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Ecosystem-based management planning across aquatic realms at the Ria de Aveiro Natura 2000 territory

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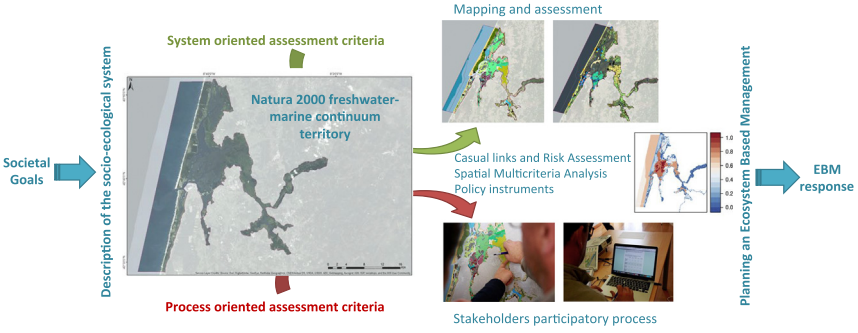
HIGHLIGHTS

- A Natura 2000 freshwater-marine continuum territory was used as showcase for EBM
- EBM planning process combining Science, Policy and Stakeholders' perspectives
- The latter matched the calculated causality links and risk assessment
- Ecosystem services were valued by stakeholders through spatial multi-criteria analysis
- EMB planning approach followed a stepwise procedure in line with resilience thinking and its principles

GRAPHICAL ABSTRACT



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ABSTRACT

Ria de Aveiro represents a coastal territory, in which its natural capital, mostly classified under a Natura 2000 network of protected areas, is of paramount importance for the regional and national economy, supporting harbour activities and maritime traffic, agriculture, commercial fisheries, aquaculture, manufacturing, tourism, sports and recreational activities. Current and foreseen changes connected to human activities, namely land and water uses and potential conflicts, in frame of environmental policies, sustainable economic development and human well-being require the implementation of ecosystem-based management (EBM) planning processes considering the connectivity across marine, transitional, freshwater, and terrestrial domains. The main objective is to elaborate on the co-development of the EBM planning process across the three water domains, all characterized by high biodiversity and by the wide range of services provided by ecosystems and their abiotic components, for the mitigation of impacts from the management plan under implementation. The approach used follows a stepwise procedure in frame of resilience principles, considering the analysis of the relationship between the social and ecological components and on how these can be connected through risk assessment and a spatial multi-criteria analysis based on the delivery of ecosystem services. Stakeholders' perception matched the ecosystem services provisioning risk assessment and supported the planning EBM response that consist in saltmarshes and seagrasses meadows restoration programs. Compliance of the proposed measures is achievable regarding policies (policy targets and policy instruments) and feasibility (scientific and technological knowledge and financial resources). The EBM response can support the Vouga estuary management plan and regional smart specialization (RIS3 Centro).

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1. Introduction

Natura 2000 represents a European coordinated network of protected areas, both on land and at sea, to ensure the existence and conservation of the most valuable and threatened habitats and species. It is also the basis of European Union (EU) Biodiversity Strategy and EU international commitment to the international Convention on Biological Diversity and its Aichi Targets (*e.g.,* Marino et al., 2014b; Beresford et al., 2016; Rouillard et al., 2018). The management of Natura 2000 sites across aquatic realms entails the coordination of EU nature directives, that is Habitats Directive (92/43/EEC) and Birds Directive (79/409/EEC), with water related directives, namely Water Framework Directive (2000/60/EC), Marine Strategy Framework Directive (2008/58/EC) and Floods Directive (2007/60/EC) (European Union, 2016). The designation of Natura 2000 implies that the sites are managed in an active and sustainable manner, considering ecological and socio-economic features, therefore, when involving coastal and marine habitats marine spatial planning should also be considered (Domínguez-Tejo et al., 2016) following the Maritime Spatial Planning Directive (89/2014/EC). At the operational level, challenges interconnected to environmental integrated management relates to: i) coordination of measures due to the multiplicity of sectors involved; ii) communication, between academics, policymakers and practitioners, and the general public; iii) compliance with relevant policies and regulations; iv) knowledge gaps and scarcity of resources, namely in the context of climate change; and v) assessment of the effects of management actions on human well-being (*e.g.,* Cavanagh et al., 2016; Lillebø et al., 2016; Breslow et al., 2016; Drakou et al., 2017; Elwell et al., 2018; Fernandino et al., 2018; Rouillard et al., 2018).

Human well-being has gain increasing relevance since the consequences of ecosystem change for human well-being were assessed in the scope of the Millennium Ecosystem Assessment that was carried between 2001 and 2005 under the auspices of the United Nations (Millennium Ecosystem Assessment, 2005). One of the key questions identified was – "*what options exist to enhance the conservation of ecosystems and their contribution to human well-being*?" In this context, ecosystem-based management (EBM) planning process represents a holistic approach that aims to balance the multiple interrelated dimensions of ecological integrity (*e.g.,* natural capital and biodiversity through ecosystem processes, functions and services) and human well-being; considering different spatial and temporal scales and involving people holding stakes and the general public interested in the present and future health of the selected territory (*e.g.,* Leslie and McLeod, 2007; Long et al., 2015; Breslow et al., 2016; Barbosa et al., this issue). EBM planning process, including Natura 2000 sites, involve the coordination of policies, institutions, and practices in order to reduce negative trade-offs and/or provide positive synergies with other ecosystem services (ES) (Cavanagh et al., 2016). Some relevant examples of different approaches to operationalize EBM are: i) through the precautionary principle along with adaptive management (Curtin and Prellezo, 2010), ii) through a set of key principles (Long et al., 2015); iii) through a conceptual framework of human well-being (Breslow et al., 2016); iv) through collaborative networks considering actors with different capabilities, interests, and intentions (Bodin et al., 2016); v) through a set of detailed pre-screening of measures (Piet et al., 2017); vi) considering Policy-relevant principles (Rouillard et al., 2018); vii) through resilience thinking and principles (Curtin and Parker, 2014). The last one is a multidisciplinary approach to environmental problem solving that links social and ecological perspectives in a holistic approach. The concept emerged from resilience science, adaptive management and ecological policy design, and bridges the gap between social and ecological systems by considering ecology, management of natural capital and systems analysis (Curtin and Parker, 2014).

The area under study, *i.e.*, the Ria de Aveiro Natura 2000 territory, was selected following official reports by the Portuguese Nature Conservation and Forests, which is responsible for the Sectoral Plan for Natura 2000 Network (available at http://www2.icnf.pt/portal). The selected Natura 2000 area comprises the classified section of the Vouga River (2769 ha); the Vouga River estuary, which is part of Ria de Aveiro coastal lagoon (20,737 ha) and the adjacent coastal area (30,642 ha), and the freshwater wetland Pateira de Fermentelos (262.5 ha), also designated as Ramsar site. The location of the selected Natura 2000 territory, the identified aquatic and terrestrial realms within the area and its land use context are shown in Fig. 1. The locations of the above-mentioned sections, considered in the selected area, are presented as supplementary material (Fig. SM1). Within the selected Natura 2000 area, its natural capital, including the variety of ecosystem services and abiotic outputs, and biodiversity, are essential for socio-economic development, and has enabled the development of a wide variety of economic, cultural and recreational activities (*e.g.,* Lillebø et al., 2015; Dolbeth et al., 2016; Sousa et al., 2016; Bueno-Pardo et al., 2018). As a result, the area is subject to a complex range of land and water uses and potential conflicts, including anthropogenic pressures that impact the hydro-morphological conditions of the lagoon and the adjacent freshwater section of the Vouga River (Lillebø et al., 2015; Lillebø et al., 2016; Sousa, 2017). Stakeholders, including general public, have identified these changes as a major concern and a priority for management (Lillebø et al., 2015). The governance of the area involves a multiplicity of institutions, organizations and people holding stakes, as well as the articulation of programs and plans of local, regional and national levels (Lillebø et al., 2015; Sousa et al., 2016; Sousa, 2017).

The main objective is to contribute to the improvement of the integrated management of aquatic Natura 2000 sites, from catchment to marine waters, involving the concepts of science, policy and stakeholder interface. To do so the Natura 2000 area at Ria de Aveiro region, a coastal territory, will be presented as showcase for an EBM planning process. The management options foreseen at local/regional level that will be considered in the prospective scenarios are the dredging programme, named "Sediment Transposition for Optimization of Hydrodynamic Equilibrium in the Ria de Aveiro", that takes place in 2018/2019 (RECAPE, 2017); and the extension of a floodbank to prevent surface saltwater intrusion into agricultural areas, at the confluence of the Vouga River and the Ria de Aveiro coastal lagoon, that also takes place in 2018/2019 (DGADR, 2017). Results are discussed considering the planning process of an EBM in response to the foreseen associated unintended pressures, considering the articulation of the system-oriented assessment criteria attained from natural sciences (*e.g.,* habitats, ecosystem services provisioning, human activities), the process-oriented assessment criteria attained from social sciences (*e.g.,* stakeholders' perception, compliance with rules and regulations) and the combination of both (*e.g.,* spatial multi-criteria analysis by stakeholders), and on how this approach supports human well-being.

2. Methods

2.1. Characterization of the study area

The selected Natura 2000 area is located in the border between the Mediterranean and the north-western European bio-geographical regions (European Environment Agency, 2017). It is under the influence of a temperate maritime climate characterized by long, warm summers (June–September) and mild rainy winters (December–February), with an average temperature of 14 °C and an average precipitation of 1000 mm $year^{-1}$ (Stefanova et al., 2015). The Vouga River is characterized by episodic flood events that inundate the low-lying adjacent lands at the confluence with Ria de Aveiro coastal lagoon, the Baixo Vouga Lagunar (BVL) (for a detailed description of BVL see Martínez-López et al., this issue). The eight aquatic realms that were identified (Fig. 1) were combined into three water domains: freshwater, transitional and coastal/marine. A short description of each domain is presented in Table 1. Due to the complexity of the selected territory regarding its

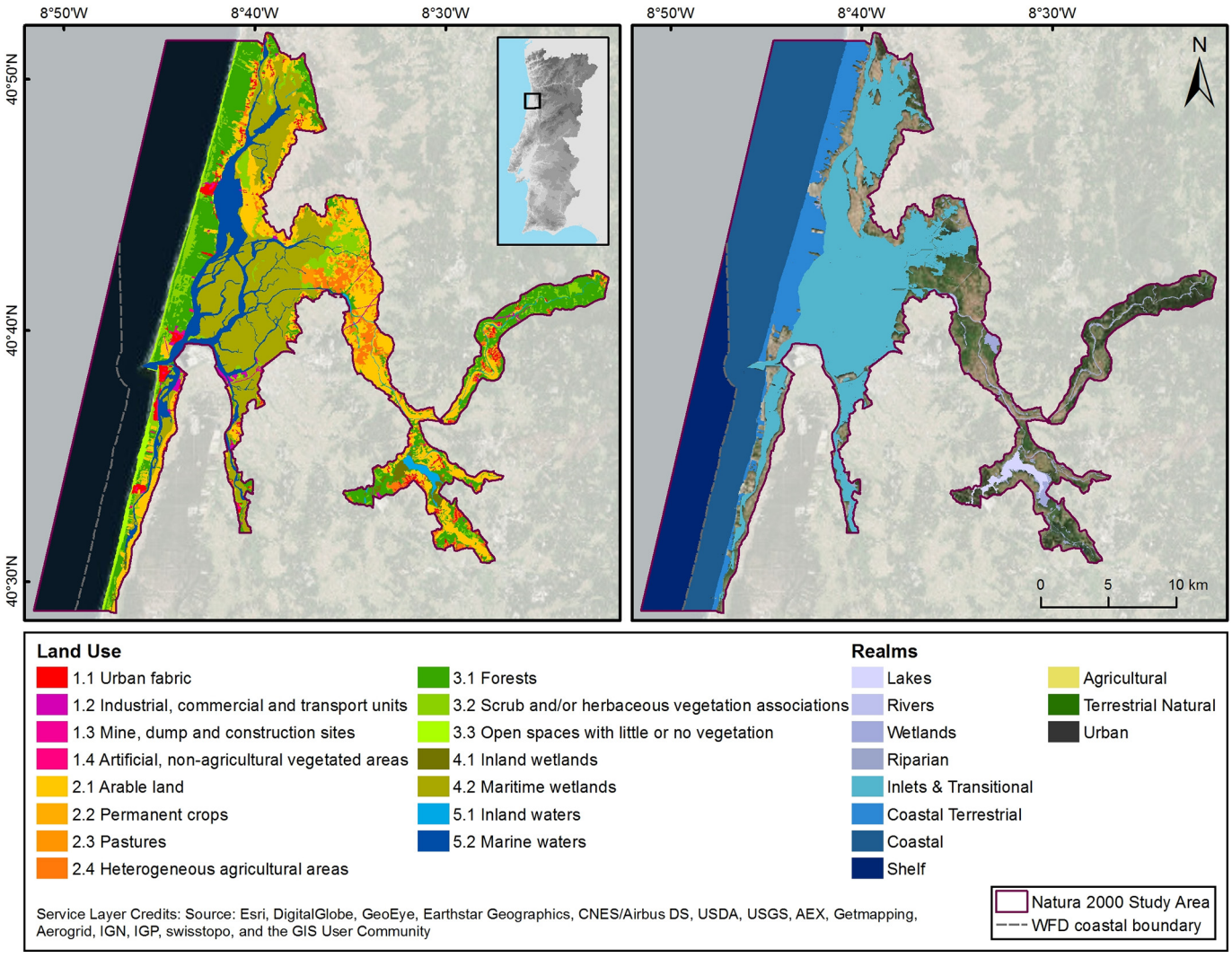

Fig. 1. The location of the Natura 2000 show case area and its characterization regarding land use (left) and selected realms (right).

governance an overview of the policy context at regional, national and EU levels was carried out based on available literature in order to select the most relevant policy instruments to be considered.

2.2. Mapping and assessment of habitats and ecosystem services

Several data sources were used such as peer-reviewed scientific data, grey literature (national/regional thematic reports), national agencies data (*e.g.,* Portuguese Environment Agency; Institute for Nature Conservation and Forests; Regional Directorate for Agriculture and Fisheries; Hydrographic Institute; Directorate-General for Marine Resources; global data from online platforms (*e.g.,* Copernicus datasets), and own datasets from the co-authors of this article stemming from previous projects (*e.g.,* Lagoons EU FP7; ADAPT-MED EU FP7 ERA-NET; MARSH-C-LEVEL CNRS/INEE OHMI; LTER-RAVE FCT). The habitats data sets, mainly following EU Habitats Directive (Annex I on habitat types), were converted into EUNIS habitat classification in order to harmonise the classification into a comprehensive pan-European system. Both classifications are available at the European Environmental Agency portal (http://eunis.eea.europa.eu/habitats.jsp). Data sets on ES, as benefits mediated by biological processes, as well as abiotic outputs from the ecosystems were updated and classified following the latest Common International Classification of Ecosystem Services (CICES, V5.1 in Haines-Young and Potschin, 2017). The classification hierarchical structure is available at the European Environmental Agency portal (https://cices.eu/).

Following the methodology described in Teixeira et al., this issue, the potential of a given habitat to supply ES was attained using a lookup table on the contribution of each EUNIS habitat and highly mobile biotic groups (considering their lifecycle) to a given ES provision, compiled on the basis of expert judgment involving researchers from across different aquatic ecosystems in Europe. For the participatory process (section 2.5) ES were aggregated into 11 ES groups (see Table 2 in Martínez-López et al., this issue) and mapped.

2.3. Assessment of human activities, drivers and pressures

As for habitats and ES, the assessment of human activities, drivers and pressures was achieved following a common exercise involving researchers from across different aquatic ecosystems in Europe. The defined methodology, using a lookup table on the relevance of a set of activities to a given habitat, allowed us defining the drivers of ecosystem change, human activities and the resulting pressures along the freshwater-marine continuum to be used in Section 2.4 (for a detailed description see Borgwardt et al., this issue). For the participatory process (Section 2.5) the identified spatial explicit activities within the selected Natura 2000 area were mapped. In the context of the present approach, a pressure is related to an effect induced by human actions following a relational chain from a social process through human

Table 1
Short description of each Natura 2000 aquatic domain that comprises the Aveiro Region showcase area.

Aquatic domain	Short description
Freshwater (Section of the Vouga river, Baixo Vouga Lagunar and Pateira de Fermentelos)	The land use at Vouga river catchment (336,200 ha) is characterized in *circa* 60% of forest and semi-natural areas, *circa* 29% by agricultural areas and the remaining 11% correspond to urbanized areas, wetlands and water bodies. In the classified section (2769 ha) the river runs in an embedded valley presenting a generally well-preserved riparian gallery. At the confluence of the Vouga river with Ria coastal lagoon, the Baixo Vouga lagunar (3000 ha) is characterized by three main landscape units: the 'Bocage' (small holdings with living edges used for agriculture), the open fields (wide agricultural plots with no arboreal vegetation) and wetlands. Pateira de Fermentelos is one of the largest natural freshwater lagoons in the Iberian Peninsula, also described as an enlargement of the river Cértima, an effluent of river Vouga. Relevant activities within the freshwater realm are agriculture, fishing (professional and recreational), industries, agriculture and livestock, tourism, leisure and recreational. The realm comprises important habitat for fish migratory species (*e.g., Alosa alosa* and *Alosa fallax*); mammals (*e.g., Luntra luntra*), birds (*e.g., Ardea purpurea*), reptiles (*e.g., Podarcis hispanica*), and amphibians (*e.g., Chioglossa lusitanica*).
Transitional (Ria de Aveiro coastal lagoon)	Ria de Aveiro is a shallow mesotidal coastal lagoon connecting Vouga River catchment area (*circa* 80% of its freshwater source) to the Atlantic Ocean through a single outlet; being hydrodynamics mainly driven by tidal forcing. The lagoon covers a wetland area of approximately 8300 ha and 6600 ha at high and low water respectively, forming four main channels (Ovar, Espinheiro, lhavo and Mira) with several branches, characterized by small channels and islands, large areas of intertidal sand and mudflats, *Zostera noltei* meadows and one of the largest continuous saltmarshes (*e.g., Spartina maritima, Juncus maritimus*) in Europe. It also supports several fish, crustacean, bivalves and worm species with economic interest. Relevant activities within the transitional waters realm are fishing (professional and recreational), aquaculture, salt production, industries, nautical activities and sports, tourism, leisure and recreational.
Coastal/marine (Coastal and shelf waters)	The adjacent coastal area is situated in the North Atlantic Upwelling system of the western coast of the Iberian Peninsula, with strong seasonal upwelling, especially in summer, which is particularly relevant for small-scale fisheries. The Maritime trade though Aveiro Port, located in the lagoon, with its terrestrial transport connections, is considered as one of the most important economic activities. The connectivity between the three aquatic realms is particularly important for the European eel that is a socioeconomic relevant species.

Table 2
Identification of the relevant stakeholders at the selected Natura 2000 area.

Policy/governance	
Environment	APA/ARHCentro - Portuguese Environmental Agengy
	ICNF - Institute for Nature Conservation and Forests
Fisheries and agriculture	DRAPC - Centro Region Department of Agriculture and Fisheries
Marine	DGRM - Directorate-general for Natural Resources, Safety and Maritime Services
Business	
Industry	Portucel - The Navigator Company
Tourism	Incrível Odisseia - Moliceiros boat rides
	Sterna - Solar boat tours and bird watching
Agriculture	ABBVL - Association of Beneficiaries of Baixo Vouga Lagunar
	ACRM - Association of Breeders of Marinhoa Breed
	ALDA - Association of Agriculture of the District of Aveiro
Fisheries	APARA - Artisanal Fishing Association of the Region of Aveiro
Aquaculture	APA – Portuguese aquaculture association
Services	APA - Port of Aveiro Administration (APA)
Public administration	
Regional administration	CCDRC - The Centro Regional Coordination and Development Commission
	CIRA - Inter-municipal Community of the Aveiro Region
Municipalities within the Natura 2000 classified area	Águeda, Albergaria-a-Velha, Anadia, Aveiro, Estarreja, Ílhavo, Mira Murtosa, Oliveira do Bairro, Ovar and Vagos.
Parish within the Natura 2000 classified area	*E.g.,* Angeja, Avanca, Beduído & Vieiros, Bunheiro, Cacia, Canelas & Fermelã, Esgueira, Espinhel, Fermentelos, Gafanha Da Boa Hora, Gafanha Da Encarnação, Gafanha Da Nazaré, Gafanha Do Carmo, Glória & Vera Cruz, Murtosa, Óis da Ribeira, Ouca, Ovar Union of parishes, Pardilhó, Requeixo, Salreu, Santo André De Vagos, São Jacinto, São Salvador, Sosa, Torreira, Vagos & Santo António De Vagos, Válega.
Other	
Local associations	À VELA - Sailing club
	ADERAV - Association for the study and protection of the Natural and Cultural Heritage of Aveiro Region
	CCPAV - Hunting and Fishing Club of Aveiro/Vouga
Non-governmental organizations (NGO's)	FAPAS - Fund for the Protection of Wild Animals
	GEOTA - Study Group on Spatial Planning and Environment
	LPN - League for the Protection of Nature
	SPEA - The Portuguese Society for the Study of Birds
	ASPEA - Portuguese Association of Environmental Education

activities and pressures to a change in ecosystem state (Section 2.4). This chain effect is strongly related to environmental policies and therefore also relevant for the proposed EBM measures (Section 2.6).

2.4. Causality links and risk assessment

The AquaLinksTool, developed in the scope of AQUACROSS project, was applied to assess the causality links in a linkage chain relating activities, pressures and habitats/highly mobile biotic groups and ES, to assess the vulnerability of ecosystem components regarding the provisioning of ES. AqualinksTool brings together the data sets for the demand and supply sides of the linkage chain (Section 2.3.). The demand side of the linkage chain allows the calculation of an impact score (IS) (Borgwardt et al., this issue and Culhane et al., this issue)

while the conservation status, area of the habitat and potential to supply ES allow the calculation of a supply score (SS) (based on approach from Teixeira et al., this issue). Both scores are used by AquaLinksTool to produce a Vulnerability Quotient (VQ) for each unique chain of activity-pressure-habitat-ES. The vulnerability quotient is calculated as

$$VQ = \frac{IS}{(1-SS) \times (1-IS)}$$

VQ was treated as analogous to a hazard quotient (Lemly, 1996). As such, $VQ \leq 0.1$ means no vulnerability, $0.1 < Q \leq 1$ means low vulnerability, $1 < VQ \leq 10$ means moderate vulnerability and $VQ > 10$ means high vulnerability. A snapshot of the AquaLinksTool interface is presented as supplementary material (Fig. SM2).

2.5. Stakeholders participatory process

The participatory process involved a stepwise procedure: i) stakeholder mapping, ii) stakeholder engagement, and iii) a participatory workshop. Relevant stakeholders at the selected Natura 2000 area were identified and are presented in Table 2. Stakeholder engagement took place at different moments of the study. In brief, the Portuguese Environment Agency, specifically through its Regional Hydrographic Administration for Portugal Centro Region was engaged since the very beginning. Other stakeholders were identified and engaged in the final conference of a previous project (ADAPT-MED, December 2015), and have since contributed to the data sets that are supporting the development of the prospective scenarios. From Table 2, *circa* 70 stakeholders were invited to participate in the workshop that took place in April 2018. From these, 17 signed an informed consent agreement form and participated in the workshop. Participants represented the four major groups identified in Table 2, namely 2 from policy/governance, 8 from public administration, 1 from the business sector, 1 from a non-governmental organization. In addition, 2 citizens (*e.g.,* residents, homeowners, interested individuals, underrepresented and vulnerable groups), and 3 participants with environmental sciences background (*e.g.,* faculty members at local colleges and universities, employees at local research institutions, scientists from state and federal agencies and independent researchers) also participated and therefore 6 groups were considered for the analysis of results. During the workshop participants were invited to express their views regarding the expected beneficial effects and persistent concerns related to the current management options by affixing their answer in post-it in the wall, and to participate at the spatial multi-criteria analysis. The participatory process for spatial multi-criteria analysis, consisting in pairwise comparisons of ES to derive a ranking of criteria for the different stakeholder groups, was done during the workshop through an online Google form. Each participant filled in the form anonymously using his or her mobile phone, tablet or PC. To support pairwise comparisons of the ES, stakeholders were given ES cards showing examples and the spatial distribution of the ES within the Natura 2000 area (Fig. SM3). Details on the spatial multi-criteria analysis methodology and modelling of results can be found in Martínez-López et al. (this issue). In brief, Inputs to the spatial multi-criteria analysis model included the list of the above-mentioned ES, the analysis of each of the

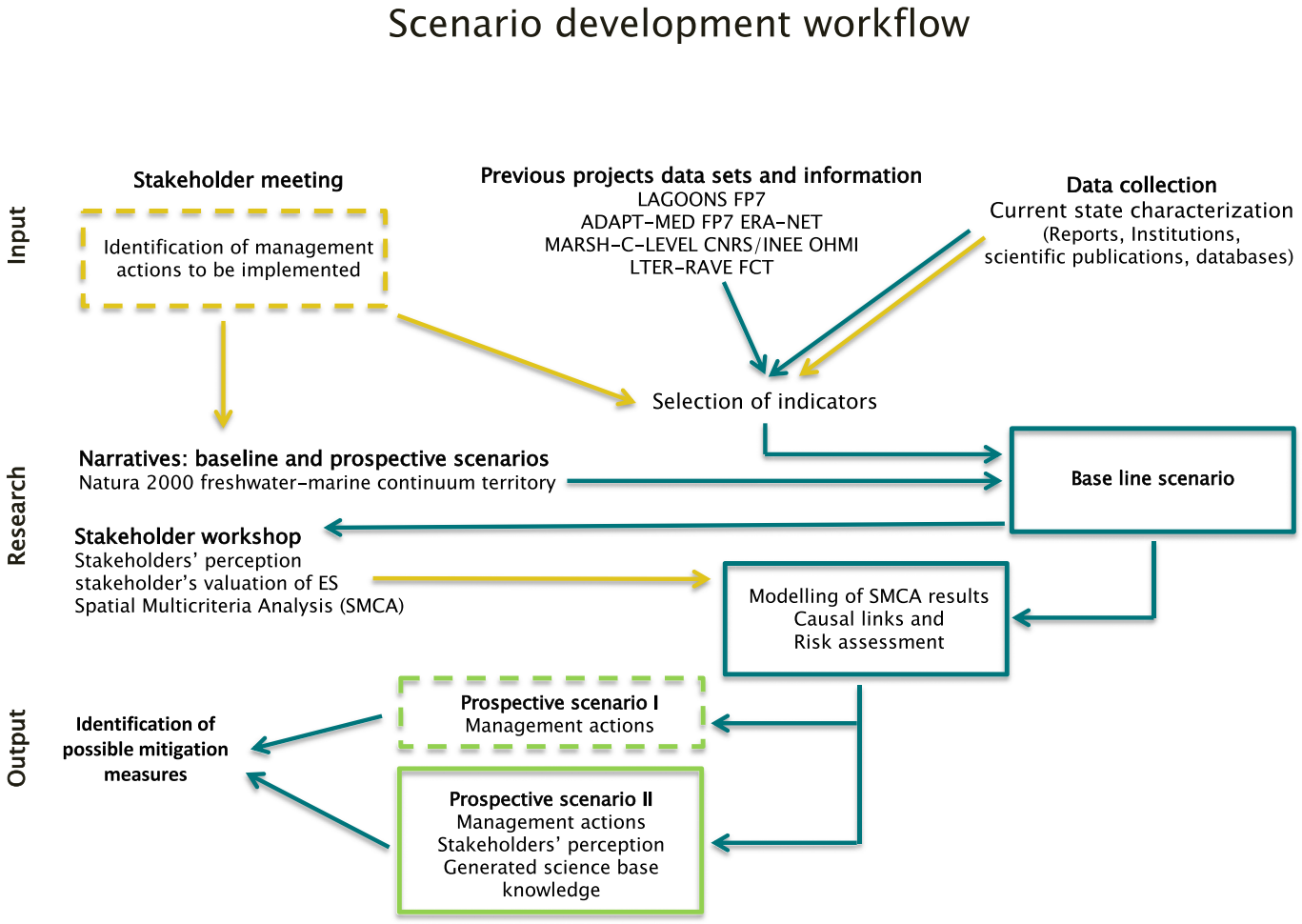

Fig. 2. Schematic representation of the scenario development workflow (yellow arrows stand for fluxes involving stakeholders engagement).

Table 3
Identification of the relevant policy instruments and objectives for the planning process of EBM responses in the selected territory. The institution responsible for the implementation of the policy instruments and the link to EU Policies is also presented.

Selected policy instruments	Objectives	Link to EU policies
River Basin Management Plan (PGBH - RH4) Portuguese Environment Agency (APA/ARHC)	Outlines the water planning for the tri-basin region of Vouga, Mondego and Lis, in accordance with WFD	WFD (2000/60/EC)
Sectoral Plan for Natura 2000 Network (PSRN2000) Institute for Nature Conservation and Forests (ICNF)	Territorial management tool for the implementation of the national policy for the conservation of biological diversity, aiming at the safeguarding and enhancement of the sites and SPAs of the continental territory, as well as the maintenance of species and habitats in a favorable conservation status in these areas	Birds Directive (2009/147/EC); Habitats Directives (92/43/EEC)
National Water Plan (Decreto-Lei n.o 76/2016) Inter-ministerial Commission for Water management: APA/ARHC; ICNF; Regional Directorate for Agriculture and Fisheries (DRAP); Directorate-General for Marine Resources (DGRM)	Governmental cross-sectoral management for the next 10 years: Increase water productivity and promoting its rational use, with maximum respect for the territorial integrity of the river basins; Protection, conservation and rehabilitation of water resources and associated ecosystems; Meeting the needs of the population and the country's economic and social development; Respect for relevant national and Community legislation and satisfaction of the international commitments assumed by the Portuguese State; Access to information and participation of citizens in the management of water resources	WFD (2000/60/EC) Floods Directive (2007/60/EC) MSFD (2008/56/EC)
National Strategic Plan for Tourism (PENT) Ministry of Economy and Innovation	Serves as the basis for the implementation of a series of initiatives aimed at fostering sustained growth of national tourism over the coming 10 years, and guiding the activities of Portugal National Tourism Authority, as the key public body for the sector.	EU strategy for a smart, sustainable and inclusive growth (COM (2014) 85 final, 2014/0044)
National Strategic Plan for Climate change adaptation (ENAAC) Ministry of Environment	Sets the ground for the need for adaptation. Contains the National adaptation strategy, and the associated action plan, including reducing vulnerability and increasing the response capacity.	EU Strategy on Adaptation to Climate Change (COM (2013) 216
Polis Litoral Ria de Aveiro APA/ARHC; ICNF	Integrated Operations of Rehabilitation and Recovery of Coastal Areas. Strong collaborative work between central administration and the Ria de the Aveiro Region	This study - Link to National policies Bridge the regional policy instruments Contribute to the Vouga estuary management plan
Inter-municipal Community (CIRA)		Contribute to the Regional strategy for smart specialization (RIS3 Centro)
Coastal Zone Management Programme Ovar – Marinha Grande (POC-OMG) APA/ARHC	Reconcile the various conflicts of uses of the coastal zone, promoting the articulation of environmental, economic and social factors related to coastal management.	
Vouga Estuary Plan (PE Vouga – not yet developed) APA/ARHC	Territorial planning tool, which establish appropriate measures for the protection and valorisation of water resources in the area to which their sustainable use is applied in a secure manner, linking the Public Administration and users.	

stakeholder groups, and a set of weighing factors characterizing each criterion. The generated maps supported the narratives for EBM prospective scenarios.

2.6. Prospective scenarios development

The development of the prospective scenarios for the selected Natura 2000 freshwater-marine continuum territory is summarized in Fig. 2. For both baseline and the foreseen management scenarios three approaches were combined: i) model-based scenarios on causal links and habitats risk assessment (Section 2.4); ii) stakeholders' perception regarding the present status and future trends (Section 2.5); and iii) a combination of both, *i.e.*, modelling of the spatial multi-criteria analysis results that were attained by stakeholder's valuation of ES (section 2.5). The combination of the complementary approaches (see Martin et al., 2018) was translated into spatial explicit narratives to support EBM response.

2.7. EMB approach

The foreseen management measures to be implemented were politically acceptable (measures were under public consultation in accordance with the provisions of Portuguese law) and feasible, since financial incentives are already available and have passed institutional fitness check. Therefore, the approach was to co-define EBM complementary actions to mitigate potential negative impacts driven from the dredging programme and extension of the floodbank. As mentioned in Section 2.3, pressures follow a relational chain that is strongly related to environmental policies (*e.g.,* habitats, biodiversity, aquatic ecosystems) at EU, national and regional/local levels. Therefore, the proposed EBM response considers the policy target and the policy instrument typology relevant for the selected Natura 2000 freshwater-marine continuum territory. As well, the proposed EBM response considers its feasibility regarding scientific and/or technological knowledge and financial resources.

3. Results

3.1. Selected policy instruments

From the literature review, presented as supplementary material (Table SM1) eight policy instruments were selected considering their

relevance for the planning process of EBM responses in the selected territory, *i.e.*, covering freshwater, transitional and coastal/marine aquatic domains. Table 3 systematizes the link between each selected policy instrument and its main goal, and identifies the Institution/s responsible for the respective implementation, as well as the link to EU Policy level.

3.2. Spatially explicit results

Habitats were classified and mapped at the most detailed EUNIS levels possible (Fig. 3). The description of each identified habitat is shown in Table 4. For the purpose of the stakeholder's participatory processes the eight aquatic realms identified were merged into three aquatic domains: freshwater (lakes, wetlands, rivers, riparian), transitional (inlets and transitional) and coastal/marine (coastal terrestrial, coastal and shelf). Fig. 4 illustrates the resulting maps of aggregated ES valuation following the expert judgment procedure, considering the habitats and associated biota distribution (see Teixeira et al., this issue). The maps represent the total contribution of habitats to each aggregated service with the color scale representing the degree of aggregated services overlap in each habitat. Results show that three ES received higher scores from the experts: I) ES5 - provisioning of materials for nutrition; ii) ES9 - regulation and maintenance of physical chemical biological conditions, including atmospheric composition climate regulation, life cycle maintenance habitat gene pool protection, pest and disease control, soil formation and water condition; and iii) ES10 - cultural services regarding physical and intellectual interactions with biota, ecosystems, land and seascapes environmental settings, including Intellectual representative Interactions and physical representative interactions. Fig. 5 illustrates the spatial distribution of human activities within the selected Natura 2000 area, namely the harbour, agriculture, commercial fisheries, aquaculture, manufacturing, tourism, sports and recreational activities.

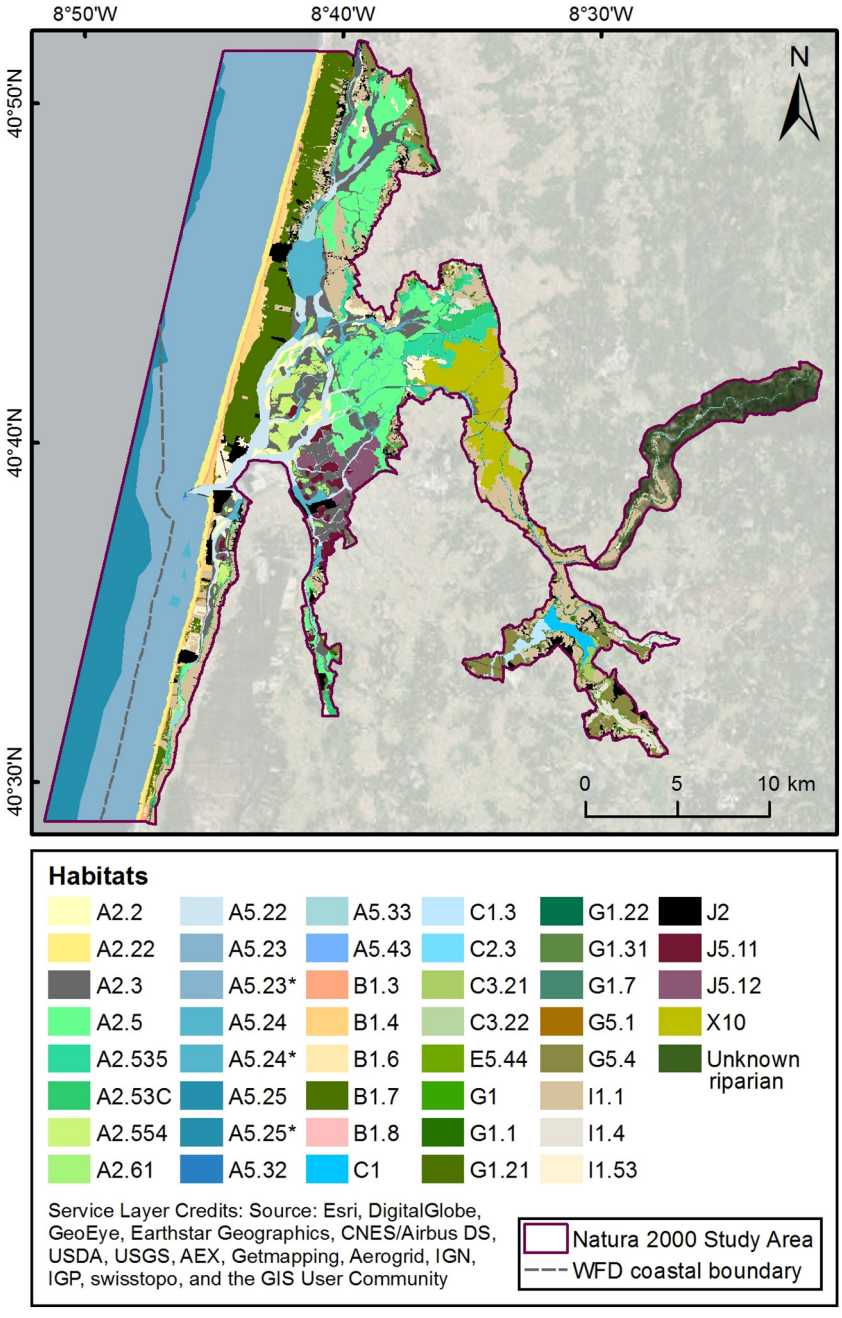

Fig. 3. Map of the habitats identified at selected Natura 2000 area following EUNIS level 3 classification.

Table 4
Description of the EUNIS Habitats identified in the selected Natura 2000 area. Note: A7 habitat was not mapped as it overlaps with the benthic habitats. In frame of EU Water Framework Directive this habitat corresponds to the five transitional water bodies (see Lopes et al., 2017).

Realm	Habitat code	Description	AquaLinksTool ESS provisioning risk assessment
Shelf	A5.23	Infralittoral fine sand	
	A5.25	Circalittoral fine sand	Coastal/marine
Coastal and coastal terrestrial	A2.22	Barren or amphipod-dominated mobile sand shores	Waters domain
	A5.23	Infralittoral fine sand	B1.3
	A5.24	Infralittoral muddy sand	B1.4
	A5.25	Circalittoral fine sand	B1.6
	A5.43	Infralittoral mixed sediments	B1.7
	B1.3	Shifting coastal dunes	B1.8
	B1.4	Coastal stable dune grassland (grey dunes)	
	B1.6	Coastal dune scrub	
	B1.8	Moist and wet dune slacks	
Inlets and transitional	A2.2	Littoral sand and muddy sand	Transitional waters domain
	A2.3	Littoral mud	A2.2
	A2.5	Coastal saltmarshes and saline reedbeds	A2.3
	A2.535	*Juncus maritimus* mid-upper saltmarshes	A2.5
	A2.53C	Marine saline beds of *Phragmites australis*	A6.1
	A2.554	Flat-leaved Spartina swards	A5
	A2.61	Seagrass beds on littoral sediments	A7
	A5	Sublittoral sediment	
	A7	Pelagic water column	
	J5.11	Saline and brackish industrial lagoons and canals	
	J5.12	Saltworks	
Lakes	C1	Surface standing waters	Freshwater domain
	C1.3	Permanent eutrophic lakes ponds and pools	C1.3
Wetlands	C3.21	Common reed (*Phragmites*) beds	C3.21
	C3.22	Common clubrush (*Scirpus*) beds	C3.22
Rivers	C2.3	Permanent non-tidal smooth flowing watercourses	C 2.3
Riparian	G1	Broadleaved deciduous woodland	
	G1.1	Riparian and gallery woodland, with dominant Alnus Betula Populus or Salix	
	G1.21	Riverine Fraxinus - Alnus woodland, wet at high but not at low water	
	G1.22	Mixed Quercus - Ulmus - Fraxinus woodland of great rivers	
	G1.31	Mediterranean riparian Populus forests	

3.3. ES provisioning risk assessment

The most vulnerable habitats selected through AquaLinksTool are located in the three aquatic domains, as highlighted in Table 4 (column in the right). In freshwater domain the selected habitats were a permanent eutrophic lake (C1.3) and wetlands (C3.2), both present in Pateira de Fermentelos, and flowing watercourses (C2.3). Freshwater wetlands include common reed (C3.21) and common clubrush (C3.22). In

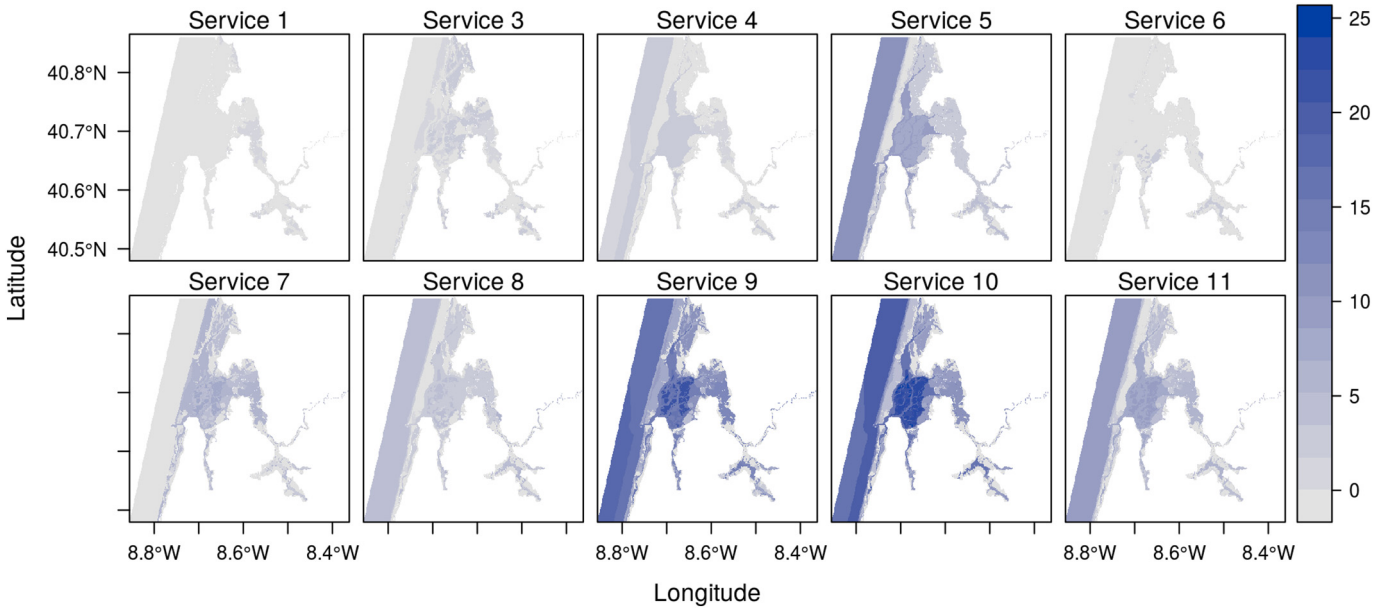

Fig. 4. The resulting maps representing the total contribution of habitats to each aggregated service, following ES valuation using expert knowledge, with the color scale representing the degree of aggregated services overlap in each habitat. Legend: Provisioning ES1 - Biotic based energy sources; ES3 - Biotic materials; ES4 - Abiotic materials; ES5 - Nutritional biotic substances; ES6 - Nutritional abiotic substances; Regulation and Maintenance ES7 - Mediation of flows; ES8 - Mediation of waste toxics and other nuisances; ES9 - Maintenance of physical chemical biological conditions; Cultural ES10 - Physical and intellectual interactions with biota, ecosystems, land and seascapes environmental settings; ES11 - Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings (see also Table 2 in Martínez-López et al., this issue).

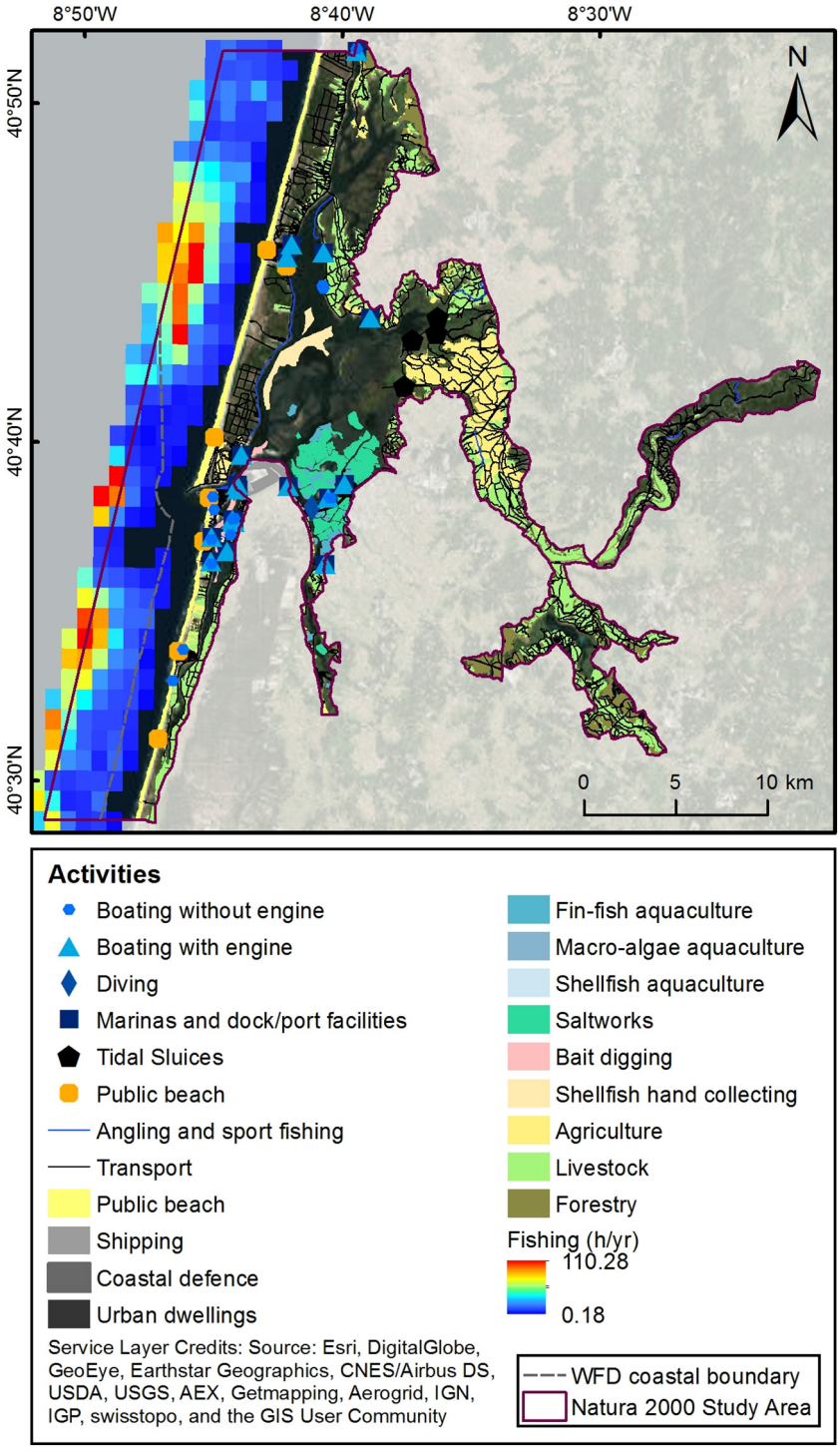

Fig. 5. Map of the activities identified at selected Natura 2000.

transitional waters domain, the selected habitats are within Ria de Aveiro coastal lagoon, namely mud and sand flats (A2.2, A2.3), tidal wetlands (A2.5), seagrass meadows (A2.6.1), the main channels of the lagoon (A5) and the lagoon water body (A7). Tidal wetlands include *Spartina maritima* saltmarshes, *Juncus maritimus* mid-upper saltmarshes and marine saline beds of *Phragmites australis*. In coastal/marine waters domain the selected habitats regard the coastal sand dune system. This includes shifting coastal dunes (B1.3), the dune system associated vegetation like coastal stable dune grassland (B1.4), coastal dune scrub (B1.6) and coastal dune woods, and the dune system moist/wet depressions (B1.7). Regarding provisioning risk assessment C2.3 is the most vulnerable habitat regarding provisioning of nutrition, regulations and maintenance through mediation of flows, and cultural services due to angling and sport fishing, extraction of flora and/or fauna; physical and intellectual interactions with land seascapes physical settings (*data not shown*).

3.4. Stakeholders perspective

Stakeholder answers regarding beneficial effects and persisting concerns after current management interventions is presented as supplementary material (see English translation in Table SM2). Table 5

Table 5
Summary of the major beneficial effects (a) and the persisting concerns (b) regarding the selected Natura 2000 area identified by stakeholders at the participatory workshop.

a)

Realm	Beneficial effects					
	Ecosystems biodiversity	Water management	Agriculture	Fisheries Aquaculture	Tourism Recreational	Transversal
Freshwater	Preservation of aquatic biodiversity; higher balance between farming and natural environment	Fresh water for irrigation	Completion of the flood bank; increase in agricultural land area; stimulus for agriculture	Migratory species	Marked walking trails usually in natural environments, supporting recreational activities; Stimulus for ecotourism	Development of economic activity in all sectors; Scientific knowledge on habitats and species
Transitional	Habitat richness	Oriented dredging				
Marine						

b)

Realm	Concerns that persist					
	Ecosystems biodiversity	Water management	Agriculture	Fisheries	Tourism Recreational	Transversal
Freshwater	Increase of aquatic and terrestrial exotic species, some of them invasive		Incentives and compensations for the maintenance of traditional agricultural activities that generate the maintenance of ecosystems and biodiversity; abandonment of 'Bocage'			Lack of integrated management and communication between entities; lack of land owners' involvement; need for more information and awareness in the municipal councils; lack of policy surveillance
Transitional	Impact of dredging on seagrasses, saltmarshes and juvenile fauna due to changes in eco-hydrology; increase mobilization of contaminants due to dredging	Low navigability in inner channels; increase of ocean water volume in the lagoon and increase in tidal prism; ecosystem (habitats, housing and infrastructures) oriented dredging		Incentives and compensations for the maintenance of traditional aquaculture activities that generate the maintenance of ecosystems and biodiversity		
Marine	Loss of habitats in coastal zone					

summarizes the major beneficial effects and the persisting concerns organized by aquatic domain and considering six major sectors (ecosystems and biodiversity; water management; agriculture; fisheries and aquaculture; tourism and recreational activities and transversal issues). Overall, beneficial effects were mainly oriented to benefits from natural capital, which fall within ES and economic development. Regarding persisting concerns, in freshwater realm the major concern related to habitat loss and exotic/invasive species. In transitional waters, results showed that oriented dredging appears as having beneficial effects on water management, but at the same time, participants revealed concern regarding its impact on ecosystems and biodiversity. The need for ecosystem (habitats, housing and infrastructures) oriented dredging was also acknowledged. In the coastal/marine domain concerns were focused on the loss of habitats in the coastal zone.

The analysis of consistency ratios of individual judgments followed by a cluster analysis revealed 14 individuals, whose scores were considered meaningful, that formed two major stakeholder groups (for more details see Martínez-López et al., this issue). The mean of the ESS scores given by individuals belonging to the same cluster was computed and used as the final weights for the ES in the spatial multi-criteria analysis. The prioritization maps by the two stakeholder cluster groups resulting from the application of the spatial multi-criteria analysis in the selected Natura 2000 area did not differ significantly. The ES prioritization maps by the two stakeholder cluster groups are presented as supplementary material (Fig. SM4). In absence of strong and significant differentiation between stakeholder valuations a compromise map (average valuation) was generated (Fig. 6). ES valuation by stakeholders clearly revealed the valuation of the water domains continuum (freshwater, transitional, and coastal/marine), with special emphasis to transitional waters domain, *i.e.*, to the ES provided by the lagoon ecosystem.

3.5. Prospective scenarios

The development of the proposed prospective scenarios considered the past and current conditions of the selected Natura 2000 freshwater-marine continuum territory, as well as the foreseen management measures. Three qualitative scenarios were considered: i) base-line scenario; ii) prospective scenario reflecting the foreseen management measures; and iii) co-developed prospective scenario reflecting the

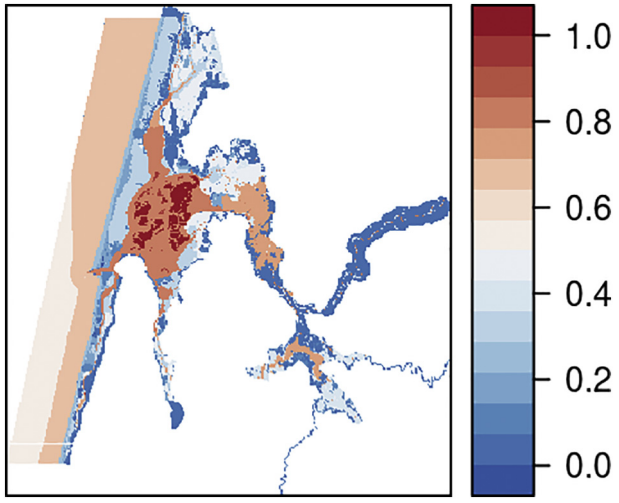

Fig. 6. Ecosystem services prioritization map resulting from the application of the spatial multi-criteria analysis by stakeholders in the selected Natura 2000 area. The units correspond to concordance values ranging from 0 to 1.

foreseen management measures, stakeholders' perception, and the generated science-based knowledge. Fig. 7 illustrates the projection of the foreseen management options, namely the areas that will be affected by the dredging programme and by the extension of the floodbank. This spatial explicit information was combined with stakeholder's ES prioritization map, with the ES provisioning risk assessment and with stakeholders persisting concerns regarding the foreseen measures. The most critical areas for the implementation of EBM responses are highlighted in Fig. 8.

3.6. EBM measures

Table 6 summarizes the planning EBM response considering the co-developed prospective scenario that reflects stakeholder's perception and the generated science based-knowledge on top of the foreseen management measures. Two restoration measures were proposed: saltmarshes restoration and seagrass meadows restoration. In the next section these measures are discussed considering the challenges towards implementation, in the perspective of science (knowledge gaps), policies (articulation of policy instruments), people who hold a stake in the task (funding instruments and trade-offs) and human well-being.

4. Discussion

At the Ria de Aveiro Natura 2000 territory the foreseen changes connected to human activities, that are taking place in 2018/2019, specifically the dredging programme in the lagoon (RECAPE, 2017) and the extension of the floodbank to prevent surface saltwater intrusion at the confluence of the Vouga River and the lagoon and for water management during flood events (DGADR, 2017), constituted the societal goal that triggered the need for an EBM planning process. EBM planning process acknowledges the articulation between ecological and social components with the inclusion of people holding stakes as a critical step necessary to legitimize the process (Curtin and Prellezo, 2010; Long et al., 2015). Even so, as part of an integrated and adaptive management approach the implementation of selected management actions might still request compensatory measures for the mitigation of impacts from the plans and projects (*e.g.*, Millennium Ecosystem Assessment, 2005; Long et al., 2015). The following discussion will focus on the complementarities and contact points between the system and the process

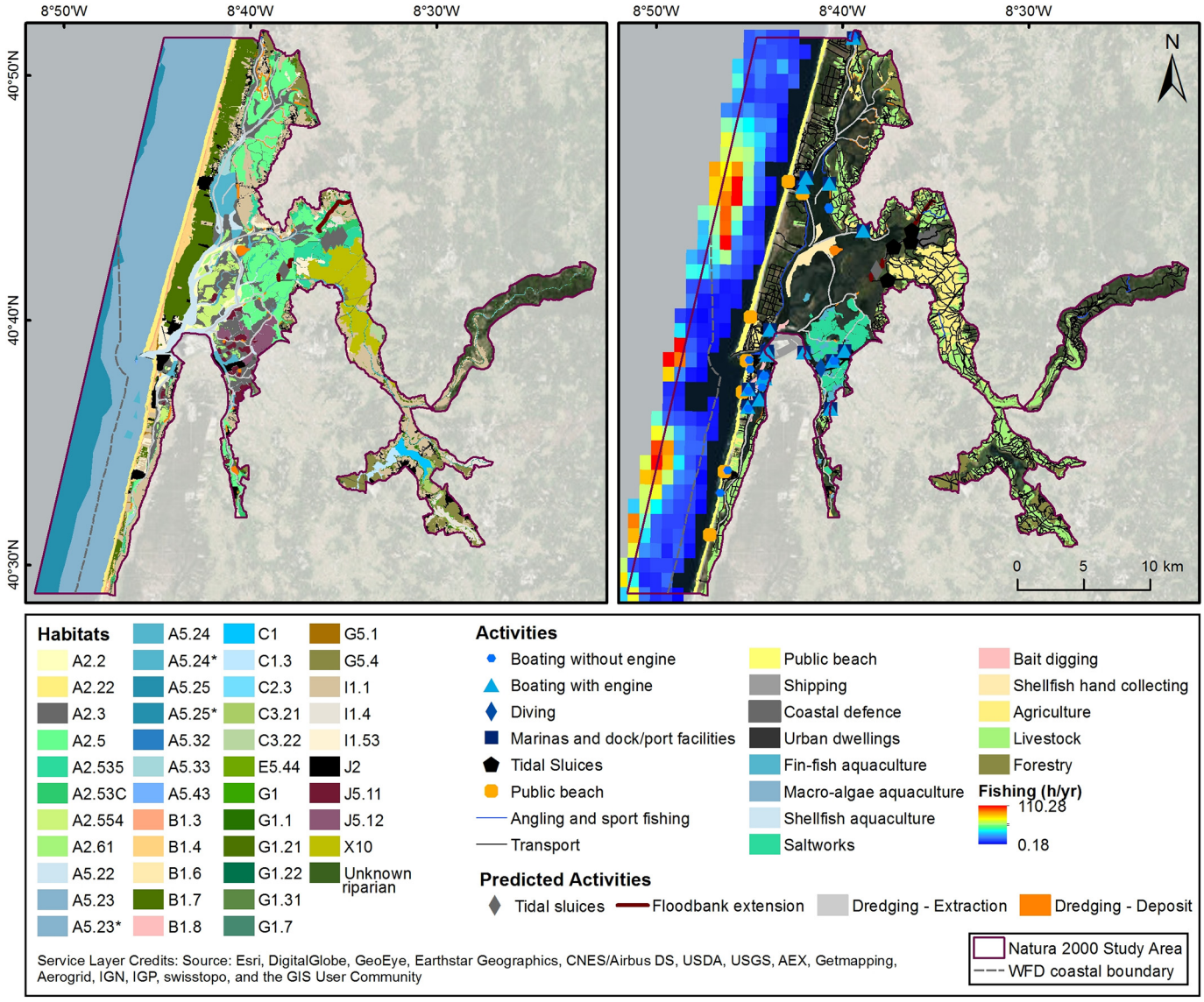

Fig. 7. Maps of the identified habitats (left) and activities (right) combined with the projection of the foreseen management options, namely the areas that will be affected by the dredging programme and by the conclusion of a floodbank.

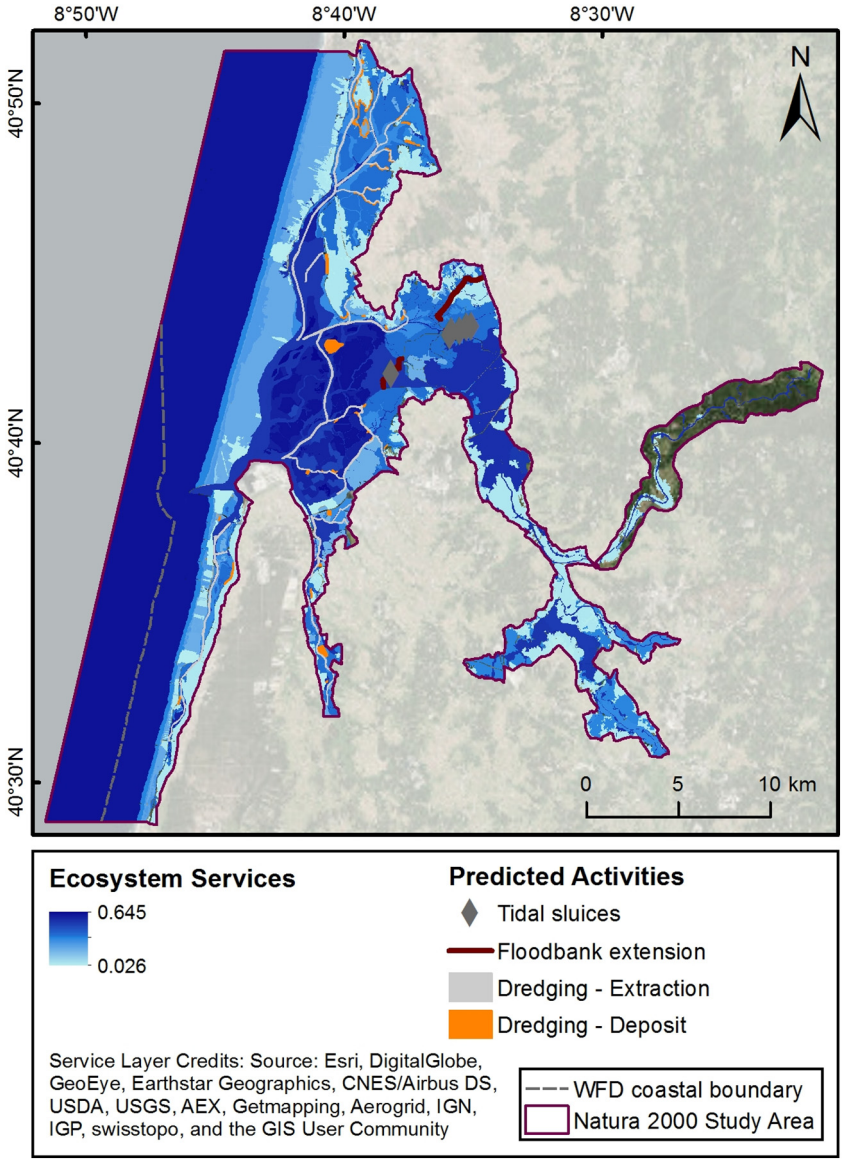

Fig. 8. Ecosystem services prioritization map resulting from the application of the spatial multi-criteria analysis combined with the projection of the foreseen management options and critical areas. The units correspond to concordance values ranging from 0 to 1.

assessment criteria, regarding Ria de Aveiro Natura 2000 territory; foreseeing sustainable environmental and socio-economic development and human well-being.

Like in the past (Lillebø et al., 2015; Lillebø et al., 2016; Sousa, 2017; Luís et al., 2018) stakeholders acknowledged the governance complexity of the territory and identified as a persistent concern the need for more integrated management, including the involvement of the general public and communication between entities. In fact, one of the critical requirements of EBM planning process is the assessment and thoughtful use of information on stakeholder perspectives (*e.g.,* Leslie and McLeod, 2007; Cavanagh et al., 2016). However, from other studies it can be seen that the number of stakeholder groups involved or consulted as part of combined Science, Policy and Stakeholder approach can be quite variable (*e.g.,* Drakou et al., 2017). On the system-oriented assessment, when combining ES valuation by the group of experts with spatial explicit results, it's possible to see the relevance of the marine domain for small-scale fisheries (nutrition provisioning, ES5) and beach related activities (cultural, ES10); the diversity of activities taking place within the lagoon area (nutrition provisioning and cultural, *e.g.*, Sousa et al., 2016) and the importance of the freshwater domain for agriculture related activities (nutrition provisioning, Martínez-López et al., cross reference). Pateira de Fermentelos wetland was also considered an important fishing and recreational area (cultural, Roebeling et al., 2016). The importance of habitats *per se* (regulation and maintenance ES9, *e.g.,* Sousa et al., 2016, 2017) is explained by its natural capital classified under Habitats and Birds Directives (Natura 2000 Network).

Besides governance, the sectors in which stakeholders expressed persisting concerns were ecosystems and biodiversity, water management, agriculture fisheries and aquaculture, and recreational activities. Stakeholders' perception matched the ES provisioning risk assessment in the three water domains considered. In freshwater domain a major concern regarded the increase of aquatic and terrestrial exotic species, some of them invasive, which are recognized as threats to the habitats selected through AquaLinksTool. The selected freshwater habitats are part of Pateira de Fermentelos. From these, permanent non-tidal, smooth-flowing watercourses (C2.3) was the most vulnerable habitat, considering nutrition provisioning (ES5), regulation and maintenance (ES9), and cultural services (ES10) related to angling and sport fishing, extraction of flora and/or fauna, and physical and intellectual interactions with land seascapes physical settings. This freshwater wetland is particularly relevant for recreational activities, yet in frame of WFD the chemical status of Pateira water body is good though the ecological

Table 6
Description of a) the foreseen measures to be implemented in 2018/19 and b) the proposed EMB responses taking into account results from the prospective scenarios. Note: The Sectoral Plan for Natura 2000 Network and the National Strategic Plan for Climate change adaptation are considered transversal to the proposed EMB responses.

a)

Realm	Measure	Type of measure	Policy target	Policy instrument	Activity	Area	Time period	Undesirable pressures	Reference
Freshwater	#1 Flood-bank	Water management to prevent downstream surface saltwater intrusion and upstream floods	WFD Floods Directive	River Basin Management Plan; National Water Plan	Agriculture	Agricultural areas, at the confluence of the river Vouga and the lagoon	2018/19	Loss of saltmarsh habitats due to 'coastal squeeze' effect in the transitional realm	DGADR, 2017; Martínez-López et al., this issue
Transitional	#2 Dredging programme	Promote maritime traffic and mobility within the lagoon	n.a.	National Water Plan	Maritime	Deepening of main gravitation channels (Ovar, Murtosa, Ilhavo) and the lagoon central area	2018/19	Changes in the system ecohydrology, namely Increase in tidal prism and water velocity; loss of seagrasses and saltmarshes habitats	RECAPE, 2017; Lillebø et al., 2015
Marine	#3 Beach sand replenishment	Mitigation action by adding large quantities of sand from the lagoon dredging programme to beaches to combat erosion and increase beach width	Habitats Directive; MSFD, POC-OMG; Polis Litoral Ria de Aveiro	National Water Plan; National Strategic Plan for Tourism; National Strategic Plan for Climate change adaptation	Tourism Recreational	Coastal zone included in the selected Natura 2000 area	periodic	n.a.	CEDRU/UA/IDAD 2015

b)

Realm	Measure	Type of measure	Policy target	Policy instrument	Target area	Science-based knowledge requests for implementation
Transitional	#1.1, #2.1 Saltmarshes restoration	Mitigation measures to compensate the loss off saltmarshes due to 'coastal squeeze' and to the increase in tidal prism	WFD Birds Directive Habitats Directive	River Basin Management Plan; National Water Plan	To be selected within the lagoon tidal wetland area	Application of a GIS based modelling tool to select the potential areas taking into account the generate information. Attending to the site-specific characteristics of the selected areas different restoration techniques might be requested. These might be combined with supportive nature-based solutions to protect shorelines, as well as actions to promote sediment accretion.
	#2.2 Seagrasses meadows restoration	Mitigation measures to compensate the loss off seagrasses due to changes in water current velocity and light availability	WFD Birds Directive Habitats Directive	River Basin Management Plan; National Water Plan	Currently under study	There is an ongoing study on intertidal *Zostera noltei* modelling in Ria de Aveiro aiming for supporting restoration measures (*e.g.,* Azevedo et al., 2013, 2016, 2017). In addition, two recently funded projects (MAR2020 BioPradaRia and Remoliço) will test under controlled laboratory conditions and *in situ* different restoration techniques for *Zostera noltei* meadows.

status is moderate (Roebeling et al., 2016). In the transitional waters domain the vulnerable habitats selected through AquaLinksTool clearly matches stakeholders' concerns regarding the undesirable effects of the dredging activities on benthic habitats and water column within Ria de Aveiro coastal lagoon. At the same time, from the spatial multicriteria analysis by stakeholders, these are also acknowledged as the most valuable habitats concerning the provisioning of ES. As well, in the marine/coastal domain, dunes specific sub-habitats were classified through AquaLinksTool as vulnerable habitats and stakeholders expressed their concern on the loss of habitats in coastal zone. The agreement and complementarity of results attained from different approaches is also acknowledged in other studies, namely the combination of modelling tools with valuation methods involving stakeholders for spatial planning (Elwell et al., 2018) and for the management of water resources (Basco-Carrera et al., 2017).

The implementation of the proposed EBM response should be framed in the Sectoral Plan for Natura 2000 Network, under the coordination of the Portuguese Nature Conservation and Forests, which is the territorial management tool for the implementation of the national policy for the conservation of biological diversity. EBM responses should also consider climate change projections (Fernandino et al., 2018) and the National Strategic Plan for Climate change adaptation. The last contains the National adaptation strategy, and the associated action plan, including reducing vulnerability and increasing the response capacity and is particularly relevant in Aveiro region coastal area (Pereira and Coelho, 2013; Lillebø et al., 2015; Stefanova et al., 2015; Luís et al., 2018).

Attending to the selected pre-screening criteria regarding policy and feasibility, seagrasses and saltmarshes restoration seeks to recover natural ecosystems ecological processes and services, therefore it is ecologically sustainable and socially required. Actually, local population acknowledges these natural habitats as important nursery areas, being fundamental for economic activities in the region (Dolbeth et al., 2016; Newton et al., 2018). These can be related to fisheries and recreational activities, including eco-tourism, as stakeholders in this study also acknowledged. In this context, the National Strategic Plan for Tourism should also be considered, as it sets the basis to foster sustained growth of national tourism over the coming 10 years. In the context of the freshwater marine continuum restoration of seagrasses is of paramount importance for the European eel (*Anguilla anguilla*) as it is an important habitat for this migratory species (O'Higgins et al., 2019). In fact, the recognition of the socio-economic benefits associated to these habitats and water domains, and therefore Natura 2000 sites, can be seen as an important tool for an active and sustainable management, integrating protected areas into regional development planning (*e.g.,* Marino et al., 2014a; Elwell et al., 2018).

Although technologically feasible (*e.g.,* Valle et al., 2015; Soissons et al., 2016; Rezek et al., 2017) the implementation of the proposed EBM measures still requires additional, but tangible, science based-knowledge for the selection of the most suitable areas at Ria de Aveiro.

The Sectoral Plan for Natura 2000 Network establishes the strategic orientation and programme norms for the actions of central and local government, and the measures and guidelines provided for therein need be transposed to the municipal planning of the territory and special plans. Thus, the management measures provided for in the Sectoral Plan for Natura 2000 Network will only be binding measures when they are inserted in these plans. Regarding financing sources for the implementation of the response measures, applications in the scope of EU funding instruments, namely LIFE environmental programme, Regional Development and/or Territorial Cooperation funds, and R&I H2020 programme could be considered (Marino et al., 2014a; European Union, 2016).

Both measures have the same policy target (*i.e.,* WFD, Birds Directive Habitats Directive) as well as the same policy instrument (River Basin Management Plan; National Water Plan), therefore they are administratively achievable, although it implies the articulation of different Institutions. In line with the two policy instruments, this study can bridge regional policy instruments, namely by contributing to the Vouga estuary management plan and to the regional strategy for smart specialization (RIS3 Centro). The Vouga estuary management plan is a territorial planning tool, not yet developed, that establishes appropriate measures for the protection and valorisation of water resources in the area to which their sustainable use is applied in a secure manner, linking the Public Administration and users (Fidelis and Carvalho, 2015). RIS3 Centro is under the coordination of the Centro Regional Coordination and Development Commission and one of the four established priority platforms concerns efficient use of natural resources (Rodrigues and Teles, 2014). Therefore, the effective implementation of the proposed habitat restoration in the selected Natura 2000 area is consistent with existing policy Instruments for environmental and natural resource management in support of ecological and social dimensions of sustainable development and human well-being.

5. Conclusions

Ria de Aveiro region illustrates the challenges of an ecosystem-based management (EBM) planning process in a Natura 2000 freshwater-marine continuum territory. The applied approach fit a stepwise procedure in frame of resilience principles (Martin et al., 2018) where: i) the baseline condition was framed taking into account the foreseen management measures under implementation in 2018/19; ii) the objectives were formulated considering the undesirable pressures, as side effects of the dredging programme and the extension of the floodbank; iii) the screening of measure and instruments took into account the articulation between ecological and social components, *i.e.*, the system oriented-criteria and the process oriented-criteria, combining fundamental and applied sciences; iv) the narrative reflecting the foreseen management measures, the stakeholders' perception on ES valuation through spatial multi-criteria analysis and the generated science-based knowledge supported the planning EBM response that consist in saltmarshes and seagrasses meadows restoration programs; v) the proposed measures were evaluated through EBM criterion regarding policies and feasibility, showing that compliance is achievable.

Biodiversity is interlinked with habitats, namely with aquatic habitats, and in most coastal territories habitats cannot be dissociated from human activities and well-being. Therefore, Natura 2000 sites require an active and sustainable management involving the integration of science-based knowledge, environmental related policies and people holding stakes. In the case of Ria de Aveiro region the proposed EBM response can contribute to the Vouga estuary management plan (not yet developed) and the regional strategy for smart specialization (RIS3 Centro). Considering the adaptive management principles, the following steps after restoration would be: i) value the ES supported by the restored Natura 2000 habitats; ii) value the costs for the management of the Natura 2000 habitats regarding future dredging programmes, and iii) value the costs for the management of the Natura 2000 habitats in the context of climate change (*e.g.,* mean sea level rise).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.09.317.

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