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Identifying ecosystem services research hotspots to illustrate the importance of site-specific research: An Atlantic coastal region case study

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ABSTRACT

The mismatch between the conceptual understanding of the Ecosystem Services (ES) in science, and their practical application, remains. Among the many issues under discussion is the link between knowledge and implementation. Base knowledge built over cases studies exist, but their usefulness for site-specific management purposes is limited. The goal of this work is to illustrate how gap analysis at the local level may contribute to the development of ES research and knowledge transfer. A review of coastal ES was performed, based on peer-reviewed journals, grey literature and other sources, allocating the information per European Nature Information System aquatic habitat coupled with the Common International Classification of Ecosystem Services. Then, a multicriteria decision-making approach was applied to find ES research hotspots, i.e., habitats for which ES research should be prioritized. Three criteria were used: abundance of ES, evidence for the supply of ES, and strength of evidence. The criteria were considered suitable for coastal areas where profound gaps in ES research exist. The Atlantic coastal region adjacent to the Mondego River was used as case study. 231 current and potential ES were listed and mapped for 21 coastal habitats. Cultural services arose as the dominant category. Saltworks emerged as the most recommended habitat for ES research. Results are in accordance with local decision-makers trends of management; we consider the approach to be appropriate as a first step towards the operationalization of the ES concept and flexible enough to be readapted to focus on critical questions that characterize ES research.

1. Introduction

Ecosystem Services, i.e., the final outcomes of the internal structures, processes and functions, derived from ecosystems, that fulfil social demands, sustaining and enhancing human wellbeing (Müller et al., 2000; Martinez-Harms et al., 2015; Potschin – Young et al., 2018), are an increasingly used concept (Hamel and Bryant, 2017), mainly due to its potential to link the functioning of ecosystems to human welfare (Fisher et al., 2009). The concept allows building a bridge between economy, ecology and social sciences to communicate the way ecosystems underpin human existence (Keenan et al., 2019), and has thus become a crucial topic incorporated in a broad range of decision – making processes (Fisher et al., 2009).

Efforts have been made to operationalize the Ecosystem Services (ES) concept (European Commission, 2011; Potschin et al., 2014; Donovan et al., 2015), but the mismatch between the considerable conceptual understanding of the concept in science, and the limited practical application thereof, remains (Díaz et al., 2015; Saarikoski et al., 2018). Operationalization is “the process by which concepts are made useable by decision makers” (Potschin et al., 2014). This discussion has several strands that can be generally summarized into: (1) need for a common understanding; (2) role of institutions; (3) linking knowledge to implementation; (4) best practice for action (Carmen et al., 2018; Jax et al., 2018; Saarikoski et al., 2018; Lautenbach et al., 2019). The current work is focused on the available knowledge on ES for pratical implementation of the concept.

Successful knowledge transfer from ES case studies to decision-making processes relies on a significant base knowledge regarding the

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socio-ecological interrelationships between ecosystems, the benefits society retrieves from the natural capital and human activities and its pressures in the considered area (Lautenbach et al., 2019). Several initiatives aim at providing such a base knowledge (e.g. TEEB, 2010; ELD, 2014; IPBES, 2019; WAVES, 2019) to support high-level policy frameworks, such as the Convention on Biological Diversity[5] and the EU Biodiversity Strategy[6]. But at the local level, leaning on existing databases may lead to unfitted data collection processes, which in turn may lead to additional costs and highly uncertain results (Gómez-Baggethun and Barton, 2013; Jax et al., 2018). As such, at the local level, a clear problem definition and pathways for solution should be framed towards an effective and efficient way of applying the ES concept in a useful manner (Wittmer and Gundimedia, 2012).

Within this process, the contribution of a multistakeholder team is essential to tackle the environmental, social, institutional, economic and cultural issues of these usually complex problems (Jax et al., 2018). Researchers play an important role by identifying problems and partially supporting future work based on previous research (Jax et al., 2018).

The purpose of this work is to illustrate how gap analysis at the local level may contribute to the development of ES research and ultimately to knowledge transfer. To do so, a multicriteria decision-making approach is applied to find those habitats for which research should be prioritized. We assume that prioritizing research will support the delivery of the most relevant ES information for decision-makers (Wright et al., 2017), supporting policy development (McKenzie et al., 2014) and/or allowing the evaluation of alternative policy options (Laurans et al., 2013).

The Atlantic coastal region adjacent to the Mondego River has been selected for a case study. In this region, decision-makers have been struggling to apply an ecosystem approach to foster social and economic growth while guaranteeing the functioning of local ecosystems (Teixeira et al., 2018). The ES concept may have a key role to play in the further development and the functional orientation of such a strategy as it provides knowledge and a rational basis for management decisions (De Lucia, 2018). Despite its potential to support policy development.

(McKenzie et al., 2014) and the evaluation of alternative policy options (Laurans et al., 2013), limited site-specific research applying explicitly the ES concept has been performed (Pinto et al., 2010, 2013a; 2013b, 2014a; 2014b; Teixeira et al., 2018). We expect the current study to unlock the existing void by guiding future research towards habitats that may represent an added value to the region. Ultimately, the upscaling of the current study, and in particular its methodology, to other habitats and coastal systems worldwide, will have the potential to reveal blindspots in ecosystem services research at the global scale (Lautenbach et al., 2019).

1.1. Study area

The coastal region adjacent to the Mondego River lies at the centre of mainland Portugal, in the Atlantic east coast. The Mondego is the longest river located exclusively on Portuguese territory. It has its source 1425 m above (mean) sea level (a.s.l.) on the northern slopes of the Estrela Mountain Range, the highest mountain range in mainland Portugal. The Mondego River flows for 234 km in a southwestward direction to its mouth into the Atlantic Ocean (Fig. 1), next to the town of Figueira da Foz (Western central mainland Portugal). It is a perennial fluvial system with an average annual flow of 79 m^3/s that could increase up to 140 m^3/s in rainy years and drop up to 27 m^3/s in dry years (Teixeira et al., 2008). In the Lower Mondego, located downstream of Coimbra, the river valley has several fluvial and coastal terraces and an alluvial plain (Cunha et al., 1997a; Ramos et al., 2012), the Holocene alluvium, which comprises fluvial gravels and sands that grade downstream into estuarine sands and muds (Cunha et al., 2006).

The study area encompasses one coastal water body (CWB-1-3) and four transitional water bodies (coded as WB1, WB2, WB-HMWB and WB3), from the Atlantic coastal region adjacent to the Mondego River,as defined by the Water Framework Directive (WFD, 2000/60/EC; https://sniamb.apambiente.pt) (Fig. 1).

The coastal water body is flanked by two aeolian dune fields, located north of the Serra da Boa Viagem (e.g. Almeida, 1997; Danielsen, 2008) and south of the River Mondego (André, 1996; André et al., 2009). The modern shore platform is associated with a coarse sandy, locally gravelly, beach (e.g., Cunha and Dinis, 1998). Classified as Mesotidal Exposed Atlantic Coast (Bettencourt et al., 2003), the coastal waters are characterized by high energy hidrodynamics, struck by storms from the North Atlantic, particularly from October to March. The dominant wave direction is from west and northwest and the wave periods are in the range of 8–12 s and significant heights in the range of 1–3 m (Bettencourt et al., 2003).

The transitional water bodies that compose the estuary are located c. 26 km downstream the town of Montemor-o-Velho (upper limit of the tide range), totalizing an area of 860 ha. The last 7.5 km of the estuary (the Lower and Middle reaches) are divided into two branches separated by the Morraceira Island (Cunha et al., 1995). The Northern Branch belongs to the Mondego estuary subsystem and the Southern Branch is designated as the Pranto estuary subsystem. The Morraceira island was generated by deposition, fixed by vegetation, and occupied by saltworks ("salinas") and aquaculture ("fish-farms") (Cunha et al., 1997b). The Mondego subsystem is deeper (4–10 m during high tide) and characterized by strong salinity changes and the river bed mainly comprises medium to coarse sands (Dinis and Cunha, 1999; Cunha and Dinis, 2002); this Branch is used as the main navigation channel (Marques et al., 1993). The Pranto River subsystem (Southern Branch) is shallower (only 2–4 m depth during high tide) and is characterized by stronger salinity and temperature changes (Dinis and Cunha, 1999; Flindt et al., 1997), and sediments with high percentage of silt and clay (Cunha and Dinis, 2002). During low tide, large areas of intertidal sandflats, mudflats and seagrass meadows are exposed (Cunha and Dinis, 2002; Neto et al., 2008). This polihaline and mesotidal well-mixed estuary, with a tidal variation between 0.35 and 3 m and irregular river discharge (Kenov et al., 2012, Teixeira et al., 2008). Biodiversity in the Mondego Estuary is influenced by seasonal changes and water quality, where salinity (Van der Linden et al., 2012), temperature (Ceia et al., 2013; Marques et al., 2018) and sediment texture/composition (Cunha and Dinis, 2002) are determinant for species distribution.

The engineering works carried out in the Figueira da Foz harbour and in the Mondego River drainage basin (damming and fow regulation), mainly since 1960, lead to fast and large scale changes in the dynamics of the Mondego estuary and adjacent coastal area. The sedimentary system responses to artificial sand extraction and mud dredging in the lower estuary were fast. The main impacts of the successive anthropic interventions were (Cunha et al., 1995; Dinis and Cunha, 1998; Baeta et al., 2011): (i) interference with the longshore drift; (ii) increase sand deficit in the coast; (iii) reduction of the tidal prism; (iv) increased upstream penetration of the tide; (v) shoaling and eutrophication of the estuary southern branch; (vi) increase trend to estuarine siltation by marine sediments.

2. Methodology

Habitats for which ecosystem services' research should be prioritized were analyzed following the methodological steps presented on Fig. 2, which we designated as the SHOT Method - Ecosystem **S**ervices research **HOT**spot. The next subsections explain in detail each stage.

2.1. Habitat spatial distribution

To identify the aquatic ES of the Atlantic coastal area under study, a list of habitat categories was used (Table 1) and their distribution mapped based on different sources of spatial information (Appendix A. Supplementary tables). A correspondence of these habitats was then established with the EUNIS habitat classification system (Table 1).

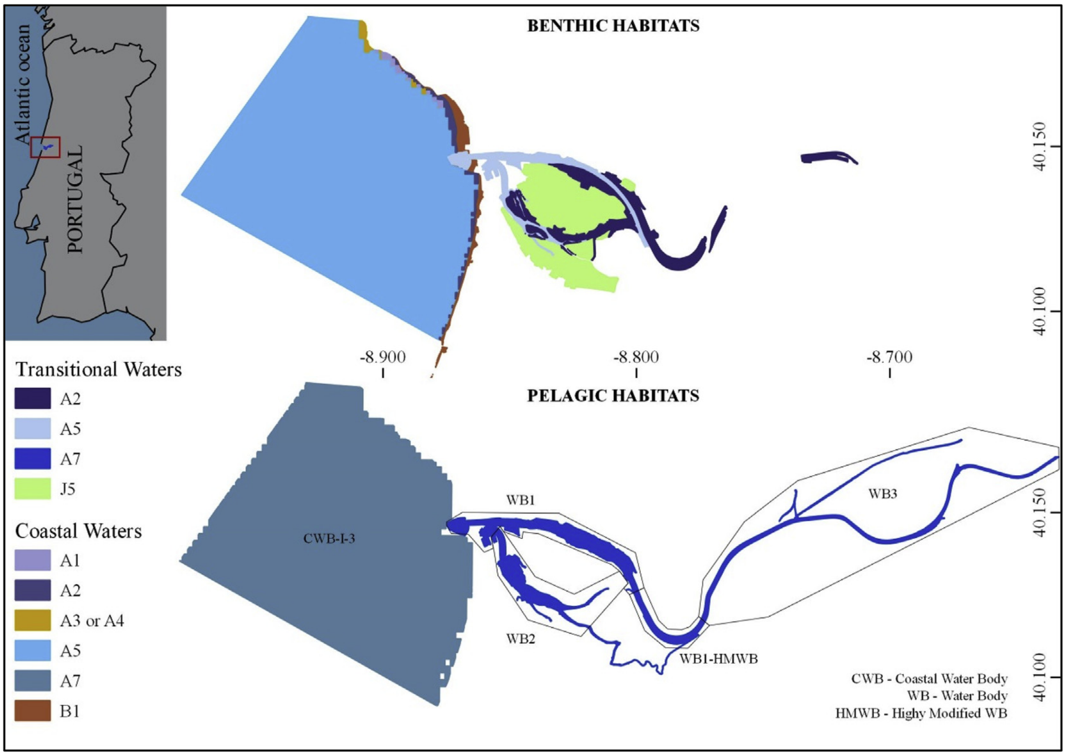

Fig. 1. Map in the upper left shows the location of the study site in the centre of mainland Portugal. The study area is the Atlantic coastal region adjacent to the Mondego River The upper right map shows the benthic habitats, according to EUNIS habitat classification – level 2, for which spatial information was available. The lower map shows the pelagic habitats, according to the EUNIs habitat classification – level 2, for which spatial information was available. A1 - Littoral rocky and other hard substrata; A2 – Sandy littoral; A3 – Infralittoral rocky & other hard substrata; A4 - Circalittoral rocky & other hard substrata; A5 – Sandy sublittoral; A7 – Pelagic water column; B1 – Coastal aeolian dunes and sandy shores; J5 - Highly artificial man-made structures and associated structures.

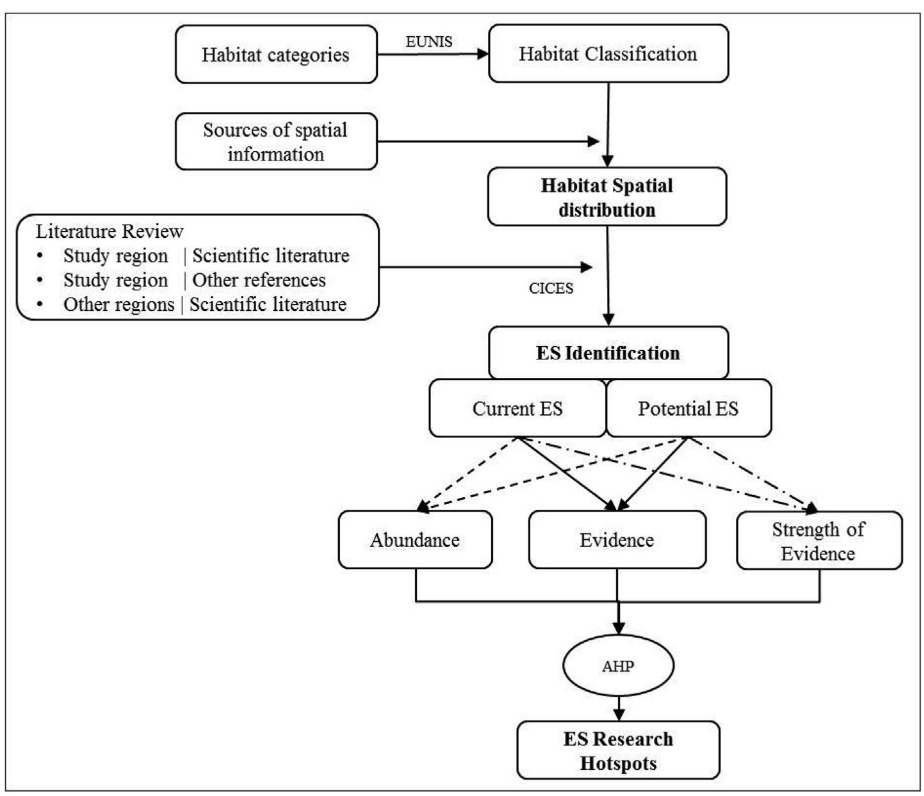

Fig. 2. The SHOT Method - Ecosystem Services Research HOTspot method. Diagram listing the methodological steps to find habitats for which ecosystem services' research should be prioritized. EUNIS - EUNIS habitat classification; CICES - Common International Classification of Ecosystem Services; AHP – Analytic Hierarchy Process.

2.2. Ecosystem services identification

ES were identified based on literature review and following the CICES hierarchical classification system (CICES) (Haines-Young and Potschin, 2013) (Fig. 2). Literature review encompassed three steps: 1) systematic review of scientific literature focused on the study area; 2) non-exhaustive review of other references focused on the study area; 3) non-exhaustive review of scientific literature focused on other geographic areas with similar habitats. The first step encompassed a systematic search on Web of Science (WoS) to explore references focused on the study area. No data limits were included. Three separate searches were performed to guarantee the three main coastal geographic areas encompassed in this study: 1) "Buarcos" AND "Portugal", which returned 12 studies; 2) "Lavos" AND "Portugal", which returned 4 studies; and 3) "Mondego Estuary", which returned 281 studies. Other known relevant articles, not provided by WoS but focused on the study area, were also included to guarantee a full review of the geographic area. In the end, a total of 292 papers focused on the Atlantic coastal region adjacent to the Mondego River were listed (Appendix A. Supplementary tables). The second step encompassed a non-exhaustive review of grey literature and other references focused on the study area that would allow us to explore empirical evidence of ES supply and/or demand for local services that could stimulate research and discussion on ES assessments. The review includes reports, ongoing scientific projects, online videos, *in* situ observations supported by a long term monitoring program, among other. The third step encompassed a review of scientific literature focused on ES supply at other geographic areas with similar aquatic habitats. In this third step, due to the high diversity of habitats, biological components and types of ecosystem services, we opted for a non-exhaustive review and considered that a minimum of one reference would sustain the

Table 1
List of habitats according to the EUNIS habitat classification system and sources of spatial information.

	Habitat ID	Habitat	EUNIS L1	EUNIS L2	EUNIS L3	Source[a]
Transitional Waters	hab1	Estuarine saltmarshes	A Marine Habitats	A2 Littoral Sediment	A2.5 Coastal saltmarshes and saline reedbeds	Field sampling
	hab2	Aquaculture tanks	J Constructed, industrial and other artificial habitats	J5 Highly artificial man-made waters and associated structures	J5.1 & J5.11 Saline and brackish industrial lagoons and canals J5.11 Saline and brackish industrial lagoons and canals	Teixeira et al. (2018)
	hab3	Water ponds	J Constructed, industrial and other artificial habitats	J5 Highly artificial man-made waters and associated structures	J5.1 & J5.11 Saline and brackish industrial lagoons and canals J5.11 Saline and brackish industrial lagoons and canals	Teixeira et al. (2018)
	hab4	Saltworks	J Constructed, industrial and other artificial habitats	J5 Highly artificial man-made waters and associated structures	J5.1 & J5.12 Saltworks J5.12 Saltworks	Teixeira et al. (2018)
	hab5	Estuarine littoral granule and very coarse to coarse sands	A Marine Habitats	A2 Littoral Sediment	A2.1 Littoral coarse sediment	Cunha and Dinis (2002)
	hab6	Estuarine littoral sandy mud and very fine to medium sands	A Marine Habitats	A2 Littoral Sediment	A2.2 Littoral sand and muddy sand	Cunha and Dinis (2002)
	hab7	Estuarine littoral mud	A Marine Habitats	A2 Littoral Sediment	A2.3 Littoral mud	Cunha and Dinis (2002)
	hab8	Estuarine seagrass bed	A Marine Habitats	A2 Littoral Sediment	A2.6 Littoral sediments dominated by aquatic angiosperms	Field sampling
	hab9	Estuarine sublittoral granule, very coarse to coarse sands	A Marine Habitats	A5 Sublittoral Sediment	A5.1 Sublittoral coarse sediment	Cunha and Dinis (2002)
	hab10	Estuarine sublittoral sandy mud and very fine to medium sands	A Marine Habitats	A5 Sublittoral Sediment	A5.2 Sublittoral sand	Cunha and Dinis (2002)
	hab11	Estuarine sublittoral mud	A Marine Habitats	A5 Sublittoral Sediment	A5.3 Sublittoral mud	Cunha and Dinis (2002)
	hab12	Estuarine pelagic waters of the South Mondego Branch and Pranto River	A Marine Habitats	A7 Pelagic water column	A7.4 Partially mixed water column with reduced salinity and medium or long residence time	SNIAmb, 2019
	hab13	Estuarine pelagic waters of the North Branch of the Mondego River and upstream system	A Marine Habitats	A7 Pelagic Water Column	A7.6 Vertically stratified water column with reduced salinity	SNIAmb, 2019
Coastal Waters	hab14	Sandy beaches	B Coastal Habitat	B1 Coastal dunes and sandy shores	B1.2 Sand beaches above the driftline	IGP (2010)
	hab15	Coastal rocky middle and supralitoral areas	A Marine Habitats	A1 Littoral rock and other hard substrata or Littoral Sediment	–	Ecosystem types of Europe (2015)
	hab16	Coastal supralittoral sedimentary areas	A Marine Habitats	A2 Littoral sediment	–	Ecosystem types of Europe (2015)
	hab17	Infra and circalittoral rocky areas	A Marine Habitats	A3 or A4 Infra&Circa rock&other hard substrata	–	Ecosystem types of Europe (2015)
	hab18	Infralittoral or circalittoral sedimentary areas	A Marine Habitats	A5 Sublittoral Sediment	A5.2 Sublittoral sand (Infrallittoral or Circalittoral)	EUSeamap (2016)
	hab18_1	Infralittoral fine sand or infralittoral muddy sand areas	A Marine Habitats	A5 Sublittoral Sediment	A5.23 or A5.24 Infralittoral fine sand or infralittoral muddy sand	EUSeamap (2016)
	hab18_2	Circalittoral fine sand or muddy sand areas	A Marine Habitats	A5 Sublittoral Sediment	A5.25 or A5.26 Circalittoral fine sand or circalittoral muddy sand	EUSeamap (2016)
	hab19	Marine pelagic (0–200) waters	A Marine Habitats	A7 Pelagic water column	A7.3 Completely mixed water column with full salinity	EMODNET bathymetry portal (2019)

[a] The methodological approach to define the spatial distribution of the coastal habitats is described inAppendix A. Supplementary tables.

evidence for potential ES (Appendix A. Supplementary tables).

For the purpose of this study we used the definition of ES supply from Tallis et al. (2012) and an adapted definition of ES demand from Burkhard et al. (2012). Supply is "the full potential of ecological functions or biophysical elements in an ecosystem to provide a potential ES, irrespective of whether humans actually use or value that function or element currently" (Tallis et al., 2012). Demand is the sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period, considering only those ES that are actually provided within the study area. This definition differs from the one proposed by Burkhard et al. (2012) and others (Wolff et al., 2015) in that it excludes ES that are consumed in the study area but have been provided by ecosystems outside the study area. This adaptation to the definition is necessary to use Demand as a proxy for the provision of ES.

Based on the literature, the ES were then divided into Current and Potential. Current ES include those for which ES supply and/or demand in the study area is confirmed by the scientific literature and/or other references from the study area. This wide definition, including ES not confirmed by scientific literature, allowed us to map ES from empirical evidences, important to analyze gaps in local ES assessment. Potential ES include those for which ES supply of and/or the demand in the study area are not confirmed by any means, but scientific literature suggests the presence of biophysical structures and/or functions in the study area with potential to supply ES, and, at the same time, scientific literature from other geographic areas suggests the supply of ES by those biophysical structures and/or functions (Salomidi et al., 2012; Liquete et al., 2013; Tempera et al., 2016). This definition allowed us to map ES from evidences at other geographic areas, also important to analyze gaps in local ES assessment.

2.3. Ecosystem Services Research Hotspots

An Analytic Hierarchy Process (AHP) approach (Vaidya and Kumar, 2006; Teixeira et al., 2018; De Marinis and Sali, 2020) was followed to find ES Research Hotspots (RH) based on a set of criteria and subcriteria.

2.3.1. Criteria and subcriteria

For the purpose of this study, Ecosystem Services Research Hotspots are aquatic habitats for which research on ES is recommended based on three selected criteria. In order of importance, these are: 1) abundance of ES; 2) evidence for ES; 3) strength of evidence (Table 2). According to this definition, a highly recommended habitat shows a high abundance of ES, for which there is current evidence for the presence of ES in the geographic area under study, supported by scientific literature. Research Hotspots were identified applying an Analytic Hierarchy Process, which allowed us to prioritize coastal aquatic habitats based on the weighted relevance of the above-mentioned criteria.

The abundance of ES is defined as the percentage of ES encountered at each habitat. The percentage was calculated taking into consideration the maximum number of types of ES (defined by CICES codes) for each habitat and each category (Provisioning, Regulation, Cultural), regardless of whether ES have been classified as current or potential. Currently the CICES classification points to 42 types of provisioning ES, 28 types of regulation ES and 15 types of cultural ES (Haines-Young and Potschin, 2018). This means that if the same type of ES (defined by the CICES code) was provided in the same habitat, but by different biophysical structures (e.g. fish and macroalgae), it was counted only once. This procedure was a necessary simplification to allow calculating abundance percentages. To define abundance subcategories suitable to be included in the AHP calculations, it was necessary to classify the percentage of abundance into abundance intervals (Table 2). For this purpose, and as a reference, it was considered that high abundance habitats are those with more than 20% of the possible ES. This limit was set upon the average number frequently found in coastal habitats (Hutchinson et al., 2013).

The evidence for ES is defined as the type of proof found for the occurrence of ES. It was calculated as the percentage of current ES in relation to potential ES (Table 2). For example, if an habitat shows 1 current provisioning ES and 4 potential provisioning ES, we assume it shows 20% of current ES, showing thus evidence that there are less current than potential ES in the habitat under analysis (Moderately Low evidence for ES).

Table 2
Subcategories for the three categories used in the AHP process: abundance; evidence for ES and strength of evidence.

Level_id	Level	Description
Category | Abundance of ES		
5	High	More than 50%
4	Moderately High	From 20% up to 50%
3	Moderate	From 10% up to 20%
2	Moderately Low	From 5% up to 10%
1	Low	Less of equal to 5%
0	No ES	Equal to 0. No ES
Category | Evidence for ES		
5	Robust	Evidence that all ES identified are currently occurring
4	Moderately Robust	Evidence that there are more current than potential ES
3	Moderate	Evidence for as many current as potential
2	Moderately Fragile	Evidence that there are less current than potential ES
1	Fragile	There is no evidence for current ES. All evidence is for potential ES
0	No Evidence	There is no evidence for the current or potential occurrence of ES
Category | Strength of Evidence		
6	Strong	Evidence for current ES based on scientific literature that does not have the concept of ES explicitly into account (Current/non-Explicit ES)
5	Moderately Strong	Evidence for current ES based on grey literature (Current/Grey literature)
4	Moderate	Evidence for current ES based on other types of references (Current/other)
3	Moderately Weak	Evidence for potential ES based on scientific literature that has the concept of ES explicitly into account (Potential/Explicit ES)
2	Weak	Evidence for potential ES based on scientific literature that does not have the concept of ES explicitly into account (Potential/non-Explicit ES)
1	Very Weak	Evidence for current ES based on scientific literature that has the concept of ES explicitly into account. Though this is in reality the strongest evidence, it was considered that if a study had already been taken in the geographic area under study, explicitly considering the concept of ES, than there was no urgency in planning a new one (Current/Explicit ES), which is the overall goal of this study, i.e., to plan research based on evidence of occurrence and lack of studies.
0	No Evidence	There is no evidence for ES

The strength of evidence for each habitat was calculated based on the most frequent type of references found for each habitat (Table 2). For example, a habitat with strong evidence (score 6) is one for which the most frequent evidence for ES confirms the current presence of an ES and is based on scientific literature that does not have the concept of ES explicitly into account.

2.3.2. Ranked list of factors based on AHP

The absolute measurement method (Saaty, 1990) was applied to determine criteria and sub-criteria priorities. With the absolute approach, the criteria are pairwise compared to derive priorities, and the sub-criteria are rated within the criteria to which they belong (Saaty, 1990). The free web based *BPMSG AHP Online System* (Goepel, 2017) was applied to develop the comparison matrices, their consistency ratio (CR) and the weights. The comparison matrices were established using an evaluation scale divided into nine levels, where level 1 represents equal importance between factors, and level 9 represents nine times more importance of one factor compared to another. Four pairwise matrices were created, one for the criteria (Appendix A. Supplementary tables) and three for the subcriteria (Appendix A. Supplementary tables). The consistency of the matrices' was determined based on the consistency ratio (CR). A CR of 0.10 or less was considered acceptable to continue the AHP analysis (Saaty, 2012). The CR measures the consistency of a given evaluation matrix by comparing its consistency index with a random consistency index (Mu and Pereyra-Rojas, 2017). The priority ranks that set the importance of each factor were obtained multiplying the criteria and the sub-criteria weighted priorities (Saaty, 1990). The highest priority rank of Abundance, for example, was established multiplying the weight of *Abundance* criteria by the weight of *High* sub-criteria.

2.3.3. Research priorities

After defining the importance of each factor, research priority for each habitat was established summing the priorities of the corresponding factors. The highest rank priority was assigned to habitats with *High Abundance* and with *Robust* and *Strong Evidence*, but for which there is a gap in ES research. For this reason these spots are preferred for ES Research. Because the results provide a ranked list of factors that is unmanageable, the overall priority ranks were further classified within intervals of recommendation for ES research. The intervals of recommendation were determined based on the Equal Intervals Method defining *a priori* five classification intervals: highly recommended, very recommended, recommended, little recommended and very little recommended. The distance between classification intervals (*D*) was calculated following Eq. (1).

$$D = (H + L) / 5 \quad (1)$$

where *H* is the highest rank value and *L* is the lowest rank value. The intervals allowed us to classify habitats (from coastal and transitional waters) based on the ES *Abundance*, *Evidence* for ES and *Strength* of evidence for ES, but also to find the ES Research Hotspots.

3. Results

3.1. Ecosystem services at the Atlantic coastal region adjacent to the Mondego River

In the habitats of the Atlantic coastal studied area (Fig. 3), the abundance of ES per habitat does not exceed 28% of the possible ES, when considering the CICES classification (Fig. 4a). Saltworks (hab4), coastal rocky middle and supralitoral areas (hab15) and marine pelagic (0–200) waters (hab19) show the highest percentage of ES, higher than 20%. More specifically, and as an example, saltworks show a total of 23 ES, which corresponds to 27.38% in an universe of 84 possible ES (Appendix A. Supplementary tables). Estuarine habitats with sediment bed consisting of granule to coarse sands (hab5 and hab9), sedimentary supralittoral areas (hab16) and sedimentary infralittoral and circalittoral habitats (hab18, hab18_1, hab18_2) reveal the lowest percentage of ES (Fig. 4a), lower than 5%.

When considering the three ES categories separately (Fig. 4b), the presence of cultural services seems to dominate at almost all habitats. With exception for the marine pelagic waters (hab19), all habitats show more cultural ES than provisioning or regulation, such as saltworks (hab4) which exhibit 93% of the possible CICES cultural ES types, corresponding to a total of 14 ES out of a total of 15 possible cultural services (Appendix A. Supplementary tables). In fact, for some there is only evidence for cultural ES and not for provisioning and cultural, which is the case for the estuarine littoral granule and very coarse to coarse sands (hab5) and infralittoral to circalittoral sedimentary environments (hab18, hab18_1, hab18_2).

The evidence for ES in the Atlantic coastal region adjacent to the Mondego River differs among habitats (Fig. 4b). The evidence for ES in coastal rocky middle and supralitoral areas (hab15) and marine pelagic (0–200) waters (hab19) points for more potential ES than for current. On the contrary, estuarine littoral granule and very coarse to coarse sands (hab5), estuarine sublittoral granule and very coarse to coarse sands (hab9), coastal supralitoral sedimentary areas (hab16) and infralittoral

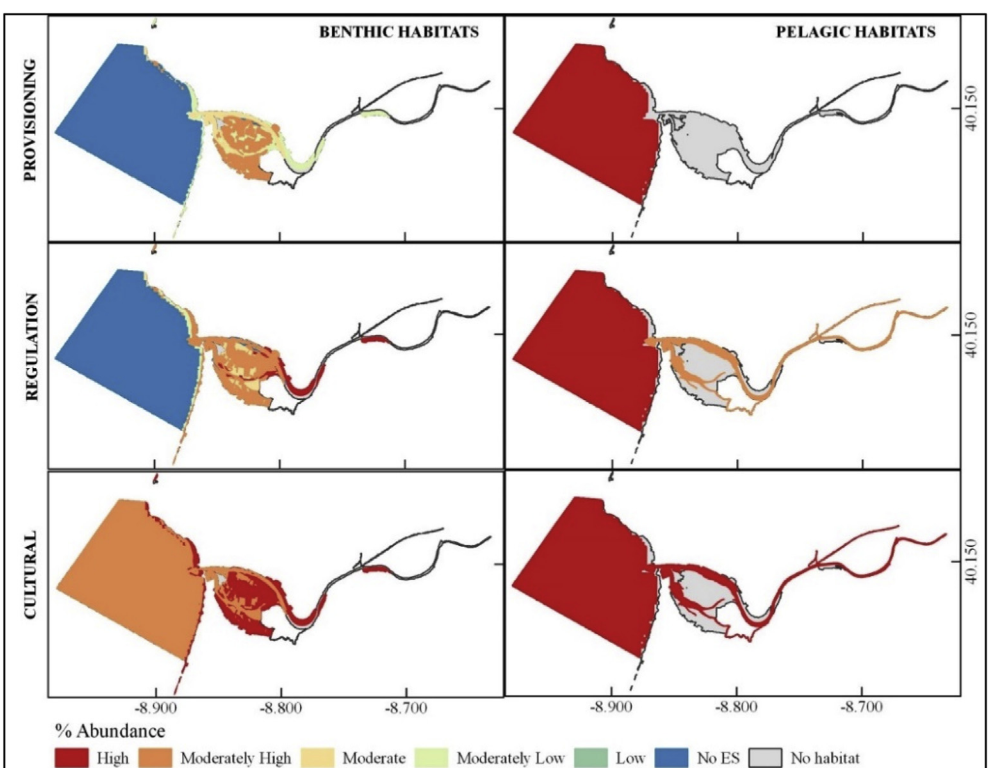

Fig. 3. Abundance (% of CICES types) of ecosystem services per categories and type of habitats.

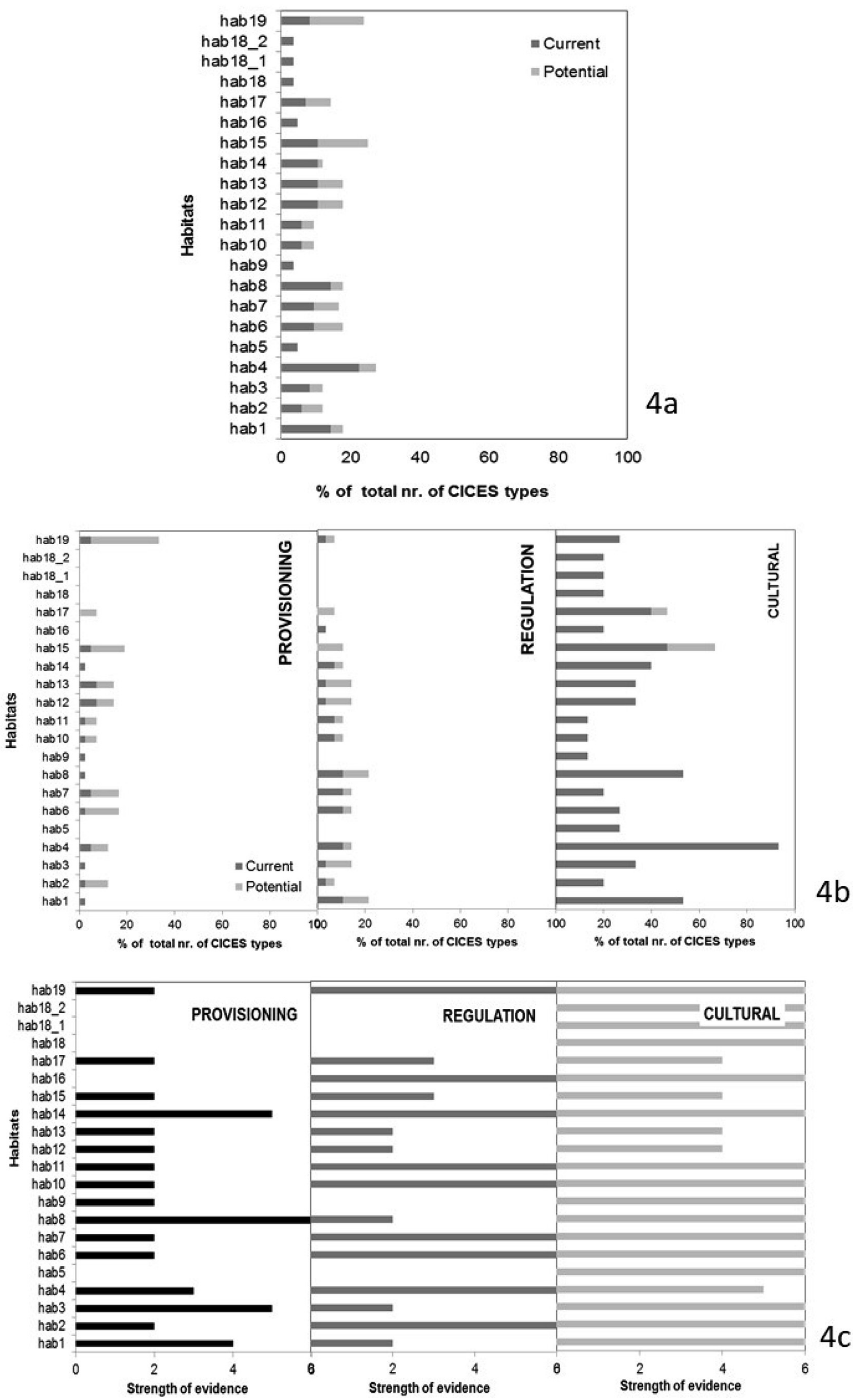

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Fig. 4. 4a. Abundance (% of CICES Types) per habitat and type of evidence (Current or Potential; 4b. Abundance (% of CICES Types) per habitat, type of evidence and category (Provisioning, Regulation and Cultural); 4c. Strenght of Evidence per habitat and category. hab1 - Estuarine saltmarshes; hab 2 - Aquaculture tanks; hab3 - Water ponds; hab4 – Saltworks; hab5 - Estuarine littoral granule and very coarse to coarse sands; hab6 - Estuarine littoral sandy mud and very fine to medium sands; hab7 - Estuarine littoral mud; hab8 - Estuarine seagrass bed; hab9 - Estuarine sublittoral granule and very coarse to coarse sands; hab10 - Estuarine sublittoral sandy mud and very fine to medium sands; hab11 - Estuarine sublittoral mud; hab12 - Estuarine pelagic waters of the South Mondego Branch and Pranto River; hab13 - Estuarine pelagic waters of the North Branch of the Mondego River and upstream system; hab14 - Sandy beaches; hab15 - Coastal rocky middle and supralitoral areas; hab16 - Coastal supralittoral sedimentary areas; hab17 - Infra and circalittoral rocky areas; hab18 - Infralittoral or circalittoral sedimentary areas; hab18_1 - Infralittoral fine sand or infralittoral muddy sand areas; hab18_2 - Circalittoral fine sand or muddy sand areas; hab19 - Marine pelagic (0–200) waters.

and circalittoral sedimentary areas (hab18, hab18_1, hab18_2) show only evidence for current supply of ES and no evidence for potential ES. The remaining habitats show evidence for more current ES than potential.

The strength of evidence seems to be generally stronger for the cultural services than for the regulation or the provisioning services (Fig. 4c). No habitats show weak evidence for the cultural services, whereas up to 11 habitats show weak evidence for provisioning services, when present.

3.2. Ranked list of factors

The ranked list of factors obtained when applying the AHP approach (Table 3) is suitable for any analysis that applies the same criteria and sub-criteria defined in this study. Such list determines the prioritization of habitats for research. The results indicate that the most preferred habitats for ES research have a maximum priority value of 0.378 (0.207 + 0.114+0.058), which corresponds to habitats with *High Abundance* and with *Robust* and *Strong Evidence* (Table 3); and that the least preferred habitats for ES research have a priority of 0.034 (0.019 + 0.010+0.004), which corresponds to habitats for which no evidence of ES has been found (Table 3).

When classifying the rank priorities (Table 3) into intervals of recommendation, a manageable scale of priorities is obtained (Table 4). Such scale supports data interpretation and ultimately decision-making.

3.3. Ecosystem Services Research Hotspots

The ES Research Hotspots in the studied area i.e., habitats for which research on ES is recommended, differ if one is considering the three categories of ES altogether (Provisioning, Regulation and Cultural), or one at a time. When considering altogether, saltworks (hab4), for instance, emerges has the habitat most recommended for research (Table 5) and the remaining habitats are considered either "very recommended" or "recommended". This pattern changes when evaluating one category at a time. If one ought to study provisioning services, Marine pelagic (0–200) waters (hab19) is a "very recommended" habitat, while five other habitats are "very little recommended". If one ought to study regulation services eight habitats are "very recommended", and six other are "little recommended". If one ought to study cultural services, nine habitats are "highly recommended", while the remaining are all "very recommended".

Table 3
Rank list of criteria and sub-criteria.

Criteria	Subcriteria	Priorities
Abundance	High	0.207
	Moderately high	0.136
	Moderate	0.087
	Moderately Low	0.053
	Low	0.037
	No ES	0.019
Evidence	Robust	0.114
	Moderately Robust	0.075
	Moderate	0.048
	Moderately Fragile	0.031
	Fragile	0.020
	No Evidence	0.010
Strength of Evidence	Strong	0.058
	Moderately Strong	0.039
	Moderate	0.026
	Moderately Weak	0.017
	Weak	0.011
	Very Weak	0.008
	No Evidence	0.004

4. Discussion

4.1. Habitats and ecosystem services maps

Coastal and marine maps are an essential source of information for resource exploitation and management purposes (Galparsoro et al., 2014; Tempera et al., 2016). At the European level, recent efforts have been made to deliver databases with a spatial component (Caro et al., 2018). However, not all databases are suitable for high resolution analysis, which hampers the ability to perform site-specific research (Tempera et al., 2016; Caro et al., 2018) and the capacity to operationalize the ES concept (Carmen et al., 2018; Jax et al., 2018; Saarikoski et al., 2018; Lautenbach et al., 2019). Despite the challenges associated to the spatial distribution of coastal and marine habitats for local-level research, the current study successfully provides the first comprehensive coastal habitats map of the Atlantic coastal region adjacent to the Mondego River region. The spatial information used was retrieved from a wide variety of sources with different resolutions, data certainty and geographic scope. At least three reasons can be outlined to explain this data diversity: (1) global and regional spatial databases fail to provide extensive high resolution data (Tempera et al., 2016; Caro et al., 2018); (2) spatial information at the national level is scarce, more even for the aquatic realms (Instituto Geográfico Português, 2010), and, when available, frequently not with free access; (3) site-specific spatial information is also scarce and often not publicly available (e.g. the 1/10.000 cartography of Mondego Estuary subsedimentary environments presented by Cunha and Dinis, 2002). Spatial analysis is not mandatory for the methodological approach presented in this study, but studies have shown that practitioners and policy makers are increasingly seeking spatially-explicit information to use in decision-making and the implementation of policies (Tempera et al., 2016). Coastal and marine maps are also an important baseline type of information used to produce ES maps (Galparsoro et al., 2014), when primary data (i.e., direct ecosystem function/service measurements) from within the study area is absent (Tempera et al., 2016). For our case study, literature review revealed that providing comprehensive ES maps based solely on primary data is still not possible. On the contrary, using habitats as proxies has proven to be a successful approach to map the distribution of ES in the Atlantic costal region adjacent to the

Table 4
Classification levels.

Priority	Levels	Interval	
		maximum	minimum
Priority 1	Highly recommended	0.378	0.310
Priority 2	Very Recommended	0.310	0.241
Priority 3	Recommended	0.241	0.172
Priority 4	Little Recommended	0.172	0.103
Priority 5	Very Little Recommended	0.103	0.034

Table 5
Analytic Hierarchy Process rank priorities after classification.

	Habitat ID	Provisioning	Regulation	Cultural	Total
Transitional Waters	hab1	Recommended	Very Recommended	Highly recommended	Very Recommended
	hab2	Recommended	Recommended	Very Recommended	Recommended
	hab3	Recommended	Recommended	Highly recommended	Very Recommended
	hab4	Recommended	Very Recommended	Highly recommended	Highly recommended
	hab5	Very Little Recommended	Little Recommended	Highly recommended	Recommended
	hab6	Recommended	Very Recommended	Very Recommended	Very Recommended
	hab7	Recommended	Very Recommended	Very Recommended	Very Recommended
	hab8	Recommended	Very Recommended	Highly recommended	Very Recommended
	hab9	Recommended	Little Recommended	Very Recommended	Recommended
	hab10	Little Recommended	Very Recommended	Very Recommended	Recommended
	hab11	Little Recommended	Very Recommended	Very Recommended	Recommended
	hab12	Recommended	Recommended	Highly recommended	Recommended
	hab13	Recommended	Recommended	Highly recommended	Recommended
Coastal Waters	hab14	Recommended	Very Recommended	Highly recommended	Very Recommended
	hab15	Recommended	Recommended	Very Recommended	Very Recommended
	hab16	Very Little Recommended	Recommended	Very Recommended	Recommended
	hab17	Little Recommended	Little Recommended	Very Recommended	Recommended
	hab18	Very Little Recommended	Little Recommended	Very Recommended	Recommended
	hab18_1	Very Little Recommended	Little Recommended	Very Recommended	Recommended
	hab18_2	Very Little Recommended	Little Recommended	Very Recommended	Recommended
	hab19	Very Recommended	Recommended	Highly recommended	Very Recommended

hab1 - Estuarine saltmarshes; hab 2 - Aquaculture tanks; hab3 - Water ponds; hab4 – Saltworks; hab5 - Estuarine littoral granule and very coarse to coarse sands; hab6 - Estuarine littoral sandy mud and very fine to medium sands; hab7 - Estuarine littoral mud; hab8 - Estuarine seagrass bed; hab9 - Estuarine sublittoral granule and very coarse to coarse sands; hab10 - Estuarine sublittoral sandy mud and very fine to medium sands; hab11 - Estuarine sublittoral mud; hab12 - Estuarine pelagic waters of the South Mondego Branch and Pranto River; hab13 - Estuarine pelagic waters of the North Branch of the Mondego River and upstream system; hab14 - Sandy beaches; hab15 - Coastal rocky middle and supralitoral areas; hab16 - Coastal supralittoral sedimentary areas; hab17 - Infra and circalittoral rocky areas; hab18 - Infralittoral or circalittoral sedimentary areas; hab18_1 - Infralittoral fine sand or infralittoral muddy sand areas; hab18_2 - Circalittoral fine sand or muddy sand areas; hab19 - Marine pelagic (0–200) waters.

Mondego River. One of the advantages of producing ES maps is the ability to extract quantitative indicators based on the areal extent where the service is suggested to be present (Galparsoro et al., 2014). One must however, bear in mind that aquatic habitats are dynamic, i.e., their spatial distribution and characteristics is likely to change as a result of the hydromorphological conditions of the system, its sedimentary characteristics (Cunha et al., 1995; Dinis and Cunha, 1998; Duarte et al., 2001), and the anthopogenic pressures acting upon the system (Crespo et al., 2010; Baeta et al., 2011; Teixeira et al., 2014; Teixeira and Marques, 2016). This means that habitat maps, at the local level, should be updated as frequently as possible to reflect the most recent conditions (McKerrow et al., 2014).

4.2. Decision-making approach for ES research prioritization

The multicriteria method used in this study is conceptually different from those approaches that explore blindspots in research (e.g. Lautenbach et al., 2019). More than looking for gaps in ES research, our goal was to find those habitats for which research should be prioritized. The criteria were selected from a science management point of view, i.e., 'which habitats show less scientific research', but also from a decision-making point of view, i.e., 'which habitats show less scientific research, despite the number of ES and the evidence for relevant resources?' The number of ES and evidence for relevant resources are proxies for the habitat potential to deliver ecosystem benefits valued by humans (Gos and Lavorel, 2012). The results obtained with the methodology applied seem to be in accordance with the recent efforts of local authorities to mainstream the cultural and social heritage associated to human activities in the coastal Mondego region (Teixeira et al., 2018). Results show that the region is dominated by cultural services and that saltworks should be a priority for research. Teixeira et al. (2018) had already stated that saltworks' conservation and rehabilitation is one of the main goals of local authorities for a number of socio-cultural reasons. If this social meaning, rather than ecological health, is the major factor underpinning cultural ES (Irvine and Herrett, 2018), it may be an indication that decision-makers are depreciating ecosystem characteristics, such as species richness, population dynamics and resilience. If this is the case, the importance assigned to cultural services in the AHP model, as a result of the percentage of cultural ES found, may be arguable from an ecological point of view, as the model is prioritizing habitats based more on social objectives than ecological health. As mentioned, this may be relevant, for decision-making and management purposes, as it is of utmost importance to focus on the most relevant ES, however one should not forget that it is also crucial to consider the relationships between them (e.g., Kandziora et al., 2013), as the selection of the ES to benefit may involve losing one quality or aspect of something in return for gaining another quality or aspect (McShane et al., 2011; Iniesta-Arandia et al., 2014; Martín-López et al., 2014). In the Atlantic coastal region adjacent to the Mondego River region, social meaning might be behind ES such as 'Area of Outstanding Natural Beauty', while ecological health might be behind ES such as 'Site of special scientific interest: RAMSAR site and Important Bird and Biodiversity Area (IBA)', and 'Site used for conservation activities'. Future work could highlight the public's perceptual characterization of coastal aquatic habitats to understand the values underpinning ES preferences. Regardless of the reason behind the abundance of cultural ES – either social or ecological -, the results indicate that they play an important role in the studied region and thus the best available methods (Cheng et al., 2019) and indicators (Hernández-Morcillo et al., 2013) should be applied in order to not omitt cultural services from ES assessments or limit the capacity of the analysis (Cheng et al., 2019; Zhang et al., 2019). To this matter, the type of evidences found for the presence of cultural ES point to the opportunity of including novel approaches such as the analysis of social networks (Kilonzi and Ota, 2019).

4.3. AHP criteria challenges

The maximum abundance of total ES found for the Atlantic coastal region adjacent to the Mondego River region is in line with abundances found for other systems (Barbier et al., 2011; Hutchinson et al., 2013). These findings support the categorization for the abundance criteria implemented in our approach, i.e., any habitat with more than 20% of ES is a highly abundant habitat. This statement is less clear when analyzing the cultural services independently, as their percentage per habitat frequently surpassed the 20% boundary, reaching a maximum of 93.3%. Three causes could explain the high percentages found for cultural services. The first one comes from mathematics. The CICES classification describes 42 provisioning services, 28 regulation services and 14 cultural services, this means that for any cultural ES identified, the percentage is automatically higher. For instance, 2 provisioning ES represent 2.4%, 2 regulation services represent 4.8% and 2 cultural services represent 13.3%. This still means that 20% in an universe of 14 types is a high percentage. Second, cultural ES are relatively easy to spot in the absence of scientific literature by identifying the local ES through other references. For instance, the presence of educational programs as an indicator of sites used for *insitu* teaching (Lovell et al., 2010), the presence of scenic views used for photos as indicators of archive records (Everard et al., 2010) and the existence of bird watching activities (Tzoulas and James, 2010) can be identified through a simple internet searching. Selecting references other than scientific, as for example grey literature, videos and books, has proven useful to spot the current supply and/or demand for ES provided locally, but for which no scientific literature is yet available. In fact, this information can later become good indicators of ES supply (Lovell et al., 2010; Everard et al., 2010; Tzoulas and James, 2010). The third cause, might be associated to the social motivations advanced in the previous section (section 4.2). Highly scored habitats, e.g. saltworks, might be showing high number of cultural ES as a result of the socio-cultural importance given to these habitats. Taking into account the reasons advanced to explain the high percentages of cultural ES, we consider that using the same boundary, to determine abundance scores, for all ES categories remains the best approach as it harmonizes calculations and simplifies interpretations.

The AHP methodology allows limiting the influence of less trustable criteria, by assigning lower weights. In our case, the lowest weight was assigned to the "strength of evidence" criteria. The approach applied to determine the strength of evidence considers only the most frequent types of references found for each habitat and whenever there is a tie the highest score is selected. This means that the methodology ignores weak evidence for some ES if the majority of the ES in the habitat show strong evidence. Because we are aware of the loss of information with the approach followed, we considered it was important to limit the influence of this criteria and, thus, to the strength of evidence a weight of only 16.3% was assigned. Other approaches to calculate the strength of evidence are possible. Namely, calculating the average of the criteria scores by habitat. However, other weaknesses would have been introduced with this approach as it would be ignoring the categorical nature of the score system while treating it as nominal (Stevens, 1946). With this approach one would be assuming that the strength of evidence criteria has interval properties (in the sense of the classification given by Stevens (1946)) and no ordering characteristics, which is not the case.

5. Conclusion

Ecosystem services (ES) maps using habitats as proxies has, once more, revealed to be a useful approach for ES mapping, but map quality and resolution will depend on the characteristics of the underlying habitat maps used. For this work, a comprehensive map of habitats of the Atlantic coastal region adjacent to the Mondego River was produced, integrating not only inedit 1/10,000 cartography of the sedimentary subenvironments of the study area but other relevant data. To our knowledge it is the first map of its kind, but its production highlighted gaps in the availability of high resolution spatial information for site-specific analysis.

The AHP method applied suggests that saltwork habitats should be a priority for research in the Atlantic coastal region adjacent to the Mondego River and that cultural services play an important role in the studied region. These results are in accordance with decision-makers trends of management, i.e., in line with the recent efforts of local authorities to mainstream the cultural and social heritage associated to human activities in the region, such as traditional salt production. Other recommended habitats for ES research in the study area are Marine pelagic (0–200) waters, Sandy beaches, Estuarine seagrass bed and Estuarine saltmarshes. Analysing ES in these habitats will provide baseline information for decision-making, as it may clarify, and possibly quantify, the potential of these habitats to deliver services and the actual demand by services provided by the region. This information, together with data on the main pressures that could put under risk the ES resilience, could support evaluation with regard to the carrying capacity of the aquatic habitats under study, which is crucial to guarantee the environmental, social and economic sustainability of the region.

The criteria used is suitable for regions where profound gaps in ES research exist. For regions where ES research has already been undertaken, the methodology could be extended or readapted to focus on critical questions that characterize ecosystem services research (Lautenbach et al., 2019). For instance, prioritization could be based on criteria determining whether research on the relationships between ES (i.e. trade-offs, synergies, or no-effects) has already been taken (Lee and Lautenbach, 2016); or on criteria that take into account if a comprehensive integration of ES supply and demand has been assessed (Wei et al., 2017). The approach is appropriate as a first step towards an effective operationalization of the ES concept (Grêt-Regamey et al., 2017). By finding gaps in site-specific ES research, the work is able to find knowledge breaches that hamper the use of the ES concept by decision-makers. The site-specific ES research that may arise from the analysis performed is of utmost importance not only for decision-makers at the local-level but also at high-level decision processes, as the existence of case studies is crucial to develop sound knowledge bases that support the development of ES research (Lautenbach et al., 2019).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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