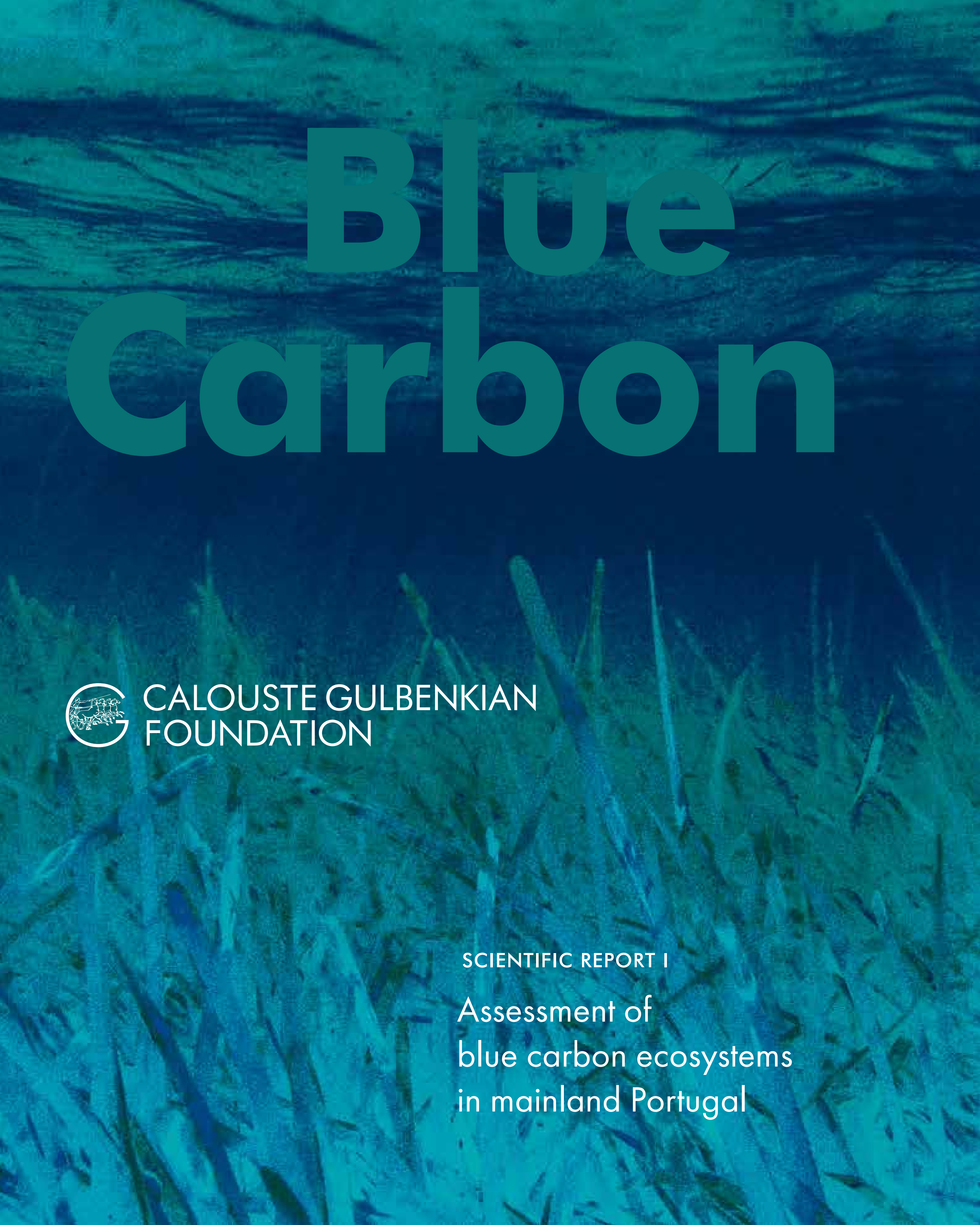

Blue Carbon

CALOUSTE GULBENKIAN FOUNDATION

SCIENTIFIC REPORT I

Assessment of blue carbon ecosystems in mainland Portugal

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Table of contents

List of abbreviations

ANP|WWF	Associação Natureza Portugal, in partnership with World Wildlife Fund
APA	Agência Portuguesa do Ambiente [Portuguese Environment Agency]
BCE	Blue carbon ecosystem
C	Carbon
CGF	Calouste Gulbenkian Foundation
CO_2	Carbon dioxide
DL	Decree-Law
DW	Dry weight
GIS	Geographic Information Systems
ICNF	Instituto da Conservação da Natureza e das Florestas [Institute for Nature Conservation and Forests]
NP	Natural Park
NR	Nature Reserve
OC	Organic carbon
OM	Organic matter
RJCNB	Regime Jurídico da Conservação da Natureza e da Biodiversidade [Legal Framework for Nature Conservation and Biodiversity]
RNAP	Rede Nacional de Áreas Protegidas [National Network of Protected Areas]
SCI	Site of Community Importance
SPA	Special Protection Area
WoS	Web of Knowledge
WW	Wet weight

List of units and conversions

cm^3	Cubic centimetre
g	Gram
ha	Hectare (1 ha = 10 000 m^2)
kg	Kilogram
m^2	Square metre
Mg	Megagram (1 Mg = 1 000 kg = 1 metric tonne)
Gg	Gigagram (1 Gg = 1 000 Mg = 1 000 metric tonnes)

List of tables

Gulbenkian Oceano

List of figures

Figure 16.
Carbon stock of blue carbon ecosystems – seagrass and saltmarsh – per system.

Figure 17.
Carbon stock in seagrass meadows in each of the systems, ordered from highest to lowest, according to their contribution to the total seagrass stock (%).

Figure 18.
Carbon stock in the saltmarshes in each of the systems, ordered from highest to lowest, according to their contribution to the total saltmarsh stock (%).

Figure 19.
Organic carbon sequestration rate in the sediment of the two blue carbon ecosystems – seagrass and saltmarsh – per system.

Figure 20.
Organic carbon sequestration rates in the sediment of seagrass meadows per system, in descending order of their contribution to the total seagrass sequestration (%).

Figure 21.
Organic carbon sequestration rates in the sediment of saltmarshes per system, in descending order of their contribution to the total saltmarsh sequestration (%).

Figure 22.
Number of water bodies per system and their ecological status (based on biological elements).

Figure 23.
Number of water bodies per system threatened by different categories of human drivers in all the systems studied.

I. Context

On the occasion of the United Nations Ocean Conference, held in Lisbon in June 2022, the Calouste Gulbenkian Foundation launched the Gulbenkian Blue Carbon project, in partnership with the Centre for Marine Sciences (CCMAR) of the University of the Algarve and Associação Natureza Portugal in association with the WWF - World Wide Fund for Nature (ANP|WWF), with the aim of investigating the information available to map all the marine and coastal ecosystems in mainland Portugal that have the potential to sequester carbon dioxide from the atmosphere - the blue carbon ecosystems. This scientific research, carried out from north to south of the country, characterises ecosystems (location, distribution areas, environmental status, reserves and carbon sequestration rates, among other characteristics) and proposes appropriate protection and restoration measures.

In this way, the Calouste Gulbenkian Foundation aims to highlight the potential of blue carbon ecosystems to contribute to reducing emissions in the fight against climate change and to the decarbonisation of the economy in Portugal, while providing co-benefits such as supporting biodiversity or improving water quality in coastal areas. It also aims, through this scientific report, to disseminate the most up to date knowledge in this area, clarifying where we are at regarding the scientific research on blue carbon ecosystems in Portugal.

The availability of this information to governmental and private sector organizations aims to encourage investment in conservation and ecological restoration of these marine and coastal habitats, through the financing of blue carbon projects in the identified areas. Such funding will not only allow us to deepen the level of existing scientific knowledge about these coastal and marine ecosystems, but also create the basis for the integration of blue carbon projects in the voluntary carbon market in Portugal.

This is a vital step towards achieving the goals set for ocean conservation and sustainability by the European Union Mission "Restore our Ocean and Waters" by 2030 and by the United Nations Decade of Ocean Science for Sustainable Development (2021-2030). It is also essential to implement the National Strategy for the Conservation of Nature and Biodiversity 2030 and the National Ocean Strategy 2021-2030, and to promote the fight against climate change and the protection of biodiversity, global commitments made in the Paris Agreement of 2015 and the Kunming-Montreal Global Biodiversity Framework of 2022.

II. Summary

As part of the Calouste Gulbenkian Foundation (CGF) Blue Carbon project, all available information on the distribution, protection regimes, threats, and conservation of blue carbon ecosystems (BCE) of the main estuarine-lagoon systems on the coast of mainland Portugal has been collated. In addition, a database that includes all relevant variables for estimating stocks and carbon sequestration rates has been created. This work aims to highlight the gaps that will need to be overcome for a reliable assessment of blue carbon in Portugal, to provide the reference basis for the delineation and implementation of future CO_2 offset projects, and to contribute to the appreciation of the inclusion of BCEs in the national inventory of greenhouse gas emissions.

This summary reports on the most important conclusions and recommendations that resulted from the assessment of the BCEs of the ten largest estuarine-lagoon systems on the coast of mainland Portugal: the Ria de Aveiro, the Mondego Estuary, the Óbidos Lagoon, the Tagus Estuary, the Sado Estuary, the Mira Estuary, the Ria de Alvor, the Arade Estuary, the Ria Formosa, and the Guadiana Estuary. It is divided into sections that generically follow the structure of the work:

i) **Available information**

— The BCEs in mainland Portugal consist of 86% saltmarsh and 14% seagrass meadows.

— The data available to calculate blue carbon stock in mainland Portugal are scarce or, when available, are outdated and incomplete. Consequently, the blue carbon stock estimates in this report are imprecise and should be used cautiously.

— The only system for which carbon sequestration rates of BCEs were estimated was the Ria Formosa. Therefore, calculations performed for other systems use these values. Consequently, carbon sequestration rates in other systems depend only on the areas occupied by BCEs in those systems and are, therefore, very unreliable.

ii) Estimates of carbon stocks and sequestration rates

— It is crucial to invest in research focused on obtaining specific data on the stocks and carbon sequestration rates of the BCEs of each estuarine-lagoon system in mainland Portugal to obtain more reliable estimates.

— The total carbon stock in the BCEs of mainland Portugal is estimated at 845 Gg, with 87% stored in saltmarsh areas (733 Gg) and 13% in seagrass meadows (113 Gg).

— The Ria Formosa, the Ria de Aveiro, and the Tagus Estuary contain 89% of the carbon stock in saltmarshes in mainland Portugal, while 75% of the carbon stock in seagrasses is located in the Ria Formosa.

— The carbon sequestration rate of mainland Portugal's BCEs was estimated at 3 717 Mg per year, with saltmarsh contributing 79% of the total (2 930 Mg per year^{-1}) and seagrass beds 21% (787 Mg per year^{-1}).

iii) Conservation status of BCEs

— Five out of the ten estuarine-lagoon systems that have been assessed in mainland Portugal are not part of the National Network of Protected Areas; two are not part of Natura 2000; and four are not recognised as wetlands of international importance by the Ramsar Convention. One of the systems is not covered by any of these protection regimes.

— The ecological status of the 37 bodies of water within the researched systems – as measured in 2019 based on biological elements – was mostly *Moderate* (49%) or *Good* (32%). Only one body of water was rated *High*. Five bodies of water were rated as *Poor*, and one as *Bad*.

— The bodies of water of the systems researched are under pressure from human activities, mostly related to coastal and tourism development, leading to pollution and alteration of the coast through coastal interventions and constructions. The introduction of exotic species is a problem in one third of the systems.

— The historical loss of area covered by BCEs in mainland Portugal was estimated at 33% for saltmarshes and 10% for seagrasses. The estimate of seagrass loss is certainly underestimated due to historical records of large areas occupied by seagrass that have not yet been quantified.

iv) **Recommendations**

— To prevent the decline of the BCEs of each estuarine-lagoon system along the Portuguese coast, specific protection measures are recommended. For example, by designating new protected areas or regulating threatening human activities. Protection is the most effective conservation measure since restoring degraded BCEs can take a long time.

— There are a few saltmarsh restoration actions in Portugal. However, large-scale saltmarsh restoration should be prioritised as it covers larger areas, saltmarsh has suffered greater historical losses, and it is more accessible yet less influenced by adverse hydrodynamic conditions than seagrass. In addition, the restoration of saltmarsh areas in other countries has proved successful.

— There are few seagrass restoration actions in Portugal, and those that have been done are small-scale and have had limited success, largely due to environmental pressures (storms, herbivory, invasive species).

— Investment is needed in developing more effective seagrass restoration methodologies that do not damage the natural populations used as transplant donors. Seagrass cultivation is recommended in semi-natural systems where hydrodynamic flow and other environmental parameters can be controlled to optimise the production of seagrasses for restoration actions (transplants and seeds) and recovery of the associated co-benefits, such as carbon sequestration or biodiversity support.

— It is necessary to carry out a national survey of coastal areas of maritime public domain, both artificialized and inactive, where saltmarsh and seagrass have been historically present – similarly to what has been done by the Portuguese Environment Agency (APA) for the estuarine-lagoon systems in the Algarve. These areas are a priority for implementing large-scale restoration projects of BCE, potentially fundable by carbon offset projects.

III. Scope and objectives of the report

Blue carbon is the term used for the carbon captured and stored by the world's marine and coastal ecosystems (Nellemann et al., 2009), i.e., it refers to the amount of carbon dioxide (CO_2) that is removed from the atmosphere and is stored as plant biomass in coastal ecosystems, or as refractory organic matter stored in the sediment of coastal ecosystems for hundreds or thousands of years. This carbon sequestration capacity means that coastal zones provide a unique nature-based solution to mitigate climate change as they reduce the concentration of CO_2 in the atmosphere, which is one of the greenhouse gases responsible for climate change. Mangroves, seagrass meadows, and saltmarshes are currently recognised as the coastal ecosystems with the greatest potential for mitigating the increase of CO_2 in the atmosphere. Blue Carbon Ecosystems (BCEs) in Portugal include saltmarshes and seagrass meadows, given that mangroves only grow in tropical areas (**Figure 1**).

Figure 1. Examples of blue carbon ecosystems in Portugal

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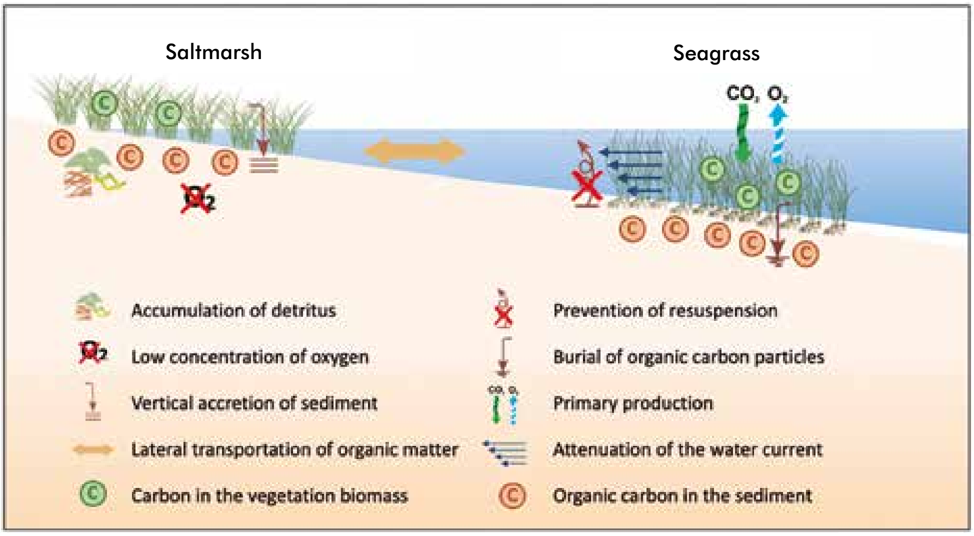
↖ Subtidal seagrass meadows
↗ Intertidal seagrass meadows during low tide
↙ Low marsh during low tide
↘ Middle and high marsh

The capacity of BCEs to capture and store large quantities of carbon is related to the fact that these are highly productive systems, i.e., with high rates of photosynthesis absorbing CO_2 and producing the organic matter that constitutes the leaves, branches, roots, and rhizomes of the vegetation. The living biomass is one of the reservoirs (stocks) of organic carbon and may be epigean (aboveground biomass) or hypogean (belowground biomass). The other, much larger in the case of saltmarshes and seagrasses, is the reservoir of organic matter that accumulates in the sediment and is not broken down by fungi and bacteria, which would result in CO_2 production. The anoxic or hypoxic conditions (i.e., with little or low oxygen concentration) observed in the sediments of the BCEs, cause the decomposition of organic matter to be slower, limiting the emission of CO_2 back into the atmosphere **(Figure 2)**. On the other hand, saltmarshes and seagrass meadows attenuate currents, reducing the resuspension of fine sediments and promoting the sedimentation of allochthonous organic matter transported in the water column, resulting in a continuous vertical accretion of sediment and organic carbon (**Figure 2**).

Figure 2. Processes of carbon accumulation in biomass and sediment of blue carbon ecosystems – saltmarsh and seagrass.



Source of symbols: IAN Symbol libraries, Integration and Application Network.

Globally, despite occupying much smaller areas than terrestrial forests, BCEs sequester carbon in their sediment at a rate up to 40 times faster than forest soils (Ouyang & Lee, 2014). This carbon remains stabilised in sediments for hundreds or even thousands of years (Duarte et al., 2005; McLeod et al., 2011), whereas the carbon stock of forests can be released into the atmosphere by wildfires. During the 20th century, wildfires decreased the global carbon sequestration across terrestrial ecosystems by about 1.0 Pg C $year^{-1}$ (Li et al., 2014).

Due to their absorption capacity and carbon retention, the BCEs of the Portuguese coast could integrate the national strategies to achieve carbon neutrality by 2050 (APA, 2019), as well as complement carbon sequestration through terrestrial forests for the national inventory of greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC). Although Portugal has recently recognised the role of these habitats in climate change mitigation (Law no. 98/2021 of 31 December, the Climate Framework Law), more baseline information on the stocks and sequestration rates of Portuguese BCEs is needed.

The present report, prepared under the Calouste Gulbenkian Foundation (CGF) Blue Carbon project, of which ANP|WWF (Associação Natureza Portugal, in partnership with WWF) is also a partner, aims to collect and analyse all available information on the BCEs of the main estuarine-lagoon systems of the coast of mainland Portugal, to assess the quality of the available information, to identify gaps on carbon stocks and sequestration rates, as well as measures to protect and restore the BCEs, which can be used for projects to offset CO_2 emissions into the atmosphere, namely those of the CGF.

This report presents the methodologies used, the results and conclusions obtained regarding 1) the identification, mapping, and characterisation of BCEs in the main estuarine-lagoon systems of mainland Portugal, 2) the available data for estimating stocks and sequestration rates, and 3) the threats, and the intervention, conservation, and restoration measures of BCEs in each system. Technical sheets have been prepared for all the systems assessed, which include all the collected information, and which are presented in the "Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal".

IV. Methodology

4.1 Systems studied

The blue carbon ecosystems (BCEs) that develop in the estuarine and lagoon areas on the coast of mainland Portugal include subtidal seagrass meadows of the species *Zostera marina L.* and *Cymodocea nodosa* (Ucria) Asch., intertidal *Zostera noltei Hornem* seagrass meadows, and saltmarshes, which develop in the intertidal zone above *Z. noltei*. The main species constituting the saltmarshes are listed in the "Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal". Aquatic meadows of the genus *Ruppia*, which grow in brackish waters, were not considered in this work.

The main estuarine and lagoon systems of the coast of mainland Portugal that host BCEs, which are the object of this study, are the Ria de Aveiro, the Mondego Estuary, the Óbidos Lagoon, the Tagus Estuary, the Sado Estuary, the Mira Estuary, the Ria de Alvor, the Arade Estuary, the Ria Formosa, and the Guadiana Estuary (**Figure 3**).

4.2 Compilation of information on blue carbon

4.2.1 Systematic review and types of information

The identification and mapping of BCEs and the estimates of their carbon stocks and sequestration rates were carried out based on a systematic review of all published information in the scientific literature and other unpublished sources of information. Three levels of information were defined and systematically reviewed:

Level 1: Geographic data
Includes all historical data on the distribution of BCEs in each system studied, namely georeferenced information in vector format (polygons) or raster and non-georeferenced information of occupation areas.

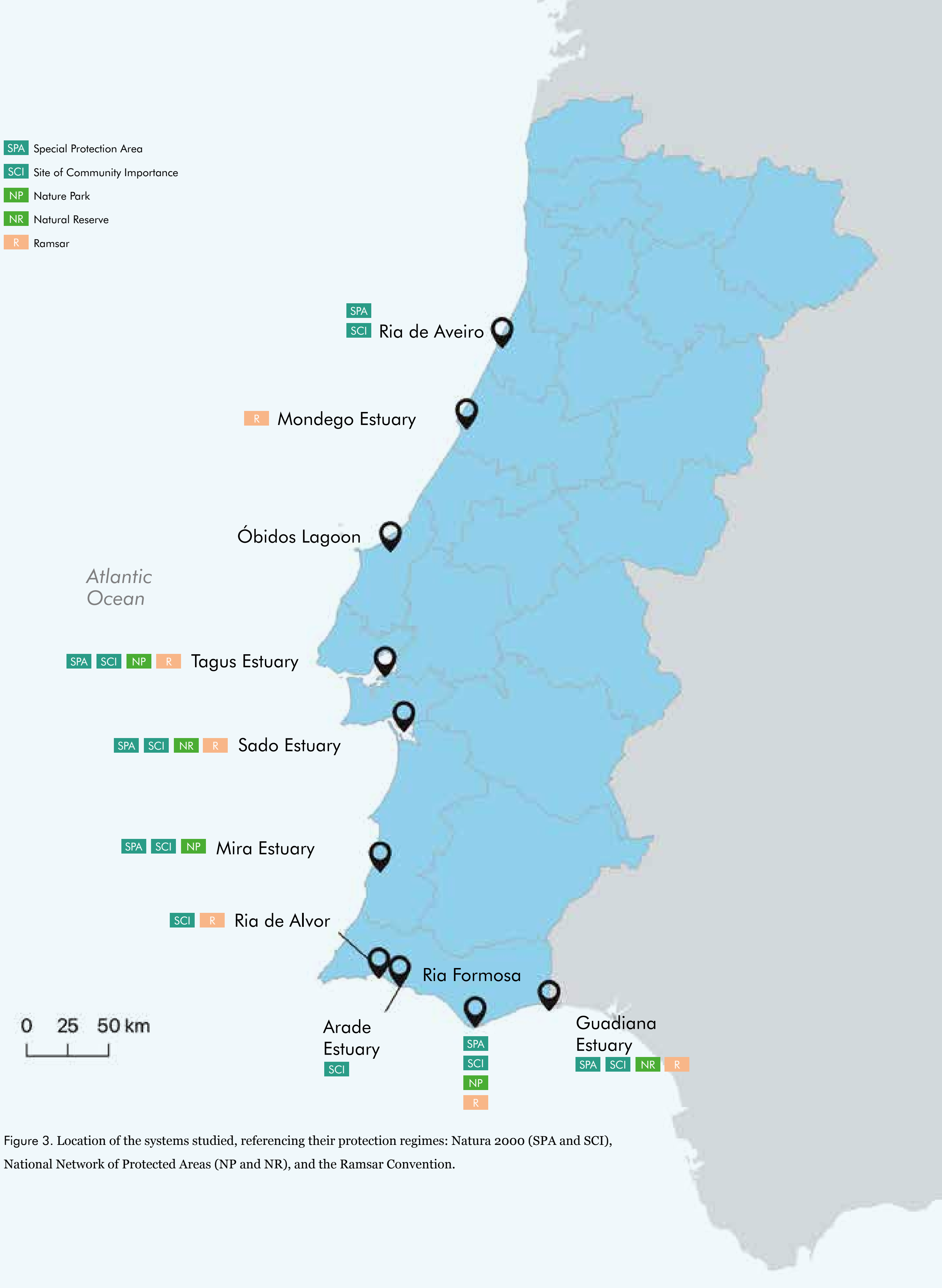


Figure 3. Location of the systems studied, referencing their protection regimes: Natura 2000 (SPA and SCI), National Network of Protected Areas (NP and NR), and the Ramsar Convention.

Level 2: Vegetation
Integrates all data obtained on vegetation biomass, including the variables: biomass density (epigean, hypogean, or total), the carbon content in plant tissues (leaves, branches, rhizomes, and roots) and existing estimates of vegetation biomass or carbon stocks.

Level 3: Sediment
Integrates all available sediment data, namely the variables: organic carbon or organic matter content in sediment, sediment accumulation rate, and carbon stocks (Level 3A) and carbon sequestration rates (Level 3B).

The variables integrated into the databases resulting from these levels of a systematic review are necessary to estimate the carbon stocks and sequestration rates of the BCEs as well as the total stocks and sequestration rates in each system.

The systematic review of relevant information for the three levels followed the PRISMA protocol (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*; Page et al., 2021), which is developed in three steps: data identification, screening, and inclusion (**Figure 4**). In the identification phase, the *Web of Science database* (WoS, www.webofknowledge.com) was consulted on July 4, 2022, and all document records with information about each system were extracted. The search algorithm used was: [("seagrass" OR "saltmarsh" OR "salt marsh" OR "sapal" OR "ervas marinhas") AND ("name of system")], "name of system" being: "Aveiro", "Arade", "Castro Marim" OR "Guadiana", "Mira", "Mondego", "Óbidos", "Alvor", "Ria Formosa", "Sado", and "Tejo" OR "Tagus". All documents (scientific articles and conferences) from any year and language were searched. In addition to the sources obtained through WoS, other sources of information known by the authors of the report and other national researchers who were contacted were also used.

Of the total records compiled (WoS + other sources), those for which it was not possible to access the original document and duplicate records were excluded. In the screening phase, each record was consulted – those that did not address the target systems or BCEs as well as those that did not include relevant information about at least one of the three levels were excluded. The resulting records were assessed for eligibility by excluding non-original data, data with non-valid units, experimental data, data that could not be retrieved or extracted, data repeated in other records, data completed in other studies, and poor-quality data. Finally, in the inclusion phase, the total number of studies included in the review was counted, and the relevant data were extracted and stored on three databases, one per level (**Figure 4**).

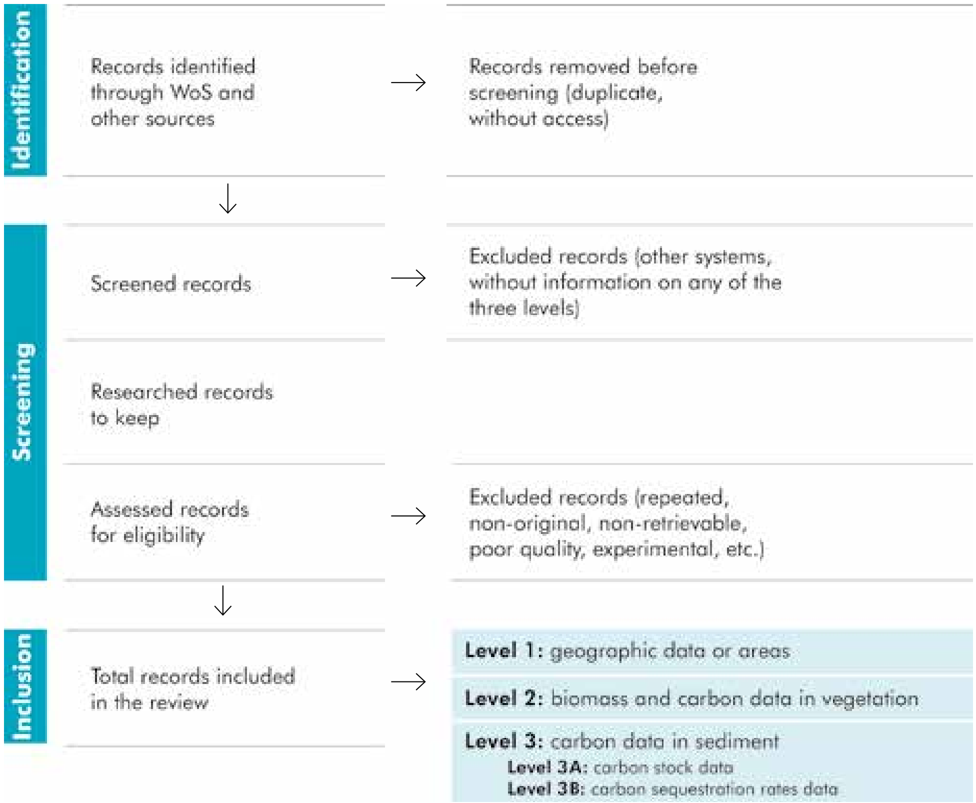


Figure 4. Workflow diagram used for data research following the PRISMA protocol.

The information on the BCEs and their plant species was extracted from the documents compiled for each system. The species' names included in this report were updated in accordance with the *Plants of the World Online* (POWO) database of the Royal Botanic Garden, Kew (https://powo.science.kew.org). The correspondence between the scientific names referred to in the references and their current names is presented in the "Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal".

4.2.2 Geographic data extraction and standardisation

Two types of geographic information data on BCEs were compiled: a) explicit spatial information in vector form, i.e., georeferenced presence polygons, and b) quantitative information on occupation areas. When necessary, spatial information not originally in vector format but in raster format was extracted and georeferenced in a Geographic Information System (GIS). All spatial information in vector format was standardised to the ETRS 89/PT-TM06 coordinate reference system (EPSG:3763) with an attribute table with relevant fields for metadata and other types of information (**Table 1**) and was saved in *geopackage* format.

The quality of the geographic data extraction and mapping methodology was classified into four categories, from 0 to 3 (**Table 2**), which were included in the attribute table (**Table 1**). The criteria used for the classification are set out in **Table 2**. The final category of data quality (*final quality*) was then defined, as calculated by the sum of the two previous indexes (*extraction quality* + *methodology quality*), whose values range from 0 to 6 (**Table 1**).

Table 1. Fields included in the attribute table of the geographic information vector layers.

Field name	Description
ID	Unique element identifier
Source ID	Unique identifier for the information source
Year	Year of observation or mapping
System	System studied
BCE class	BCE classification: seagrass (intertidal, subtidal, or unknown) or saltmarsh (low, middle, high, or unknown)
Species	Name of species present, if known
Data source	Type of data source (original, derived, or unknown)
Extraction quality	Quality of data extraction
Quality methodology	Quality of the mapping methodology
Final quality	Final quality category (sum of extraction quality and quality methodology)
Area	Area represented in hectares, calculated on GIS
Notes	Additional notes (optional)

Table 2. Quality categories of the spatial data. The *extraction quality* considered the quality of data extraction, and the *methodology quality* considered the quality of the methodology used in obtaining the spatial data by the original authors.

Category	Extraction quality	Methodology quality
0	Cannot be extracted	Unknown or hand-drawn
1	Lack of detail, with few points for georeferencing	Aerial or satellite imagery without validationof data
2	Sufficient georeferencing points for good extraction	Fieldwork with direct georeferencing
3	Accurate extraction and/or data provided directly from the author or product	Aerial or satellite imagery with validationof data

The final database for level 1 – geographic data included information on the occupation areas of each BCE, either obtained from vector data (polygons) or from direct quantitative information, including metadata (system, year of observation, type of BCE (seagrass or saltmarsh), species included, and whether the area reported is the total or partial area of that BCE in that system). The most recently reported area and a historical reference area were selected for each system to make a rough estimate of changes in the areas of BCEs at the national level.

4.2.3 Vegetation data extraction and standardisation

The information extracted from the records identified for level 2 – vegetation includes the variables related to biomass and carbon content in plant tissues (**Table 3**). Where necessary, *WebPlotDigitalizer* software (Rohatgi, 2022) was used to extract the data presented in the figures from the information sources. The biomass data were standardised to dry weight (DW) (**Table 3**). Carbon content data (in units of DW %) in different plant tissues (leaves, branches, roots, and rhizomes) were also extracted. The compiled data were accompanied by information on the system, type of BCE, species, and year of sampling. The final data presented in each technical sheet (Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal) represent the average value where more than one value is available.

Table 3. Variables compiled for the estimates of carbon stored in the vegetation of blue carbon ecosystems. DW: dry weight.

Variable name	Units of measurement
Epigean vegetation biomass	g DW m^{-2}
Hypogean vegetation biomass	g DW m^{-2}
Total vegetation biomass	g DW m^{-2}
Biomass stock by area	Mg DW ha^{-1}
Total biomass stock	Mg DW
Carbon content in plant tissue	% DW
Carbon stock in the biomass	Mg C ha^{-1}

4.2.4 Sediment data extraction and standardisation

The information extracted from the records identified for level 3 – sediment includes the geochemical variables required for the calculations of carbon stocks and sequestration rates in sediment (**Table 4**). Where necessary, *WebPlotDigitalizer* software (Rohatgi, 2022) was used to extract the data presented in the figures from the sources of information. Compiled data were accompanied by the system studied, type of BCE, species, year of sampling, and sediment depth where variables were measured from. The mean and standard deviation were calculated when a study presented more than one value for stock or sequestration rates for the same site or ecosystem. The final data presented in the technical sheets for each system (Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal) represent the mean value whenever more than one value is available.

Table 4. Variables compiled for the estimates of carbon stored and sequestered in the sediment of blue carbon ecosystems. DW: dry weight. OC: organic carbon.

Variable name	Units of measurement
Sediment density	g DW cm^{-3}
Organic carbon content in sediment	% DW
Organic matter content in sediment	% DW
Sediment organic carbon stock	Mg OC ha^{-1}
Sediment accumulation rate (linear)	mm ano^{-1}
Sedimentary organic carbon sequestration rate	g OC m^{-2} ano^{-1}

Data on level 3 – sediment were summarised into two relevant levels, carbon stock data (level 3A) and carbon sequestration rate data (level 3B). The available information on carbon sequestration rates of BCEs on the coast of mainland Portugal was found to be extremely deficient. The only available data is from subtidal (mixed *Z. marina* and *C. nodosa* meadows) and intertidal (*Z. noltei*) seagrasses and the low marsh (*S. maritimus*) in the Ria Formosa.

4.2.5 Data quality in each system

The information extracted from each system was compiled on a database, and missing variables for the estimates of blue carbon stock in vegetation and sediment were identified. Considering the quality of the available data, how updated they were (data was considered outdated if produced more than five years ago, i.e., before 2018), and whether the data were considered deficient or not, each system was ranked in a category from 0 to 3 (**Table 5**). From those tables, a list of data to be obtained for each system to improve the quality of blue carbon estimates was created.

Table 5. Data quality categories per system defined for each level of information (geographic data or areas, vegetation data, and sediment data) for each system

Category	Description
0	No data available for this system
1	Some data available, but they are incomplete or of poor quality (methodologynot very precise) to make the estimates
2	Complete data, but are either non-representative or outdated (< 2018)
3	Complete, representative, and up-to-date data are available (≥ 2018)

4.3 Carbon stocks and sequestration rates

4.3.1 Carbon stocks in vegetation

The carbon stored in vegetation biomass (SV) was calculated as the sum of the carbon stocks of each vegetation component, the epigean (aboveground) component and the hypogean (belowground) component (**Equation 1**).

Equation 1. $SV = AGB \times AGC/100 + BGB \times BGC/100$

Where SV is the carbon stock in vegetation (Mg C ha^{-1}), AGB the aboveground biomass (Mg DW ha^{-1}), AGC is the C content of aboveground biomass (DW %), BGB the belowground biomass (Mg DW ha^{-1}), and BGC is the C content of the belowground biomass (DW %).

When the original seagrass biomass data were expressed in wet weight (WW) units, a conversion factor of 0.15 (Phillips and McRoy, 1990) was applied to obtain the dry weight (DW). Similarly, when the original biomass data was expressed in ash-free dry weight units, a conversion factor 2 was applied to obtain the dry weight (Martins & Bandeira, 2001).

The total carbon stock in the vegetation biomass (TSV, Mg C) for each BCE in each system was obtained as the product of the area occupied by that BCE (A, ha) and the estimated stock value per unit area (SV, Mg C ha^{-1}) (**Equation 2**).

Equation 2. $SVT = A \times SV$

Where possible, the carbon stock in biomass was calculated for various classes of BCE (low, middle, and high saltmarsh; intertidal and subtidal seagrass) or by species, which were added to obtain the carbon stock of that BCE in the system. In case biomass density or carbon content data were not available for the BCE of a given system, the available values for the nearest system were used.

4.3.2 Carbon stocks in sediment

Whenever possible, the organic carbon (OC) stored in the sediment was calculated, considering a 1 m layer of sediment in units of megagrams of organic carbon per hectare (Mg OC ha^{-1}). In cases where data were not available down to this depth, the values are presented considering only the available depth referred to in the maps and tables produced.

Where carbon content in sediment was not measured but the organic matter was, the organic carbon/organic matter ratios shown in **Table 6** were used to obtain the estimates.

Table 6. Relations used for the estimates of carbon content (OC) in sediment from organic matter (OM) measurements in different ecosystem types. Source: Howard et al. (2014).

Type of BCE	Relation
Saltmarsh	OC (% DW) = 0.40 * OM + 0.0025 * OM^2 (R^2 = 0.98)
Seagrass	OC (% DW) = 0.43 * OM – 0.33 (R^2 = 0.96)

Carbon stock in sediment per unit area (SS, g C cm-3) was calculated as the sum of the product of the dry sediment density (D, g DW cm-3), the organic carbon content in sediment (OC, DW %), and the thickness of the sediment sample (T, cm), across the sampled sediment layers (**Equation 3**).

Equation 3. $SS = \sum (D \times OC \times T)$

The total carbon stock in sediment (TSS, Mg C) was obtained as the product of the area occupied by the BCE (A, ha) and the estimated stock value per unit area considering a depth of 1 m (SS, Mg C ha^{-1}) (**Equation 4**).

Equation 4. $TSS = A \times SS$

Where possible, carbon stock in sediment was calculated for various classes of BCE (low, middle, and high saltmarsh; intertidal and subtidal seagrass) or by species, which were added up to obtain the carbon stock of that BCE in the system. In case density and sediment carbon content data were not available for a BCE in a given system, the values available for the nearest system were used.

4.3.3. Total carbon stocks

Total blue carbon stocks in each BCE and each system were estimated with a simple additive two-compartment model: biomass and sediment. The total stock (TS, Mg OC ha^{-1}; **Equation 5**) was calculated as the product of the area of BCE (A, ha) and the sum of the stocks of sediment (SS, Mg OC ha^{-1}) and vegetation (SV, Mg OC ha^{-1}) obtained in sections 4.3.1 and 4.3.2.

Equation 5. $$TS = A \times (SV + SS) = TSS + TSV$$

The most recent area of each BCE obtained in compiling level 1 data was considered. When data existed for the same year but from different information sources, the one obtained with the most precise methodology was used.

4.3.4 Sequestration rates in sediment

Sediment organic carbon sequestration rates (SR) in each BCE and each system were compiled directly from the information sources and standardised to units of g OC m^{-2} $year^{-1}$.

The total annual organic carbon sequestration rate in sediment (TRS, Mg C $year^{-1}$) for each BCE in each system was obtained as the product of the area occupied by that BCE (A, ha) and the rate value per unit area (SR, g OC m^{-2} $year^{-1}$) (**Equation 6**).

Equation 6. $$TRS = A \times SR/100$$

Where possible, carbon sequestration rate in sediment was calculated for various classes of BCE (low, middle, and high saltmarsh; intertidal and subtidal seagrass) or by species, which were added up to obtain the carbon sequestration of that BCE in the system. When organic carbon sequestration rate data were not available for a system's BCE, the values available for the nearest system were used.

4.4 Protection regimes, threats, conservation, and stakeholders

The protection regimes considered at the national level were those of the National Network of Protected Areas (RNAP), with any of the typologies defined by the Legal Framework for Nature Conservation and Biodiversity (RJCNB): National Park, Natural Park, Nature Reserve, Protected Landscape, and Natural Monument. At the European level, consideration was given to areas included in Natura 2000, which comprises areas classified as Site of Community Importance (SCI) and Special Areas of Conservation (SAC) under the Habitats Directive and areas classified as Special Protection Areas (SPA) under the Birds Directive. Areas classified under international commitments were also considered, namely Ramsar Sites of the Convention on Wetlands (Ramsar Convention Secretariat, 1971). Information on protected areas was obtained from the websites of the Institute for Nature Conservation and Forests (ICNF, https://www.icnf.pt), the Convention on Wetlands or Ramsar Convention (https://www.ramsar.org/), and the European Nature Information System (EUNIS; https://eunis.eea.europa.eu/) of the European Environment Agency. For each classified area, the following information was compiled: protection regimes, year of designation, designation reference, the extent (in hectares) of the protected area, and the limits for GIS use. Concerning the species, the protection categories defined by the Bern Convention (Council of Europe, 1979), the Red List of Vascular Flora of mainland Portugal (Carapeto et al., 2020), and the OSPAR Convention (OSPAR Commission, 1992) were considered.

The assessment of the environmental quality and threats in the systems studied and their BCEs were based on the environmental quality reports of the Portuguese Environment Agency (APA) and the scientific documents compiled in the systematic review. Regarding the quality of the bodies of water that form part of the systems, information was compiled from the most recent River Basin Management Plans in each region, relating to the 3rd Cycle, 2022-2027 (https://www.apambiente.pt/node/1598), which meet the requirements of the Water Framework Directive (WFD).

The review of past or ongoing conservation actions was carried out through internet searches, including websites of academic institutions, associations, national newspapers, and other sources. The list of local stakeholders identified in each system was drawn up from the information found in the information sources consulted and from the knowledge of the report's authors. This list includes local institutions of any kind (public or private, academic, business, associative, etc.) that could or should be involved or contacted for the conservation actions proposed in the technical sheets.

4.5 Maps and technical sheets for each system

Maps were created with the available information on the distribution of BCEs by system, including geographic data from different years or information sources. The basis of the maps produced was an orthoimage of mainland Portugal from 2018, with a 25-centimetre resolution provided by the Directorate-General for Territorial Development (DGT). Following the most recent data from each BCE, additional maps were created by overlaying the boundaries of the protection regimes in force in each system.

The compiled information and estimates were integrated into each system's technical sheet (Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal). These sheets include the following sections: geographical location, type of BCE, protection regimes, the total area of each BCE, estimates of carbon stocks and sequestration rates, environmental quality and threats, conservation actions, local stakeholders, and bibliography. In the conservation actions section, intervention proposals were included considering the information compiled and the knowledge and experience of the authors of this report.

V. Results

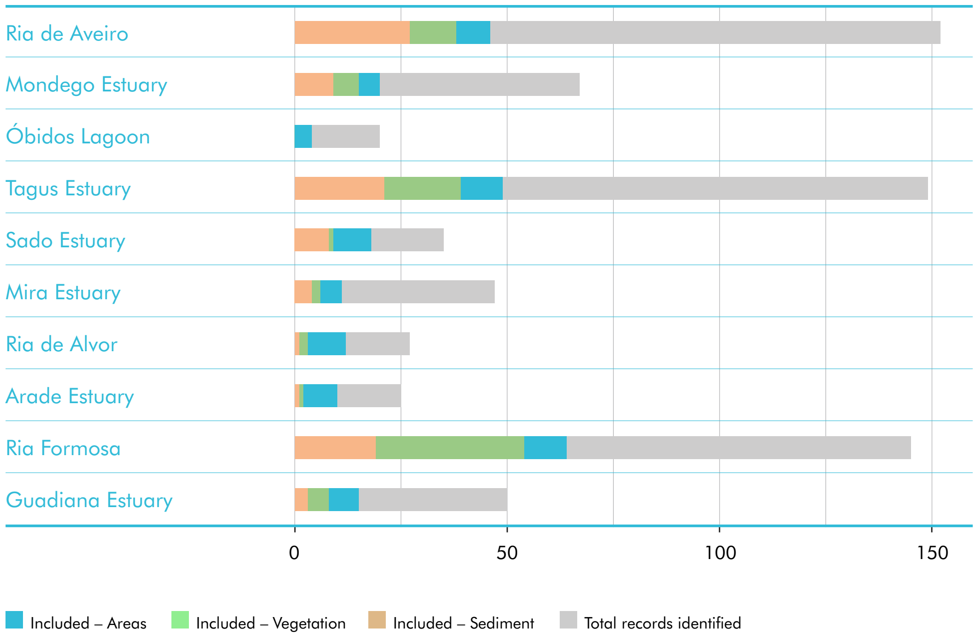
5.1. Compilation of data

A total of 717 documents were compiled among all the systems, of which only 75 contained area data, 82 vegetation data, and 92 sediment data (**Table 7**, **Figure 5**). The distribution of records among the systems was not balanced, as the Ria de Aveiro, the Tagus Estuary, and the Ria Formosa had the most information available (**Table 7**, **Figure 5**). The Óbidos Lagoon was the system with the least amount of available information.

Table 7. Relevant information from the PRISMA protocol during the research process for data of interest in each of the study systems (geographic data or areas, vegetation data and sediment data) for each system.

System	Identified records (WoS)	Records identified (other sources)	Records included in the category "areas"	Records included in the category "vegetation"	Records included in the category "sediment"
Ria de Aveiro	142	10	8	11	27
Mondego Estuary	50	17	5	6	9
Óbidos Lagoon	2	18	4	0	0
Tagus Estuary	132	17	10	18	21
Sado Estuary	18	17	9	1	8
Mira Estuary	32	15	5	2	4
Ria de Alvor	2	25	9	2	1
Arade Estuary	2	23	8	1	1
Ria Formosa	128	17	10	36	18
Guadiana Estuary	36	14	7	5	3
TOTAL	**544**	**173**	**75**	**82**	**92**

Figure 5. Distribution of records identified and included in the area, vegetation and sediment databases, for each study system.



5.2 Mapping of blue carbon ecosystems

Based on the most recent data obtained per system, it is estimated that there is a total area of 11 724 ha of BCE in mainland Portugal, 86% of which is saltmarsh (10 040 ha) and 14% is seagrass (1 684 ha) (**Table 8**, **Figure 6**). The Ria Formosa is the system with the largest area of BCE, with a total of 4 604 ha, followed by the Ria de Aveiro (3 681 ha), the Tagus Estuary (1 830 ha), and the Sado Estuary (1 060 ha) (**Table 8**, **Figure 7**).

The Ria Formosa and the Ria de Aveiro are the systems where the largest saltmarsh area in mainland Portugal is concentrated (35% and 34%, respectively), followed by the Tagus Estuary (18%) and the Sado Estuary (8%) (**Table 8**, **Figure 8**). All other systems have saltmarsh areas contributing 1% or less to the total estimated area. Regarding seagrass meadows, the Ria Formosa has the largest area in Portugal (67% of the total), followed by the Ria de Aveiro and the Sado Estuary (13% each) and the Tagus Estuary (4%).
In all other systems, the meadow area is 1% of the total or less (**Table 8**, **Figure 9**).

Most surveys of Portugal's BCEs were conducted before 2018; therefore, they are considered outdated. Furthermore, the mapping techniques used and their accuracy are highly variable (information compiled but not shown in the report). Consequently, the figures provided in this report should be used with caution. Maps showing the spatial distribution and temporal evolution of the areas occupied by each BCE can be found in the technical sheets (Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal).

Table 8. Area occupied by seagrass and saltmarsh blue carbon ecosystems per system in mainland Portugal.

System	Saltmarsh area (ha)	Saltmarsh % of total	Seagrass area (ha)	% Seagrass of total	Total area (saltmarsh + seagrass) (ha)	% of total
Ria de Aveiro	3 455	34%	226	13%	3 681	31%
Mondego Estuary	54	1%	15	1%	69	1%
Óbidos Lagoon	15	< 0,1%	1	< 0,1%	17	< 0,1%
Tagus Estuary	1 763	18%	67	4%	1 830	16%
Sado Estuary	839	8%	221	13%	1 060	9%
Mira Estuary	125	1%	15	1%	139	1%
Ria de Alvor	72	1%	3	< 0,1%	75	1%
Arade Estuary	118	1%	< 0,1	< 0,1%	118	1%
Ria Formosa	3 473	35%	1 131	67%	4 604	39%
Guadiana Estuary	127	1%	5	< 0,1%	132	1%
TOTAL	**10 039**	**86%**	**1 684**	**14%**	**11 724**	**100%**

Figure 6. Area occupied by the two blue carbon ecosystems – seagrass and saltmarsh – in mainland Portugal.

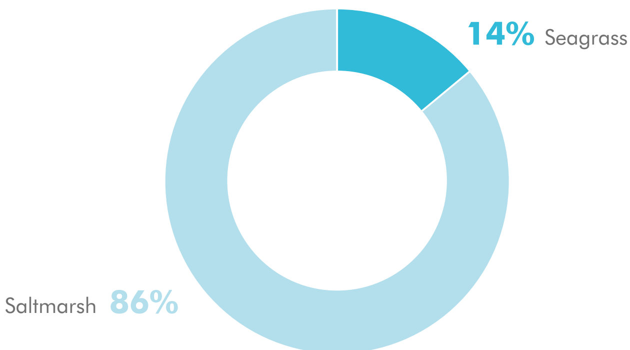


Figure 7. Area occupied by the two blue carbon ecosystems – seagrass and saltmarsh – per system studied in mainland Portugal.

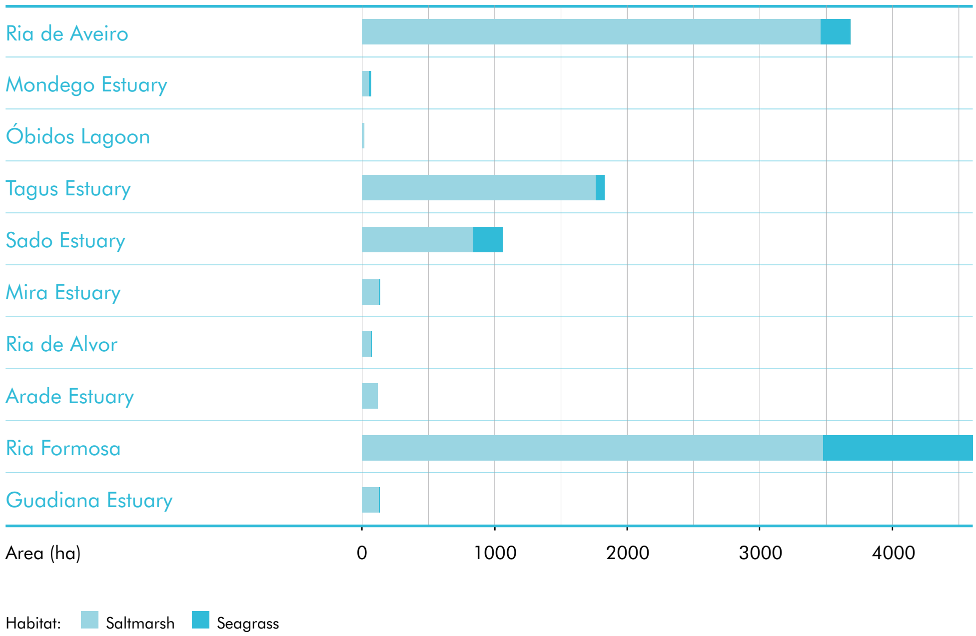


Figure 8. Saltmarsh area (ha and % of total) per system studied in mainland Portugal.

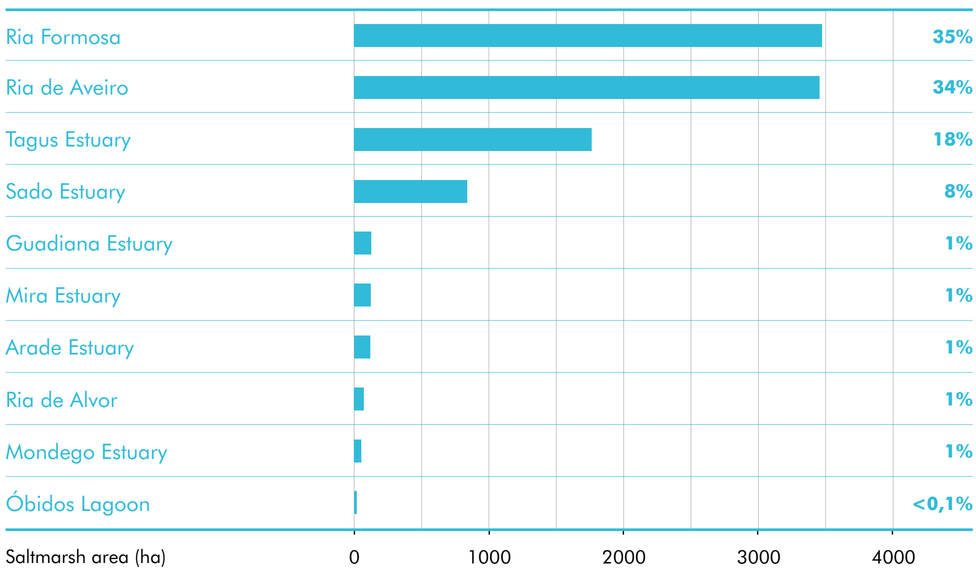
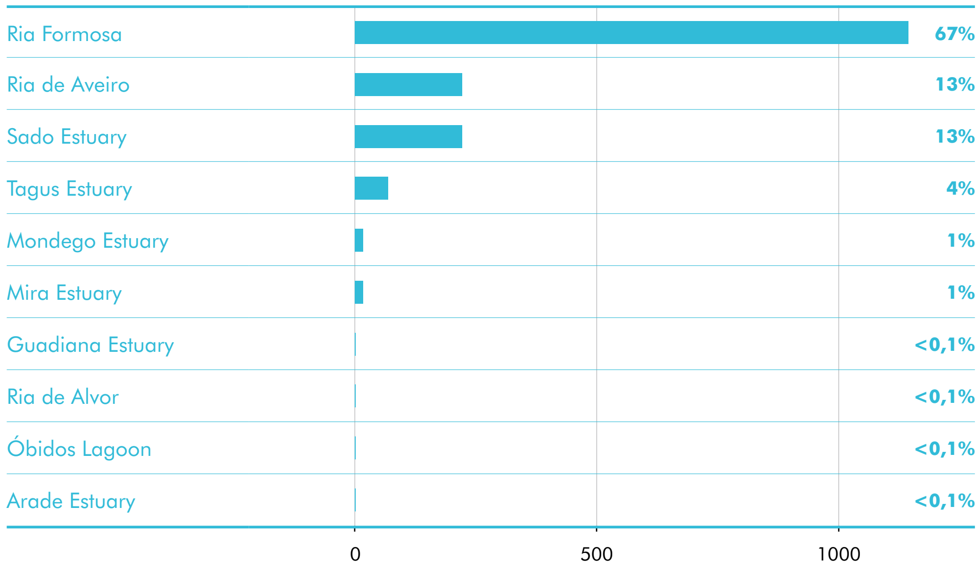


Figure 9. Seagrass area (ha and % of total) per system studied in mainland Portugal.



5.3 Blue carbon data

5.3.1 Vegetation data

A total of 505 values of biomass for saltmarsh and 525 for seagrass were compiled (**Figure 10**), and 79 values of carbon content for saltmarsh and 219 for seagrass (**Figure 11**). The mean (± SD) epigean biomass of saltmarsh in Portugal is 814 ± 949 g DW m^{-2}, and the mean hypogean biomass is 1608 ± 1588 g DW m^{-2}. The mean seagrass biomass is 166 ± 164 g DW m^{-2} in the epigean part and 182 ± 163 g DW m^{-2} in the hypogean part (**Figure 10**). Carbon content varied less between the two components, with mean values of 39 ± 5% and 35 ± 8% in the epigean and hypogean saltmarsh tissues, respectively, and 39 ± 3% and 37 ± 4% in epigean and hypogean seagrass tissues, respectively (**Figure 11**).

Figure 10. Epigean (aboveground) and hypogean (belowground) biomass in the two blue carbon ecosystems – seagrass and saltmarsh – across all systems. The mean value is represented with the symbol +.

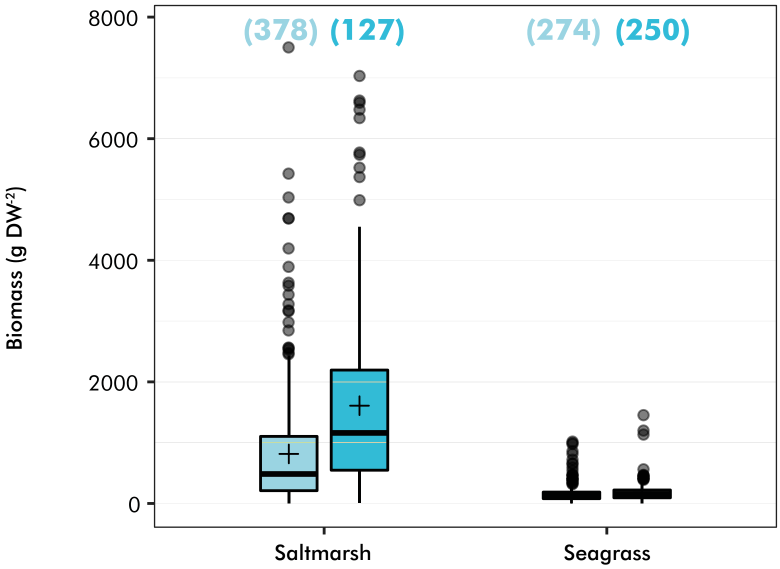
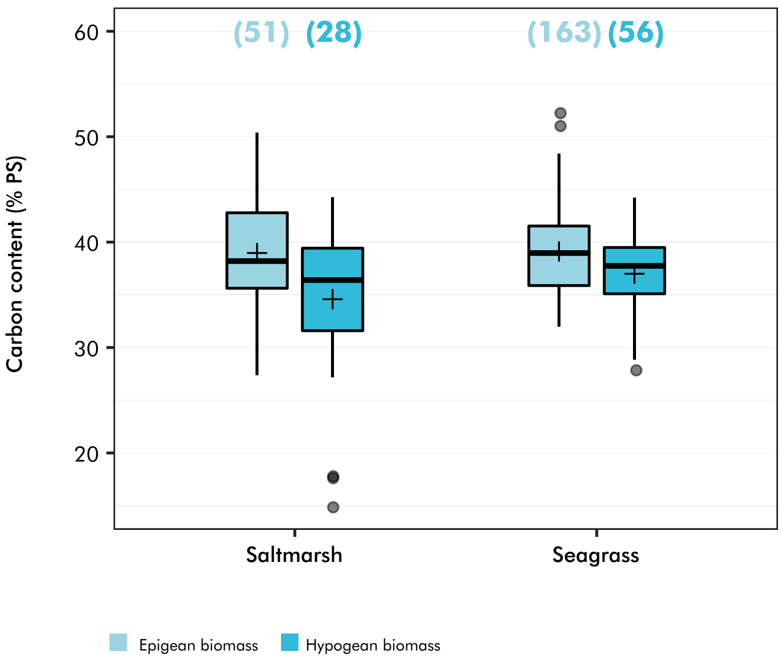
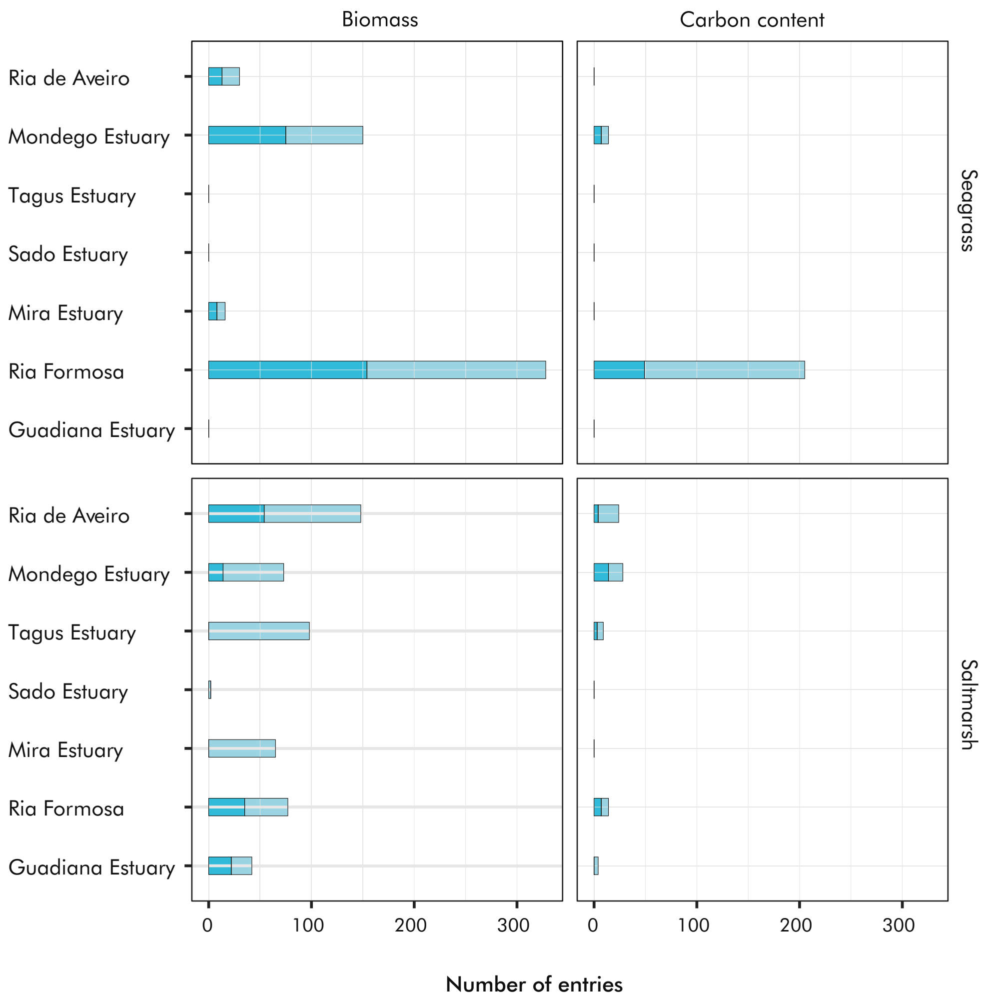


Figure 11. Carbon content in epigean (aboveground) and hypogean (below ground) biomass in the two blue carbon ecosystems – seagrass and saltmarsh – across all systems. The mean value is represented with the symbol +.



Data availability varied greatly among the different saltmarsh and seagrass species and the different systems, with no vegetation data found for three of them (Óbidos Lagoon, the Ria de Alvor, and the Arade Estuary; **Figure 12**). For this reason, blue carbon estimates often had to be developed with data from other systems by choosing the closest system where data were available.

Figure 12. Number of compiled values for epigean and hypogean (above and belowground) biomass and carbon content in blue carbon ecosystems – seagrass and saltmarsh – in each studied system in mainland Portugal. No vegetation data were found for the Óbidos Lagoon, the Ria de Alvor, and the Arade Estuary; therefore, these two systems were excluded from the graph.



5.3.2 Sediment data

Organic matter or organic carbon content data were compiled for most systems (see details in the technical sheets, Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal). However, the data were not accompanied by sediment density, which is necessary to calculate organic carbon stocks. Only the Ria de Aveiro and the Ria Formosa presented complete carbon stock data in saltmarsh and seagrass sediment, including for different zonation levels or species of saltmarsh and seagrass species (**Table 9**).

Data on carbon sequestration rates are even more deficient. While sedimentation rate data were found for some systems (see details in the technical sheets, Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal), it was not possible to estimate carbon sequestration rates as there were no available sediment carbon content data. The Ria Formosa was the only system where carbon sequestration rate data were available for seagrass and for one of the three saltmarsh subtypes, the low marsh (**Table 9**).

5.4 Data quality

Table 9. Data availability for the calculations of carbon stocks and sequestration rates in the sediment of each system.

System	Saltmarsh stocks	Saltmarsh rates	Seagrass stocks	Seagrass rates
Ria de Aveiro	Yes (5 species)	No	Yes (1 species)	No
Mondego Estuary	No	No	No	No
Óbidos Lagoon	No	No	No	No
Tagus Estuary	No	No	No	No
Sado Estuary	No	No	No	No
Mira Estuary	No	No	No	No
Ria de Alvor	No	No	No	No
Arade Estuary	No	No	No	No
Ria Formosa	Yes (3 subtypes)	Yes (1 subtype)	Yes (2 subtypes)	Yes (2 subtypes)
Guadiana Estuary	No	No	No	No

Data quality for the estimates of blue carbon stocks in Portugal was mostly low (0 or 1) for vegetation (level 2) and sediment (level 3) data (**Figure 13**). On the other hand, level 1 – geographic/area data were of higher quality (2 and 3), and comprehensive data on most systems and BCEs were available, although many of them need to be updated (**Figure 13**).

In general, the systems with the highest data deficiency were the smaller ones (the Óbidos Lagoon, the Ria de Alvor, the Arade Estuary, the Guadiana Estuary), while the larger ones like the Ria Formosa, the Ria de Aveiro, the Sado Estuary, and the Tagus Estuary showed higher data quality (**Figure 14)**. The system that presented the highest quality data was the Ria Formosa, which presented maximum quality in all levels of variables except for vegetation and saltmarsh carbon sequestration rates (**Figure 14**).

5.5 Estimates of carbon storage and sequestration

Figure 13. Number of systems by data quality category (on a scale of 0 to 3) at the three levels (area, vegetation, and sediment) for each type of blue carbon ecosystem – seagrass and saltmarsh.

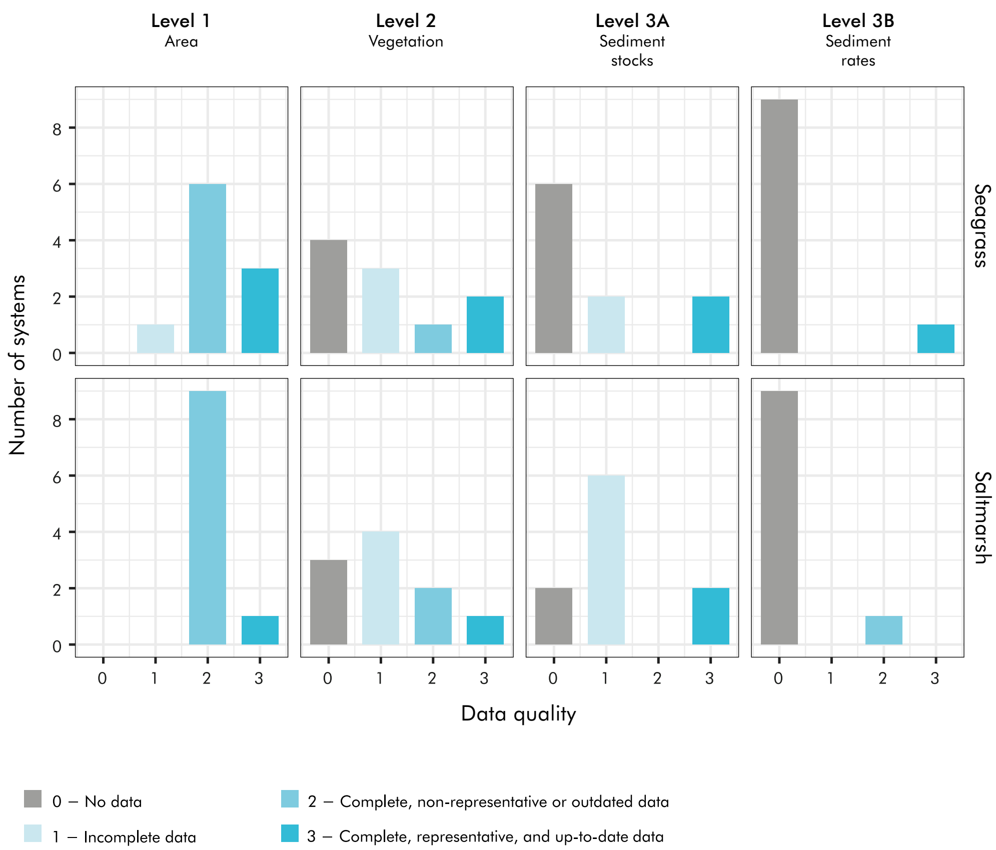
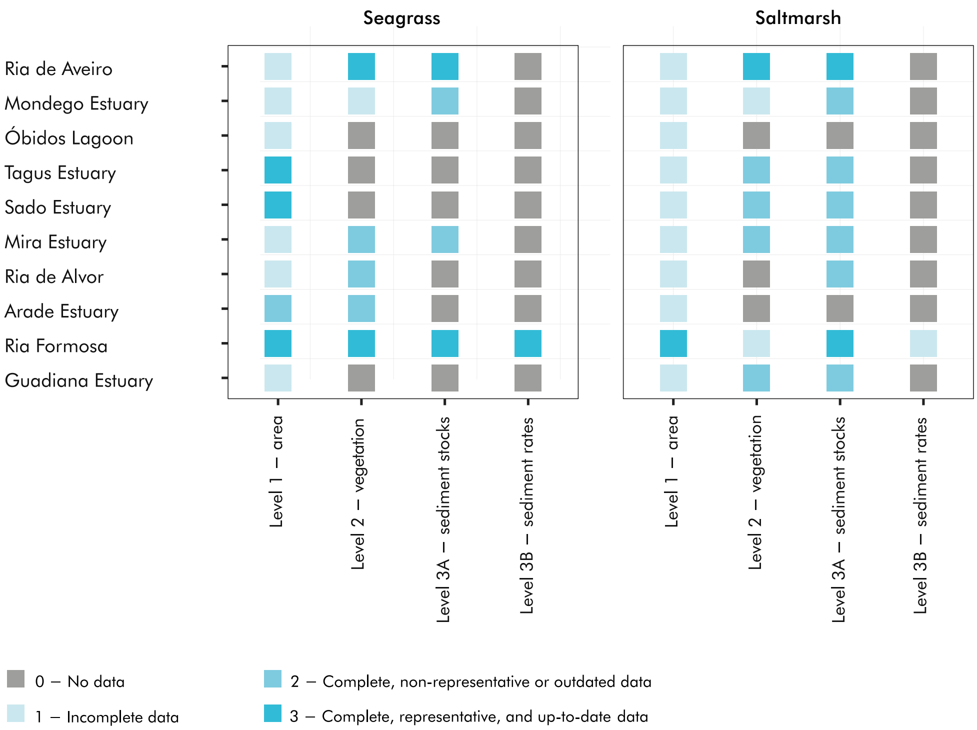


Figure 14. Data quality per system (on a scale of 0 to 3) at the three levels (area, vegetation, and sediment) for each type of blue carbon ecosystem – seagrass and saltmarsh, in the systems studied.



5.5.1 Carbon stocks

It is estimated that there is a carbon stock of 845 Gg in the BCEs of mainland Portugal, with 87% stored in saltmarsh areas (733 Gg) and 13% in seagrass meadows (113 Gg) (**Table 10**). In seagrass meadows, 98% of the carbon is stored in the sediment and only 2% in the biomass, a value which increases to 13% in the saltmarsh (**Figure 15**).

The Ria Formosa is the system that contributes the largest proportion to the total national carbon stock (38%), followed by the Ria de Aveiro (30%), the Tagus Estuary (21%), and the Sado Estuary (8%). The other systems contribute 1% or less (**Table 10**, **Figure 16**). Most national carbon stock in seagrass meadows can be found in the Ria Formosa (75%), followed by the Sado Estuary (16%) (**Figure 17**). The carbon stock in seagrasses in the Ria de Aveiro is likely to be underestimated as data are only available for the uppermost sediment layer (Sousa et al., 2019). The Ria Formosa (32%), the Ria de Aveiro (34%), the Tagus Estuary (23%), and the Sado Estuary (7%) are the systems with the largest saltmarsh carbon stocks (**Figure 18**).

Table 10. Carbon stock stored in the two blue carbon ecosystems – seagrass and saltmarsh – per system.

System	Stock C saltmarsh (Gg)	% Saltmarsh	Stock C seagrass (Gg)	% Seagrass	Stock Total (Gg) (saltmarsh + seagrass)	% of total
Ria de Aveiro	252,1	34	0,5	< 1	252,6	30
Mondego Estuary	1,9	< 1	1,4	1	3,3	< 1
Óbidos Lagoon	0,9	< 1	< 0,1	< 1	0,9	< 1
Tagus Estuary	167,5	23	6,2	5	173,6	21
Sado Estuary	48,4	7	18,3	16	66,7	8
Mira Estuary	6,4	1	1,3	1	7,7	1
Ria de Alvor	4,2	1	0,2	< 1	4,5	1
Arade Estuary	6,9	1	< 0,1	< 1	6,9	1
Ria Formosa	235,1	32	84,4	75	319,5	38
Guadiana Estuary	9,2	1	0,5	< 1	9,6	1
TOTAL	732	87	113	13	845	100

Figure 15. Carbon stock in the vegetation biomass and sediment of blue carbon ecosystems – seagrass and saltmarsh ecosystems – in mainland Portugal.

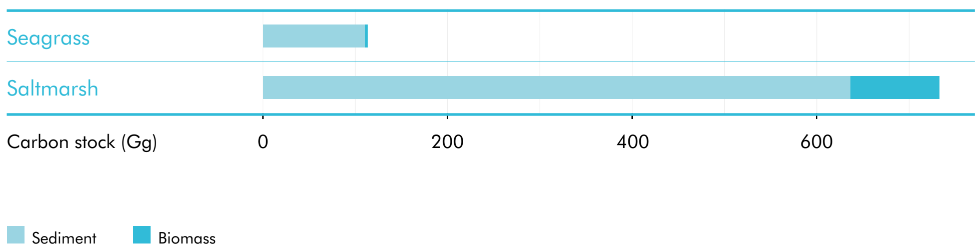


Figure 16. Carbon stock of blue carbon ecosystems – seagrass and saltmarsh – per system.

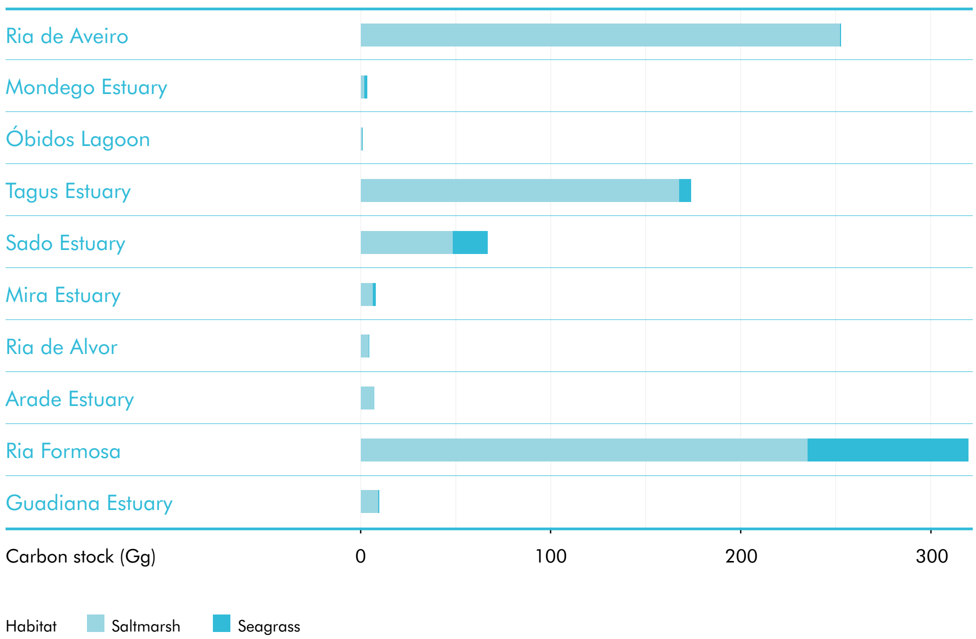


Figure 17. Carbon stock in seagrass meadows in each of the systems studied, ordered from highest to lowest, according to their contribution to the total seagrass stock (%).

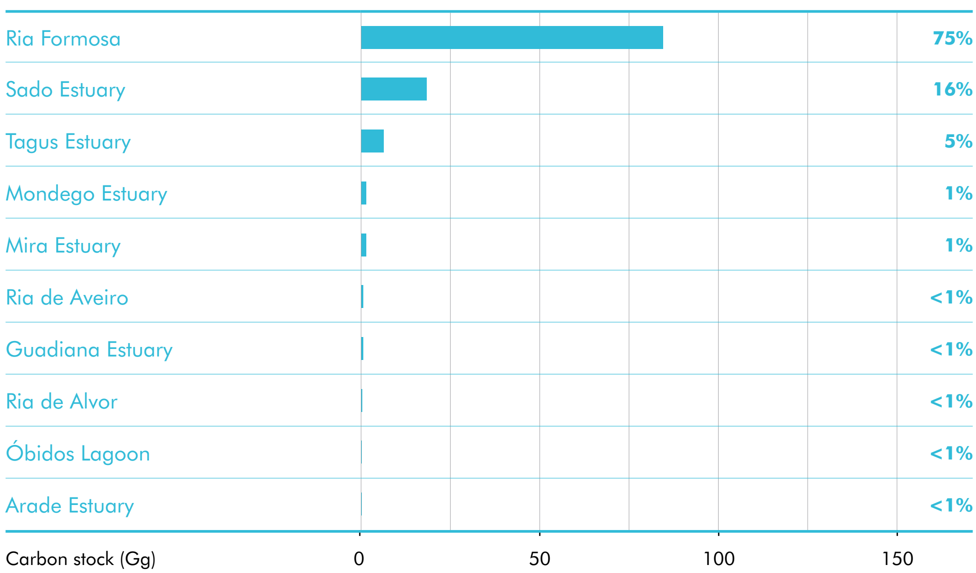
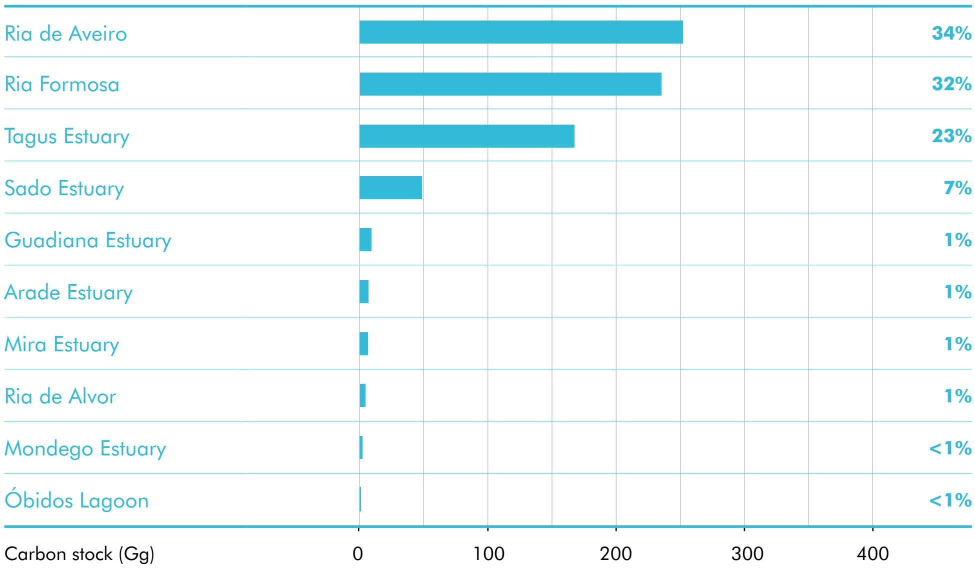


Figure 18. Carbon stock in the saltmarshes in each of the systems studied, ordered from highest to lowest, according to their contribution to the total saltmarsh stock (%).



5.5.2. Carbon sequestration rates

Annual carbon sequestration in the BCEs of mainland Portugal is estimated at 3 717 Mg, with 79% sequestered in saltmarsh areas (2 930 Mg year^{-1}) and 21% in seagrass meadows (787 Mg year^{-1}) (**Table 11**).

The Ria Formosa is the system that contributes the most to the national carbon sequestration, with 40% of the total, followed by the Ria de Aveiro (31%), the Tagus Estuary (15%), and the Sado Estuary (10%). The remaining systems contribute 1% or less (**Table 11**, **Figure 19**). Regarding carbon sequestration in seagrass meadows, the Ria Formosa (62%), the Ria de Aveiro (16%), and the Sado Estuary (14%) are the systems with the highest contribution (**Figure 20**), while the saltmarshes of the Ria Formosa (35%), Ria de Aveiro (34%), and the Tagus Estuary (18%) are the systems with the highest contribution (**Figure 21**).

Table 11. Estimated organic carbon sequestration rate in the sediment of seagrass and saltmarsh blue carbon ecosystems for each of the systems studied.

System	Saltmarsh rate (Mg ano-1)	Saltmash % of total	Seagrass rate (Mg ano-1)	% Seagrass over the total	Total fee (Mg ano-1) (saltmarsh + seagrass)	% of total
Ria de Aveiro	1 009	34	127	16	1 136	30
Mondego Estuary	16	1	9	1	24	1
Óbidos Lagoon	5	< 1	< 1	< 1	5	< 1
Tagus Estuary	514	18	38	5	552	15
Sado Estuary	245	8	110	14	355	10
Mira Estuary	36	1	8	1	45	1
Ria de Alvor	21	1	1	< 1	22	1
Arade Estuary	34	1	< 1	< 1	34	1
Ria Formosa	1 013	35	490	62	1 503	40
Guadiana Estuary	37	1	3	< 1	40	1
TOTAL	2 930	79	787	21	3 717	100

Figure 19. Organic carbon sequestration rate in the sediment of the two blue carbon ecosystems – seagrass and saltmarsh – for each of the systems studied.

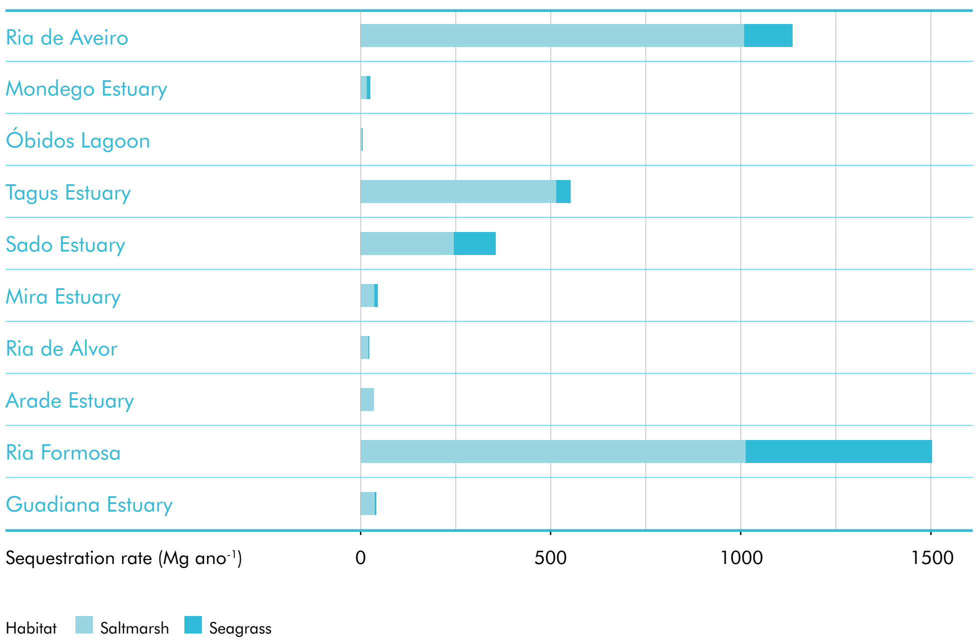


Figure 20. Organic carbon sequestration rates in the sediment of seagrass meadows, per system, sorted in descending order of their contribution to the total seagrass sequestration (%).

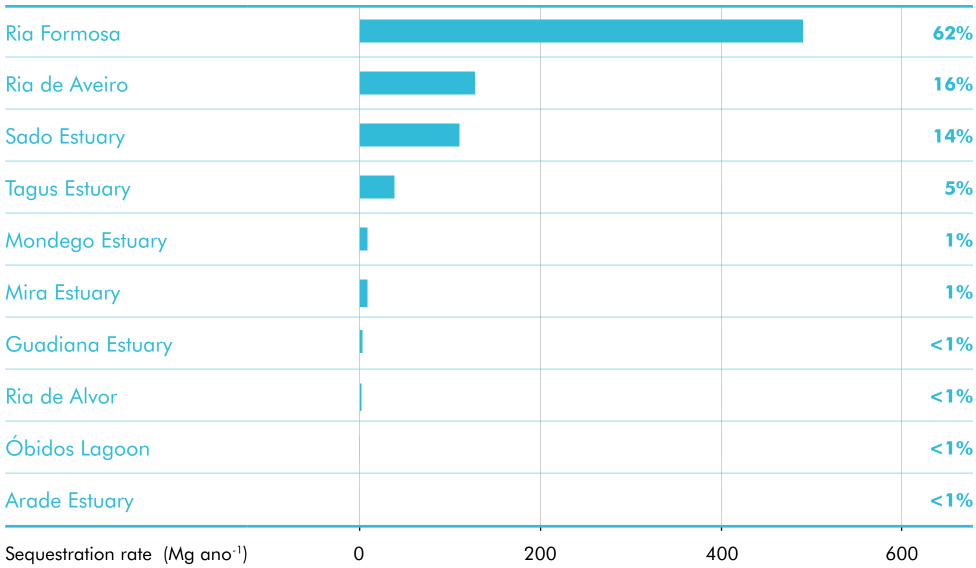
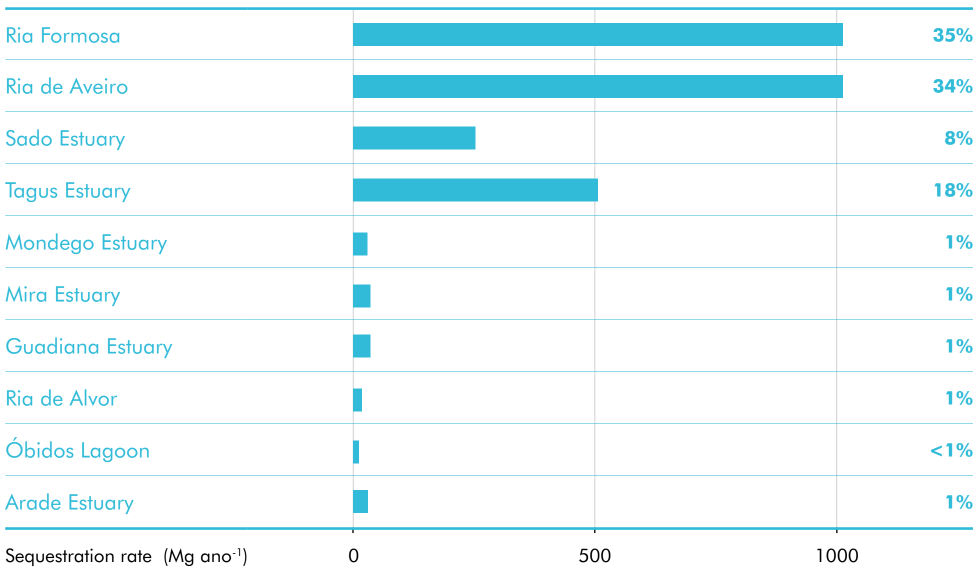


Figure 21. Organic carbon sequestration rates in the sediment of saltmarshes, per system, sorted in descending order of their contribution to the total saltmarsh sequestration (%).



5.6. Protection regimes

All systems, except the Óbidos Lagoon, are under one or more protection regimes – either at the national level within the National Network of Protected Areas (RNAP) or at the European level within Natura 2000 – namely as Site of Community Importance (SCI), Special Protection Area (SPA), or designed wetlands of international importance under the Ramsar Convention (Ramsar Sites) (**Table 12**).

At the national level, only two systems with BCEs are designated as Natural Parks: the Ria Formosa (Ria Formosa Nature Park) and the Mira Estuary, which is part of the Southwest Alentejo and Vicentine Coast Natural Park. The Tagus, the Sado, and the Guadiana estuaries are classified as Nature Reserves. However, these protected areas do not always cover the whole extension of the BCEs (more information on the technical sheets, Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal). The Ria de Aveiro is also partially protected as a Nature Reserve – Dunas de São Jacinto Nature Reserve – but this reserve does not include wetlands. At the European level, eight Portuguese estuarine-lagoon systems are part of Natura 2000 as SCIs or as both SCIs and SPAs, with six of them recognised as Ramsar sites (**Table 12**).

Table 12. Protection regimes currently covering blue carbon ecosystems in mainland Portugal.

System	Ramsar site	SCI (Natura 2000)	SPA (Natura 2000)	Natural Park (RNAP)	Nature Reserve (RNAP)
Ria de Aveiro	-	PTCON0061	PTZPE0004	-	DL n.º 41/79*
Mondego Estuary	n.º 1617	-	-	-	-
Óbidos Lagoon	-	-	-	-	-
Tagus Estuary	n.º 211	PTCON0009	PTZPE0010	-	DL n.º 565/76
Sado Estuary	n.º 826	PTCON0011	PTZPE0011	-	DL n.º 430/80
Mira Estuary	-	PTCON0012	PTZPE0015	DL n.º 241/88	-
Ria de Alvor	n.º 827	PTCON0058	-	-	-
Arade Estuary	-	PTCON0052	-	-	-
Ria Formosa	n.º 212	PTCON0013	PTZPE0017	DL n.º 373/87	-
Guadiana Estuary	n.º 829	PTCON0013	PTZPE0018	-	DL n.º 162/75
No. of systems	6	8	6	2	4

SCI: Site of Community Importance | SPA: Special Protection Area | RNAP: National Network of Protected Areas | DL: Decree-Law.

* Does not cover wetlands

In short, five of the estuarine-lagoon systems do not have awny type of protection regimes at the national level (Ria de Aveiro, Mondego Estuary, Óbidos Lagoon, Ria de Alvor, and Arade Estuary), two are not part of Natura 2000 (Mondego Estuary and Óbidos Lagoon), and four are not recognised as wetlands of international importance by the Ramsar Convention (the Ria de Aveiro, the Óbidos Lagoon, the Mira Estuary, and the Arade Estuary).

On the other hand, even in the systems under protection regimes, the analysis of the overlap of saltmarsh and seagrass areas with the boundaries of protected areas showed that some BCE areas are not legally protected (more information in the technical sheets, Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal).

5.7 Environmental quality and threats

5.7.1 Environmental quality

The systems of study include a total of 37 water bodies categorised in the River Basin Management Plan (3rd Cycle, 2022 - 027; APA, 2022): the Ria de Aveiro and the Mondego Estuary in the Vouga, Mondego and Lis region (RH4A); the Óbidos Lagoon and the Tagus Estuary in the Tagus and Ribeiras do Oeste region (RH5A); the Sado Estuary and the Mira Estuary in the Sado and Mira region (RH6); the Ria de Alvor, the Arade Estuary, and the Ria Formosa in the Ribeiras do Algarve region (RH8); and the Guadiana Estuary in the Guadiana (RH7). Of the total 37 bodies of water, 8 are coastal waters (in the Ria Formosa, the Ria de Alvor, and the Mira Estuary), and 29 are transitional waters (all the other systems).

The ecological status of the bodies of water assessed based on biological elements (fish, benthic macroinvertebrates, phytoplankton, seagrass, marshes) in the last monitoring in 2019 was mostly *Moderate* (49%) or *Good* (32%); 5 bodies of water were categorised as *Poor*, one as *Bad*, and one as *High* (**Figure 22**). The systems that showed bodies of water with an ecological status below *Moderate* were the Ria de Aveiro, the Mondego Estuary, the Arade Estuary, and the Guadiana Estuary (**Figure 22**).

5.7.2 Pressures and threats

According to a report prepared by the Portuguese Environment Agency (APA) in 2019 (APA, 2022) on the diagnosis and characterisation of the water bodies in these systems, port infrastructure (wharves, marinas, ports, etc.) and pollution (point source and diffuse, due to the industrial, urban, and tourism sectors) are the most frequent pressures (**Figure 23**). Other threats are the alteration of river and lagoon beds, coastal interventions (for example, the construction of breakwaters, dams, jetties, etc.), the introduction of exotic species, and by removal of sediments (for example, by dredging) (**Figure 23**). These pressures may have a direct or indirect negative effect on BCEs. The technical sheets' (Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal) present the details on each system's pressures and other threats.

Figure 22. Number of water bodies per system and their ecological status (based on biological elements).

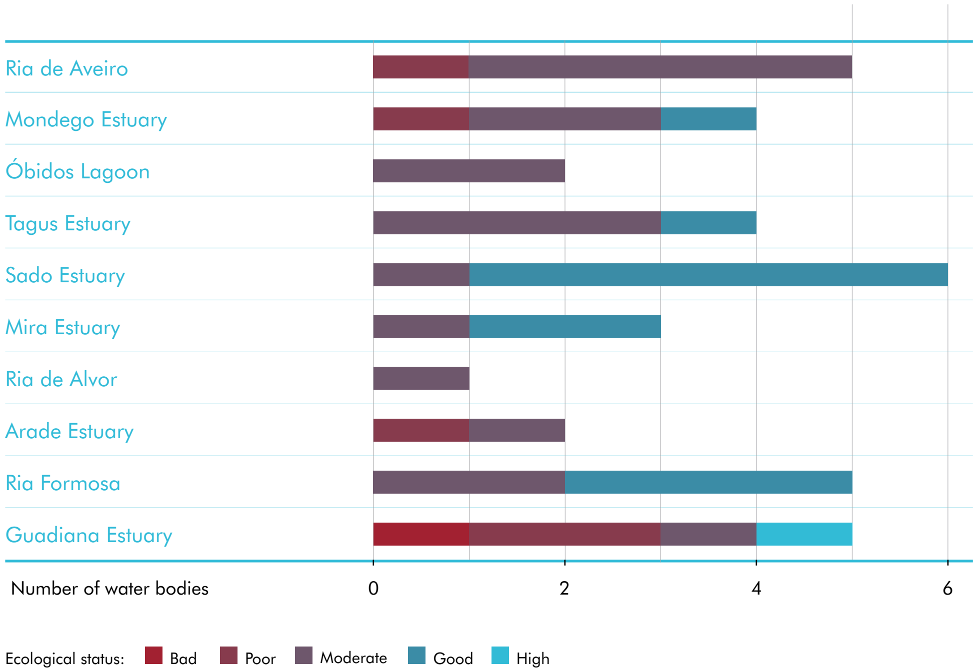
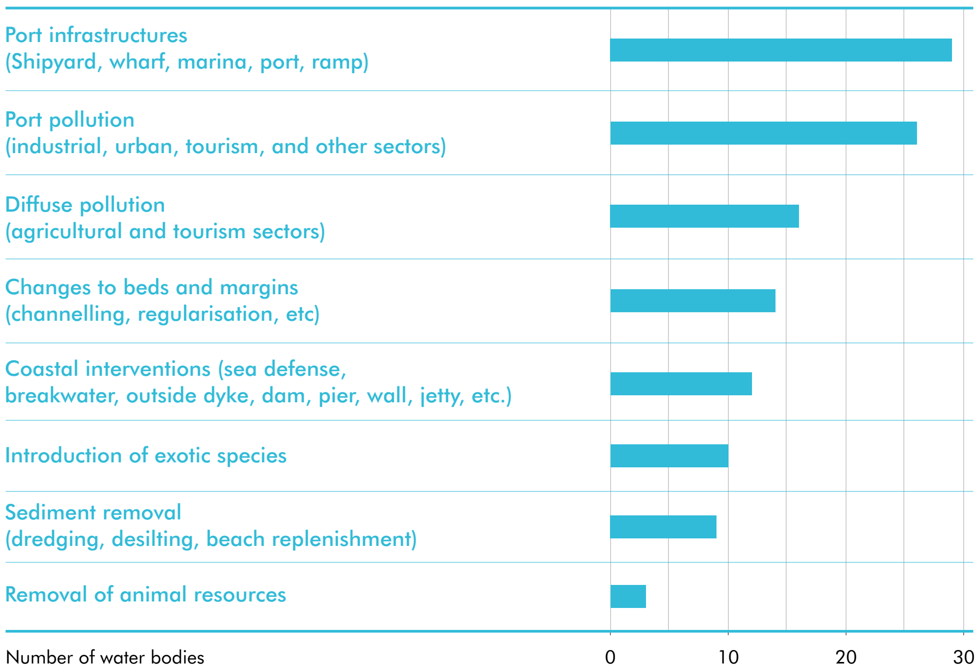


Figure 23. Number of water bodies threatened by different categories of human pressures in all studied systems.



5.7.3 Decline of blue carbon ecosystems

It is difficult to accurately quantify the variation of BCE areas over time as the methods used for their mapping have been diverse, especially because the criteria for habitat classification have not been the same, particularly in the case of saltmarshes. Different types of saltmarshes were considered in diverse studies, and it was often impossible to determine whether the mapped saltmarsh areas were natural saltmarsh or saltmarsh reclaimed for other activities (aquaculture or salt pans). On the database that has been collated for this work, the sum of the historical saltmarsh areas reported in each system was 15 042 ha (reference area), and the most recently assessed total area was 10 040 ha, which represents a loss of 33% in relation to the total reference area. This is a credible figure, considering that Sousa et al. (2020) reported a 20% loss of saltmarsh in the Ria Formosa, compared to the estimated area at the end of the 19th century.

In the case of seagrasses, the reference area obtained was 1 867 ha, and the current area is 1 648 ha, which represents a decrease of 10%. This loss refers only to the most recent period for which there are estimates of the areas occupied by seagrass. From a historical perspective, this loss estimate is certainly underestimated, as there are reports of seagrass meadows which have disappeared from areas where they were historically very abundant (Cunha et al., 2013). However, this report does not consider those historical areas as there are no quantitative data on the occupied seagrass areas. For more details on the assessment of BCEs over time in the systems studied and the causes of their decline, see the technical sheets (Scientific Report II: The 10 main blue carbon ecosystems in mainland Portugal).

5.8 Intervention measures

5.8.1 Monitoring

The quality of the data on the Portuguese coastal BCEs is generally very low, except for the distribution and mapping of each system (**Figure 14**). However, this type of data is mostly outdated and was obtained through diverse methodologies, which makes it difficult to assess the evolution of BCEs over time in each system and to draw a comparison between them. It is particularly important to thoroughly evaluate the areas of BCEs that were reclaimed over time for various uses, which could be the focus of restoration projects, in order to recover the capacity for carbon sequestration and the co-benefits related to lost ecosystem services. It is, therefore, proposed to map the current distribution of BCEs on the Portuguese coast, using state-of-the-art remote sensing methodologies recently developed using artificial intelligence algorithms to map the target habitats (Pham et al., 2019); and that a monitoring programme is implemented in the short term, so that significant changes in the extent of BCEs and, consequently, their carbon sequestration potential, can be assessed. This information is essential to implement policies for t'e protection, sustainability, and conservation of these ecosystems.

Regarding the data required for the estimates of blue carbon stocks and sequestration rates for the 'BCEs of mainland Portugal, it should be stressed that adequate specific data are not available; hence the estimates presented in this report are too imprecise to be used as the baseline for carbon offset projects or to estimate the contribution of BCEs to national greenhouse gas emissions. The only exception is the Ria Formosa, where carbon stocks and sequestration rates have been well assessed (down to a depth of 1 m, as internationally stipulated). However, data from the middle and high marsh are sparse. The spatial variation in carbon stocks and sequestration rates is high, even within the same system (Martins et al., 2021; de los Santos et al., 2022), so the use of the Ria Formosa data for the estimates made in other Portuguese coastal systems, as done in this report, is scientifically unsuitable. It is, therefore, essential to implement the in-situ assessment of the stocks and sequestration rates of the Portuguese coastal BCEs.

5.8.2 Protection

Most estuarine-lagoon systems on the Portuguese coast are covered by national or international protection regimes, except the Óbidos Lagoon. In some of the systems assessed, not all BCE areas are within the boundaries of protection regimes, but this is only a small number of areas compared to those under protection regimes.

It is recommended to reinforce the protection and conservation measures of the areas occupied by BCEs as well as to support some initiatives currently underway, such as the creation of a Natural Park in the Aveiro Region or the candidacy of the Óbidos Lagoon to be classified as a Wetland of International Importance under the Ramsar Convention.

5.8.3 Restoration

Ecological restoration can be either passive or active. Passive restoration occurs when the drivers that led to the decline of the ecosystem are removed so that it recovers naturally without direct intervention. In active restoration, management techniques, such as planting seeds, seedlings, or mature plants, are implemented to speed up natural recovery.

BCEs in Portuguese estuarine-lagoon systems have historically been subject to great anthropogenic pressures that resulted in the reclamation of large natural areas for various uses, such as agriculture, urban and port development, aquaculture, salt production, etc. These areas, previously occupied by BCE and which are currently inactive, should be considered a priority for the passive restoration of these ecosystems, provided that the environmental conditions conducive to their development are reconstituted. Ecological engineering methods of intervention on the walls and water levels (Portela, 2004) should be used to re-establish the tidal water regime and a suitable topography for the natural establishment of subtidal and intertidal seagrasses and, above all, of low, middle, and high saltmarsh. A survey of these inactive areas is proposed for the estuarine-lagoon systems on the Portuguese coast, similar to what the APA has done for the Algarve region (Furtado et al., 2021). It should be noted that the ecological restoration of seagrass and saltmarsh is slow to reach the initial carbon stock values. For example, after 2.5 years of restoration, a restored saltmarsh in Huelva still held a carbon stock in the sediment of about five times lower than that of natural saltmarshes (Curado et al., 2013).

Active ecological restoration should be done in a way that does not damage natural populations, which are usually used as transplant donors. It is crucial to develop large-scale cultivation methodologies for saltmarsh plants and seagrasses (van Katwijk et al., 2021). Conventional farming methods of seed germination can be used in the case of saltmarsh plants since these are terrestrial plants. In the case of seagrasses, in many instances, it is difficult to obtain viable shoots from seeds to use in large-scale restoration projects (Cabaço & Santos, 2010; Alexandre et al., 2018); hence, the best strategy is to grow seagrasses in semi-natural systems, for example, in inactive, artificialized areas where environmental conditions can be controlled.

VI. References

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