiria) in central Portugal (**Figure 3.1**). It is a shallow mesotidal coastal lagoon (average depth 2 m) that covers an area of 7 km² (Carvalho et al., 2006). It is separated from the sea by several coastal dunes, but there is a connection through a small inlet (called aberta in the local toponymy). In the upstream area, it is divided into two interior branches, the Braço da Barrosa on the right bank (where the Rio da Cal meets) and the Braço do Bom Sucesso on the left bank, where the Vala de Ameal flows. In the central area, the Arnóia River flows.

Figure 3.1 Location of the Óbidos Lagoon in the municipalities of Óbidos and Caldas da Rainha. Elements of the base map: Geographical information provided by the Directorate-General for Territorial Development.

3.2 Types of habitats

The Óbidos Lagoon presents seagrass meadows and saltmarsh areas. The seagrass meadows comprise the *Zostera marina*, *Ruppia cirrhosa*, and *Ruppia maritima* (Cunha et al., 2013). The *R. cirrhosa* population in this system has a reduced genotypic diversity resulting from low rates of sexual reproduction (Martínez-Garrido et al., 2017). The saltmarsh is dominated by the species *Atriplex portulacoides* and *Salicornia perennis* (Negrin et al., 2017).

3.3 Protection regimes

The Óbidos Lagoon is not under any protection regime. However, it is considered a Core Area in the Secondary Network integrated into the ERPVA (Regional Structure for Environmental Protection and Enhancement: Municipality of Óbidos, 2010). It was also classified as a Corine Biotope (C21100067) in 1985, with an area of 2,600 ha.

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06). In the Red List of the Vascular Flora of Mainland Portugal (Carapeto et al., 2020), the species *Zostera marina* is classified as *Vulnerable* (VU).

3.4 Total area of each habitat

3.4.1 Seagrasses

There have been seagrass meadows in the Óbidos Lagoon at least since the 19^{th} century, yet they have dramatically declined due to bivalve harvesting with hand dredges (Cunha et al., 2013). Local fishermen report the presence of the *Zostera marina* in the 1960s, covering an area of about 150 ha. In 2010, *Zostera marina* could be found in two areas in the Óbidos Lagoon, namely 36 patches ranging from 1 m to 2 m in diameter in a shallow area near Ponta do Arinho and a larger patch at a depth of 4 m to 6 m in an area in the centre of the lagoon. Cunha et al. (2013) estimated that the total area covered by *Z. marina* in the Óbidos Lagoon was about 1.05 ha (**Table 3.1**). According to this last monitoring, *Z. marina* was mixed with *Ruppia sp*. Since this 2010 survey, no data have been available on the seagrass area in this system.

For the blue carbon estimates in the Óbidos Lagoon seagrass areas, an area of 1.05 ha was considered. These data were categorised as *Cat 2* as they are not up to date.

Table 3.1 Estimates of seagrass meadow areas in the Óbidos Lagoon over time.

Habitat	Year	Area (ha)	Source
Subtidal seagrasses	c. 1960	150	Fishermen (in Cunha et al., 2013)
Subtidal seagrasses	2010	1,05	Cunha et al. (2013)

3.4.2 Saltmarsh

In 1917, there was an extensive patch of saltmarsh in the southern alluvial plain, which was heavily destroyed by the installation of salt pans in 1947 and until 1963 (Martins-Loução, 2008). The saltmarsh in this area has recovered and expanded since 1989, following partial renaturation of the dredged deposits. In other areas of the lagoon, the saltmarshes are found as narrow strips on the upper part of the muddy shores, which have not undergone major modifications over time, except for the Buinheira patch, where the area has been reduced by one-third due to the dumping of dredged spoil (Martins-Loução, 2008). Recent data from the year 2000 show saltmarsh areas in Foz do Arelho, Braço do Barrosa, and Braço do Bom Sucesso (Gonçalves, 2016; Martins-Loução, 2008), covering an area of 63.26 ha. The information available on the global saltmarsh distribution database (Mcowen et al., 2017) shows that 157.5 ha in 2006 decreased to 15.46 ha in 2010 (**Figure 3.2**, **Table 3.2**). No further data have been available since this last survey.

For the blue carbon estimates in the Óbidos Lagoon saltmarsh areas, the most recent area (2010) of 15.46 ha (**Table 3.2**) was considered. A *Cat 2* quality category was assigned to the data as it is not up to date.

Table 3.2 Estimates of the evolution of saltmarsh areas in the Óbidos Lagoon over time.

Habitat	Year	Area (ha)	Source
Saltmarsh (total)	1917	75,23	Martins-Loução (2008)
Saltmarsh (total)	1947	57,47	Martins-Loução (2008)
Saltmarsh (total)	1963	65,87	Martins-Loução (2008)
Saltmarsh (total)	1982	36,15	Martins-Loução (2008)
Saltmarsh (total)	1989	39,28	Martins-Loução (2008)
Saltmarsh (total)	2000	63,26	Martins-Loução (2008)
Saltmarsh (total)	2006	157,5	Mcowen et al. (2017)
Saltmarsh (total)	2010	15,46	Mcowen et al. (2017)

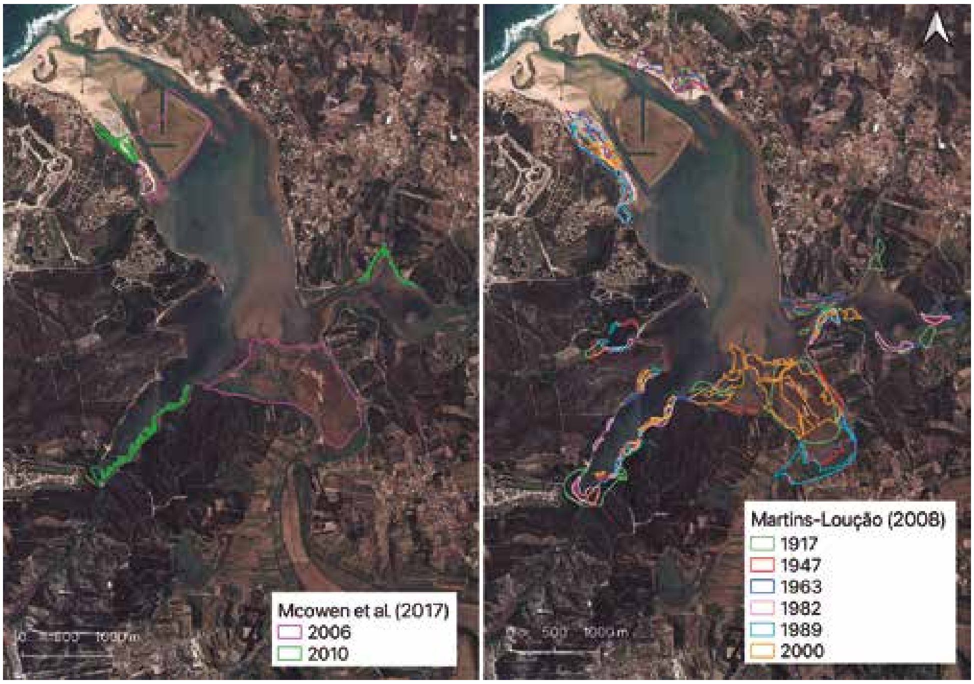

Figure 3.2 Location of saltmarsh areas in the Óbidos Lagoon between 1917 and 2010. Adapted from Mcowen et al. (2017) and Martins-Loução (2008). Base image: Geographical information provided by the Directorate-General for Territorial Development image date 22-05-2018).

3.5 Estimates of carbon stocks and sequestration rates

3.5.1 Data compilation

No vegetation or sediment data have been found to estimate carbon stocks in the Óbidos Lagoon; therefore, the data were assigned a Cat 0 quality category (**Table 3.3**) for both types of habitats.

Table 3.3 Data quality for calculating carbon stocks and sequestration rates in the Óbidos Lagoon.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 0	Cat 0
Level 3: Sediment	Cat 0	Cat 0

Quality categories for each of the parameters assessed: Cat 0 (no data for this system), Cat 1 (incomplete data, so estimates cannot be made), Cat 2 (complete data but non-representative or outdated, i.e., < 2018), Cat 3 (data is complete, representative, and up to date, i.e., ≥ 2018)

3.5.2 Estimates

As no data is available to estimate blue carbon stocks and sequestration rates in the Óbidos Lagoon, the data available for the nearest systems, the Tagus Estuary and the Ria Formosa, were used. Hence, these estimates are very imprecise. It is estimated that the Óbidos Lagoon has a total stock (sediment and biomass) of 1,322 Mg OC in blue carbon habitats and that it sequesters an annual total of 4.5 Mg OC year^{-1}. The contribution of seagrasses is very reduced, < 5 %, due to the small area they currently occupy in the lagoon (**Table 3.4**).

Table 3.4 Estimates of blue carbon stocks and sequestration rates in the Óbidos Lagoon.

Variable	Seagrasses (subtidal)	Saltmarsh (total)	TOTAL
Total OC stock in biomass (Mg OC)	1,9	137	**139**
Total OC stock in biomass (Mg OC)	29,2	742	**771**
Total stock (Mg OC)	31,2	879	**910**
Annual sequestration rate (Mg C year^{-1})	0,1	4,5	**4,6**

OC: organic carbon.

3.6 Environmental quality and threats

The Óbidos Lagoon is located near a small town (Caldas da Rainha), relatively close to industries that produce a moderate impact by heavy metals (Pereira et al., 2009). The main economic activities in this system are fishing, including bivalve production, tourism (beach and leisure), and agriculture in the adjacent areas.

According to the latest characterisation and diagnosis carried out by the APA (APA, 2022a), the ecological status of the Óbidos Lagoon waters (codes PT05RDW1165A and PT05RDW1166A) is *Moderate*, based on parameters related to saltmarsh and benthic macroinvertebrate populations, and their chemical status is *Good*.

The Óbidos Lagoon is a very dynamic system with a tendency to decrease its submerged area, caused by the natural process of siltation on its bed and the closure of the connection with the sea (Oliveira et al., 2006). The lagoon is frequently dredged to mitigate these natural processes, and its inlet is opened. The last dredging occurred in 2021–2022 (APA, 2022b). While dredging can be a threat to carbon habitats due to its direct physical impacts and the increased water turbidity during that process, it is crucial to the water quality rehabilitation in this system (APA, 2022b). From the 1980s onwards, part of the sandy materials from desilting have been placed on the saltmarsh, leading to its decline, for example, in the Buinheira area (Martins- Loução, 2008). However, these areas of material deposits from dredging may be re-naturalised, recovering the saltmarsh habitats and the ecosystem services they provide (Martins-Loução, 2008).

The eutrophication process is considered a potential threat to the natural habitats of the Óbidos Lagoon (APA, 2022a) not only due to the long periods the water remains in the system but also due to the high concentration of nutrients and organic matter present in its effluents (Santos et al., 2008). This situation causes dinoflagellate blooms to develop, leading to the so-called red tides (Santos et al., 2005) or green macroalgae tides of the genera *Ulva* and *Enteromorpha* (Santos et al., 2006).

According to the latest characterisation and diagnosis of the Ribeiras do Oeste (APA, 2022a), the Óbidos Lagoon waters (PT05RDW1165A and PT05RDW1166A) show changes in their natural habitats due to morphological changes, nutrient pollution, organic pollution, and other types of impacts. The pressures identified in this study were: physical alteration of the channel and its waterway, introduction of species and diseases, occasional aquaculture, and diffuse urban drainage.

3.7 Conservation interventions

3.7.1 Past and ongoing interventions

In the 1990s, the Óbidos Lagoon was included in the National List of Sites under the Habitats Directive draft proposal. However, it was not included in the final lists published by the Resolutions of the Council of Ministers No. 142/97 of 28 August and No. 76/2000 of 5 June.

In June 2004, a process was initiated to propose the classification of the Óbidos Lagoon as a Regional Protected Landscape Area to be integrated into the National Network of Protected Areas (Santos et al., 2005). The proposal was submitted by the ICN (now ICNF), the Municipalities of Caldas da Rainha and Óbidos, and the *Associação de Defesa do Paul de Tornada* (PATO), yet it was unfavourably welcomed.

The Municipalities of Óbidos and Caldas da Rainha are collaborating to submit a joint application to classify the Óbidos Lagoon as a Wetland of International Interest under the Ramsar Convention. The intention of this application was presented on 2 February 2022 during the presentation of the "BioLagoa de Óbidos – Aves aquáticas da Lagoa de Óbidos" project (https://www.biolagoadeobidos.com), which is being developed by the PATO Association in partnership with *Água do Tejo Atlântico*, the organisation responsible for cleaning up the lagoon's watershed.

The APA has recently developed an action to rehabilitate and improve the quality of the lagoon's ecosystems through the "Dredging of the upper area of the Óbidos Lagoon" (APA, 2022b) project. The project consisted of the deepening and stabilisation of a group of channels and the deposition of dredged sediments in the sea to reinforce sediment transport. The project also includes the environmental and landscape requalification of an area currently occupied by old dredged residual deposits upstream of the mouth of the Real River.

The APA also proposes several corrective and preventive measures to be adopted to improve the quality of the Óbidos Lagoon waters during the 3rd cycle (2022-2027) of the Tagus and Ribeiras do Oeste River Basin Management Plan (RH5) (APA, 2022a). These measures include the requalification of watercourses, the implementation of improvements in aquaculture companies, the identification of recurring situations of direct discharge of wastewater, and the implementation of the National Strategy for the Rehabilitation of Rivers and Streams, among others.

No conservation interventions have been found focusing particularly on seagrasses or saltmarshes in the Óbidos Lagoon.

3.7.2 Proposed interventions

a) Monitoring
An update of the mapping of seagrass and saltmarsh meadows is recommended, as well as the assessment of blue carbon stocks and sequestration rates in the Óbidos Lagoon. It will also be important to implement a monitoring programme for both habitats to detect potential increases in coverage or, on the contrary, the decline of saltmarshes and seagrasses. The reasons for potential decline should be investigated in order to mitigate them.

b) Protection
Saltmarsh and seagrass habitats in the Óbidos Lagoon are not covered by any protection regime. Creating protected areas where *Zostera marin*a and saltmarsh meadows still exist or have existed is suggested (**Figure 3.4**).

c) Restoration
Active seagrass meadow restoration projects could be carried out in the shallow areas where these developed in the past, particularly in the central and downstream part of the system, and where there is no strong sediment transport that could bury the restored patches. It will be necessary to ensure that the factors that led to their past decline are no longer present.

A detailed survey of the saltmarsh areas destroyed in the past and are currently abandoned is recommended. These areas could be used for passive and active restoration projects. The sandbank area downstream of the lagoon, which was reported as a saltmarsh area by Mcowen et al. (2017) (**Figure 3.2**) in 2006, appears to have great potential for saltmarsh and seagrass restoration.

Figure 3.3 Location of saltmarsh areas in the Óbidos Lagoon. There are no spatial data on the presence of seagrass. The saltmarsh and seagrass habitats in this system are not protected by any protection regime. Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

3.8 Local stakeholders

Municipality of Óbidos
Municipality of Caldas da Rainha
Associação de Defesa do Paul de Tornada (PATO) – Non-governmental environmental organisation (ONGA). https://www.facebook.com/associacao.pato
Associação de Mariscadores e Pescadores Amigos da Lagoa de Óbidos *[Óbidos Lagoon Shellfish Harvesters and Fishermen Friends Association]*. https://www.facebook.com/Apmalo-101570888426825/
Águas do Tejo Atlântico *[Tejo Atlântico Water Services]* – Institution leading the depollution of the Óbidos Lagoon hydrographic basin. https://www.aguasdotejoatlantico.adp.pt
Nemus – Gestão e Requalificação Ambiental, Lda– International consultant that carried out the requalification of the Óbidos Lagoon. https://www.nemus.pt/
Cetemares MARE Polytechnic of Leiria
Associação Real 21 – Associação de Defesa do Rio Real *[Rio Real Association]*, whose area of operation covers the entire Rio Real hydrographic basin.

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04. Tagus Estuary

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4.1 Geographical location

The Tagus Estuary is the largest estuary in Portugal, covering an area of 300 km² at low tide and 340 km² at high tide, and is located in the Lisbon area in central Portugal (**Figure 4.1**). The estuary has an average depth of 10.6 m and a complex topography, including channels, islands, and tidal flats.

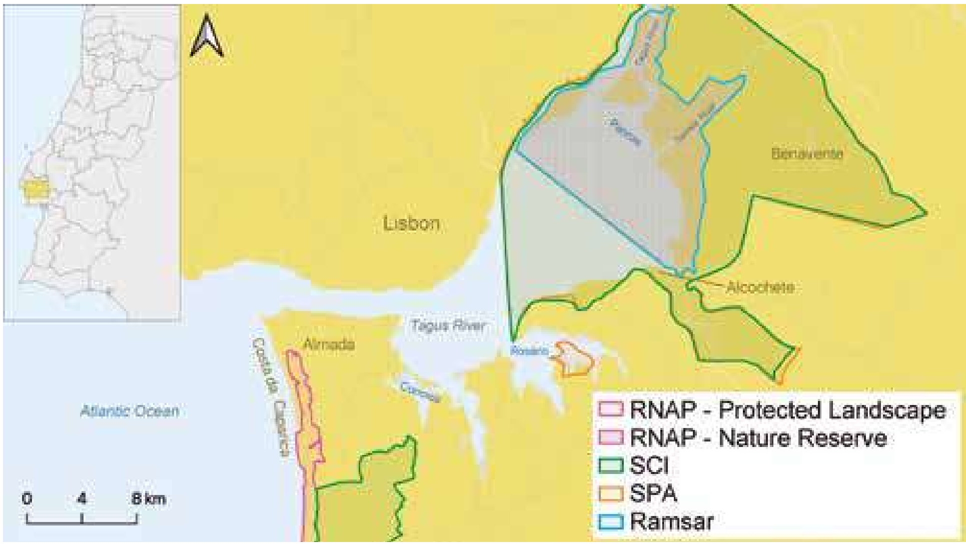

Figure 4. Location of the Tagus Estuary in the Lisbon region and the area covered by the legal regimes Nature Reserve and Protected Landscape in the National Network of Protected Areas (RNAP), SPA (Special Protection Area, Natura 2000 network), SCI (Site of Community Importance, Natura 2000 network), and the Ramsar Convention. Elements of the base map: Geographical information supplied by the Directorate-General for Territorial Development.

4.2 Types of habitats

The Tagus Estuary presents seagrass meadows and saltmarsh areas. The seagrass meadows are exclusively of the species *Zostera noltei* and may be found in the Samouco intertidal area (Cunha et al., 2013; Mendes and Melo, unpublished; Mendes et al., 2012). There are also small patches in Alcochete, in the western part of the jetty (R. Melo, observation made in 2016 at www.seagrassspotter.org). In 1989, there was a *Z. noltei* intertidal meadow at Ponta dos Corvos (Alfeite, Corroios saltmarsh, Cunha et al., 2013), but its current state is unknown.

There are three main areas of saltmarsh in the estuary: Pancas, Corroios, and Rosário. Pancas is a recent saltmarsh area located in the eastern area of the estuary, close to the Sorraia River. The Alcochete, Vale Frades, and Vasa Sacos saltmarsh areas are also found here. They are protected as part of the Tagus Estuary Nature Reserve (**Figure 4.1**). The Corroios and Rosário areas are older saltmarshes that are located downstream in the Mar da Palha, away from the main river channel and close to urbanised and industrial areas (Caçador et al., 2004, 2007; Lopes et al., 2020; Tanacković et al., 2008; **Figure 4.1**). Corroios has an area of upper and middle marsh dominated by the species *Atriplex portulacoides*, *Salicornia fruticosa*, and *S. perennis,* while Pancas includes an area of high-mid marsh similar to that of Corroios and also a low marsh colonised mostly by the species *Sporobolus maritimus* (Caçador et al., 2004; Lopes et al., 2020). Other species found in the Tagus Estuary marsh are *Juncus maritimus*, *Puccinellia maritima*, *Tripolium pannonicum*, *Limbarda crithmoides*, and the invasive species *Sporobolus pumilus* (Caçador et al., 2007; Carvalho et al., 2001; Human et al., 2020). The composition of the saltmarsh in the Corroios area, i.e., the coverage by species, changed between 1951 and 2003 with a decrease in *S. fruticosa* and an increase in *S. maritimus* (Caçador et al., 2007).

4.3 Protection regimes

The Tagus Estuary has been internationally recognised as a Ramsar site by the International Convention on Wetlands (**Figure 4.1**, **Table 4.1**) since 1980. Part of the estuary is included within the boundaries of areas designated as a Site of Community Importance (SCI) and Special Protection Area (SPA) under the Habitats and Birds Directives, respectively (**Figure 4.1**). At the national level, the northern estuary area was included in the National Network of Protected Areas (RNAP) in 1976 under the Nature Reserve category (Decree-Law No. 565/76 on 19 July, **Figure 4.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06).

Table 4.1 Summary of the protection regimes in the Tagus Estuary. RNAP: National Network of Protected Areas.

Regime	Reference	Year of designation	Area (ha)
Ramsar site	No 211	1980	14 563
Site of Community Importance (Natura 2000 network)	PTCON0009	2008	44 011,28
Special Protection Area (Natura 2000 network)	PTZPE0010	1988	44 772,46
Tagus Estuary Nature Reserve (RNAP)	Decree-Law No. 565/76	1976	14 416

4.4 Total area of each habitat

4.4.1 Seagrasses

The intertidal *Zostera noltei* seagrass meadows in the Samouco area have increased by 65 ha in 24 years, from 2 ha in 1995 to 67 ha in 2019 (Mendes and Melo, unpublished; **Table 4.2**, **Figure 4.2**). This increase is associated with the construction of the Vasco da Gama Bridge, which has altered the local hydrodynamic conditions (Cunha et al., 2013). However, before the construction of the bridge, there was already an important seagrass area similar to the one that exists today, which declined due to the construction of the bridge (visible in the 1985 Google Earth image). The selected seagrass area for the blue carbon estimates was 67 ha, having been assigned a *Cat 3* quality category as it is complete, representative, and up to date.

Table 4.2 Estimates of seagrass meadow areas in the Tagus Estuary over time

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	1995	1,97	Mendes e Melo (unpublished)
Intertidal seagrasses	2002	16,21	Mendes e Melo ((unpublished)
Intertidal seagrasses	2007	12,29	Mendes e Melo (unpublished)
Intertidal seagrasses	2008	21	Cunha et al. (2013)
Intertidal seagrasses	2009	26,08	Mendes e Melo (unpublished)
Intertidal seagrasses	2011	35,21	Mendes e Melo (unpublished)
Intertidal seagrasses	2015	50,66	Mendes e Melo (unpublished)
Intertidal seagrasses	2019	67,45	Mendes e Melo (unpublished)

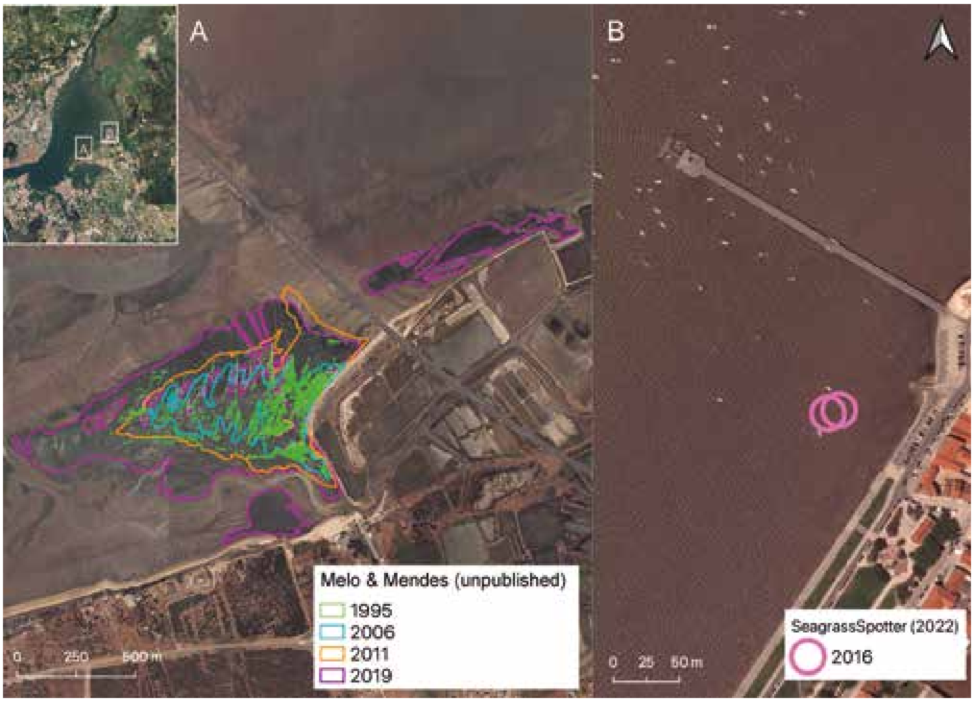

Figure 4.2 Location of seagrass meadow areas in the Tagus Estuary. Adapted from Mendes and Melo (unpublished) and the citizen science platform SeagrassSpotter. Base image: Geographical information provided by Directorate-General for Territorial Development (image date 22-05-2018).

4.4.2 Saltmarsh

There are several surveys of the saltmarsh areas in the Tagus Estuary (Cartaxana and Catarino, 1997; Freitas et al., 1999; Lopes et al., 2020; Mcowen et al., 2017; Mendes et al., 2012), but only three of those studies carried out a survey across the estuary (**Table 4.3**, **Figure 4.3**). Cartaxana and Catarino (1997) estimated a saltmarsh area of 2 695 ha across the whole estuary. According to the global saltmarsh distribution database (Mcowen et al., 2017), the saltmarsh covered an area of 2 092 ha in 2006 and 1 763 ha in 2010 (**Table 4.3**, **Figure 4.3**). Mendes et al. (2012) conducted another survey in 2007 and reported an area of 1 880 ha. It should be noted that the methodology used in these surveys was not similar; therefore, any comparison between different years should be made with caution.

Since the last survey conducted in 2010 (Mcowen et al., 2017), no data have been available on the saltmarsh area in this system. For the blue carbon estimates, the most recent (2010) area of 1 763 ha was considered. The data were assigned a *Cat 2* quality category as they are not up to date.

Table 4.3 Estimates of saltmarsh areas in the Tagus Estuary over time. Only data from studies that surveyed saltmarsh throughout the estuary are presented.

Habitat	Year	Area (ha)	Source
Saltmarsh	1997*	2 695	Cartaxana & Catarino (1997)
Saltmarsh	2006	2 092	Mcowen et al. (2017)
Saltmarsh	2007	1 880	Mendes et al. (2012)
Saltmarsh	2010	1 763	Mcowen et al. (2017)

* Year of publication, not of observation.

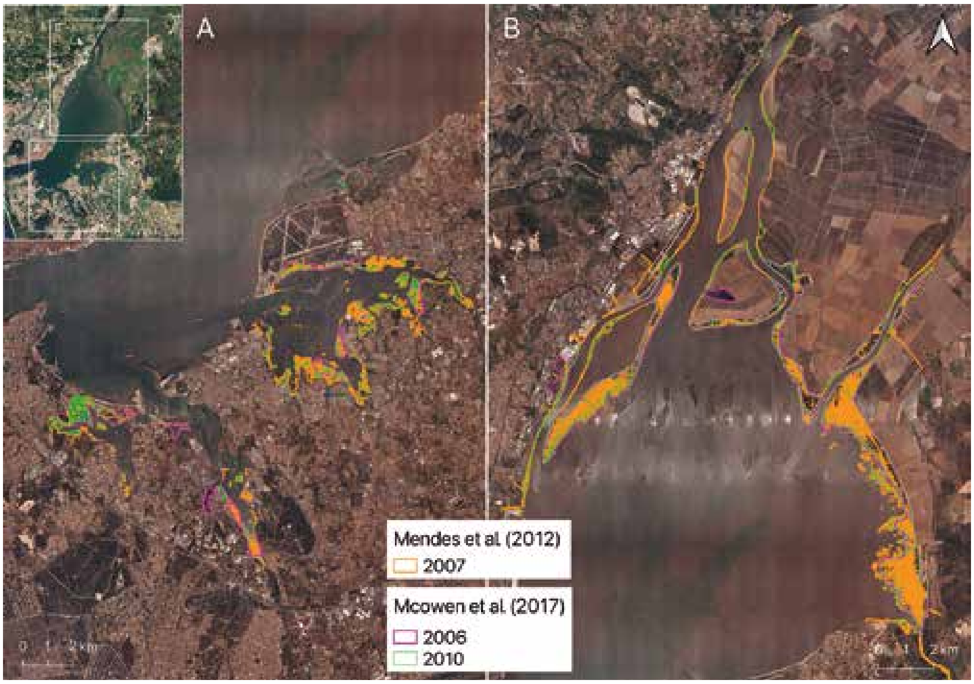

Figure 4.3 Location of saltmarsh areas in specific sections of the Tagus Estuary. Adapted from Mcowen et al. (2017) and Mendes et al. (2012). Base image: Geographical information provided by Directorate-General for Territorial Development (image date 22-05-2018).

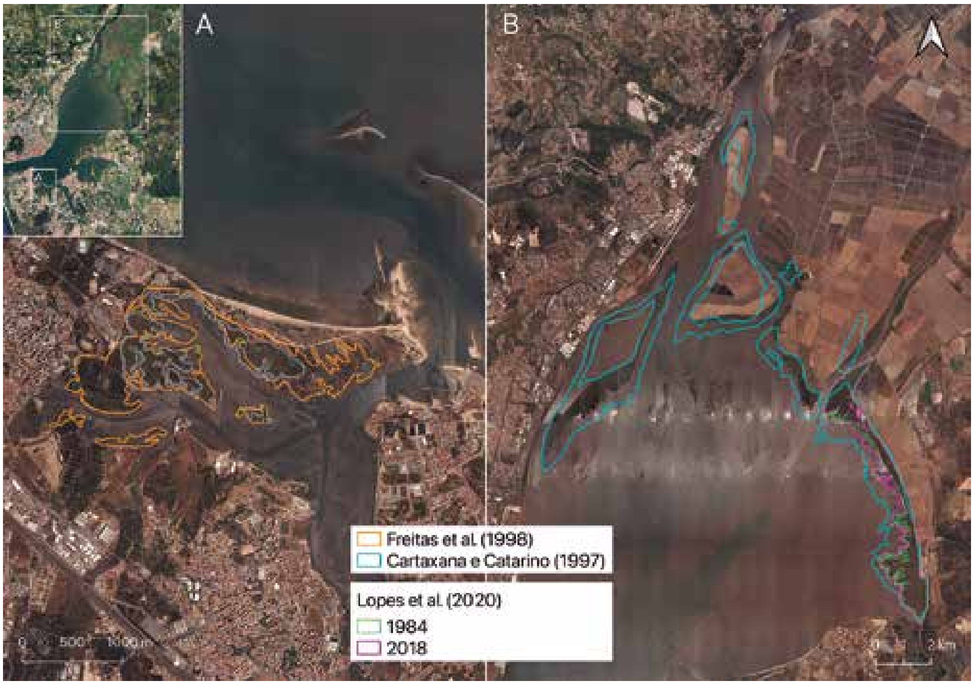

Figure 4.4 Location of saltmarsh areas in specific areas of the Tagus Estuary. Adapted from Cartaxana & Catarino (1997), Freitas et al. (1998), and Lopes et al. (2020). Base image: Geographical information provided by Directorate-General for Territorial Development (image date 22-05-2018).

4.5 Estimates of carbon stocks and sequestration rates

4.5.1 Data compilation

No biomass or carbon content data have been found for *Z. noltei* in the Tagus Estuary, but several studies, including data for the four most abundant saltmarsh species, namely *Atriplex portulacoides*, *Salicornia fruticosa*, *S. perennis*, and *Sporobolus maritimus* have been found (Caçador et al., 2004, 2007, 2009; Caetano et al., 2007, 2008, 2012; Canário et al., 2010; Cartaxana & Catarino, 1997, 2002; Catarino & Caçador 1981; Reboreda & Caçador 2007a, b, 2008; Santos et al., 2007; Santos-Echeandía et al., 2010; Sousa et al., 2008, 2012; Tanacković et al., 2008) (**Table 4.4**). For the calculations of carbon stocks in saltmarsh biomass, the area covered by each of these species, as reported in 2010, was considered, as well as the percentages of coverage of each within the Corroios area (Caçador et al., 2007): 49% for *S. maritimus*, 41% for *S. fruticosa*, 9% for *S. perennis*, and 1% for *A. portulacoides*.

Regarding the sediment, no data were found for seagrasses, only for the main saltmarsh species (Almecija et al., 2016; Brito et al., 2018, 2020, 2021; Caçador et al., 2004, 2009; Canário et al. 2017; Cartaxana & Catarino, 1997; Duarte et al., 2013a,b; Human et al., 2020; Pedro et al., 2015; Reboreda et al., 2007, 2008a,b; Salgueiro & Caçador, 2007; Sousa et al., 2010, 2012) (**Table 4.4**). Although some total carbon content in sediment data (Caçador et al., 2004; Cartaxana & Catarino, 1997; Duarte et al., 2013b) and total carbon burial rate data have been compiled (Caçador et al., 2007; Sousa et al., 2010), these data were not considered for the estimates as they do not correspond to the fraction of organic carbon (**Table 4.4**).

A *Cat 0* quality category was assigned to seagrass biomass data (since not available), a *Cat 1* quality category to saltmarsh data (as they were incomplete), and a *Cat 1* quality category to sediment data for both types of habitats (as they were incomplete) (**Table 4.5**).

Table 4.4 Values compiled for the calculations of carbon stocks and sequestration rates in the Tagus Estuary after making the necessary conversions for data standardisation and statistical analyses.

Variable	Seagrasses (ZN)	Saltmarsh (SM)	Saltmarsh (AP)	Saltmarsh (SF)	Saltmarsh (SP)
Area (ha)	67,45	1 763			
Epigean biomass (g DW m^{-2})	-	529 ± 418	967 ± 687	1 483 ± 2 262	239 ± 186
Hypogean biomass (g DW m^{-2})	-	3 416 ± 2 586	3 766 ± 3 708	4 528 ± 1 147	4 055 ± 724
Biomass stock per area (Mg DW ha^{-1})	-	-	-	-	-
Total biomass stock (Mg DW)	-	-	-	-	-
Carbon content (epigean biomass) (% DW)	-	40,6*	35,3*	-	34,7*
Carbon content (epigean biomass) (% DW)	-	17,9	15,0	-	17,7
Organic carbon content (sediment) (% DW)	-	2,6 ± 1,7**	2,7 ± 1,6**	3,1 ± 1,2**	1,7 ± 0,9**
Organic matter (sediment) content (% DW)	-	12,9 ± 9,8	10,5 ± 5,2	9,3 ± 5,0	10,2 ± 4,0
Carbon stock in the sediment (Mg OC ha^{-1})	-	-	-	-	-
Sediment accumulation rate (mm $year^{-1}$)	-	10	-	-	9,3
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	-	540**	-	-	-

DW: dry weight. OM: organic matter. Species code: ZN, *Zostera noltei*; SM, *Sporobolus maritimus*; AP, *Atriplex portulacoides*; SF, *Salicornia fruticosa*; SP, *Salicornia perennis*.

Table 4.5 Data quality for calculating carbon stocks and sequestration rates in the Tagus Estuary.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 3	Cat 2
Level 2: Vegetation	Cat 0	Cat 1
Level 3: Sediment	Cat 0	Cat 1

Quality categories for each level: Cat 0 (no data), Cat 1 (incomplete data), Cat 2 (complete but non-representative or outdated data, i.e., < 2018), Cat 3 (complete, representative, and up-to-date data, i.e., ≥ 2018).

4.5.2 Estimates

Blue carbon habitats in the Tagus Estuary are estimated to have a total stock (sediment and biomass) of 173 627 Mg OC and sequester an annual total of 552 Mg OC year^{-1}, with seagrasses contributing 3.5% and 6.9% to these values (**Table 4.6**). As there are no data available for the Tagus Estuary to make these calculations, stock values and carbon sequestration rates from the Ria Formosa were used. For this reason, the estimates presented are very imprecise.

Table 4.6 Estimates of blue carbon stocks and sequestration rates in the Tagus Estuary.

Variable	Seagrasses (ZN)	Saltmarsh (SM)	Saltmarsh (AP)	Saltmarsh (SF)	Saltmarsh (SP)	TOTAL
Total OC stock in biomass (Mg OC)	83	14 567	160	9 513	1270	25 593
Total OC stock in sediment (Mg OC)	6 071	103 663	751	30 791	6 759	148 035
Total stock (Mg OC)	6 154	118 229	911	40 304	8 029	173 627
Annual sequestration rate (Mg C year^{-1})	38	252	5	211	46	552

OC: organic carbon.
Species code: **ZN**, *Zostera noltei*; **SM**, *Sporobolus maritimus*; **AP**, *Atriplex portulacoides*; **SF**, *Salicornia fruticosa*; **SP**, *Salicornia perennis*.

4.6 Environmental quality and threats

The Tagus Estuary is in a highly urbanised and industrialised area, surrounded by densely populated cities. Only 1% of the riverbanks are estimated to be in their natural state (Batista et al., 2022). The saltmarsh presents high values of sediment contamination, mostly due to the Montijo and Barreiro industrial areas (Caçador et al., 2012; Cruz de Carvalho et al., 2020; Duarte et al., 2010). Within the estuary, the Alcochete saltmarsh is less contaminated than the Rosário and Seixal saltmarshes (Cruz de Carvalho et al., 2020). According to the latest characterisation and diagnosis of the Tagus and Ribeiras do

Oeste River Basin Management Plan (RH5) carried out by the APA in 2019, three of the four transitional bodies of water in the estuary (PT05TEJ1075A1, PT05TEJ1100A, PT05TEJ1116A, PT05TEJ1139A) present an ecological status below *Good* (APA, 2022). Among the greatest pressures on these bodies of water, including their saltmarshes and seagrasses, are changes due to morphological modifications such as physical changes in the riverbanks, nutrient pollution (urban wastewater), chemical pollution, and the introduction of alien species. The sectors causing the most significant pressures are, in equal proportion, navigation, the urban sector (urban wastewater), chemical pollution, and the introduction of species and diseases. These sectors originate 86% of the pressures affecting the three transitional bodies of water in the Tagus Estuary with a status below *Good*.

4.7 Conservation interventions

4.7.1 Past and ongoing intervention

Presently, the project “RESTAURA 2020 – Assessment and Restoration of saltmarsh communities affected by invasive species: management and conservation actions to revitalise ecosystem services and improve their function as a fish nursery” (operation 16-01-04-FMP-0014) funded by the MAR2020 Programme (https://restaura2020.wixsite.com), is being developed. This project includes some objectives that could generate conservation interventions on blue carbon habitats in the estuary:

Objective 1: To identify and map the presence of the invasive species *S. patens* in the Tagus Estuary Nature Reserve.

Objective 3: To restore the ecosystem's capacity to reproduce species and protect juveniles, as well as to protect and enhance the environment within the Natura 2000 network, both from the point of view of the protection of endemic biodiversity, as well as in favour of sustainable management of resources and fishing activities.

Objective 5: To develop adequate methodologies of restoration and protection of endemic vegetation for application in saltmarsh areas equally affected by the presence of invasive species.

The 2020 Local Action Plan for Biodiversity in Lisbon, led by the Municipality of Lisbon (https://www.lisboa.pt/fileadmin/cidade_temas/ambiente/biodiversidade/documentos/Plano_Acao_Biodiversidade_Lisboa_2020.pdf) includes the action C1.3. “Definition and restoration of natural ecosystems”, which will “demarcate areas resulting from ecosystems or catalysing their natural successional process to be included in the Territorial Management Instruments in force in the Municipality”, “the renaturation of the Tagus Estuary riverside area”, and the “stabilisation of the Tagus Estuary saltmarsh”. There is also environmental monitoring of the Lisbon riverfront by the Municipality, which includes different biological components, among which are the saltmarsh species *Salicornia* *fruticosa*, *S. perennis*, *Atriplex portulacoides*, and *Tripolium pannonicum* (https://www.lisboa.pt/cidade/ambiente/estuario-do-tejo).

The APA proposes the "Elaboration of the Special Management Programme for the Tagus Estuary" (measure PTE9P07M03_SUP_RH5) for the Tagus region in the River basin Management Plan–3rd Cycle (RH5–Tagus and Ribeiras do Oeste, APA, 2022), which could promote the conservation of blue carbon habitats in the estuary.

4.7.2 Proposed interventions

a) Monitoring
An update of the mapping of seagrass and saltmarsh meadows in the Tagus Estuary is recommended, as well as the assessment of blue carbon stocks and sequestration rates.

b) Protection
There are saltmarsh and seagrass areas in the Tagus Estuary that are not under any protection regime either at the national or European level (**Figure 4.5**).

c) Restoration
There are relevant areas of inactive saltmarshes with potential for blue carbon ecosystem restoration projects in the Samouco area, namely those areas that have been expropriated following the construction of the Vasco da Gama Bridge and that are now being managed by the Foundation for the Environment Management of the Samouco Salt Pans. On the other hand, it is necessary to survey old saltmarsh areas that were claimed for other uses and are now inactive. These areas can be subject to passive or active restoration of the original saltmarsh ecosystems.

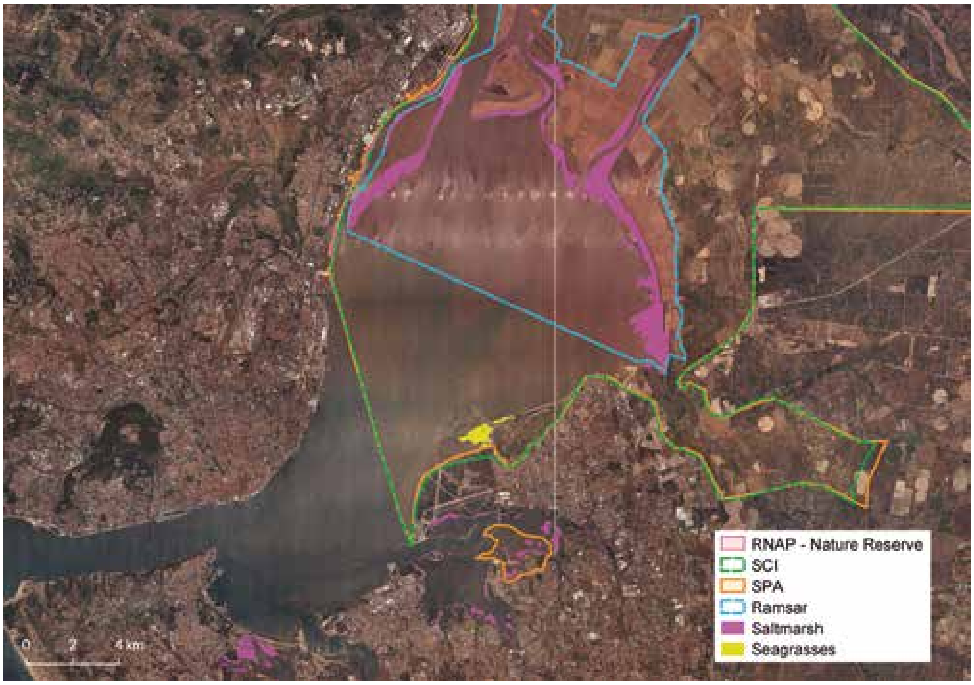

Figure 4.5 Location of saltmarsh and seagrass areas in the Tagus Estuary and the boundaries of current protection regimes. Base image: Geographical information provided by the Directorate-General of Territorial Development (image date 22-05-2018).

4.8 Local stakeholders

Municipality of Lisbon
Municipality of Montijo
Municipality of Moita
Municipality of Seixal
Municipality of Alcochete
Regional Coordination and Development Commission – Lisbon and Tagus Valley (CCDR-LVT)
University of Lisbon
NOVA School of Science and Technology – NOVA University Lisbon
Faculty of Sciences of the University of Lisbon
Marine and Environmental Sciences Centre – University of Lisbon (MARE-UL)
Biosystems and Integrative Sciences Institute (BioISI) – University of Lisbon
Foundation for the Protection of Environmental Management of the Samouco Salt Pans

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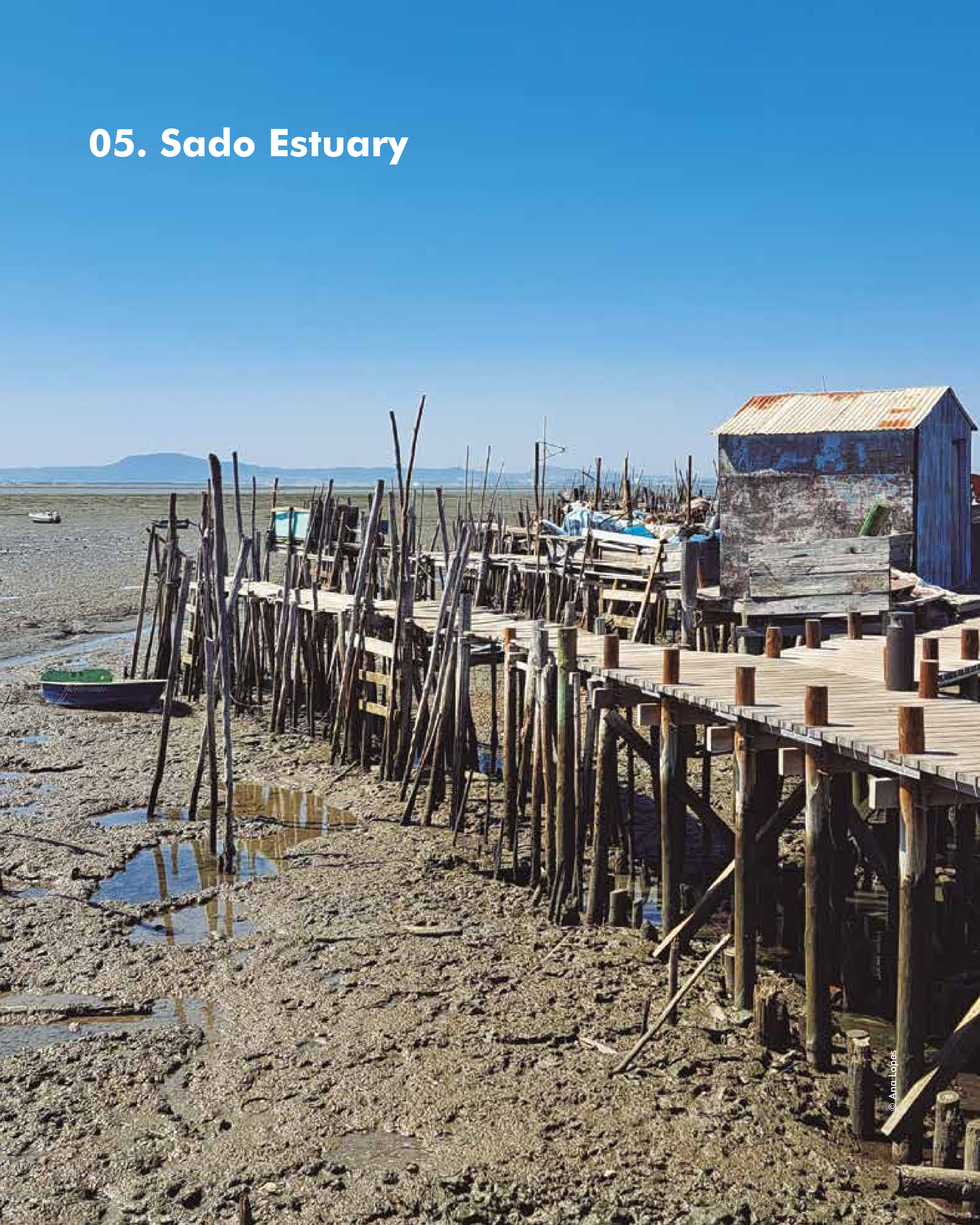
05. Sado Estuary



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5.1 Geographical location

The Sado Estuary is located in the centre of the west coast of Portugal in the municipalities of Setúbal, Alcácer do Sal, Grândola, and Palmela (Setúbal district) (**Figure 5.1**). It is the second-largest estuary in Portugal, covering an area of 180 km^2. The upper estuary has two channels, resulting from the Sado River's confluence with the Ribeira da Marateca. The Alcácer Channel on the south side is 35 km long and 700 m wide. This is where the Sado River flows into the estuary, providing 80% of its fresh water. The Águas de Moura Channel on the north side, where the Ribeira da Marateca flows into the sea, contributes 10% of the fresh water to the estuary. The middle estuary is a large basin, 5 km wide, 20 km long, and approximately 10 m deep. A narrow, deep channel connects it to the ocean.

Figure 5.1 Location of the Sado Estuary in the Setúbal, Alcácer do Sal, Grândola, and Palmela municipalities, and the area covered by the protection regimes SCI (Site of Community Importance, Natura 2000 network), the Ramsar Convention, SPA (Special Protection Area, Natura 2000 network), Natural Park, and Nature Reserve of the National Network of Protected Areas (RNAP). Elements of the base map: Geographical information supplied by the Directorate-General for Territorial Development.

5.2 Types of blue carbon habitats

The Sado Estuary presents intertidal and subtidal seagrass meadows (Andrade and Ferreira, 2011; Cunha et al., 2009, 2013), as well as saltmarsh areas (Freitas et al., 2008; Moreira, 1987; Sousa 2006).

The three seagrass species present in Portugal can be found in the Sado Estuary*: Zostera marina*, *Z. noltei*, and *Cymodocea nodosa* (Cunha et al. 2009, 2013). The main seagrass areas are in Ponta de Adoche on the Tróia peninsula (with all three species present) and in the Cabeços do Rio, Comporta, and Pé de Cavalo areas (Cunha et al., 2009).

The main saltmarsh areas are concentrated in the Lisnave, Comporta, Carrasqueira, Malha da Costa, Faralhão, Monte Novo de Palma, and Herdade do Pinheiro areas. The dominant saltmarsh species are *Sporobolus maritimus*, *Salicornia perennis*, *Puccinellia maritima*, *Salicornia nitens*, *Atriplex portulacoides*, *Arthrocaulon macrostachyum*, *Salicornia europaea*, *Salicornia fruticosa*, *Limonium vulgare*, *Sueda maritima*, *Suaeda vera*, *Juncus maritimus*, and *Limbarda crithmoides*, among others (Freitas et al., 2008; Moreira, 1987; Sousa 2006).

5.3 Protection regimes

The Sado Estuary has been internationally recognised as a Ramsar site by the International Convention on Wetlands since 1996 (**Figure 5.1**, **Table 5.1**). Part of the estuary is included within the boundaries of areas designated as a Site of Community Importance (SCI) and Special Protection Area (SPA) under the Habitats and Birds Directives, respectively (**Figure 5.1**). At the national level, a large part of the estuary was included in the National Network of Protected Areas (RNAP) in 1980 under the Nature Reserve category (Decree-Law No. 430/80 on 1 October; **Figure 5.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06). In the Red List of the Vascular Flora of Mainland Portugal (Carapeto et al., 2020), the species *Zostera marina* and *Cymodocea nodosa* are classified as *Vulnerable* (VU).

Table 5.1 Summary of the protection regimes in the Sado Estuary. RNAP: National Network of Protected Areas.

Regimes	**Reference**	**Year of designation**	**Area** (ha)
Ramsar site	No 826	1996	25 588
Site of Community Importance (Natura 2000 network)	PTCON0011	2008	31 074,07
Special Protection Area (Natura 2000 network)	PTZPE0011	1988	24 632,85
Sado Estuary Nature Reserve (RNAP)	Decree-Law 430/80	1980	23 971,30

5.4 Total area of each habitat

5.4.1 Seagrasses

In 2007, seagrass meadows occupied an area of 33 ha, 87% of which were intertidal *Zostera noltei* seagrass meadows (203 patches, 28 ha). The remainders were subtidal *Cymodocea nodosa* and *Z. marina* seagrass meadows, which occupied an area of 3.14 ha (46 patches) and 1.16 ha (93 patches), respectively (Cunha et al., 2009, 2013; **Table 5.2**). Two estimates were compiled of the total seagrass area. The first estimate was 241 ha, based on the 2019/2020 surveys conducted by the citizen science project “Guardians of the Seagrasses” (https://www.ocean- alive.org/guardians-of-seagrasses) developed by the Ocean Alive cooperative. The other estimate, 221 ha, was based on the surveys conducted in 2021 by Mendes and Melo (unpublished) using aerial image analysis and field validation (**Table 5.2**, **Figure 5.2**).

In the Ponta do Adoche area, on the edge of the Tróia peninsula, there is a *Zostera noltei* and *Z. marina* meadow that has been monitored over time. Between 2002 and 2009, its area increased by 46 %, from 0.49 ha to 0.71 ha (Andrade and Ferreira, 2011), and it completely disappeared in the winter of 2009-2010 due to major storms. This meadow recovered to 1.2 ha in September 2010 (Cunha et al., 2013).

Regarding blue carbon estimates of seagrass meadows in the Sado Estuary, the most recent total area of 221 ha in 2021 (Mendes and Melo, unpublished) was considered. These data were assigned a *Cat 3* quality category as they are complete, up-to-date, and representative.

Table 5.2 Estimates of seagrass meadow areas in the Sado Estuary over time.

Habitat	**Year**	**Area** (ha)	**Source**
Intertidal seagrasses (*Zostera noltei*)	2007	28,38	Cunha et al. (2009)
Subtidal seagrasses (*Cymodocea nodosa*)	2007	3,14	Cunha et al. (2009)
Subtidal seagrasses (*Zostera marina*)	2007	1,16	Cunha et al. (2009)
Seagrasses (total)	2007	32,68	Cunha et al. (2009)
Seagrasses (total)	2019/2020	240,87	https://www.ocean-alive.org/guardias-das-pradarias-marinhas
Intertidal seagrasses	2021	176,9	Mendes e Melo (unpublished)
Subtidal seagrasses	2021	15,9	Mendes e Melo (unpublished)
Intertidal / subtidal seagrasses	2021	28,0	Mendes e Melo (unpublished)
Seagrasses (total)	2021	220,8	Mendes e Melo (unpublished)

Figure 5.2 Location of the seagrass meadow areas in the Sado Estuary. Base image: Google Satellite.

5.4.2 Saltmarsh

The only information available on the saltmarsh area for the entire Sado Estuary can be found on the global saltmarsh distribution database (Mcowen et al., 2017), with an area of 1 448 ha in 2006 and 839 ha in 2010 (Mcowen et al., 2017; **Table 5.3**, **Figure 5.3**). Gutierres et al. (2013) assessed the evolution of the saltmarsh in three areas of the estuary (Comporta, Carrasqueira, and Ilha do Cavalo), showing a decrease in the high and low saltmarshes between 1958 and 2007 that led to a decrease in the total area of occupation. The authors suggested that this decrease may be related to the increase in the mean sea level combined with all the anthropic occupation of the estuary margins that limits sediment supply and, consequently, the saltmarsh expansion towards the interior. Moreira (1992) also refers that the average retreat of saltmarsh in the Sado Estuary was about 17 cm per year at the end of the 20th century, mainly due to the increase in human activity and probably also related to the increase in the mean sea level.

There have been no data on the saltmarsh area in this system since 2010; therefore, the most recent (2010) area of 839 ha, as reported by Mcowen et al. (2017), was considered for blue carbon estimates in the Sado Estuary saltmarsh. These data were assigned a *Cat 2* quality category as they are not up to date.

Table 5.3 Estimates of saltmarsh areas in the Sado Estuary over time.

Habitat	Year	Area (ha)	Source
Saltmarsh	2006	1 448,35	Mcowen et al. (2017)
Saltmarsh	2010	838,75	Mcowen et al. (2017)

Figure 5.3 Location of saltmarsh areas in the Sado Estuary in 2006 and 2010. Adapted from Mcowen et al. (2017). Base image: Google Satellite.

5.5 Estimates of carbon stocks and sequestration rates

5.5.1 Data compilation

No biomass or carbon content data were found for seagrasses in the Sado Estuary, and only one study with hypogean biomass data was found for the saltmarsh plant *Salicornia fruticosa* in 2004-2005 (Martins et al., 2008) (**Table 5.4**).

Regarding sediment, no data were found for seagrasses, but organic matter and organic carbon content data are available for the sediment of some saltmarsh species between 1988 and 2006 (Almeida et al., 2008; Freitas et al., 2008; Machado et al., 2012; Martins et al., 2008; Moreira, 1992; Moreno et al., 2017; Reboredo 1992; Sousa, 2006) (**Table 5.4**). Some sedimentation rate data were also compiled (Freitas et al., 2008; Moreira, 1992) (**Table 5.4**).

Seagrass vegetation and sediment data were assigned a *Cat 0* quality category (no data), and both saltmarsh vegetation and sediment data a *Cat 1* quality category as they were incomplete (**Table 5.5**).

Table 5.4. Values compiled for the calculations of carbon stocks and sequestration rates in the Sado Estuary after making the necessary conversions for data standardisation and statistical analyses.

Variable	Seagrasses (total)	Saltmarsh (total)
Area (ha)	220,8	838,75
Epigean Biomass (g DW m^{-2})	-	-
Hypogean Biomass (g DW m^{-2})	-	1 920 ± 283*
Biomass stock by area (Mg DW ha^{-1})	-	-
Total biomass stock (Mg DW)	-	-
Carbon content (epigean biomass) (% DW)	-	-
Carbon content (epigean biomass) (% DW)	-	-
Organic carbon content (sediment) (% DW)	-	2,76 ± 1,25**
Organic matter (sediment) content (% DW)	-	4,4 ± 3,8 ***
Carbon stock in sediment (Mg OC ha^{-1})	-	-
Sediment accumulation rate (mm $year^{-1}$)	-	2,43 ± 1,21
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	-	-

DW: dry weight. **OM**: organic matter.

* Only for the species *Salicornia fruticosa*.

** For *Salicornia fruticosa* species and up to 10 cm deep.

*** For mid and high marsh.

Table 5.5 Data quality for calculating carbon stocks and sequestration rates in the Sado Estuary.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 3	Cat 2
Level 2: Vegetation	Cat 0	Cat 1
Level 3: Sediment	Cat 0	Cat 1

Quality categories for each level: Cat 0 (no data), Cat 1 (incomplete data), Cat 2 (complete but non-representative or outdated data, i.e., < 2018), Cat 3 (complete, representative, and up-to-date data, i.e., ≥ 2018).

5.5.2 Estimates

Blue carbon habitats in the Sado Estuary are estimated to contain a total stock (sediment and biomass) of 66 661 Mg OC and sequester a total of 355 Mg OC year^{-1} annually, with seagrasses contributing 28% and 31% to these values, respectively (**Table 5.6**). Since not all the necessary data from the Sado Estuary were available for these calculations, the available values of stocks and sequestration rates from the Ria Formosa and the Tagus Estuary were used. The estimates presented are very imprecise.

Table 5.6 Estimates of blue carbon stocks and sequestration rates in the Sado Estuary.

Variable	Seagrasses (intertidal)	Seagrasses (subtidal)	Saltmarsh (total)	TOTAL
Total OC stock in biomass (Mg OC)	235	55	8 096	**8 386**
Total OC stock in sediment (Mg OC)	17 183	832	40 260	**58 276**
Total stock (Mg OC)	17 418	888	48 356	**66 661**
Annual sequestration rate (Mg C year^{-1})	108	2,4	245	**355**

OC: organic carbon

5.6 Environmental quality and threats

The Sado Estuary is in a densely occupied area. The northern bank of the lower estuary is highly artificialized due to the city of Setúbal, where one of the country's largest commercial and fishing ports is located. This is also a highly industrialised area, particularly on the Mitrena peninsula, due to the petrochemical industry, thermoelectric production, paper industries, pesticides, herbicides, fungicides, fertilisers, metal processing, plastic components and shipyards, and vehicle repair services (Caeiro et al., 2005; Freitas et al., 2008). In the remainder of the estuary, there are large areas of agricultural activities (with great relevance to rice cultivation; Vale et al., 1993), aquaculture, and salt pans. All these activities have led to the destruction of saltmarsh areas (Gutierres et al., 2013). Some saltmarsh areas are or used to be highly polluted (Caeiro et al., 2005).

According to the latest characterisation and diagnosis of the Ribeiras do Sado and Mira River Basin Management Plan (RH6) conducted in 2019 (APA, 2022), transitional waters in the estuary have a *Good* or *Moderate* ecological status (PT06SAD1207, PT06SAD1210, PT06SAD1211, PT06SAD1217, PT06SAD1219, PT06SAD1222) based on several biological indicators.

In addition to the threats to blue carbon ecosystems already mentioned, there are also coastal and tourism development and the physical impact caused by trawling and boat anchors. Cunha et al. (2013) refer that these were the main causes of the disappearance of seagrass *Zostera marina* meadows on the Arrábida coast, outside the estuary, which occupied extensive areas in Portinho da Arrábida (10 ha) and have completely disappeared since the winter of 2006-2007.

5.7 Conservation interventions

5.7.1 Past and ongoing interventions

Recently, in 2022, an active seagrass restoration intervention was carried out in the Tróia peninsula area after the removal of a mooring cable that was damaging the plants. The restoration project was coordinated by the Ocean Alive cooperative funded by the Viridia – Conservation in Action association (https://viridia.pt/why-we-exist/our-projects/reforesting-the-sea/). The intervention aimed to stabilise the sediment and to transplant plants from the same meadow. No data on seagrass meadow restoration and recovery are available. The Ocean Alive cooperative also conducts awareness and environmental education activities on the Sado Estuary seagrass meadows. These include the “Guardians of the Sea” programme, where women from the fishing and shellfish harvesting community work to safeguard and map the estuary’s seagrass meadows (https://www.ocean-alive.org/guardias-do-mar).

The “VALPRAD: Ecological importance, economic development, and conservation of the seagrass meadows of the Sado Estuary” project was carried out between 2018 and 2021 by researchers from the Faculty of Sciences of the University of Lisbon, and its main objective was to contribute to the protection, restoration, and sustainable use of seagrass meadows in the Sado Estuary by increasing knowledge regarding their ecological importance, as well as their economic development. That project was funded by the Mar2020 Operational Programme (MAR-01.04.02-FEAMP- 0007). No reports or scientific contributions produced by that project on seagrass protection and restoration in the Sado Estuary have been found.

5.7.2 Proposed interventions

a) Monitoring
Updating the mapping of the Sado Estuary saltmarsh and assessing blue carbon stocks and sequestration rates in seagrass meadows and saltmarsh is recommended.

b) Protection

Ponta de Adoche seagrass meadows on the Tróia peninsula are not within the boundaries of any legally protected area (**Figure 5.4**). Since it hosts the greatest biodiversity of seagrass species in Portugal (*Cymodocea nodosa*, *Zostera marina,* and *Z. noltei*), it is a meadow of high ecological value. Protecting it within the National Network of Protected Areas (RNAP) is recommended.

c) Restoration

As in other coastal systems on the Portuguese coast, blue carbon ecosystems in the Sado Estuary have been subject to great anthropogenic pressures that have resulted in the claiming of large natural areas for several other uses. In particular, large areas of saltmarsh have been destroyed; therefore, it is necessary to survey the inactive artificialized areas that could be used to restore this ecosystem. The area occupied by seagrass in the Sado Estuary may also be increased by removing the disturbance factors that have caused its decline and implementing active restoration actions. This will require an in-situ assessment of the best areas to do this, taking advantage of the vast local knowledge of seagrass meadows.

Figure 5.4 Location of saltmarsh and seagrass areas in the Sado Estuary and the boundaries of current protection regimes. Base image: Google Satélite.

5.8 Local stakeholders

Municipality of Grândola
Municipality of Setúbal
Municipality of Alcácer do Sal
Municipality of Palmela
Regional Coordination and Development Commission – Lisbon and Tagus Valley (CCDR- LVT)
Alentejo Coordination and Regional Development Commission (CCDRA)
Ocean Alive Association
Clube Naval Setubalense
Port Authority of Setúbal and Sesimbra

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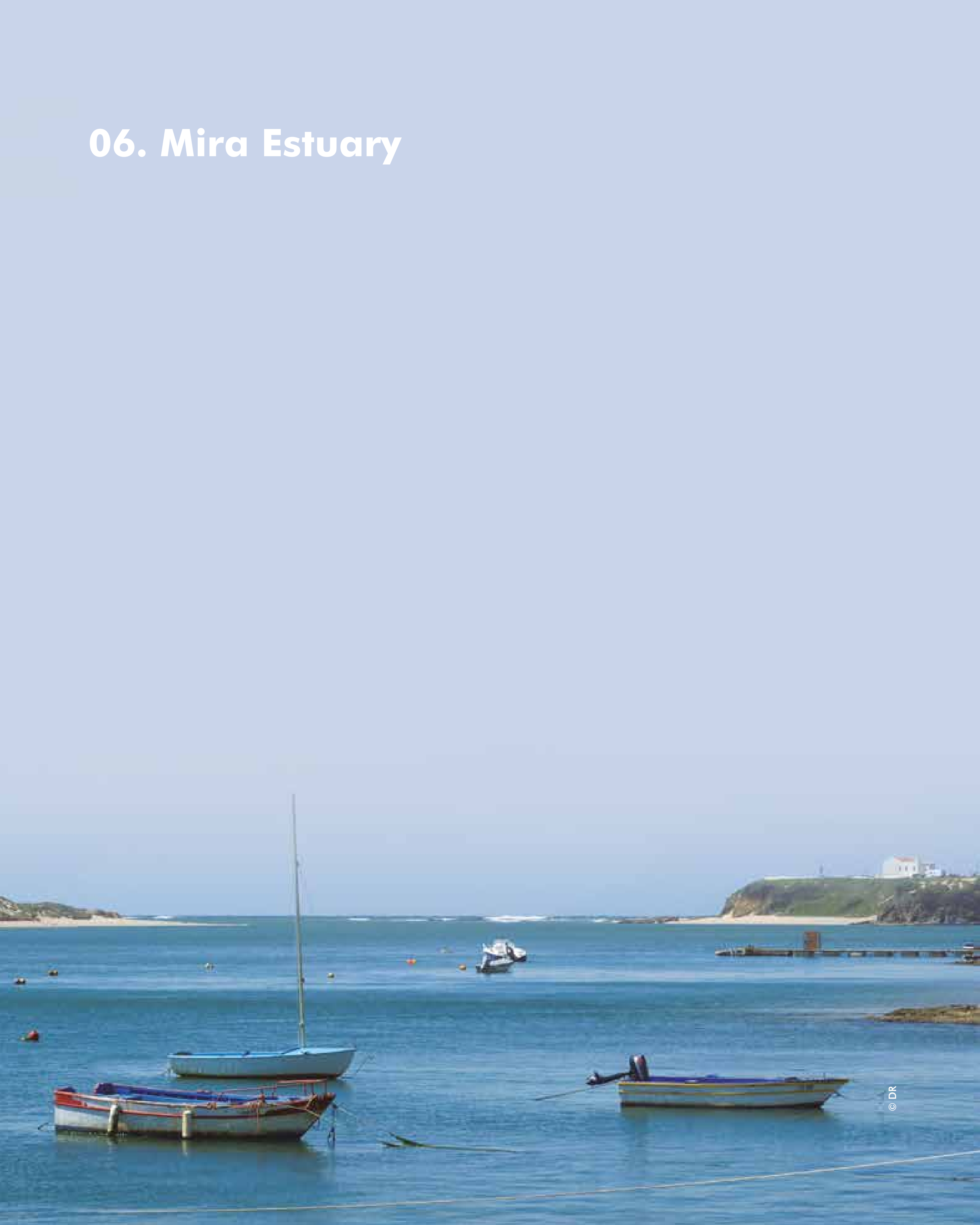
06. Mira Estuary



6.1 Geographical location

The Mira Estuary is located in the municipality of Odemira on the southwest coast of Portugal, between Vila Nova de Milfontes (north bank) and Nascedios (south bank; **Figure 6.1**). It is a relatively small estuary, 40 km long and 400 m wide at its widest part, with a single channel, the Mira River. The average depth of the estuary is 6 m, with a maximum depth of 8-10 m near Vila Nova de Milfontes bridge.

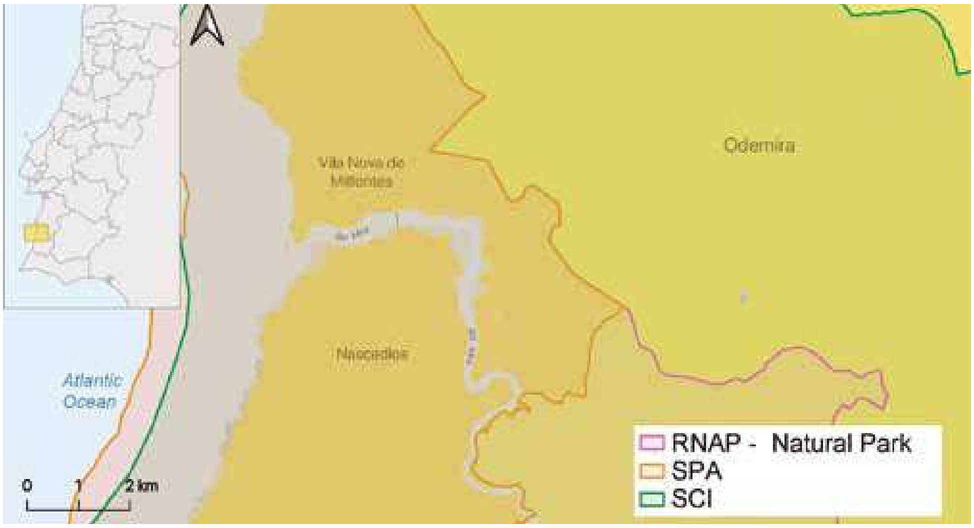


Figure 6.1 Location of the Mira Estuary in the municipality of Odemira and the area covered by the protection regimes Natural Park (RNAP, National Network of Protected Areas), SPA (Special Protection Area, Natura 2000 network), and SCI (Site of Community Importance, Natura 2000 network). Elements of the base map: Geographical information provided by the Directorate-General for Territorial Development

6.2 Types of blue carbon habitats

There are *Zostera noltei* seagrass meadows in the estuary's intertidal zone (Almeida 1988, 1994; Amaral et al., 2008; Cunha et al., 2013; Materatski et al., 2016), and *Z. marina* seagrass meadows in the adjacent subtidal zone (Almeida, 1988; Andrade, 1986; Cunha et al., 2013). Saltmarshes are located on the riverbanks up to 20 km upstream (Amaral and Paula, 2007), and their dominant species are *Sporobolus maritimus* and *Salicornia perennis* (Costa et al., 2001).

6.3 Protection regimes

The Mira Estuary is considered an area of high ecological importance and is under European and national protection regimes (**Figure 6.1**). It is part of the Natura 2000 network and was designated as a Special Protection Area (SPA) in 2015 and a Site of Community Importance (SCI) in 2008 under the Birds and Habitats Directives, respectively. The estuary is part of the Southwest Alentejo and Vicentine Coast Natural Park of the National Network of Protected Areas (RNAP) since 1988 (Decree-Law No. 241/88 on 7 July; **Table 6.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06). In the Red List of the Vascular Flora of Mainland Portugal (Carapeto et al., 2020), the species *Zostera marina* is classified as *Vulnerable* (VU).

Table 6.1 Summary of the protection regimes in the Mira Estuary. RNAP: National Network of Protected Areas..

Regime	Reference	Year of designation	Area (ha)
Site of Community Importance (SCI, Natura 2000 network)	PTCON0012	2008	2 623
Special Protection Area (SPA, Natura 2000 network)	PTZPE0015	2015	1 007
Southwest Alentejo and Vicentine Coast Natural Park (RNAP)	Decrete-Law No 241/88	1988	896

6.4 Total area of each blue carbon habita

6.4.1 Seagrasses

The intertidal *Zostera noltei* seagrass meadows occupied a large extension until 2007, before they almost completely disappeared after a major flood. After the flood, they covered an area of 0.006 ha with only one patch (Cunha et al., 2009, 2013). In a study published in 2008, the area of intertidal meadows was estimated at 11.84 ha (Amaral et al., 2008; **Table 6.2**, **Figure 6.2**). By 2010, the meadows had recovered, reaching an area of 7.5 ha (Cunha et al., 2013; **Table 6.2**). By 2015, their area was considerably large although the extent was unknown (Branco et al., 2018). The last survey was conducted in 2019, in which it was estimated an area of 14.8 ha (Mendes & Melo, unpublished).

Subtidal *Zostera marina* seagrass meadows occupied an area of 0.4 ha in 1985 (Andrade, 1986). In 2009, that species occupied 400 m2, and in 2010 it was quite rare since it only occupied an area of 40 x 40 cm (Cunha et al., 2013; **Table 6.2**). It is unknown whether that species can still be found in this system.

For the blue carbon estimates of seagrass areas in the Mira Estuary, the most recent intertidal seagrass area of 14.8 ha and 0.000016 ha of subtidal seagrass (**Table 6.2**) was considered. Seagrass area data were assigned a *Cat 2* quality category as subtidal seagrass data are not complete and up-to-date even though intertidal data are up-to-date, complete, and representative.

Table 6.2 Estimates of seagrass meadow areas in the Mira Estuary over time.

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	2007	0,006	Cunha et al. (2009)
Intertidal seagrasses	na.	11,84	Amaral et al. (2008)
Intertidal seagrasses	2010	7,5	Cunha et al. (2009)
Intertidal seagrasses	2019	14,8	Mendes & Melo (unpublished)
Sub-tidal seagrasses	1985	0,4	Andrade (1986)
Sub-tidal seagrasses	2007	0	Cunha et al. (2013)
Sub-tidal seagrasses	2009	0,04	Cunha et al. (2013)
Sub-tidal seagrasses	2010	0.000016	Cunha et al. (2013)

Figure 6.2 Location of seagrass meadow areas in the Mira Estuary based on a study published in 2008 (Amaral et al., 2008), and a survey carried out in 2019 (Mendes & Melo, unpublished). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

6.4.2 Saltmarsh

The information available on the global saltmarsh distribution database (Mcowen et al., 2017) indicates an occupied area of 109.21 ha in 2006 and 166.8 ha in 2010 (**Table 6.3**, **Figure 6.3**). A survey performed in 2018 reported a saltmarsh area of 130.62 ha (Amaral et al., 2008). The last survey, carried out in 2019, estimated an area of 124.6 ha (**Table 6.3**, **Figure 6.3**). Even though the 2019 survey does not cover the whole estuary, it covers most of it (**Figure 6.3**).

For the blue carbon estimates in the Mira Estuary saltmarsh areas, the most recent (2019) area of 124.6 ha (**Table 6.3**) was considered. Although saltmarsh area data are up to date, they were assigned a *Cat 2* quality category since they are incomplete (there are no categories by saltmarsh type – *low*, *mid*, and *high* – nor by species).

Table 6.3 Estimates of saltmarsh areas in the Mira Estuary over time.

Habitat	Year	Area (ha)	Source
Saltmarsh (total)	2007	109,21	Mcowen et al. (2017)
Saltmarsh (total)	na.	130,62	Amaral et al. (2008)
Saltmarsh (total)	2010	166,8	Mcowen et al. (2017)
Saltmarsh (total)	2019	124,6	Mendes & Melo (unpublished)

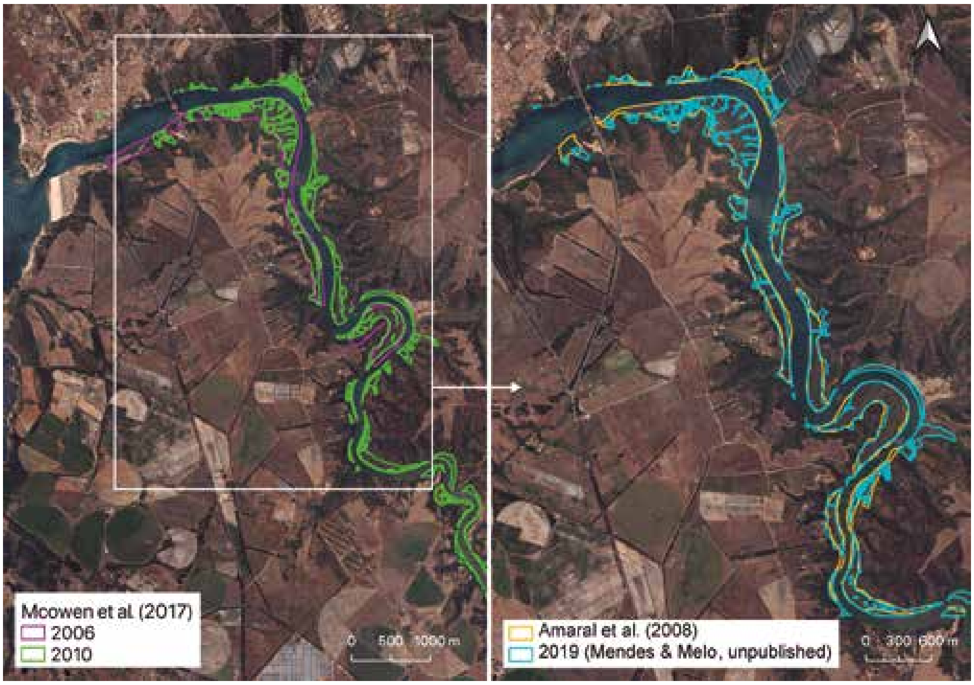


Figure 6.3 Location of saltmarsh areas in the Mira Estuary in 2006, 2010, 2019, and from a study published in 2008. Adapted from Mcowen et al. (2017), Amaral et al. (2008) and Mendes & Melo (unpublished). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

6.5 Estimates of carbon stocks and sequestration rates

6.5.1 Data compilation

Zostera noltei biomass data sampled in 2010 – 2011 were compiled, with a mean value of the epigean biomass of 2.1 ± 1.8 g DW m^{-2} and hypogean biomass of 8.3 ± 5.3 g DW m^{-2} (Materatski et al. 2016; **Table 6.4**). No biomass data were found for *Z. marina*. For the saltmarsh, there is a temporal series of epigean biomass data for the species *Sporobolus maritimus* and *Salicornia perennis* between 1990 and 1991, and their mean values are 460 ± 115 g DW m^{-2} and 1 264 ± 1 127 g DW m^{-2}, respectively (Costa et al., 2001). Considering both species, the average epigean biomass was 782 ± 813 g DW m^{-2} (**Table 6.4)**. No carbon content data were found in the tissues of either plant species.

Regarding sediment, a study reported total carbon content data down to a depth of 59 cm, with an average of 3.71 ± 0.72% DW, and a sediment accumulation rate of 6.8 mm year^{-1} in *Zostera noltei* meadows (Castro et al., 2007). As for the saltmarsh, organic matter content data in a sediment core of around 1 m was compiled, with an average concentration of 8.0 ± 3.5% DW (Moreno et al., 2017).

Seagrass vegetation and sediment data and saltmarsh vegetation and sediment data were assigned a *Cat 1* quality category as they were not complete (**Table 6.5**).

Table 6.4. Values compiled for the calculations of carbon stocks and sequestration rates in the Mira Estuary after making the necessary conversions for data standardisation and statistical analyses.

Variable	Intertidal seagrasses (ZN)	Subtidal seagrasses (ZM)	Saltmarsh (total)
Area (ha)	14,8	0,00002	124,6
Epigean Biomass (g DW m^{-2})	2,1 ± 1,8	-	782 ± 813
Hypogean Biomass (g DW m^{-2})	8,3 ± 5,3	-	-
Biomass stock per area (Mg DW ha^{-1})	-	-	-
Total biomass stock (Mg DW)	-	-	-
Carbon content (epigean biomass) (% DW)	-	-	-
Carbon content (epigean biomass) (% DW)	-	-	-
Organic carbon content (sediment) (% DW)	3,71 ± 0,72*	-	-
Organic matter (sediment) content (% DW)	-	-	8,0 ± 3,5
Carbon stock in sediment (Mg OC ha^{-1})	-	-	-
Sediment accumulation rate (mm year^{-1})	6,8	-	-
Carbon sequestration rate in sediment (g OC m^{-2} year^{-1})	-	-	-

DW: dry weight. **OC**: organic carbon. Species code: **ZN**, *Zostera noltei;* **ZM**, *Zostera marina*.

* Value for total carbon (not used in the estimates).

Table 6.5 Data quality for calculating carbon stocks and sequestration rates in the Mira Estuary.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 1	Cat 1
Level 3: Sediment	Cat 1	Cat 1

Quality categories for each level: Cat 0 (no data),
Cat 1 (incomplete data), Cat 2 (complete but non-representative or outdated data, i.e., < 2018),
Cat 3 (complete, representative, and up-to-date data, i.e., ≥ 2018).

6.5.2 Estimates

Blue carbon habitats in the Mira Estuary are estimated to contain a total stock (sediment and biomass) of 7 735 Mg OC and to sequester a total of 45 Mg OC year^{-1} annually, with intertidal seagrasses contributing 17% and 19% to these values, respectively (**Table 6.6**). Given the lack of local data for these calculations, available data on stock and sequestration rate from the nearest system (Ria Formosa) were used to calculate these values. Consequently, these estimates are very imprecise.

Table 6.6 Estimates of blue carbon stocks and sequestration rates in the Mira Estuary.

Variable	Seagrasses (intertidal)	Seagrasses (subtidal)	Saltmarsh (total)	TOTAL
Total stock OC in biomass (Mg OC)	0,54	< 0,1	421	**422**
Total stock OC in sediment (Mg OC)	1 332	< 0,1	5 981	**7 313**
Total stock (Mg OC)	1 333	< 0,1	6 402	**7 735**
Annual sequestration rate (Mg C year^{-1})	8,3	< 0,1	36,3	**45**

OC: Organic carbon.

6.6 Environmental quality and threats

There is an urban area at the mouth of the Mira River, Vila Nova de Mil Fontes, with seasonal tourism and two aquaculture areas, one at the first bend of the river and another upstream, closer to the town of Odemira (Castro et al., 2007). Freshwater discharge is controlled at the Santa Clara reservoir upstream of Odemira (about 20 km away). The Mira River receives nutrients from agriculture, livestock activities, and wastewater from urban areas (Castro et al., 2007).

According to the APA monitoring for the Sado and Mira River Basin Management Plan (RH6), the Mira River water quality status (PT06MIR1375) deteriorated between the 2nd cycle and the 3rd cycle (APA, 2022). This body of water was classified as below *Good* in the last cycle (APA, 2022), and the significant pressures identified were occasional pollution due to wastewater, diffuse pollution from agriculture, and hydrological change for agriculture. No other studies were found, direct or indirect, regarding the conservation status of the saltmarsh and seagrass ecosystems in the Mira Estuary.

6.7 Conservation interventions

6.7.1 Past and ongoing interventions

The "ProMira – Development of methodologies with application in the Recovery, Protection and Management of seagrass meadows and saltmarshes in the Mira Estuary as a vital support to fishing activities, aquaculture, and as a nursery for species" project (more information here) aimed to achieve a set of objectives to create favourable conditions for implementing research-based measures targeting flora and fauna recovery and protection in coastal ecosystems with vegetation. The project was led by researchers from the University of Évora from 2013 to 2015 and was funded by QREN/Promar-Operational Programme for Fisheries 2007-2013. The specific objectives related to blue carbon habitats were:

1. To know the physical and chemical environment and to understand the risk factors for its species.

2. To seasonally investigate and monitor the evolution of sediment and water physiological quality in the estuary during the natural recovery process of *Zostera noltei* meadows.

3. To monitor the eco-physiological state of *Zostera* plants during recovery.

4. To investigate the changes and the biodiversity evolution pattern of the biological communities that structure the functioning of these ecosystems and are responsible for the balance between sediment, flora, and fauna: sediment microbial communities, macrophyte plants and benthic communities (meiofauna and macrofauna), and ichthyofauna.

5. To assess the impact of fishing and shellfish harvesting (human predation) on natural habitat recovery.

6. To integrate data obtained from sediment recovery, flora, fauna, and fisheries impacts to understand the ecological basis of habitat recovery.

7. To prepare proposals on the methodologies to be applied in the recovery, protection, and management of seagrass meadows and saltmarshes.

8. To raise awareness among stakeholders.

Additionally, management measures for the Mira River body of water are proposed in the 3rd Cycle of the Sado and Mira River Management Plan (RH6) (APA, 2022).

6.7.2 Proposed interventions

a) Monitoring
Mapping updates of seagrass and saltmarsh meadows in the Mira Estuary and assessing blue carbon stocks and sequestration rates are recommended. Distribution data could be included in the "LTSER Mira Estuary" on the DEIMS-SDR (Dynamic Ecological Information Management System – Site and dataset registry) website.

b) Protection
Saltmarsh and seagrass areas in the Mira Estuary are under the RNAP and SCI protection regimes (**Figure 6.4**).

c) Restoration
There are inactive, artificialized saltmarsh areas along the Mira River, separated from the river by embankments. These could be removed for passive or active saltmarsh restoration. In addition, active restoration interventions of *Zostera marina* seagrass meadows may be carried out where they used to be but can no longer be found.

6.8 Local stakeholders

Municipality of Vila Nova de Milfontes
Alentejo Co-ordination and Regional Development Commission (CCDRA)
University of Évora
Southwest Alentejo and Vicentine Coast Natural Park, PNSACV

Figure 6.4 Location of saltmarsh and seagrass areas in the Mira Estuary and the boundaries of current protection regimes. Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

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07. Ria de Alvor

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7.1 Geographical location

The Ria de Alvor is a small estuary located in the municipalities of Portimão and Lagos (Faro district) on the south coast of Portugal (**Figure 7.1**), covering an area of 14.5 km^2. The estuary is formed by four watercourses, the Ribeira do Farelo and the Ribeira da Torre (to the east), and the Ribeira de Odiáxere and the Ribeira do Arão (to the west). It is delimited by two barrier peninsulas and connected to the sea by a single inlet.

Figure 7.1 Location of the Ria de Alvor in the municipalities of Lagos and Portimão, and the area under the protection regimes SCI (Site of Community Importance) and the Ramsar Convention. Base map elements: Geographical information provided by the Directorate-General for Territorial Development.

7.2 Types of habitats

The Ria de Alvor only presents intertidal *Zostera noltei* seagrass meadows (Cunha, 1991; Martins, 2014; Salgado & Santos, 1988) and saltmarsh areas (low, middle, and high) with different degrees of modification (Almeida et al., 2014). In natural saltmarsh areas, the low saltmarsh is dominated by the species *Sporobolus maritimus*, *Salicornia perennis*, *Atriplex portulacoides*; the middle marsh by *Atriplex portulacoides* and *Salicornia fruticosa*; and the high marsh by *Suaeda vera*, *Limoniastrum monopetalum*, and *Cistanche phelypaea* (Almeida et al., 2014).

7.3 Protection regimes

The Ria de Alvor has been internationally recognised as a Ramsar site by the International Convention on Wetlands since 1996 (**Figure 7.1**, **Table 7.1**). It was designated a Site of Community Importance (SCI) under the Habitats Directive in 2008.

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06).

Table 7.1 Summary of the protection regimes in the Ria de Alvor.

Regime	Reference	Year of designation	Area (ha)
Ramsar site	No 827	1996	14,54
Site of Community Importance (Natura 2000 network)	PTCON0058	2008	14,619

7.4 Total area of each habitat

7.4.1 Seagrasses

An analysis of the temporal evolution of the intertidal *Zostera noltei* meadows area in the Ria de Alvor between 1986 and 2009 showed a 92% decline from 2.1 ha – with a rather fragmented configuration of 32 patches – to 7 patches occupying a total area of 0.16 ha, which then recovered to 2.5 ha in 2012 (Martins, 2014; **Figure 7.2**, **Table 7.2**).

To estimate carbon stocks in the Ria de Alvor seagrass meadows, the most recent (2012) area of 2.5 ha (Martins, 2014) was considered. Seagrass area data were assigned a *Cat 2* quality category as they are not up to date.

Figure 7.2 Location of seagrass meadows in the Ria de Alvor in 1986, 2009, and 2012. Adapted from Martins (2014). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

Table 7.2 Estimates of seagrass meadow areas in the Ria de Alvor over time.

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	1986	2,0599	Martins (2014), Salgado & Santos (1986)
Intertidal seagrasses	2009	0,1647	Martins (2014), Cunha (1991)
Intertidal seagrasses	2012	2,5532	Martins (2014)

7.4.2 Saltmarsh

Land occupation and changes in its use in the Ria de Alvor resulted in the loss of saltmarsh areas due to the construction of dams for agricultural reclamation. The subsequent abandonment of this activity gave rise to areas that were either used for aquaculture or abandoned (Almeida et al., 2014). Pullan (1988) estimated a loss of approximately 90% of the original marsh area in the Ria de Alvor. Between 1958 and 2010, the southeast area of the system lost 110 ha of its original 182 ha natural marsh area (Almeida et al., 2014; **Table 7.3**, **Figure 7.3**). Information available on the global saltmarsh distribution database (Mcowen et al., 2017) shows a loss of 234 ha in 2006 and 49 ha in 2010 (**Figure 7.3**). Since the last survey conducted by Almeida et al. (2014) in 2010 and the 2010 data on the global database (Mcowen et al., 2017), no further data are available on the saltmarsh area in this system. For blue carbon estimates in the Ria de Alvor saltmarsh areas, it was considered the most recent (2010) 72 ha area reported by Almeida et al. (2014) relating to the natural saltmarsh subtype. Seagrass area data were assigned a *Cat 2* quality category as they were not up to date.

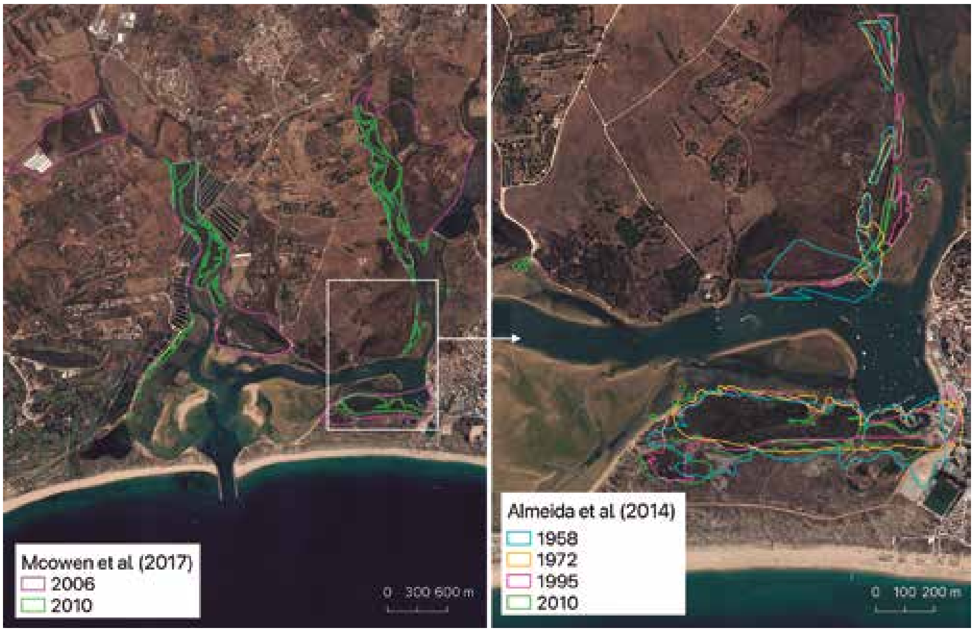

Figure 7.3 Location of saltmarsh areas in the Ria de Alvor in 1958, 1972, 1995, 2006, and 2010. Adapted from Mcowen et al. (2017) and Almeida et al. (2014). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

Table 7.3 Estimates of saltmarsh areas in the Ria de Alvor over time.

Habitat	Year	Area (ha)	Source
Saltmarsh (total)*	1958	182	Almeida et al. (2014)
Saltmarsh (total)*	1972	73	Almeida et al. (2014)
Saltmarsh (total)*	1987	69	Almeida et al. (2014)
Saltmarsh (total)*	1995	55	Almeida et al. (2014)
Saltmarsh (total)*	2005	65	Almeida et al. (2014)
Saltmarsh (total)*	2010	72	Almeida et al. (2014)
Saltmarsh (total)*	2006	234	Mcowen et al. (2017)
Saltmarsh (total)*	2010	49	Mcowen et al. (2017)

* Natural saltmarsh fraction as indicated in the source.

7.5 Estimates of carbon stocks and sequestration rates

7.5.1 Data compilation

Total seagrass biomass data were compiled for 1986 (27.2 Mg WW in 2.0599 ha; Salgado & Santos, 1988) and 1991 (14.6 Mg WW in 0.1647 ha; Cunha, 1991), but neither saltmarsh biomass data nor carbon content data were found for either type of vegetation (**Table 7.4**). Biomass data were converted to DW and expressed per unit area. Regarding sediment, no data were found for seagrass meadows, but organic matter content data up to 20 cm depth (Almeida, 2016) and short-term (< 1 year) sediment accumulation rates for different marsh subtypes were found: natural marshes, tidally restored marshes, and enclosed mixed marshes (Almeida, 2016) (**Table 7.4**).

Seagrass vegetation data were assigned a *Cat 1* quality category as they were not complete, and saltmarsh data a *Cat 0* quality category as no data were available. Regarding sediment, seagrass data were assigned a *Cat 0* quality category (no data) and saltmarsh data a *Cat 1* quality category (incomplete data) (**Table 7.5**).

Table 7.4 Values compiled for the calculations of carbon stocks and sequestration rates in the Ria de Alvor after the necessary conversions for data standardisation.

Variable	Intertidal seagrasses (ZN)	Saltmarsh (total)*
Area (ha)	2,55	72
Epigean Biomass (g DW m^{-2})	-	-
Hypogean Biomass (g DW m^{-2})	-	-
Biomass stock per area (Mg DW ha^{-1})	1,9	-
Total biomass stock (Mg DW)	3,99	-
Carbon content (epigean biomass) (% DW)	-	-
Carbon content (epigean biomass) (% DW)	-	-
Organic matter (sediment) content (% DW)	-	2,78 - 3,01
Carbon stock in sediment (Mg OC ha^{-1})	-	-
Sediment accumulation rate (mm $year^{-1}$)	-	5,19
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	-	-

DW: dry weight. OC: organic carbon. Species code: ZN: *Zostera noltei*.

* Values for natural saltmarsh only.

Table 7.5 Data quality for calculating carbon stocks and sequestration in the Ria de Alvor.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 1	Cat 0
Level 3: Sediment	Cat 0	Cat 1

Quality categories for each level: Cat 0 (no data),
Cat 1 (incomplete data), Cat 2 (complete but non-representative or outdated data, i.e., < 2018),
Cat 3 (complete, representative, and up-to-date data, i.e., ≥ 2018).

7.5.2 Estimates

It is estimated that the total stock (sediment and biomass) in the Ria de Alvor blue carbon habitats is 4 475 Mg OC, and saltmarshes are the habitat making the largest contribution (95%, **Table 7.6**). These habitats sequester annually a total of 22 Mg OC per year^{-1}, and the saltmarsh makes the highest contribution (94%).

For the calculations of blue carbon in the Ria de Alvor, stock values and sequestration rates from the nearest system, the Ria Formosa, were used. The estimates presented are, therefore, imprecise.

Table 7.6 Estimates of blue carbon stocks and sequestration rates in the Ria de Alvor.

Variable	Seagrasses (intertidal)	Saltmarsh (total)*	TOTAL
Total stock OC in biomass (Mg OC)	3,1	787	**790**
Total stock OC in sediment (Mg OC)	230	3 456	**3 686**
Total stock (Mg OC)	233	4 243	**4 475**
Annual sequestration rate (Mg C year^{-1})	1,4	21	**22**

OC: organic carbon.
*Values for natural saltmarsh only.

7.6 Environmental quality and threats

The Ria de Alvor saltmarshes and seagrasses are located in an urban area that attracts tourists and has well-consolidated residential areas in the municipalities of Lagos and Portimão, which were – and still are – a threat to this system. Human occupation in the Ria de Alvor has motivated agricultural reclamation of large marsh areas for centuries (Almeida et al. 2013, 2014). Presently, the greatest pressures on the saltmarsh and seagrasses in the Ria de Alvor are tourism, urban and industrial development, land reclamation and coastal engineering, aquaculture, and shellfish harvesting (Mateus et al., 2016).

According to the latest characterisation and diagnosis of the Ribeiras do Algarve Management Plan (APA, 2022), the Ria de Alvor is subject to nutrient pollution and other impacts related to aquaculture and the introduction of species and diseases. Other identified threats to the Ria de Alvor saltmarsh are trampling by residents (fishermen and shellfish harvesters) and tourists in very localised areas, boat parking, and abandoned boat storage (Rolo, 2007).

Regarding seagrass, habitat loss due to dredging and aquaculture, eutrophication (nutrients resulting from cropland and golf courses), and intense bivalve and bait harvesting for fishing have been identified as the greatest threats in the past decade (Cunha et al., 2013; Mateus et al., 2016). The last characterisation and diagnosis of the Ribeiras do Algarve (APA, 2022) classifies the ecological status of the Ria de Alvor waters (code PT08RDA1700) as *Moderate* based on seagrass condition, and their chemical status is *Good*.

7.7 Conservation interventions

7.7.1 Past and ongoing interventions

No seagrass restoration interventions were found in the Ria de Alvor. Regarding the saltmarshes an experimental project was implemented in 2000 to restore a saltmarsh area adjacent to Vila de Alvor, which had been affected by a landfill and excavations during some works in 1999 (Nemus, 1999; Rolo, 2007). This intervention aimed to recover an area of 2.1 ha by restoring its original topography, replacing mud layers, and replanting vegetation (*Salicornia sp.*, *Arthrocaulon sp.*, and *Atriplex portulacoides*) with specimens taken from an adjacent marsh area with a density of 4 plants m^{-2} (Nemus, 1999, 2000). Additionally, the area was fenced, and an environmental information system was implemented. Seven years after the intervention, the extent of saltmarsh recovery was assessed, and it was found that the area was recovering even though it was still an immature saltmarsh with large clearings with no vegetation (Rolo, 2007).

7.7.2 Proposed interventions

a) Monitoring
Monitoring saltmarsh and seagrass areas, updating the areas occupied by these ecosystems, and assessing carbon stocks and sequestration rates, which do not exist for the Ria de Alvor, is recommended.

b) Protection
All saltmarsh and seagrass areas are currently under the protection regime SCI and are recognised as Ramsar site (**Figure 7.4**).

c) Restoration
In 2010, about 59% of salt pans were abandoned in the Ria de Alvor (Almeida et al., 2014). They are potential areas for passive marsh restoration by means of wall removal and the reconstitution of the estuary's natural hydrodynamics. In a recent APA report (Furtado et al., 2021), it was identified 352 ha of inactive artificialized areas (3 salt pans and four confined areas, **Figure 7.5**) that could be used for spontaneous saltmarsh recovery or restoration once the dams separating them from their natural environment are removed, and topographic levels in the saltmarsh are restored. Considering the slow saltmarsh recovery observed in the only restoration experience in the Ria de Alvor (Nemus, 1999; Rolo, 2007), active restoration should be considered as it helps spontaneous renaturation of artificialized areas.

In addition, the areas occupied by seagrass (*Zostera noltei*) that were identified in the northern part of the Ria de Alvor in 1986 and have never been detected again – at least until the most recent mapping in 2012 – are potential areas for active seagrass restoration using transplantation or collection of seeds found elsewhere. It must be ensured that the causes leading to the disappearance of seagrass have already been mitigated.

Figure 7.4 Location of saltmarsh and seagrass areas in the Ria de Alvor estimated in 2012 and 2010, respectively, and the boundaries of current protection regimes. Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05- 2018).

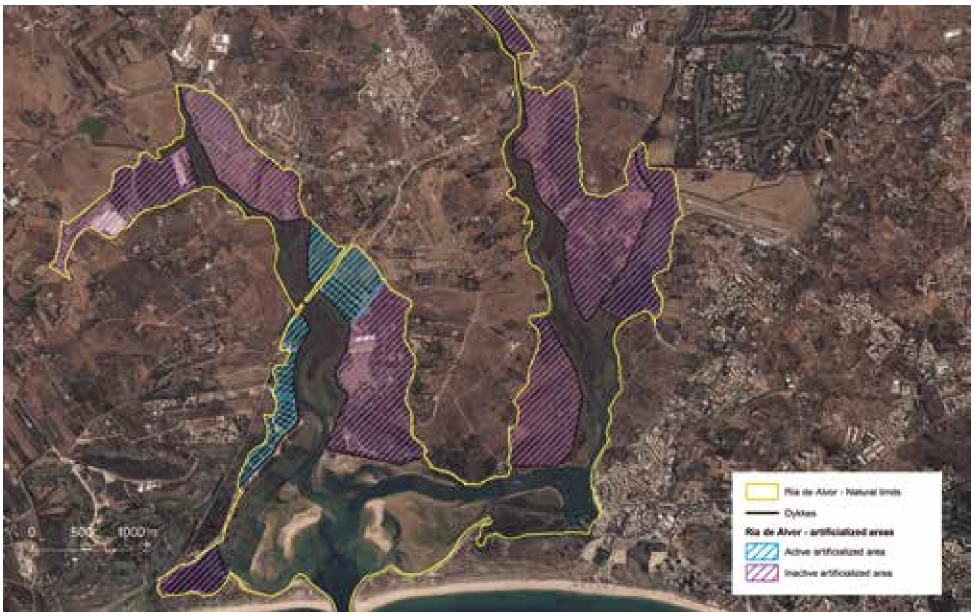

Figure 7.5 Mapping of inactive, artificialized areas (in red) in the Ria de Alvor that could be used for blue carbon ecosystem restoration. Source: Furtado et al. (2021).

7.8 Local stakeholders

Municipality of Lagos
Municipality of Portimão
Regional Coordination and Development Commission – Algarve (CCDRAlg)
Centre of Marine Sciences of Algarve (CCMAR) – University of the Algarve
Associação dos Pescadores Amadores de Alvor *[Alvor Amateur Fishermen's Association]*
Associação de Pescadores Profissionais de Alvor *[Alvor Professional Fishermen's Association]*
A Rocha Association
Almargem – Associação de Defesa do Património Cultural e Ambiental do Algarve *[Association for the Defense of Cultural and Environmental Heritage in the Algarve]*
Nemus – Gestão e Requalificação Ambiental, Lda. *[Nemus – Environmental Management and Requalification, Ltd.]*
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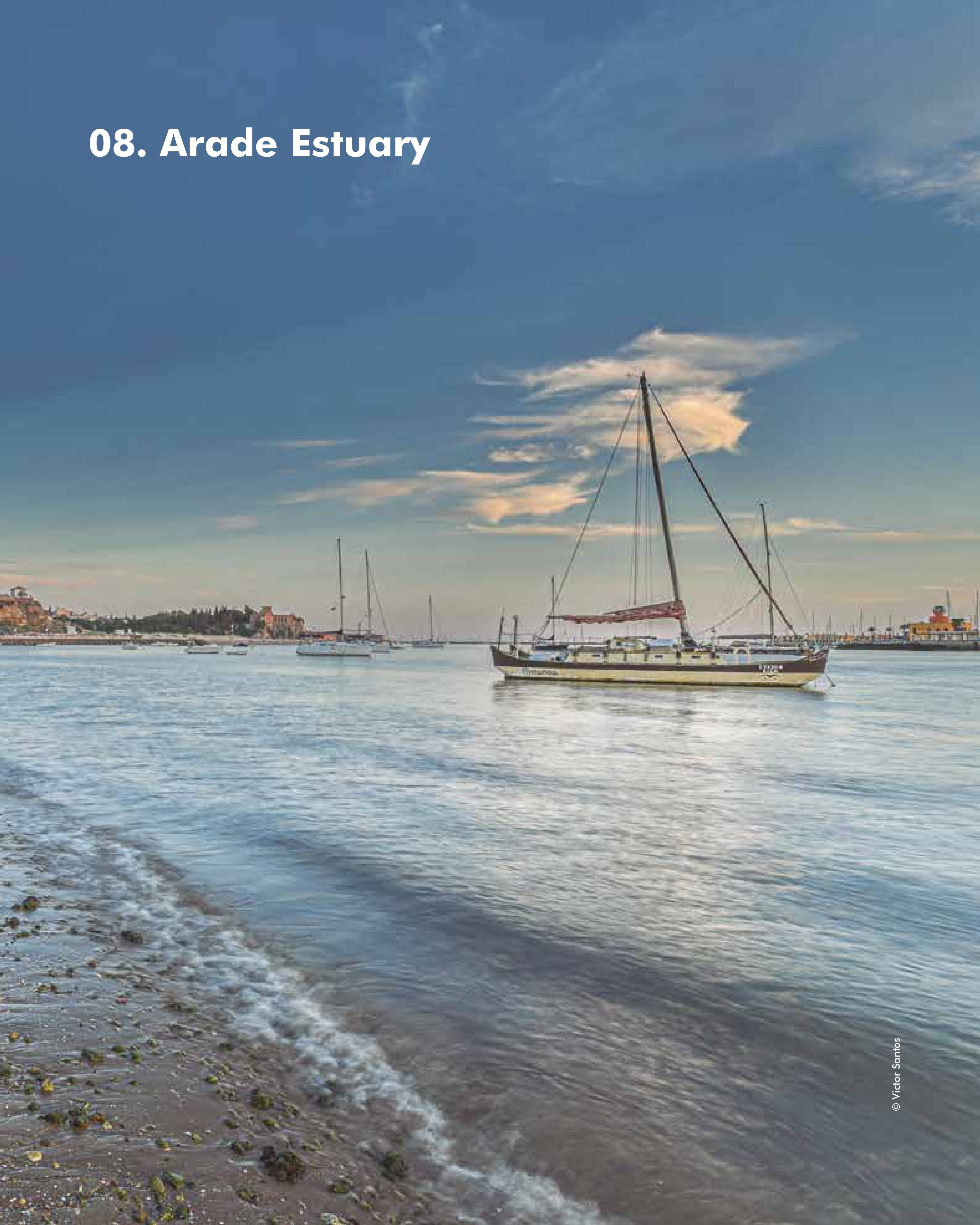
08. Arade Estuary



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8.1 Geographical location

The Arade Estuary is a small estuary that receives water from the Arade River, the Ribeira de Odelouca, and the Ribeira de Boina. It is the second-largest estuary in the Algarve. The estuary basin covers an area of 966 km² and is located in the municipalities of Portimão, Lagoa, and Silves (Faro district) on the south coast of Portugal (**Figure 8.1**).

Figure 8.1 Location of the Arade Estuary in the municipalities of Portimão, Silves, and Lagoa, and the area under the protection regime SCI (Site of Community Importance, Natura 2000 network). Elements of the base map: Geographical information provided by the Directorate-General for Territorial Development

8.2 Types of blue carbon habitats

The Arade Estuary only presents intertidal *Zostera noltei* seagrass meadows (Cabaço et al., 2007; Cunha et al., 2013; Gonçalves et al., 2013; Santos et al., 2004) whose population is made of large individuals or clones (Diekmann et al., 2005). The estuary has vast saltmarsh areas crossed by inlets, and there are different marsh subtypes: natural saltmarshes, restored saltmarshes, dyked saltmarshes, and eroding saltmarshes (Almeida et al., 2014).

8.3 Protection regimes

The Arade Estuary is a habitat under EU protection due to its natural value (**Table 8.1**). It was designated as a Site of Community Importance (SCI) under the Habitats Directive in 2008, protecting ten species listed in the Birds and Habitats Directives. However, this SCI does not include habitats with saltmarsh or seagrass vegetation, although these ecosystems are within the boundaries of that protection regime.

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06).

Table 8.1 Summary of the protection regimes in the Arade Estuary.

Regime	Reference	Year of designation	Area (ha)
Site of Community Importance (Natura 2000 network)	PTCON0052	2008	2 106,80

8.4 Total area of each habitat

8.4.1 Seagrasses

Zostera noltei seagrass meadows in the Arade Estuary were studied in 2004, occupying an area of 1.8 ha which included the species *Ruppia maritima* and the algae *Fucus vesiculosus* (Santos et al., 2004). In 2009, three patches were found, covering a total area of 0.4 ha, 78% less than in 2004 (Cunha et al., 2013) (**Table 8.2**). In 2010, as part of the survey for classifying the ecological status of the transitional waters, its seagrass area was estimated at 0.24 ha (Neto et al., 2008). Since this last survey, the only information available on seagrass meadows is in a 2013 publication, which reports their presence on the banks of an area adjacent to the Portimão WWTP (Gonçalves et al., 2013). It is claimed in this document that Arade Estuary seagrass meadows are a habitat in marked decline due to human action. More recent information may be found in an APA statement, in which it is “this species occupies restricted areas [...]” and that “it is occasionally present downstream of the *EN125* (right bank)” (APA, 2022a).

For blue carbon estimates in the Arade Estuary seagrass meadows, the most recent (2010) area of 0.24 ha was considered. Seagrass area data were assigned a *Cat 2* quality category as they are not up to date.

Table 8.2 Estimates of seagrass meadow areas in the Arade Estuary.

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	2004	1,8*	Santos et al. (2004)
Intertidal seagrasses	2005	na.	Cabaço et al. (2007)
Intertidal seagrasses	2009	0,4	Cunha et al. (2013)
Intertidal seagrasses	2010	0,24	Neto et al. (2018)
Intertidal seagrasses	2013**	na.	Gonçalves et al. (2013)
Intertidal seagrasses	2020**	na.	APA (2022a)

* Area covered by seagrass and algae.

** Year of publication, not of observation

8.4.2 Saltmarsh

An analysis of the historical evolution of saltmarsh areas in a section of the Arade Estuary (**Figure 8.2**) showed that 51% of saltmarsh was lost between 1800 (242 ha) and 2010 (118 ha) (Almeida et al., 2014; **Table 8.3**). Between 1958 and 2010, there was a net decrease of 78 ha in natural saltmarsh, i.e., a loss of 40%, but there was also an increase of 33 ha between 2005 and 2010 (Almeida et al., 2014; **Table 8.3**, **Figure 8.2**). The information available on the Arade Estuary saltmarsh on the global saltmarsh distribution database (Mcowen et al., 2017) shows a decrease in the area from 547 ha in 2006 to 87 ha in 2010 (**Table 8.3**, **Figure 8.2**). The larger area reported by Mcowen et al. (2017) compared to the area reported by Almeida et al. (2014) may be due to the inclusion of artificialized saltmarsh subtypes and natural saltmarshes. Since the last survey conducted in 2010 by Almeida et al. (2014) and the 2010 data included on the global database (Mcowen et al., 2017), there has been no further data on the saltmarsh area in this system.

For the blue carbon estimates in the Arade Estuary saltmarsh areas, the most recent (2010) area of 118 ha, as reported by Almeida et al. (2014) regarding the natural saltmarsh subtype, was considered. The data for saltmarsh areas were assigned a *Cat 2* quality category as they are not up to date.

Table 8.3 Estimates of saltmarsh areas in the Arade Estuary over time.

Habitat	Year	Area (ha)	Source
Sapal (total)*	c. 1800	242	Almeida et al. (2014)
Sapal (total)*	1958	196	Almeida et al. (2014)
Sapal (total)*	1972	129	Almeida et al. (2014)
Sapal (total)*	1987	111	Almeida et al. (2014)
Sapal (total)*	1995	109	Almeida et al. (2014)
Sapal (total)*	2005	85	Almeida et al. (2014)
Sapal (total)*	2010	118	Almeida et al. (2014)
Sapal (total)	2006	547	Mcowen et al. (2017)
Sapal (total)	2010	87	Mcowen et al. (2017)

* Natural saltmarsh fraction as indicated in the source.

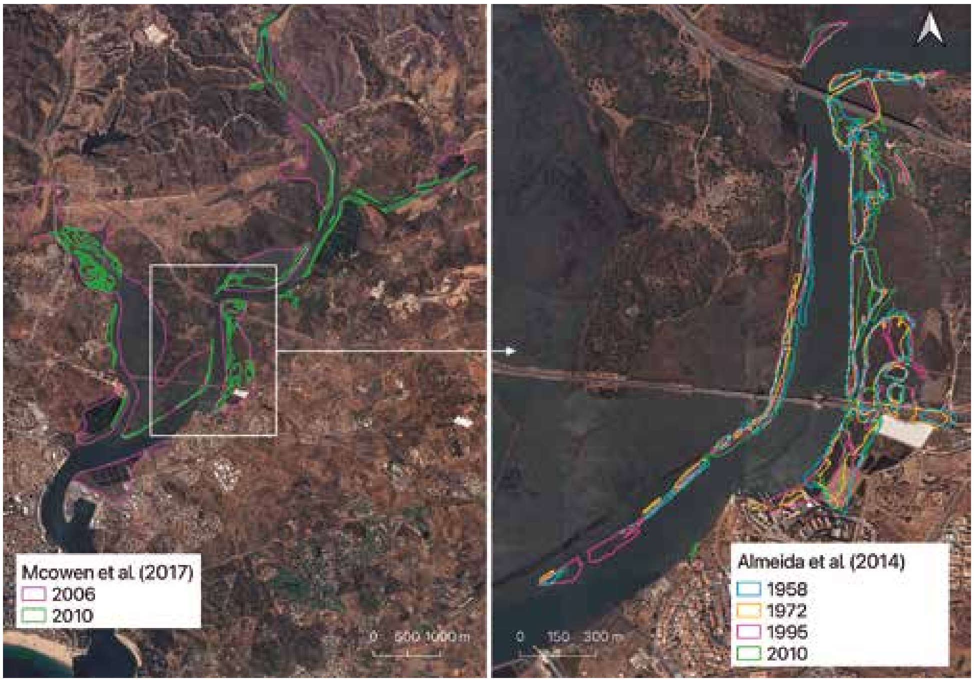

Figure 8.2 Location of saltmarsh areas in the Arade Estuary in 1958, 1972, 1995, 2006, and 2010. Adapted from Mcowen et al. (2017) and Almeida et al. (2014). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

8.5 Estimates of carbon stocks and sequestration rates

8.5.1 Data compilation

We compiled total biomass data for seagrass *Zostera noltei* at four sampling stations on the shore adjacent to the Portimão WWTP between April and November 2005, with values ranging from 6.9 ±1.3 g DW m^{-2} to 10.4 ± 1.3 g DW m^{-2}, and with mean total biomass 8.9 ± 1.8 g DW m^{-2} (n = 47) for all stations (Cabaço et al., 2007; **Table 8.4**). No carbon content data were found for seagrass tissues, nor were there any data on the biomass or carbon content in Arade Estuary saltmarsh plants (**Table 8.4**). Regarding sediment, no data were found for the saltmarsh or seagrass meadows.

Seagrass vegetation data were assigned a *Cat 1* quality category as they were not complete, and saltmarsh data a *Cat 0* quality category as no vegetation data were available (**Table 8.5**). Regarding sediment, both types of habitats were assigned a *Cat 0* quality category (no data) (**Table 8.5**).

Table 8.4 Values compiled for the calculations of carbon stocks and sequestration rates in the Arade Estuary after making the necessary conversions for data standardisation and statistical analyses.

Table	Intertidal seagrasses (ZN)	Saltmarsh (total)
Area (ha)	0,04	118
Epigean biomass (g DW m^{-2})	-	-
Hypogean biomass (g DW m^{-2})	-	
Biomass stock per area (Mg DW ha^{-1})	8,9	-
Total biomass stock (Mg DW)	-	-
Carbon content (epigean biomass) (% DW)	-	-
Carbon content (epigean biomass) (% DW)	-	-
Organic carbon content (sediment) (% DW)	-	-
Organic matter (sediment) content (% DW)	-	-
Carbon stock in sediment (Mg OC ha^{-1})	-	-
Sediment accumulation rate (mm $year^{-1}$)	-	-
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	-	-

OC: organic carbon.

DW: dry weight. Species code: ZN: *Zostera noltei*.

Table 8.5 Data quality for calculating carbon stocks and sequestration rates in the Arade Estuary.

Level	Seagrasses	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 1	Cat 0
Level 3: Sediment	Cat 0	Cat 0

Quality categories for each level: Cat 0 (no data),
Cat 1 (incomplete data), Cat 2 (complete but non-representative or outdated data, i.e., < 2018),
Cat 3 (complete, representative, and up-to-date data, i.e., ≥ 2018).

8.5.2 Estimates

Blue carbon habitats in the Arade Estuary are estimated to have a total stock (sediment and biomass) of 6 954 Mg OC and sequester a total of 34 Mg OC year^{-1} annually, with seagrasses making an insignificant contribution to these values (< 1%) due to the very small area they occupy (**Table 8.6**). Since no data were available for these calculations, available stock and sequestration rate values from the nearest system (the Ria Formosa) were used. Therefore, these estimates are very imprecise.

Table 8.6 Estimates of blue carbon stocks and sequestration rates in the Ria de Alvor

Variable	Seagrasses (intertidal)	Saltmarsh (total)	TOTAL
Total stock OC in biomass (Mg OC)	< 0,1	1 289	**1 289**
Total stock OC in sediment (Mg OC)	0,36	5 664	**5 664**
Total stock (Mg OC)	0,36	6 953	**6 954**
Annual sequestration rate (Mg C year^{-1})	< 0,1	34,4	**34**

OC: organic carbon.

8.6 Environmental quality and threats

The Arade Estuary is located in a consolidated urban area in the municipalities of Portimão and Lagoa. It is strongly impacted by urban development, the construction of a dam in the 1960s, aquaculture facilities, a fishing port, and a commercial port.

According to the latest APA report, the Arade sub-basin is under pressure due to wastewater with high nutrient concentrations (APA, 2022b). This sub-basin is also subject to diffuse phosphorus and nitrogen pollution from agriculture, livestock activities, aquaculture farms, and golf courses (APA, 2022b). There are also emissions of various pollutants, especially zinc and its compounds, as well as cadmium and mercury (APA, 2022b).

The ecological status of the Arade transitional body of water WB-1 (Arade-WB1, PT08RDA1701) has been recently classified as *Moderate* based on saltmarsh and nutrient parameters (NO_3, NH_4). The body of water WB (Arade-WB2, PT08RDA1686) has been classified as *Poor* based on benthic macroinvertebrate and nutrient parameters, reflecting the high anthropic pressure on this system (APA, 2022b). No other studies were found, direct or indirect, regarding the conservation status of saltmarsh and seagrass ecosystems in the Arade Estuary.

The construction of fishing and commercial ports destroyed large areas of seagrass and saltmarsh (Almeida et al., 2014; Cunha et al., 2013). In the past, shellfish and bait harvesting activities on the riverbanks may have also caused seagrass degradation (Cunha et al., 2013). Seagrasses were also impacted by trawl fishing, water pollution, and river dredging (Cunha et al., 2013; Gonçalves et al., 2013). In fact, the study conducted on the *Zostera noltei* population near the Portimão WWTP revealed severe plant stress caused by nutrient pollution (Cabaço et al., 2007).

After a conditional yet positive environmental impact assessment, the APA has recently approved a project to deepen and widen the Port of Portimão navigation channel at the end of the estuary. This intervention will make it possible to receive larger cruise ships at the mouth of the Arade River. The project requires dredging and the subsequent deposition of dredged sediments on beaches, thus interfering with the hydromorphological component of the estuary (APA, 2022a). Although located in an area that has already been heavily intervened, implementing this project may have a negative effect on saltmarsh and seagrass areas. In fact, the Assessment Committee leading Environmental Impact Assessment procedure no. 3316 (APA, 2022a) stated that *Zostera noltei* habitats are of “essential preservation” and that “the proximity of meadows of this species near the project’s intervention area makes it imperative to monitor them, particularly during the construction phase, and the adoption of measures to minimise possible impacts”.

8.7 Conservation interventions

8.7.1 Past and ongoing interventions

No seagrass or saltmarsh conservation interventions were identified in the Arade Estuary.

8.7.2 Proposed interventions

a) Monitoring
Monitoring saltmarsh and seagrass areas in order to update the areas occupied by these ecosystems is recommended, particularly given the threats identified in this area, namely pollutants and dredging.

b) Protection
There are saltmarsh (and possibly also seagrass) areas which lie outside the boundaries of the protection regime SCI (**Figure 8.3**). Extending the current SCI to cover these areas should be taken into consideration.

c) Restoration
In 1958, 48 ha of saltmarsh had already been lost as the system was separated due to dam construction and agricultural reclamation. Between 1958 and 2010, a further 47% of the natural saltmarsh (86 ha) was destroyed similarly (Almeida et al., 2014).

These areas should be considered for passive restoration by means of wall removal and hydrodynamic reconstitution. In a recent report (Furtado et al., 2021), the APA identified 429 ha of inactive, artificialized areas that could be used for spontaneous restoration or renaturation (**Figure 8.4**). Active saltmarsh restoration could be used to supplement passive restoration using the destruction of dams and restoration of the tidal hydrological regime to increase the rate of saltmarsh recovery.

In 2009, *Zostera noltei* meadows in the Arade Estuary, which were in sharp decline, were mapped for the last time. The active restoration of these meadows should be one of the interventions to be carried out in this system.

Figure 8.3 Location of saltmarsh areas in the Arade Estuary and the boundaries of the protection regime SCI (Site of Community Importance, Natura 2000 network). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05- 2018).

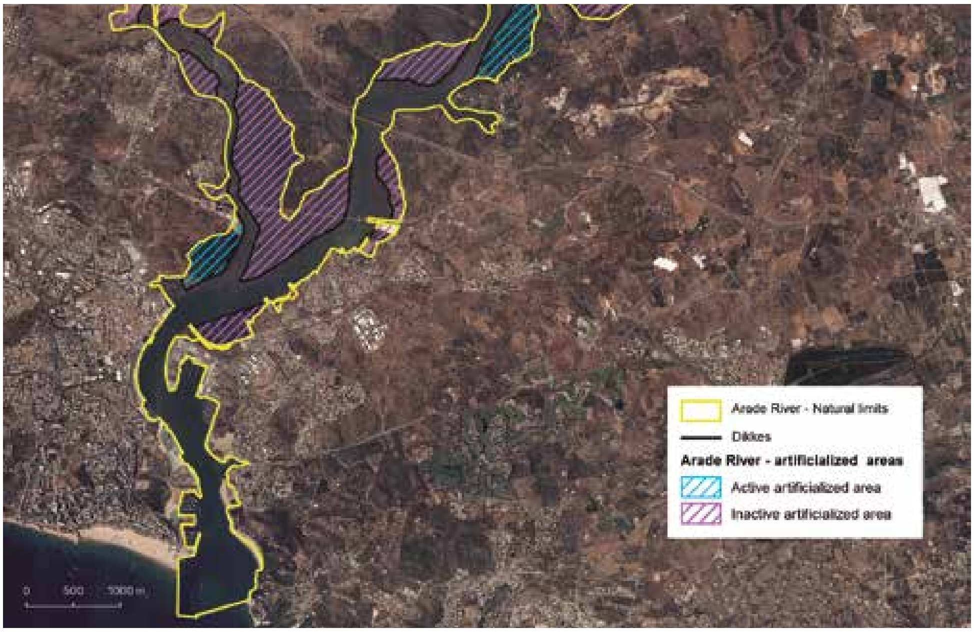

Figure 8.4 Location of inactive, artificialized areas in the Arade Estuary that could be recovered for saltmarsh restoration. Source: Furtado et al. (2021).

8.8 Local stakeholders

Municipality of Lagoa
Municipality of Portimão
Regional Coordination and Development Commission – Algarve (CCDRAlg)
Centre of Marine Sciences of Algarve (CCMAR) – University of the Algarve
Association of Artisanal Fishing Shipowners of the Barlavento Algarve
Almargem – Associação de Defesa do Património Cultural e Ambiental do Algarve
[Association for the Defense of Cultural and Environmental Heritage in the Algarve]
Ports of Sines and the Algarve Administration S.A.

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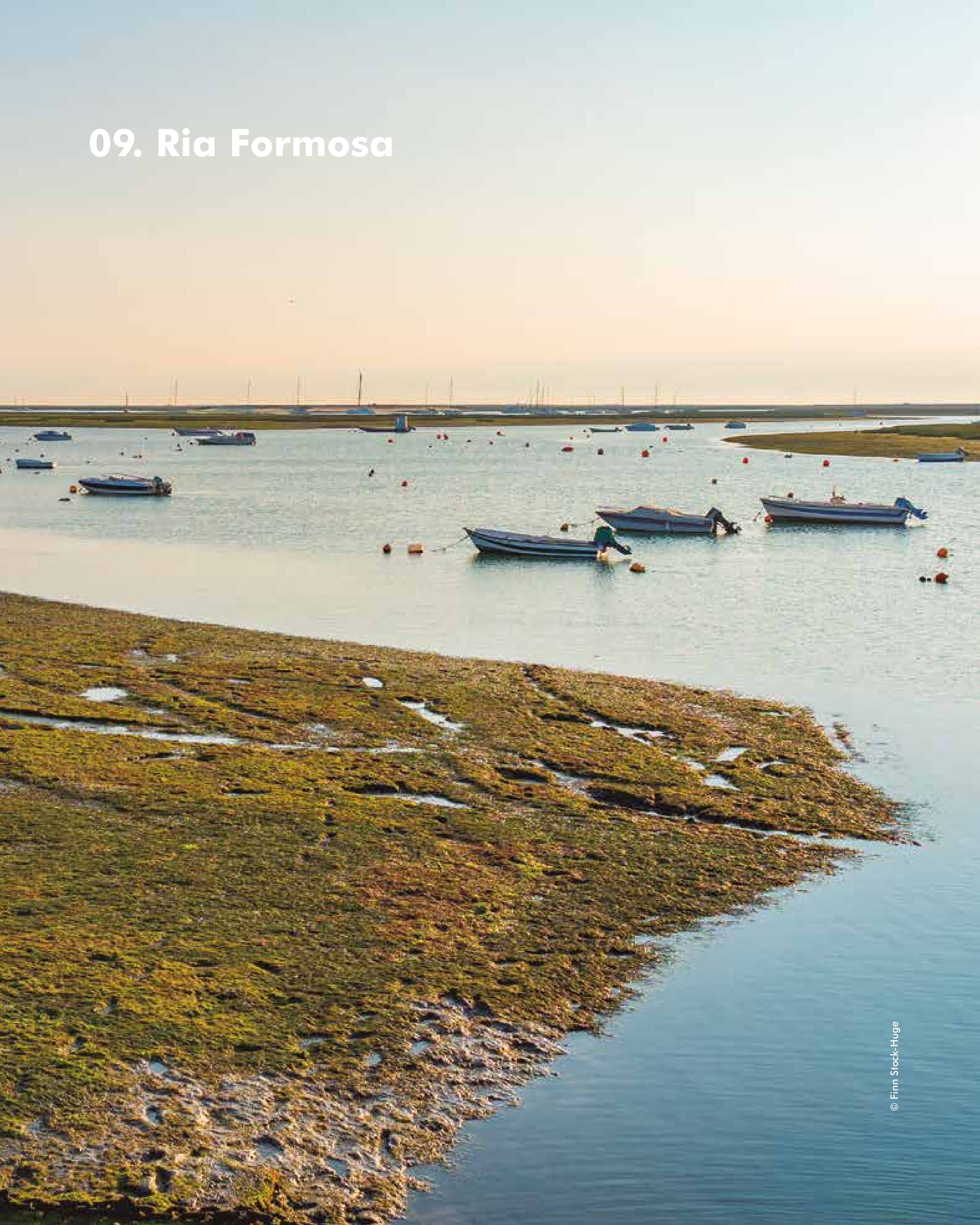
09. Ria Formosa



9.1 Geographical location

The Ria Formosa is a triangular-shaped lagoon system located in the municipalities of Loulé, Faro, Olhão, Tavira, and Vila Real de Santo António (Faro district) on the south coast of Portugal (**Figure 9.1**). It is about 60 km long from east to west and occupies an approximate area of 180 km^2. It is a system composed of five barrier islands – Barreta (or Deserta) Island, Culatra Island, Armona Island, Tavira Island, and Cabanas Island – as well as two peninsulas, Ancão and Cacela. It is connected to the ocean via six inlets. Some small waterways flow into the Ria; the most important are the Gilão River, the Ribeira de Almargem, and the Ribeira de Cacela.

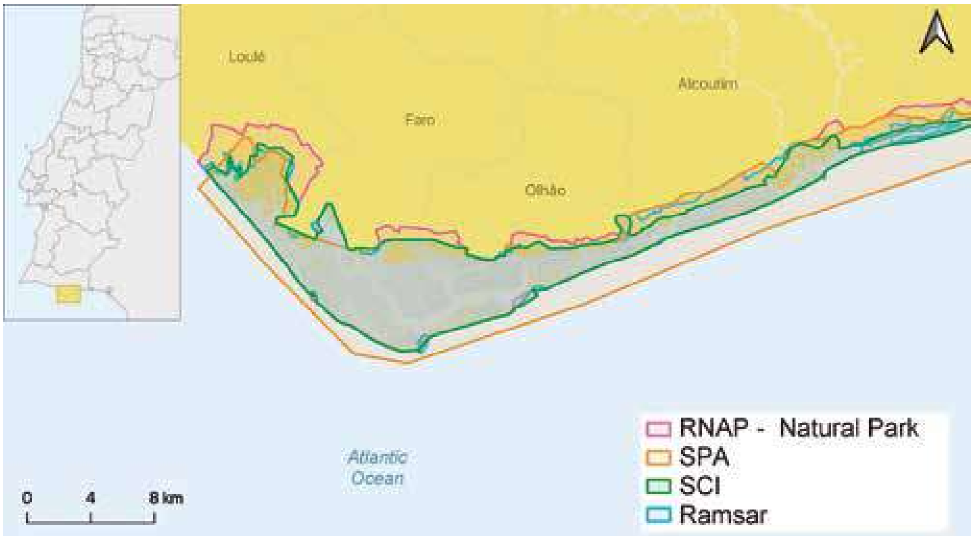


Figure 9.1 Location of the Ria Formosa in the municipalities of Loulé, Faro, Olhão, Tavira, and Vila Real de Santo António, and the area under the protection regimes Natural Park (National Network of Protected Areas, RNAP), SPA (Special Protection Area, Natura 2000 network), SCI (Site of Community Importance, Natura 2000 network), and the Ramsar Convention. Elements of the base map: Geographical information provided by the Directorate-General for Territorial Development.

9.2 Types of habitats

The Ria Formosa presents saltmarsh and seagrass meadow areas. The seagrass area are formed by intertidal *Zostera noltei* meadows and subtidal *Cymodocea nodosa*, *Z. marina*, and *Z. noltei* meadows (Cunha et al., 2009, 2013; Guimarães et al. 2012).

The Ria Formosa saltmarsh has the typical coastal vegetation zonation, with low, middle, and high marsh. The high marsh community is dominated by woody shrubs growing on sandy areas, and its main species are *Arthrocaulon macrostachyum*, *Suaeda vera*, *Limoniastrum monopetalum*, *Myriolimon diffusum*, and *Limonium algarvense* (Costa et al., 1996). The middle marsh mainly comprises the species *Salicornia fruticosa*, *Salicornia perenni*s, and *Atriplex portulacoides* (Costa et al., 1996). The low marsh is in the upper intertidal area and is mostly colonised by the species *Sporobolus maritimus*. The species *Salicornia perennis* and *Salicornia fruticosa* may also be found there (Costa et al., 1996).

It is important to emphasise that subtidal areas in the lagoon have recently been colonised by the rhizophilous green algae *Caulerpa prolifera*, which is becoming invasive as it forms extensive meadows (Parreira et al., 2021) and competes with subtidal seagrass species (Alexandre et al., 2020a, b).

9.3 Protection regimes

The Ria Formosa has been internationally recognised as a Ramsar site by the International Convention on Wetlands since 1980 (**Figure 9.1**, **Table 9.1**). The system is included within the boundaries of the areas designated as a Site of Community Importance (SCI) and Special Protection Area (SPA) under the Habitats and Birds Directives, respectively, being part of the Natura 2000 network (**Figure 9.1**, **Table 9.1**). At the national level, the Ria Formosa was included in the National Network of Protected Areas (RNAP) in 1987 under the Natural Park category (Decree-Law 373/87 on 9 December; **Figure 9.1**, **Table 9.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06). In the Red List of the Vascular Flora of Mainland Portugal (Carapeto et al., 2020), the species *Zostera marina* and *Cymodocea nodosa* are classified as *Vulnerable* (VU).

Table 9.1 Summary of the protection regimes in the Ria Formosa. RNAP: National Network of Protected Areas.

Regimes	Reference	Year of designation	Area (ha)
Ramsar site	No 212	1980	16 000
Site of Community Importance (SCI, Natura 2000 network)*	PTCON0013	2008	17 021,89
Special Protection Area (SPA, Natura 2000 network)	PTZPE0017	1988	23 269,21
Ria Formosa Natural Park (RNAP)	Decrete-law No 373/87	1987	17 900,90

* It includes the Guadiana estuary system.

9.4 Total area of each habitat

9.4.1 Seagrasses

The distribution of intertidal seagrass meadows in the Ria Formosa was assessed in 2002 by Guimarães et al. (2012). They estimated coverage of 1 304 ha, so that 45% of the intertidal areas was occupied by *Zostera noltei* (**Table 9.2**, **Figure 9.2**). In the same period, between 2001 and 2002, the ICNF also surveyed the distribution of seagrass meadows in the Ria Formosa, estimating an intertidal seagrass area of 2 872 ha (ICNF, 2003; **Table 9.2**, **Figure 9.3**). In 2007, the area covered by subtidal seagrasses was estimated at 5 ha for *Z. marina*, 91 ha for *Cymodocea nodosa*, and 145 ha for *Z. noltei* (Cunha et al., 2009; Table 9.2). In 2018 – 2019, a survey on intertidal and subtidal meadows was conducted, which estimated an area of 825 ha and 305 ha, respectively (de los Santos et al., in preparation *a*) (**Table 9.2**, **Figure 9.4**).

It should be noted that the methodologies used in these studies were not similar. Therefore, comparisons between years should be made with caution. Moreover, the value estimated by the ICNF in 2001 – 2002 seems too high compared to other values, probably indicating a potential area for establishing intertidal seagrass and not the actual area of occupancy.

Table 9.2 Estimates of seagrass meadow areas in the Ria Formosa over time.

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	2002	1 304	Guimarães et al. (2012)
Intertidal seagrasses	2001-2002	2 872	ICNF (2003)
Intertidal seagrasses	2018-2019	825,3	de los Santos et al. *(in preparation a)*
Subtidal seagrasses	2007	238	Cunha et al. (2009)
Subtidal seagrasses	2018-2019	305,5	de los Santos et al. *(in preparation a)*

Figure 9.2 Location of seagrass meadow areas in the Ria Formosa in 2002. Adapted from: Guimarães et al. (2012). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

Figure 9.3 Location of seagrass meadow areas in the Ria Formosa in 2001-2002. Adapted from: ICNF (2003). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

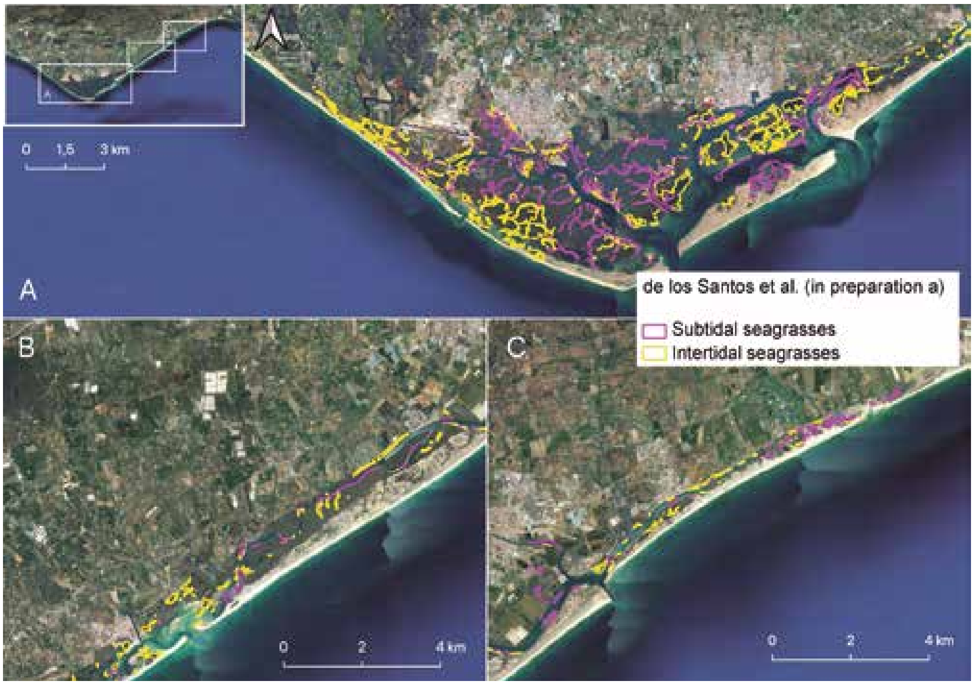


Figure 9.4 Location of seagrass meadow areas in the Ria Formosa in 2018-2019. Adapted from: de los Santos et al. (in preparation a). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

9.4.2 Saltmarsh

The Ria Formosa saltmarsh was mapped in 2001-2002 by the Portuguese Institute for Nature Conservation and Forests (ICNF), which estimated its total area at 3 565 ha, with 7% categorised as high marsh, 28% as low marsh, and 65% as middle/low marsh (ICNF, 2003; **Table 9.3**, **Figure 9.5**). On the global saltmarsh area database, the total area for the Ria Formosa was 5 852 ha in 2006 and 2 975 ha in 2010 (Mcowen et al., 2017; Figure 9.6). In 2018-2019, another saltmarsh survey was conducted that estimated its total area at 3 472 ha, with 1% categorised as high marsh, 45% as middle marsh, and 53% as low marsh (de los Santos et al., *in preparation a*) (**Table 9.3**, **Figure 9.7**). It should be noted that the methodologies used in these studies were not similar. Therefore, comparisons between years should be made with caution.

Table 9.3 Estimates of seagrass meadow areas in the Ria Formosa over time.

Habitat	Year	Area (ha)	Source
High marsh	2001-2002	257,55	ICNF (2003)
Middle/low marsh	2001-2002	2 322,60	ICNF (2003)
Low marsh	2001-2002	985,43	ICNF (2003)
Low marsh	2018-2019	1 850	de los Santos et al. (in preparation *a*)
Middle marsh	2018-2019	1 573	de los Santos et al. (in preparation *a*)
High marsh	2018-2019	50	de los Santos et al. (in preparation *a*)
Saltmarsh (total)	2006	5 852	Mcowen et al. (2017)
Saltmarsh (total)	2010	2 975	Mcowen et al. (2017)

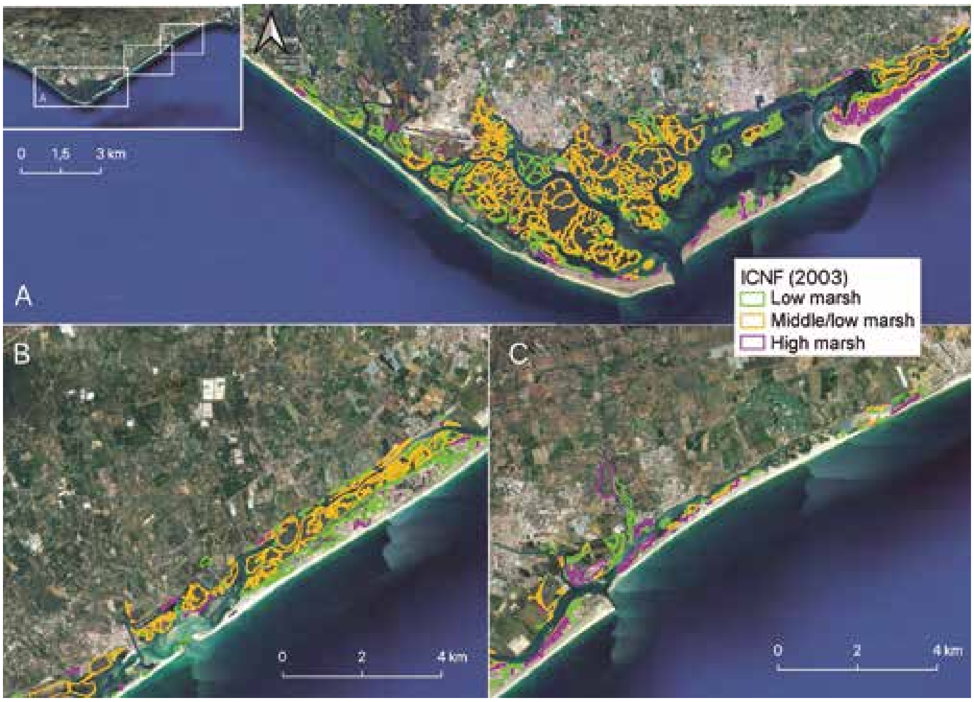


Figure 9.5 Location of saltmarsh areas in the Ria Formosa in 2003. Adapted from: ICNF (2003). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05- 2018).

Figure 9.6 Location of saltmarsh areas in the Ria Formosa in 2003. Adapted from: ICNF (2003). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05- 2018).

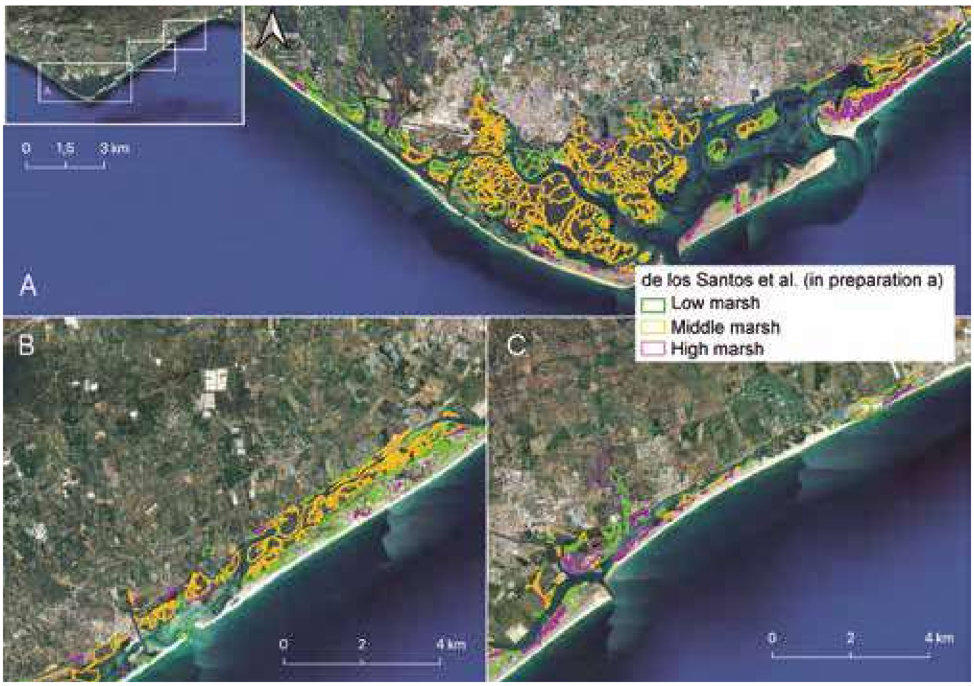


Figure 9.7 Location of saltmarsh areas in the Ria Formosa in 2006 and 2010. Adapted from: Mcowen et al. (2017). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

9.5 Estimates of carbon stocks and sequestration rates

9.5.1 Data compilation

There is an extensive collection of biomass and carbon content data for the three seagrass species in the Ria Formosa, namely *Zostera noltei*, *Z. marina*, and *Cymodocea nodosa* (**Table 9.4**).

With regard to sediment, there are several scientific studies (Arnaud-Fassetta et al., 2016; de los Santos et al., 2022; de los Santos et al., in preparation b; Herrero-Fernández, 2021; Martins et al., 2022; Santos et al., 2019; Sousa et al., 2019), which resulted in a comprehensive assessment of sedimentation rates and organic carbon stocks and sequestration rates in different types of seagrass and saltmarsh habitats, including recent studies conducted between 2017 and 2021 (**Table 9.4**).

Seagrass vegetation and sediment data were assigned a *Cat 3* quality category, whereas saltmarsh vegetation and sediment data were assigned a *Cat 2* quality category (incomplete) (**Table 9.5**).

Table 9.4 Values compiled for the calculations of carbon stocks and sequestration rates in the Ria Formosa after making the necessary conversions for data standardisation and statistical analyses.

Variable	Seagrasses (subtidal)	Seagrasses (intertidal)	Saltmarsh (low)	Saltmarsh (middle)	Saltmarsh (high)
Area (ha)	305	825	1 850	1 573	50
Epigean Biomass (g DW m^{-2})	195 ± 156	161 ± 194	279 ± 185	715 ± 257	4 267 ± 2 823
Hypogean Biomass (g DW m^{-2})	323 ± 313	173 ± 95	1 190 ± 690	806 ± 473	794 ± 528
Carbon content (epigean biomass) (% DW)	36,8 ± 2,2	40,3 ± 3,9	43,0 ± 1,4	-	-
Carbon content (epigean biomass) (% DW)	39,2 ± 2,4	33,1 ± 33,1	36,4 ± 4,3	-	-
Organic carbon content (sediment) (% DW)	0,48 ± 0,52	1,27 ± 0,74	1,48 ± 1,12	-	-
Organic matter (sediment) content (% DW)	1,77 ± 2,33	4,07 ± 2,92	3,51 ± 3,16	6,55 ± 5,57	1,16 ± 1,45
Carbon stock in the sediment (Mg OC ha^{-1})	27,8 ± 21,9	90,0 ± 55,5	58,8 ± 30,7	66,5 ± 13,3	18,7 ± 4,2
Sediment accumulation rate (mm $year^{-1}$)	1,34	6,1 ± 5,6	3,3 ± 2,4	-	-
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	8,1 ± 1,7*	56,4 ± 43,0	29,9 ± 9,1	-	-

DW: dry weight. **OC:** organic carbon.

* Preliminary value that must be revised.

Table 9.5 Data quality for calculating carbon stocks and sequestration rates in the Ria Formosa.

Level	Subtidal seagrasses	Intertidal seagrasses	Low marsh	Middle marsh	High marsh
Level 1: Area	Cat 3	Cat 3	Cat 3	Cat 3	Cat 3
Level 2: Vegetation	Cat 3	Cat 3	Cat 3	Cat 2	Cat 2
Level 3: Sediment	Cat 2	Cat 3	Cat 3	Cat 2	Cat 2

Quality categories for each level: **Cat 0** (no data), **Cat 1** (incomplete data), **Cat 2** (complete but non-representative or outdated data, i.e., < 2018), **Cat 3** (complete, representative, and up-to-date data, i.e., ≥ 2018).

9.5.2 Estimates

Blue carbon habitats in the Ria Formosa are estimated to contain a total stock (sediment and biomass) of 319 469 Mg OC and to sequester a total of 1 503 Mg OC year^{-1} annually, with seagrasses contributing 26% and 33% to these values, respectively (**Table 9.6**). Since data for these calculations are widely available, these estimates are very accurate, especially for seagrasses and the low marsh. Sequestration rate data are lacking for subtidal seagrasses and for the middle and high marsh.

Table 9.6. Estimates of blue carbon stocks and sequestration rates in the Ria Formosa.

Variável	Seagrasses (subtidal)	Seagrasses (intertidal)	Saltmarsh (low)	Saltmarsh (middle)	Saltmarsh (high)	TOTAL
Total stock OC in biomass (Mg OC)	606	1 008	10 233	9 451	1 062	**22 360**
Total stock OC in sediment (Mg OC)	8 505	74 287	108 778	104 605	935	**297 109**
Total stock (Mg OC)	9 111	75 295	119 011	114 056	1 997	**319 469**
Annual sequestration rate (Mg C year^{-1})	25	466	540	459	15	**1 503**

OC: organic carbon.

9.6 Environmental quality and threats

The Ria Formosa is located in a well-consolidated urban area of five municipalities (Loulé, Faro, Olhão, Tavira, and Vila Real de Santo António). This system is heavily impacted by a range of human activities: land reclamation for urban development, aquaculture and salt pans, and other infrastructure (an airport, and fishing, commercial and recreational ports) (Sousa et al., 2020), shellfish harvesting (Román et al., 2022) and shellfish farming (Duarte et al., 2004); tourism-related maritime activities; navigation channel dredging activities (Ferreira et al., 2016); and, inlet relocation (Kombiadou et al., 2019; Cabaço et al., 2010). The basin where the Ria Formosa is located is also subject to nutrient pollution, mainly from WWTPs and agriculture (Malta et al., 2017).

The ecological status of the Ria Formosa coastal waters (PTRF1, PTRF2, PTRF3, PTRF4, and PTRF5) has been recently classified as *Good* or *Moderate*, and its chemical status as *Good*, according to the results of the monitoring programmes implemented for this purpose by the Portuguese Environment Agency (APA, 2022).

One of the greatest threats to blue carbon habitats in the Ria Formosa, particularly to seagrass meadows, has been the massive expansion of the green algae *Caulerpa prolifera* in recent years (Parreira et al., 2021). This alga may be competing for space with subtidal seagrasses, leading to their decline (Alexandre et al., 2020a, b).

Coastal development, tourism-related maritime activities (unregulated anchorages, saltmarsh erosion due to waves generated by boats), shellfish harvesting (Román et al., 2022), aquaculture, and fishing are other current environmental pressures and threats in the Ria Formosa. In particular, there are several coastal infrastructure construction projects (a new bridge, access to Faro beach and an outdoor car park, an additional extension to Olhão marina, and an extension to Faro marina) that could have a negative effect on seagrass and saltmarsh areas either by direct habitat destruction or by changing the hydrodynamic regime, as observed in other areas of the Ria Formosa (Casal-Porras et al., 2022). Finally, sea level rise and human interventions may have a negative effect on saltmarsh resilience (Carrasco et al., 2021).

9.7 Conservation interventions

9.7.1 Past and ongoing interventions

There have been several projects, programmes, and interventions in the Ria Formosa for the conservation of blue carbon habitats. The most relevant ones are included here.

Sponsored by Lisbon Oceanarium, the "Adopt a Meadow" programme was an initiative of the Centre of Marine Sciences of Algarve in 2010, which aimed to create opportunities for citizen involvement in monitoring and protecting marine meadows. As a result, a meadow on Culatra Island was protected by the local community, freeing it from the impact of boat anchorage. Information materials were created for institutions in charge of coastal management, as well as educational activities for the general public and children to raise awareness about the importance of seagrass meadows.

In 2017, a group of researchers from the Centre of Marine Sciences of Algarve created the Environmental Education Network for Ecosystem Services (REASE, http://rease.ccmar.ualg.pt) in partnership with different school associations in the Algarve. This network has made numerous educational interventions to raise awareness among young people and to educate primary and secondary school teachers about the importance of seagrasses and saltmarshes in providing ecosystem services. In particular, the "REASE Blue Carbon" project aims to collect information about the quantities of carbon stored in the saltmarshes and seagrasses of the Algarve, involving teachers and students from local schools in field sampling and processing. These data are stored on a digital platform and are available for consultation by the general public. The REASE Blue Carbon network and project have been expanded to the Sado region in partnership with the Ocean Alive association and are currently being strengthened and expanded internationally through the "BlueForest – Boosting Blue Forests Education and Capacity Building" project (2021-2023, https://www.ccmar.ualg.pt/en/project/boosting- blue-forests-education-and-capacity-building), led by the Centre of Marine Sciences of Algarve and funded by EEA Grants 2014-2021 – Blue Growth Programme.

Currently, the SEAGHORSE project (2021-2023, https://www.seaghorse.pt/) aims to rehabilitate and promote the sustainability of seagrass habitats and seahorse populations in the Ria Formosa. The reconstruction of a seagrass meadow is taking place in the seahorse sanctuary that has been recently created (Public Notice 15/2020, Port of Faro Captaincy). Two species, *Cymodocea nodosa* and *Zostera marina*, collected in a semi-natural donor site located in the Olhão Fish Farming Pilot Station of the Portuguese Institute for Sea and Atmosphere (EPPO / IPMA) have been transplanted. These plants have been transferred to the sanctuary following specific methodologies adapted to the specific morphology of each species.

The Centre of Marine Sciences of Algarve is currently collaborating with Ghent University and two companies, Jan De Nul and DEME, in the research project "PLANT ME" to develop new sustainable techniques for large-scale seagrass restoration.

The "BlueForests: sea forests for blue carbon – natural capital from nature-based solutions" project (2021-2024, https://www.blueforests.pt/), also coordinated by the Centre of Marine Science of Algarve and funded by EEA Grants 2014-2021 – Blue Growth Programme, aims to research seagrass transplantation methods.

9.7.2 Proposed interventions

a) Monitoring
Monitoring saltmarsh and seagrass areas in the coming years is recommended, particularly given the identified threats to this system. It is necessary to monitor the impact of the invasion of the green algae *Caulerpa prolifera* in the Ria Formosa, not only on the potential decline of seagrasses but also on the system's trophic web.

b) Protection
All saltmarsh and seagrass areas in Ria Formosa are protected by national or international protection regimes (**Figure 9.8**).

c) Restoration
In a recent report (Furtado et al., 2021), the APA identified 645 ha of inactive, artificialized areas in the Ria Formosa, which can be used in active or spontaneous saltmarsh and seagrass restoration projects (**Figure 9.9**). Active saltmarsh restoration could be used complementarily to passive restoration by means of the destruction of dams and restoration of the tidal hydrological regime to increase the rate of saltmarsh recovery. For the restoration of natural seagrass populations, it is crucial to cultivate them, for example, in semi-natural areas such as those identified in the APA report, so that the biological material for transplantation does not come from natural populations that are fragile and should be protected. These cultivation areas could provide ecosystem services, namely that of carbon sequestration, which may be even higher than that of natural populations. The case of the reception tank at the Olhão Fish Farming Pilot Station of the Portuguese Institute for Sea and Atmosphere (EPPO / IPMA) proves that such semi-natural areas can host dense seagrass meadows (de los Santos et al., 2020). CCMAR is researching carbon sequestration in this system.

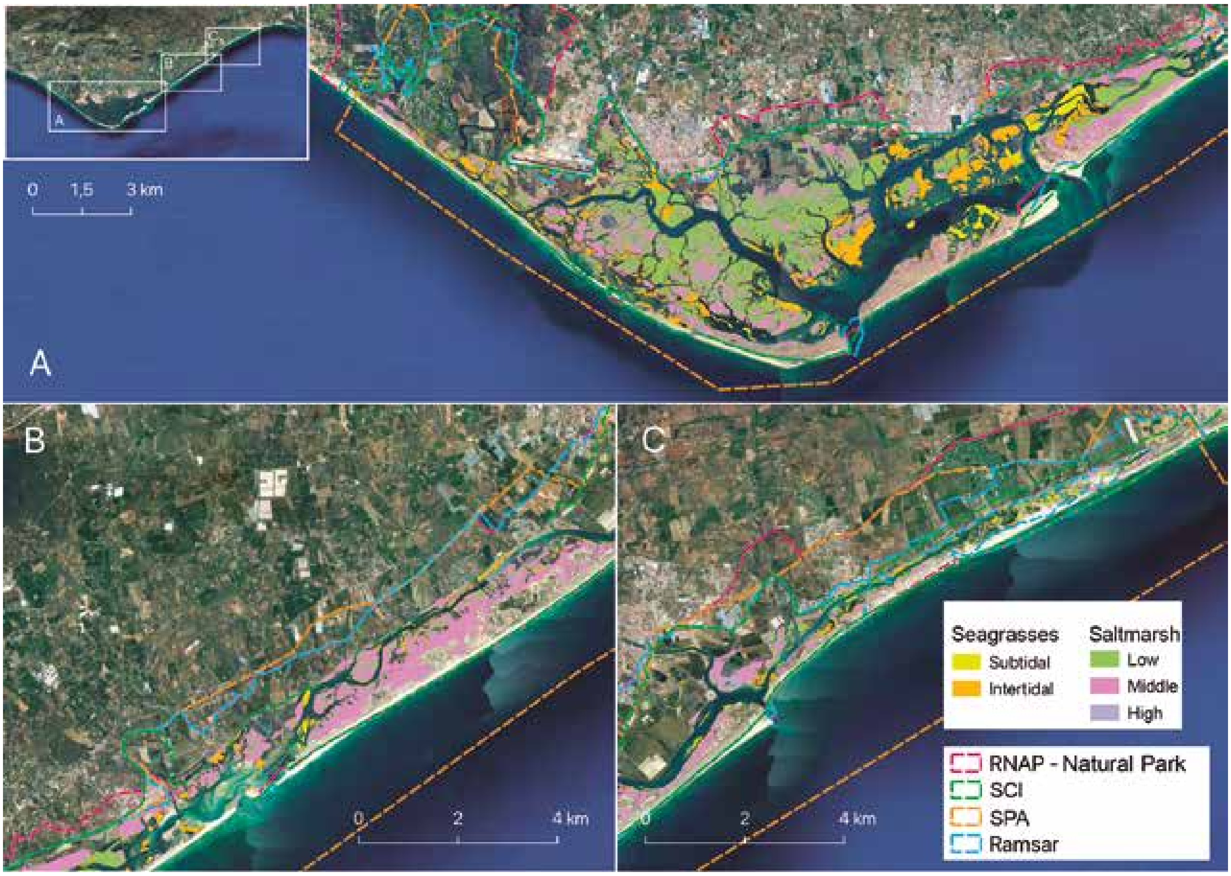


Figure 9.8 Location of saltmarsh and seagrass areas in the Ria Formosa and the boundaries of the protection regime Natural Park (National Network of Protected Areas, RNAP), SPA (Special Protection Area, Natura 2000 network), SCI (Site of Community Importance, Natura 2000 network), and the Ramsar Convention. Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

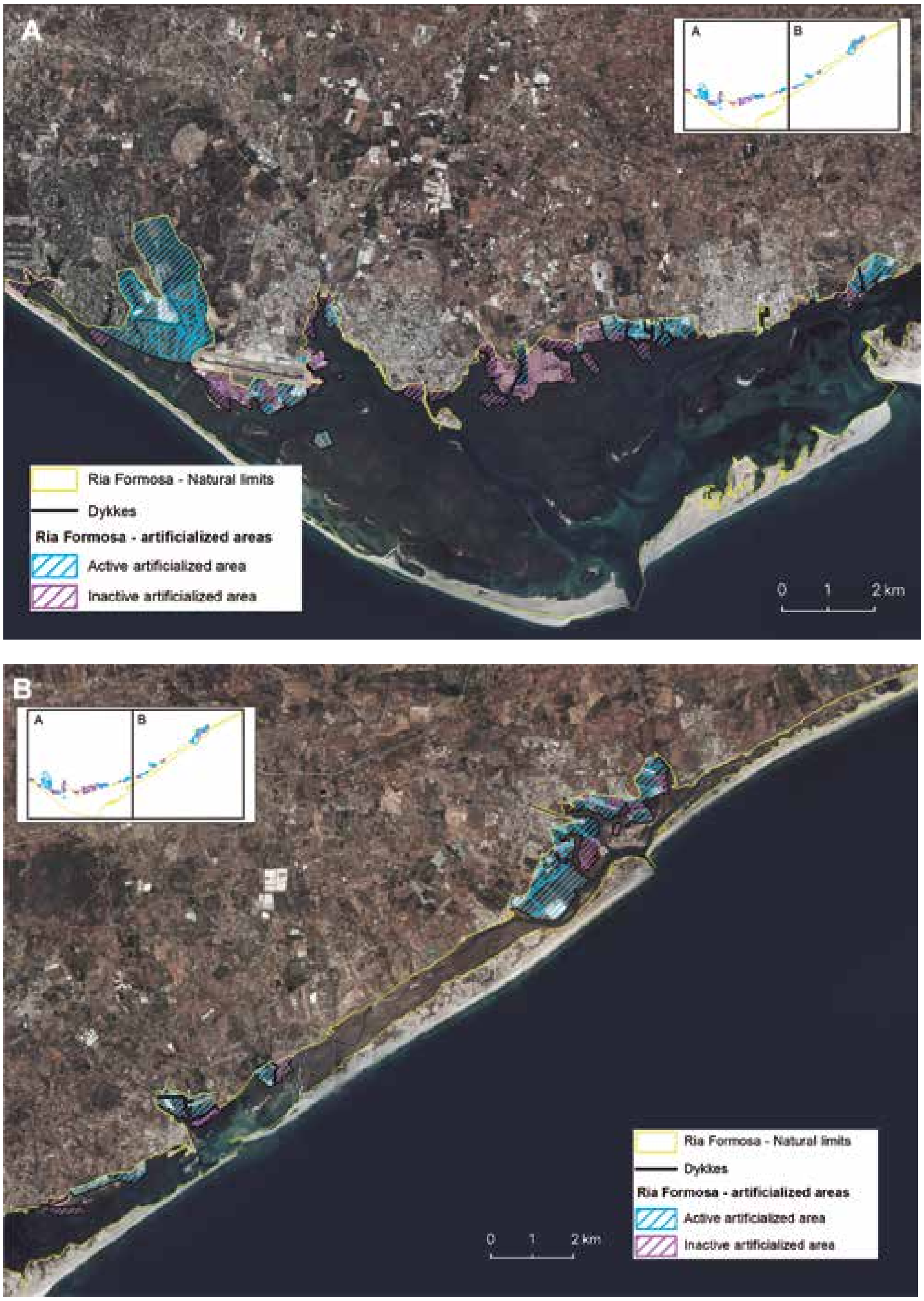


Figure 9.9 Location of inactive, artificialized areas in the Ria Formosa that could be recovered for saltmarsh and seagrass restoration. Source: Furtado et al. (2021).

9.8 Local stakeholders

Municipality of Loulé
Municipality of Faro
Municipality of Olhão
Municipality of Tavira
Municipality of Vila Real de Santo António
Regional Coordination and Development Commission – Algarve (CCDRAlg)
Centre of Marine Sciences of Algarve (CCMAR) – University of the Algarve
Olhão Fish Farming Pilot Station – Portuguese Institute for the Ocean and Atmosphere (EPPO – IPMA)
Sciaena
Associação para o movimento de defesa da Ria Formosa (SOS Ria Formosa) *[Association for the Defense of the Ria Formosa]*
Associação de Viveiristas e Mariscadores da Ria Formosa (VIVMAR)
[The Ria Formosa Nurserymen and Shellfish Harvesters Association]
Ilha da Culatra Residents' Association
Rede de Educação Ambiental para os Serviços dos Ecossistemas (REASE) *[Environmental Education Network for Ecosystem Services]*
Almargem – Associação de Defesa do Património Cultural e Ambiental do Algarve *[Association for the Defense of Cultural and Environmental Heritage in the Algarve]*
Sines and the Algarve Ports Administration S.A.
Sociedade Polis Litoral Ria Formosa S.A. – Sociedade para a requalificação e valorização da Ria Formosa
Verbos Cais, S.A.
The Algarve Ciência Viva Centre
Ciência Viva Centre, Tavira

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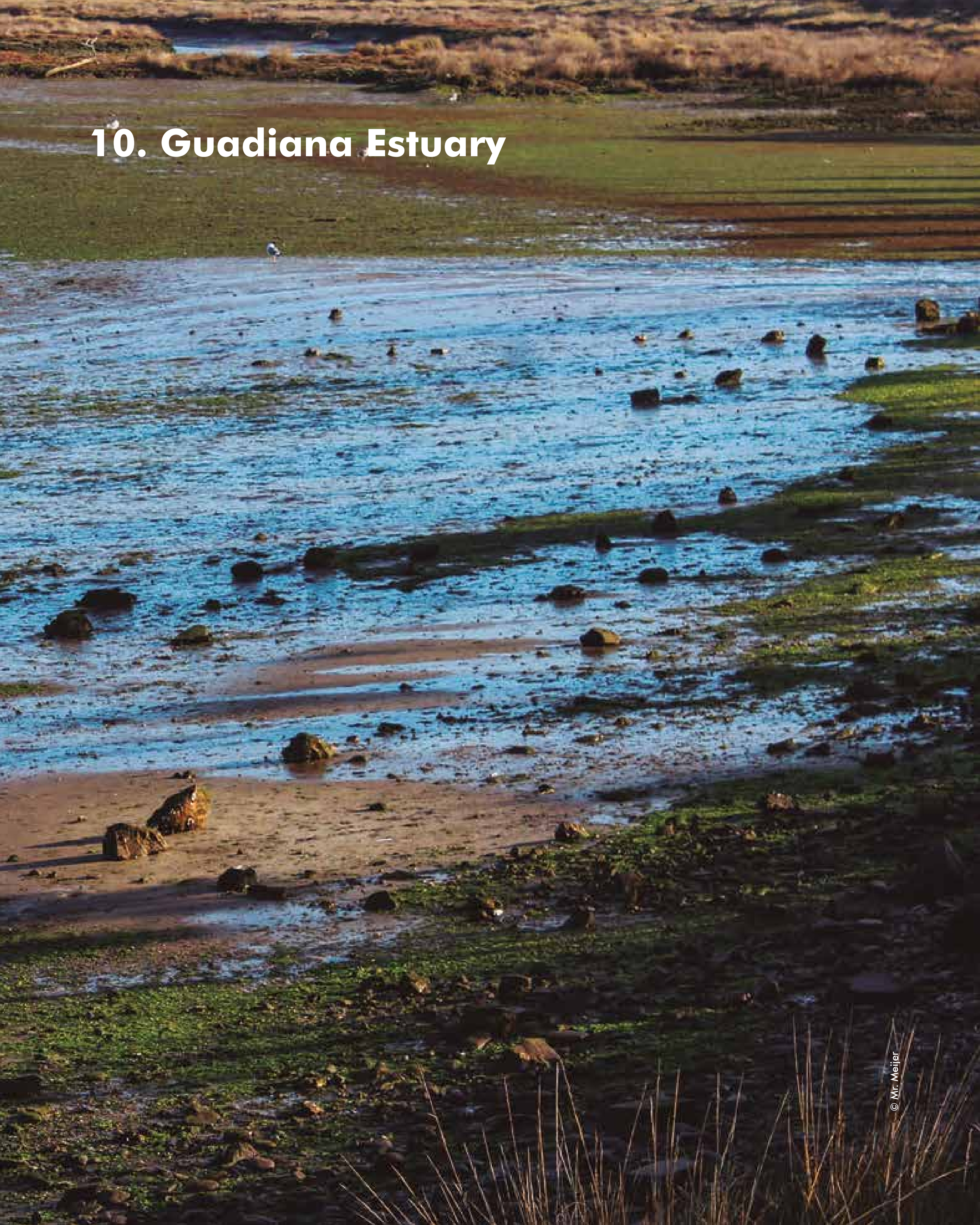
10. Guadiana Estuary



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10.1 Geographical location

The lower estuary of the Guadiana River is located on the south-eastern border between Portugal and Spain in the Portuguese municipalities of Castro Marim and Vila Real de Santo António (Faro district: **Figure 10.1**). The estuary occupies an area of about 22 km^2 and has an average depth of about 6.5 m.

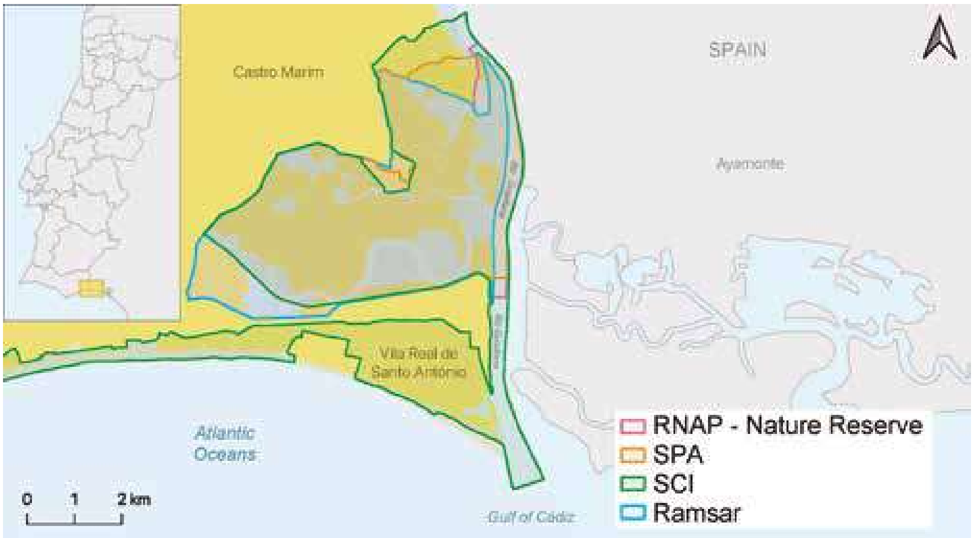

Figure 10.1 Location of the Guadiana Estuary on the south-eastern border between Portugal and Spain, an area covered by the protection regimes Nature Reserve (RNAP, National Network of Protected Areas), SPA (Special Protection Area, Natura 2000 network), SCI (Site of Community Importance, Natura 2000 network), and the Ramsar Convention. Elements of the base map: Geographical information provided by the Directorate-General for Territorial Development.

10.2 Types of habitats

The Guadiana Estuary presents an extensive area of saltmarsh characterised by typical zonation, in which the dominant species in the low saltmarsh are *Sporobolus maritimus* and *Sporobolus montevidensis*; in the middle saltmarsh are *Salicornia fruticosa*, *Salicornia perennis, Atriplex portulacoides*, *Sporobolus versicolor*, and *Arthrocaulon macrostachyum*; and in the high marsh are *Limoniastrum monopetalum* and *Suaeda vera* (ICNF, 2022; Neves et al., 2007, 2010). Intertidal *Zostera noltei* seagrass meadows are also present (Cunha et al., 2013; Lousã, 1986; Neto et al., 2018), particularly in the Carrasqueira estuary (ICNF, 2022).

10.3 Protection regimes

The Guadiana Estuary is considered an area of high ecological importance and is covered by international, European, and national protection regimes (**Figure 10.1**). It is part of the European Natura 2000 network, having been designated as a Special Protection Area (SPA) in 2015 and a Site of Community Importance (SCI) in 2008 under the Birds and Habitats Directives, respectively. It has been internationally recognised as a Ramsar site by the International Convention on Wetlands since 1996. Its extensive saltmarshes were designated as Castro Marim and Vila Real de Santo António Saltmarsh Nature Reserve of the National Network of Protected Areas (RNAP) in 1975 due to their high biological and ecological value (**Table 10.1**).

Seagrass habitats in Portugal are included on the OSPAR List of threatened and/or declining species and habitats (OSPAR Agreement 2008-06).

Table 10.1 Protection regimes in force in the Guadiana Estuary. RNAP: National Network of Protected Areas.

Regime	Reference	Year of designation	Area (ha)
Ramsar site	No 829	1996	2 235
Site of Community Importance (SCI, Natura 2000 network)*	PTCON0013	2008	17 021,89
Special Protection Area (SPA, Natura 2000 network)	PTZPE0018	2015	2 146,43
Castro Marim and Vila Real de Santo António Saltmarsh Nature Reserve (RNAP)	Decree no. 162/75 of 27 March	1975	2 307,99

*It includes the Ria Formosa system.

10.4 Total area of each habitat

10.4.1 Seagrasses

Information on seagrasses in the Guadiana Estuary is limited (**Table 10.2**). In 2009, intertidal *Zostera noltei* meadows formed a 2 – 3 m wide band along 2 km of the estuary (Cunha et al., 2013). This area of 5.4 ha is also referred to in the technical report by Neto et al. (2018) for 2010. Since this survey, no data have been available on the seagrass area in this system.

For the blue carbon estimates in the Guadiana Estuary seagrass areas, the only existing data (2010) of 5.4 ha of seagrass was considered. Seagrass area data were assigned a *Cat 2* quality category as they were not up to date.

Table 10.2 Estimates of seagrass meadow areas in the Guadiana Estuary over time.

Habitat	Year	Area (ha)	Source
Intertidal seagrasses	2009	5,4	Cunha et al. (2013)
Intertidal seagrasses	2010	5,4	Neto et al. (2018)

10.4.2 Saltmarsh

The information available on the global saltmarsh distribution database (Mcowen et al., 2017) shows an area of 940.93 ha in 2006 and 126.51 ha in 2010 (**Table 10.3**, **Figure 10.2**). In a study done in 2015, the estimated area of saltmarsh was 997.28 ha (Camacho et al., 2015; **Table 10.3**, **Figure 10.2**). Since then, no data have been available on the area of saltmarsh in this system.

For the blue carbon estimates in the Guadiana Estuary saltmarsh areas, the most recent area of 126.51 ha, estimated in 2010, was considered. Seagrass area data were assigned a *Cat 2* quality category as they were not up to date.

Table 10.3 Estimates of saltmarsh areas in the Guadiana Estuary over time.

Habitat	Year	Area (ha)	Source
Saltmarsh (total)	2006	940,93	Mcowen et al. (2017)
Saltmarsh (total)	2010	126,51	Mcowen et al. (2017)
Saltmarsh (total)	n/a	997,28	Camacho et al. (2015)

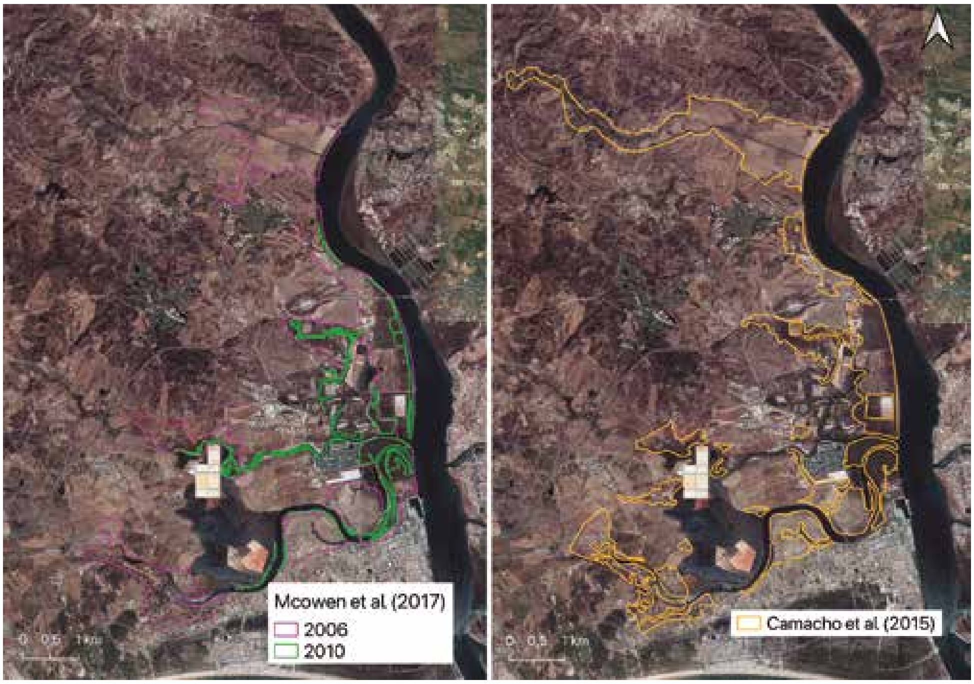

Figure 10.2 Location of saltmarsh areas in the Guadiana Estuary in 2006, 2010, and from a study published in 2015. Adapted from Mcowen et al. (2017) and Camacho et al. (2015). Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

10.5 Estimates of carbon stocks and sequestration rates

10.5.1 Data compilation

Available data on biomass (Caetano et al., 2007, 2008; Neves et al., 2007, 2010) and carbon content (Simões et al., 2011) in the Guadiana Estuary saltmarsh were compiled (**Table 10.4**). No data were found for seagrasses. The carbon content in sediment down to a depth of 1 m in the middle saltmarsh (Kumar et al., 2020) has an average of 1.5% DW. The values found in the surface sediment were 2.1% DW in the low and middle marsh and 3.6% DW in the high marsh (Camacho et al., 2014) (**Table 10.4**). Organic matter content in the surface sediment (5 cm) of three saltmarsh species (*Sporobolus maritimus*, *S. montevidensis*, and *Salicornia perennis*) was measured within the framework of the REASE environmental education network, with values between 3.7 and 5.8% DW (REASE, unpublished). However, it is not possible to calculate carbon stocks with these data (**Table 10.5**).

Table 10.4 Compiled values for the calculations of carbon stocks and sequestration rates in the Guadiana Estuary.

Variable	Intertidal seagrasses (ZN)	Saltmarsh low	Saltmarsh middle	Saltmarsh high
Area (ha)	5,4	126,51*		
Epigean biomass (g DW m^{-2})	-	3 747,4	992,8	3 618,2
Hypogean biomass (g DW m^{-2})	-	4 532,4	1 234,8	2 767,8
Biomass stock per area (Mg DW ha^{-1})	-	-	-	-
Total biomass stock (Mg DW)	-	-	-	-
Carbon content (epigean biomass) (% DW)	-	50,4	49,9	50,4
Carbon content (epigean biomass) (% DW)	-	-	-	-
Organic carbon content (sediment) (% DW)	-	2,1	1,5-2,1	3,6
Organic matter (sediment) content (% DW)	-	-	-	-
Carbon stock in sediment (Mg OC ha^{-1})	-	-	-	-
Sediment accumulation rate (mm $year^{-1}$)	-	-	-	-
Carbon sequestration rate in sediment (g OC m^{-2} $year^{-1}$)	-	-	-	-

* Total area for all three types of marsh.

OC: Organic Carbon.

Table 10.5 Data quality for calculating carbon stocks and sequestration rates in the Guadiana Estuary.

Level	Seagrass	Saltmarsh
Level 1: Area	Cat 2	Cat 2
Level 2: Vegetation	Cat 0	Cat 1
Level 3: Sediment	Cat 0	Cat 1

Quality categories for each level: **Cat 0** (no data), **Cat 1** (incomplete data), **Cat 2** (complete but non-representative or outdated data, i.e., < 2018), **Cat 3** (complete, representative, and up-to-date data, i.e., ≥ 2018).

10.5.2 Estimates

Blue carbon habitats in the Guadiana Estuary are estimated to contain a total stock (sediment and biomass) of 9 649 Mg OC and sequester a total of 40 Mg OC $year^{-1}$ annually, with seagrasses contributing 5% to the stock and 8% to the carbon sequestration rate (**Table 10.6**). Since the available data for the Guadiana Estuary are very poor, stocks and rates from the nearest system, the Ria Formosa, were used. Thus, estimates are considered very imprecise. Furthermore, the area occupied by each type of saltmarsh (low, middle, and high) is unknown, contributing to a greater error in the estimates.

Table 10.6 Estimates of blue carbon stocks and sequestration rates in the Guadiana Estuary.

Variable	Seagrasses (intertidal)	Saltmarsh (total)	TOTAL
Total stock OC in biomass (Mg OC)	6,6	3 084	**3 091**
Total stock OC in sediment (Mg OC)	486	6 072	**6 559**
Total stock (Mg OC)	493	9 156	**9 649**
Annual sequestration rate (Mg C year^{-1})	3,0	36,9	**40**

OC: organic carbon.

10.6 Environmental quality and threats

The saltmarshes and seagrasses in the Guadiana Estuary are located in an urban area in the municipalities of Vila Real de Santo António and Castro Marim. The saltmarsh area has been highly altered due to the construction of walls and embankments (Lavinas, 2004). During the last decades, the hydrodynamics of the estuary has been modified by anthropogenic impacts, and the sources of pollution in the river basin are due to urban development (sewage), agriculture (fertilisers, pesticides, herbicides), livestock, and industries (Camacho et al., 2014). Furthermore, past mining activity associated with the existence of pyrite deposits contributed to heavy metal contamination in the Guadiana River (Bettencourt et al., 2003). In the long term (2050-2100), the intertidal saltmarsh areas are threatened by rising mean sea levels (Sampath and Boski, 2016), which could be mitigated if higher adjacent areas are made available for habitat migration into these areas.

Taking into account the Portuguese Environment Agency's (APA) monitoring based on biological elements, such as benthic macroinvertebrates, fish fauna, and saltmarshes, the ecological status of the transitional body of water WB-1 in the Guadiana (PT07GUA1412) was classified as *Moderate*, the body of water WB-2 (PT07GUA1410) was classified as *Poor*, and the body of water WB3F (PT07GUA1408) as Bad, reflecting the great anthropic pressure on this system (APA, 2022).

10.7 Conservation interventions

10.7.1 Past and ongoing interventions

No information on past or ongoing conservation or restoration interventions focused on saltmarshes and seagrass meadows in the Guadiana Estuary has been found. However, the Castro Marim and Vila Real de Santo António Saltmarsh Nature Reserve Management Plan (Council of Ministers Resolution No. 181/2008 of 24 November) includes an objective to "*promote the conservation and restoration of terrestrial and aquatic natural habitats and indigenous flora and fauna species, particularly the natural values of community* *interest under the terms of Decree-Law no. 140/99 of 24 April, as amended by Decree-Law no. 49/2005 of 24 February*". The Guadiana River Basin Management Plan (RH7) also includes a series of measures for monitoring the estuary and improving the environment, as well as the integrated management of water and habitats in cross-border lower Guadiana (APA, 2022).

10.7.2 Proposed interventions

a) Monitoring
Monitoring saltmarsh and seagrass ecosystems to update the areas they occupy is recommended. It is also recommended to evaluate carbon stocks and sequestration rates in the two types of habitats

b) Protection
According to the data available on the Guadiana Estuary, no saltmarsh or seagrass areas are outside the protection regime SCI (**Figure 10.3**).

c) Restoration
In a recent report (Furtado et al., 2021), the APA identified 192 ha of inactive artificialized areas and 578 ha of active artificialized areas in the Guadiana Estuary that could be used for restoration or spontaneous renaturation projects (**Figure 10.4**). This will require the removal of the artificial barriers that have led to the degradation of the saltmarsh, as well as the re-establishment of natural hydrodynamic flow and topographic levels suitable for the development of the different marsh areas: low, middle, and high. The rehabilitation of some areas can be managed so as to implement the cultivation of halophyte plants for human consumption, such as *Salicornia sp*. This activity can contribute to local populations' environmental and economic improvement by stimulating biogeochemical processes and biomass commercialisation, respectively. Experimental studies have demonstrated the successful cultivation of those species for the re-population of abandoned saltmarshes (e.g. Santos et al., 2017). Furthermore, the channels feeding artificialized areas or even the channels feeding active saltmarshes have great potential for the restoration of seagrass meadows.

The large size of the existing degraded saltmarsh areas in the Guadiana Estuary has great potential for the restoration of blue carbon ecosystems in Portugal, not only from a carbon sequestration point of view but also regarding co-benefits related to other ecosystem services, namely water purification and biodiversity support. That degradation of the saltmarsh is why the ecological status of the Guadiana Estuary bodies of water were classified as *Bad* (WB3F), *Poor* (WB-2), and *Moderate* (WB-1).

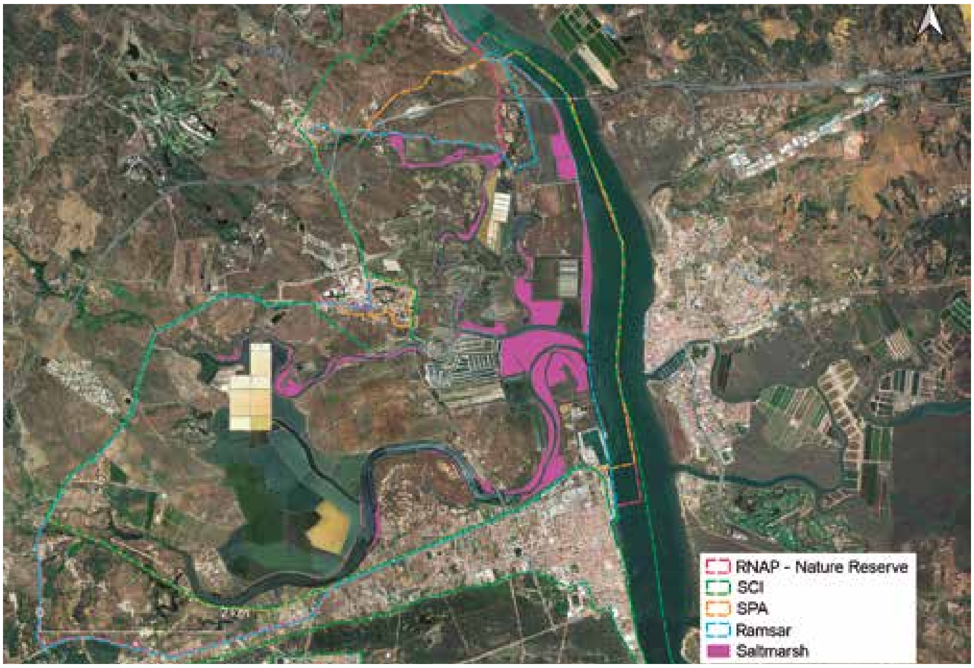

Figure 10.3 Location of saltmarsh and seagrass areas in the Guadiana Estuary and the boundaries of current protection regimes. Base image: Geographical information provided by the Directorate-General for Territorial Development (image date 22-05-2018).

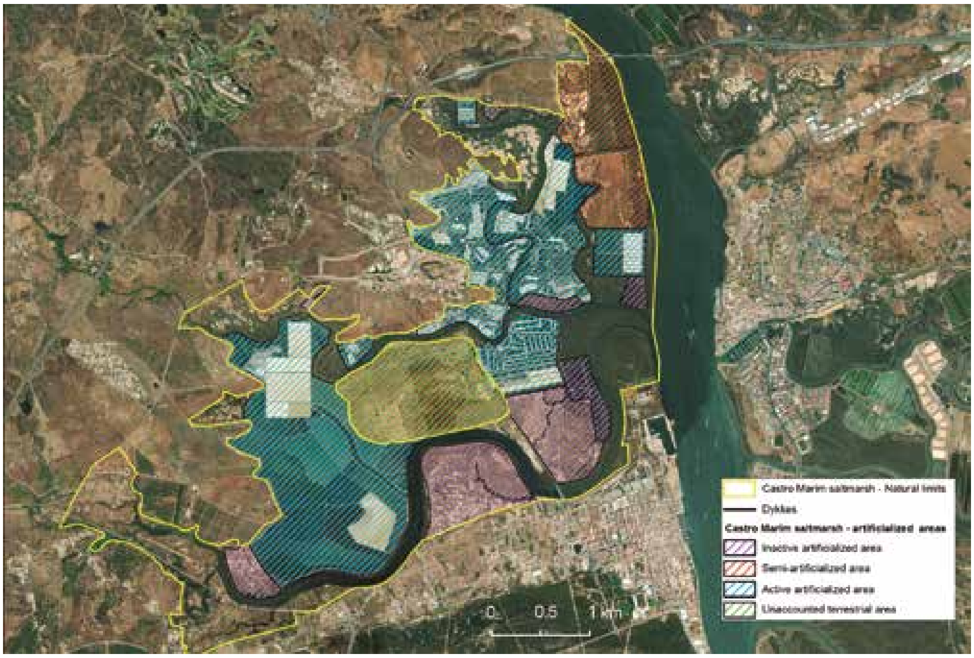

Figure 10.4 Location of inactive and active artificialized areas in the Guadiana Estuary that could be reclaimed for saltmarsh restoration. Source: Furtado et al. (2021).

10.8 Local stakeholders

Municipality of Castro Marim
Municipality of Vila Real de Santo António
Regional Coordination and Development Commission – Algarve (CCDRAlg)
Centre of Marine Sciences of Algarve (CCMAR) – University of the Algarve
Odiana – Association for the Development of Lower Guadiana
Terras de Sal CRL – Comércio e Transformação de Sal Marinho Tradicional *[Commerce and Transformation of Traditional Sea Salt]*
Associação Naval do Guadiana *[Naval Association of the Guadiana]*
Associação de Pesca Artesanal *[Artisanal Fishing Association]*

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CALOUSTE GULBENKIAN FOUNDATION

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The 10 main blue carbon ecosystems in mainland Portugal
Report produced under the Gulbenkian Blue Carbon project

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