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Ecosystem Service Mapping: A Management-Oriented Approach to Support Environmental Planning Process

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Abstract

Effective integration of ecosystem services (ESs) into spatial planning and decision-making processes has been advocated as an opportunity to improve current practices and to promote sustainable development. However, the actual uptake of ecosystem services is still challenging, in part due to the complexity of ES studies, data scarcity, and ES compartmentalization, and so on. This chapter presents a case of mapping and characterizing coastal ecosystem services in a way that deals with these issues in order to facilitate its integration in the decision-making and planning process. It gives an insight into which ESs are currently provided in Ria de Aveiro coastal region (Portugal), how are they distributed in space, and identifies multifunctional areas. We argue that the use of existing and available data, as well as tools and approaches that are similar to those used in spatial planning, notwithstanding its limitations, has the potential for bridging science and decision-making spheres. ES-related information could be thus gradually incorporated in the design of local strategies towards sustainable and transparent planning and management processes.

Keywords: social-ecological system, coastal lagoon, mapping, multifunctional areas, multiple ecosystem services, Ria de Aveiro, strategic planning

1. Introduction

Coastal and transitional regions are complex social-ecological systems in the interface of marine, terrestrial, and freshwater environments. They are characterized by providing numerous ecosystem services that contribute to the economic growth and human well-being [1–3] and, consequently, are regions where human presence and activity is especially intense

[4, 5]. Society's demands and development priorities are constantly shaping ecosystems as well as the services they provide [6]. Climate change, coastal erosion, overfishing, land use/ land cover changes, and point and non-point source pollution are among the pressures that threaten these interface and highly productive systems [5–8].

Even though there is not always agreement in the direction marine and coastal management should take, the need for improvement of convectional management practices is clear and consensual, specifically through the better acknowledge and incorporation of biodiversity, trade-offs, complexity of social-ecological systems, and stakeholders' concerns and expectations [9–11]. Any strategy designed to address these issues and to follow an ecosystem-based management approach requires the understanding of social and ecological processes and their relationships [12, 13].

The ecosystem services (ESs) concept offers a framework for revealing and better understanding the links between ecosystems and human well-being [1, 14, 15], helping to assess how ecosystems benefit humanity and how human actions impact ecosystems and the services they provide [10]. It is argued that together with spatially explicit mapping, ES information has the potential to inform sectoral policies and to enable decision-makers to develop more effective and integrated strategies [16–20].

The assessment of ecosystems and their services is increasingly being undertaken worldwide at a variety of scales: (1) regional and global assessments (e.g. biodiversity and ES assessments carried out by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)); (2) European (e.g. pilot studies carried out by mapping and assessment of ecosystems and their services (MAES) working group to support the implementation of the EU Biodiversity Strategy to 2020, action 5); (3) national, for example, [21, 22]; and (4) subnational, for example, [14, 23, 24].

Despite the growing body of work, mapping and assessment of marine ecosystems is less advanced than for terrestrial ecosystems. The main reasons pointed out are the lack of high-resolution spatially explicit information for marine ecosystems and incomplete understanding of ecosystem processes and functions in a highly dynamic three-dimensional fluid environment [2, 25, 26]. Moreover, ES studies tend to focus on a small set of ES rather than having a comprehensive overview of social-ecological systems [27]. For instance, regarding coastal and marine ecosystems, food provision (fisheries), water purification, coastal protection, life-cycle maintenance, and climate regulation are the ES most commonly studied [2]. Considering that decisions are frequently interdisciplinary and involve multiple services, a compartmentalized approach might not be enough to inform decision-makers [7, 28]. These aspects, together with the complexity involving ES studies and assessment tools, are among the reasons why ES integration into planning and decision-making processes is still limited, despite the broadly recognized potential for contributing to environmental management [27–29].

This chapter provides a comprehensive analysis and mapping of the multiple ESs currently provided by Ria de Aveiro coastal region (**Figure 1**). The used approach allows overcoming some of the challenges identified earlier and aims to bridge the spheres of ES research and environmental planning. Moreover, it discusses how ES-related information can be further used by planners in the design of local strategies.

Figure 1. Location of the case study—Ria de Aveiro coastal region—and surrounding municipalities.

The Ria de Aveiro coastal region, located in the northwest coast of Portugal, is used as a case study. It encompasses 19,058 ha of land and 43,527 ha of water, of which 71% are coastal waters. Its landscape is characterized by the presence of the coastal lagoon, plain and open territories, with few vertical elements, extensive areas of agriculture (both open fields and smallholdings), dunes, and pine forests fixing the dunes along the extensive coastline that separates the lagoon from the ocean [30].

2. Which ES are currently provided and where are they delivered?

The approach used to identify and map the ESs provided by Ria de Aveiro coastal region is described in [31]. It uses a set of qualitative indicators as well as various sources and types of information (including data on administrative processes and legal instruments) that indicate the presence of ESs. This approach allows to map a high number of ESs that otherwise would not be possible and contributes to achieving more accurate maps consistent with the case study's reality. Common International Classification of Ecosystem Services (CICES) was the adopted classification system. It follows a hierarchical structure and organizes the ESs in three main categories called 'Sections': provisioning, regulating and maintenance, and cultural services, which are then divided into 'Divisions', 'Groups', and 'Classes'. Even though

CICES V4.3 no longer includes abiotic materials and renewable abiotic energy, abiotic outputs were considered in this study (see [31] for a relation between CICES and the ESs provided by the Ria de Aveiro coastal region).

A total of 11 thematic maps, presented in the following subsections, were produced for Ria de Aveiro coastal region. Depending on the complexity and amount of overlapping ESs classes, each thematic map displays the ESs classes under each CICES's division or group (including abiotic outputs). The aim is to present clear and visually attractive maps, easily understandable by technicians, planners, and other stakeholder groups [31].

2.1. Provisioning services

2.1.1. Nutrition

Regarding nutrition (**Figure 2a**), over 23% of the study area land is used for crop production, of which 28% is also used for grazing. A large part of this area is called *Baixo Vouga Lagunar* (BVL) and is characterized by its alluvial plain/soils and three main landscape units such as open fields, wetlands, and *bocage* (a characteristic man-shaped landscape of BVL consisting of smallholdings divided by living hedges and draining ditches, providing shelter for cattle and crops) [32]. Here, the main crop production is soy, beans, corn, wheat, rice, and forage, and there is only an indigenous cattle species: the certified *marinhoa* breed [32, 33]. Over half of the entire case study area (59%) is used for fisheries. A wide range of fish and shellfish populations of commercial interest are harvested in the coastal lagoon, in the Vouga, Águeda, and Levira rivers, and in the coastal waters. Fishery is a relevant sector for the region in terms of employment, wealth creation, and sociocultural identity [34]. With smaller expressions in terms of covered area but not less important are the marine fish and shellfish production in aquaculture farms and the salt production [35, 36]. The harvesting of wild plants such as common samphire (*Salicornia*) to be sold as a *gourmet* product is an emerging activity as well as the production of marine macroalgae (*Gracilaria verrucosa*, *Chondrus crispus*, *Ulva lactuca*, *Porphyra* spp., *Codium tomentosum*) in aquaculture for human consumption [37].

2.1.2. Materials

Concerning the materials division (**Figure 2b**), woodland is estimated to cover approximately 5,397 ha, which represents 17% of the land area. During low tide, the solitary tube worm (*Diopatra neapolitana*), the ragworm (*Hediste diversicolor*), and the catworm (*Nephtys hombergii*) are collected in intertidal mudflats to be used as bait for fishing [38–40]. The harvesting of plant material for direct use, processing, or agricultural use was once an important activity in the lagoon: rush marshes were used as animal bedding and afterwards as fertilizer; it was also used as raw materials for mats and for protecting salt mounds from wind and rain; seagrasses and macroalgae were used as fertilizers in agriculture; and reeds were used for traditional products/handcraft such as mats. Currently, the use of seagrasses, reeds, and rush marshes is done in a small scale, mostly for handicraft. Also, a small amount of macroalgae is collected for in situ macroalgae farming. Concerning genetic materials, *marinhoa* cattle, registered as Protected Designation of Origin, is bred in Central region of Portugal,
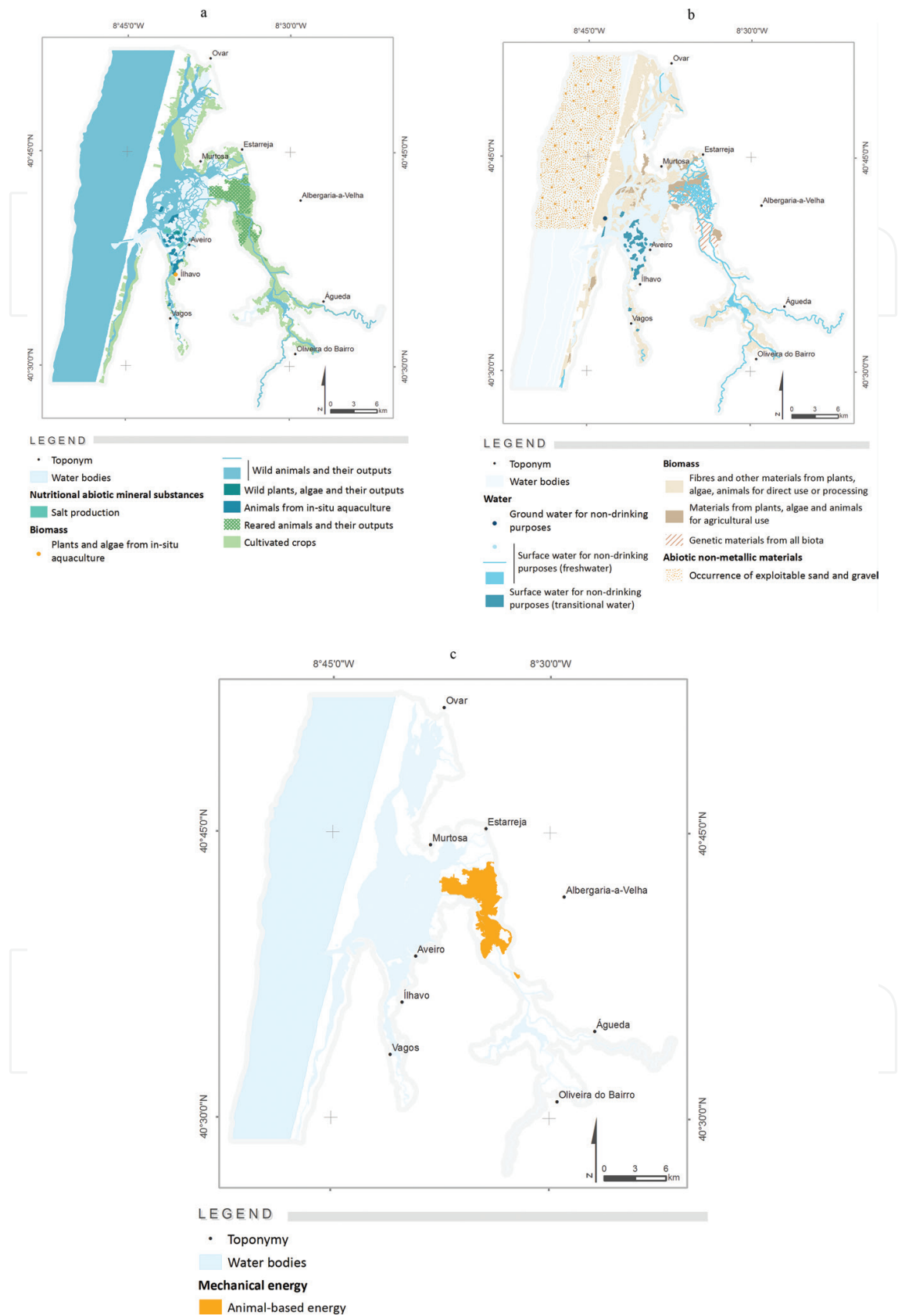
Figure 2. Spatial distribution of provisioning services in Ria de Aveiro coastal region. (a. Nutrition; b. Materials; c. Energy).

particularly in the BVL. Surface water is abstracted from the coastal lagoon, lakes, rivers, and ditches for aquaculture and salt production, crops irrigation, livestock consumption, forest-fire control, and industrial use (e.g. pulp and paper industry). Groundwater is abstracted for public supply. Regarding abiotic materials, approximately 54% of the marine area is composed of sand and gravel which can be exploited for artificial beach nourishment [41].

Ria provides the ideal conditions for exploring in situ aquaculture farms of marine fish (e.g. gilthead seabream, *Sparus aurata*; seabass, *Dicentrarchus labrax*; and turbot, *Psetta maxima*) and shellfish (Japanese oyster, *Crassostrea gigas* and clams, *Ruditapes decussatus*) [34, 38].

2.1.3. Energy

Regarding the energy division (**Figure 2c**), the use of *marinhoa* cattle in the agriculture was identified in the case study as animal-based energy.

2.2. Regulation and maintenance services

2.2.1. Mediation of waste, toxics and other nuisances

The microorganisms, algae, plants, and animals that live in Ria de Aveiro and the ecosystem itself have the ability to purify the water and regulate air quality through biochemical and physicochemical processes (e.g. filtration, absorption, decomposition, dilution). These services are grouped in the CICES' division 'mediation of waste, toxics and other nuisances', which covers 97% of the study area (**Figure 3a**). For instance, macrophytes, filter organisms (e.g. oysters, clams, and mussels), and microorganisms have the ability to reduce the availability of nutrients and potentially toxic elements (e.g. metals, organic pollutants) in the sediment and water column through storage/accumulation, biological filtration, and decomposition; salt marshes and seagrass meadows have the ability to promote the retention of pollutants; riparian areas maintain water quality by capturing and filtering water through their soils before it gets to the streams. Rivers, lakes, transitional waters, and the ocean have the capacity to dilute gases, wastewater, and solid waste through bio-physicochemical processes. *Bocage* landscape helps minimize the visual impact and the odor from the pulp mill industry.

2.2.2. Mediation of flows

Of the 'mediation of flows' division, 'buffering and attenuation of mass flows' together with 'mass stabilization and erosion control rates', and 'flood protection' are the most representative ESs classes in terms of the covered area. Overall, vegetation cover helps to stabilize the terrestrial ecosystems and control erosion rates. This service covers approximately 46% of the land (or 23% of the study area) and is mostly provided by vegetated dunes, crucial for its formation and for coastline stabilization; by riparian areas, essential for riverbanks' stabilization; and also by forests and natural grassland. Moreover, dunes, salt marshes, and seagrass meadows help to maintain the lagoon's integrity. In addition, seagrass meadows and salt marshes reduce sediment re-suspension and turbidity in the water column, contributing to increase the light availability in the water column; rivers, lakes, transitional waters, and coastal waters have the ability to transport and store sediment (**Figure 3b**). Concerning the 'mediation of
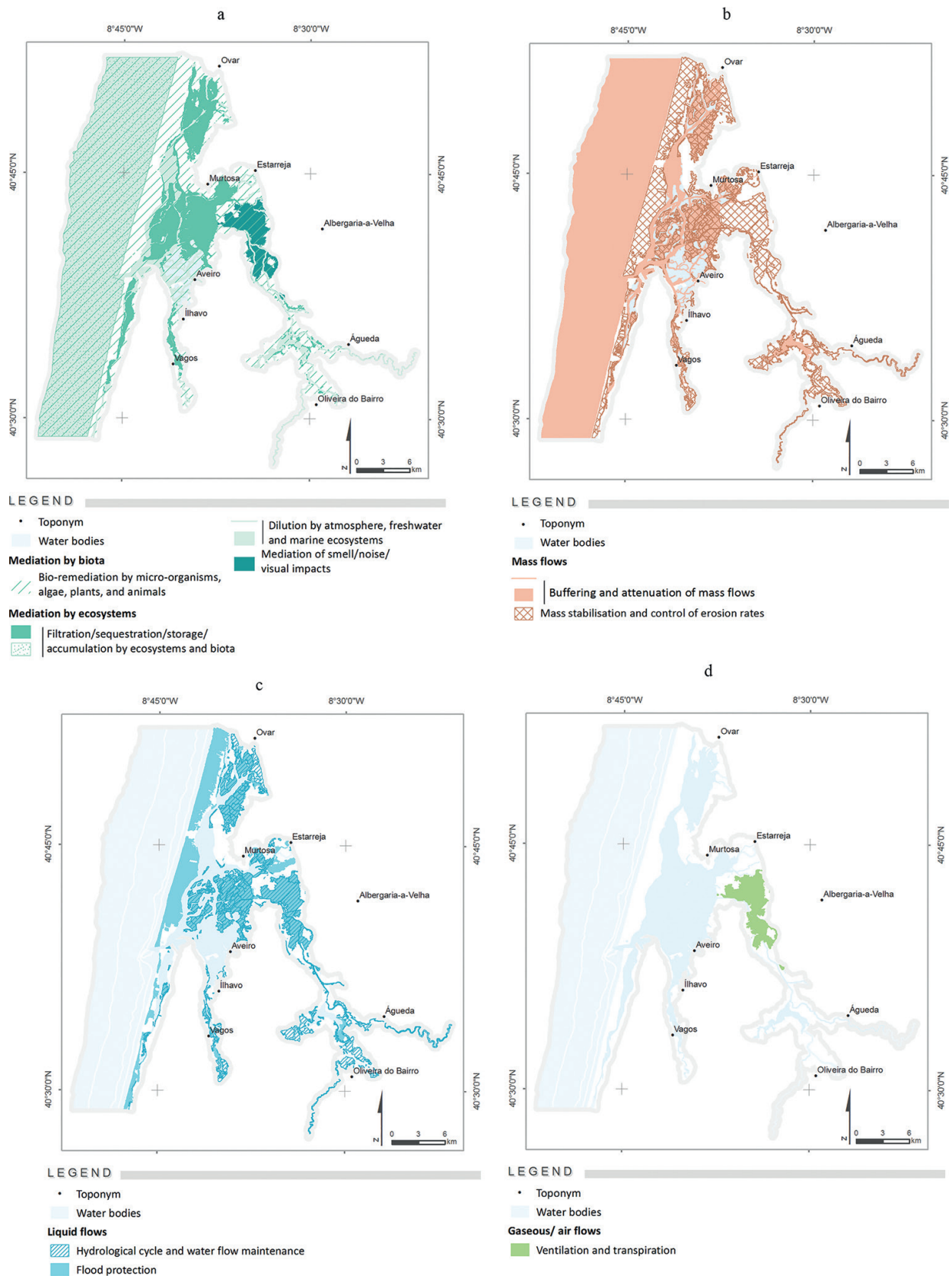
Figure 3. Spatial distribution of regulating and maintenance services in Ria de Aveiro coastal region under the divisions 'Mediation of waste, toxics and other nuisances'. (a 'Mediation of flows'; b. Mass flows; c. Liquid flows; d. Gaseous/ air flows).

liquid flows' group (**Figure 3c**), functional geographical units such as salt marshes, sand dunes, *bocage*, riparian, and alluvial forests provide resilience to extreme weather events, act as physical buffering of climate change, and provide protection from floods. For instance, salt marsh vegetation attenuates wave energy; sand dunes provide direct coastal protection; sand beaches dissipate wave energy by absorbing it; and riparian areas and *bocage* have the ability to slow/reduce the water flow. The class 'hydrological cycle and water flow maintenance' was considered to be present/relevant in the areas where evapotranspiration is higher (see [42])—which in this case coincides with *bocage*, woodland, and salt marshes—and in riparian areas, which have the capacity to store water for its future use, maintaining the water flow. Regarding 'mediation of gaseous/air flows' group (**Figure 3d**), the only ES class identified was air ventilation and evapotranspiration enabled by living hedges of *bocage*.

2.2.3. Lifecycle maintenance, habitat, and gene pool protection

The study area provides a wide variety of habitats (**Figure 4a**), some of them classified under Habitats Directive (92/43/CEE). From the diversity of habitats, we highlight the extensive areas of salt marshes (habitats 1310 pt1, 1320, and 1330), intertidal flats (habitats 1140 pt1 and 1140 pt2), estuaries (habitat 1130), salt pans, coastal dunes (habitats 2120, 2130, and 2170), forests (including habitats 91E0pt1, 91E0pt3, and 91F0), *bocage* landscape, rush marshes, reed marshes, rivers, and freshwater lakes ([35, 43], RCM no. 1125-A/2008 of July 21st]. The most representative benthic habitats present in the marine area of the case study are infralittoral fine sand (EUNIS A5.23) and circalittoral fine sand (EUNIS A5.25), which cover 55% and 44% of the total area, respectively [44]. The habitats present in the coastal lagoon and in the BVL are important feeding and breeding areas for a variety of bird species (approximately 175 species), particularly aquatic and migratory bird species ([43], RCM no. 1125-A/2008 of July 21st). Vouga, Levira, and Águeda rivers are important spawning grounds for anadromous migratory species (as *Petromyzon marinus* Linnaeus, *Alosa alosa*, and *Alosa fallax*) and *Lampetra planeri*. Infralittoral and circalittoral fine sand provide feeding and nursery grounds for several commercially exploited species [43].

Hedgerows, within *bocage* landscape, and woodlands along agricultural fields, support a wide range of pollinators. Therefore, its spatial distribution was used as an indicator of the presence of pollination and seed dispersal services.

2.2.4. Soil formation and composition

Soil composition (**Figure 4b**) is maintained by intertidal mudflats, seagrass meadows, and salt-marshes that play an important role in the nitrogen cycling (nitrogen fixing, denitrification, decomposition) and by terrestrial ecosystems such as woodlands, natural grasslands and some crops (e.g. corn, rice) that contribute to the maintenance of bio-geochemical conditions of soils by decomposition/mineralization of dead organic material, nitrification, and denitrification.

Weathering processes have less expression, being present where fluvisols and woodlands or floodplains overlap.

2.2.5. Atmospheric composition and regulation

Atmospheric carbon is sequestrated by, and stored in, ocean through oceanic algae, woodlands, and macrophytes (e.g. salt marshes, seagrass meadows). These habitats contribute to

the global climate regulation by reducing greenhouse gas concentration (**Figure 4c**). Micro and regional climate is regulated not only by green infrastructures but also by blue infrastructures (through abiotic processes), which contribute to the control of atmospheric conditions. For
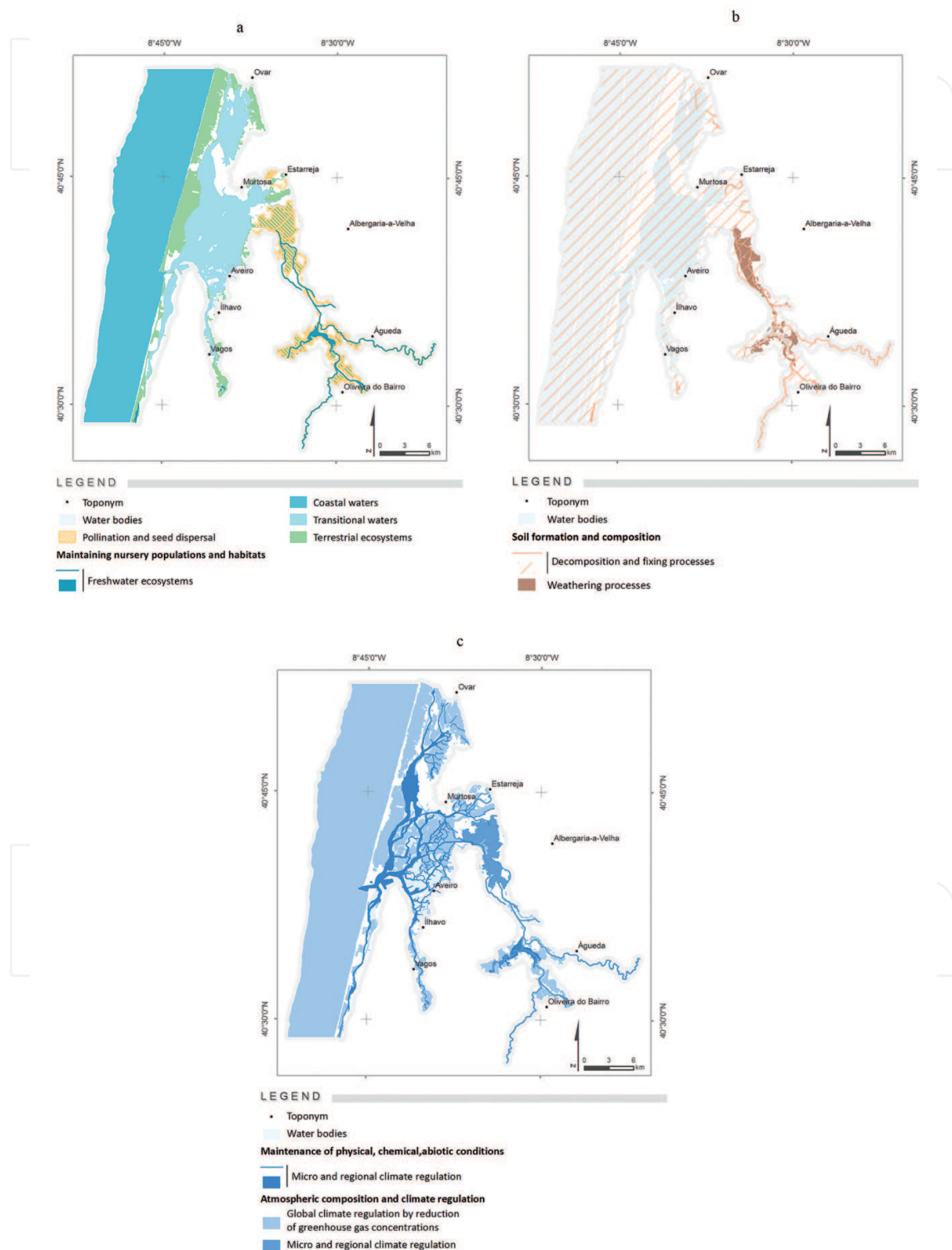

Figure 4. Spatial distribution of regulating and maintenance services in Ria de Aveiro coastal region under the division 'Maintenance of physical, chemical, biological conditions'. (a. Lifecycle maintenance, habitat and gene pool protection; b. Soil formation and composition; c. Atmospheric composition and regulation).

instance, *bocage* constitutes a barrier to the wind; freshwater ecosystems can moderate extreme temperature; and wetlands, due to higher evaporation, can increase relative humidity [45].

2.3. Cultural services

2.3.1. Physical and intellectual interactions

Cultural services provided by the region of Ria de Aveiro are extensive from both physical and intellectual points of view (**Figure 5**). For instance, natural and semi-natural beaches, salt pans, quays, public gardens along rivers and lakes, city channels, Ria's islands, São Jacinto dunes Nature Reserve, and BVL are some places favored for landscape appreciation and bird-watching. Maritime and fluvial beaches are ideal for swimming; pathways along lagoon's margins, lakes, rivers, and ditches are used for walking and cycling; watercourses are used for sailing, canoeing, rowing, surfing, kitesurfing, paddling, and also for angling. The marine and coastal area, the Ria de Aveiro and the Vouga river basin, are subject matter for scientific research as well as a source for education through environmental interpretative centers and museums. Areas such as archeological sites (e.g. shipwrecks, ship hull); traditional fisherman and salt workers neighborhoods (e.g. Beira-Mar); traditional architecture (e.g. *Palheiros* in Costa Nova); and the traditional activities related with the lagoon and the sea (e.g. *Arte Xávega*—an ancient fishing gear; salt production; seagrass, and rush collecting) have significant cultural and heritage value. The ecosystems and biodiversity are also enjoyed/appreciated ex situ through festivals (e.g. gastronomic fairs, Vagueira surf festival, Ria de Aveiro Weekend, ObservaRia—Birdwatching fair, *moliceiro* festival, *N.ª S.ª dos Navegantes* religious festival); provide artistic inspiration for writers and painters; and provide sense of place and identity.

2.4. Multifunctional areas

In order to gain an understanding of the multifunctional areas, that is, areas that have the ability to provide more than a single ES, the spatial results from individual ES classes were analyzed together. In the ArcGIS 10.0, a sequence of geoprocessing tools was performed in order to overlay the individual ES classes from the thematic maps and count the overlapping polygons, lines, and/or points. This resulted in: (1) three-section maps (one map for each CICES' section) representing the multifunctional areas with different overlapping degrees (**Figure 6a–c**) and (2) a synthesis map combining the ES classes from all CICES' sections (**Figure 6d**).

Regarding provisioning services (**Figure 6a**), 12 of 16 ES CICES' classes and 2 of 6 abiotic outputs were identified and mapped. *Bocage* landscape has the higher number of multiple provisioning services, combining four ES classes such as cultivated crops, reared animals and their outputs, genetic materials from all biota, and animal-based energy.

From the 21 ES CICES' classes plus 3 abiotic outputs under the regulating and maintenance section, 20 were identified and 16 (including one abiotic output) were mapped (**Figure 6b**). The number of overlaying ES classes ranged from a minimum of 2 to a maximum of 11. The results show that *bocage* landscape, riparian forests, *Zostera noltei* beds, salt marshes, forests and alluvial forests, coastal waters, transitional waters, forested dunes, and freshwater habitats are associated with a high number of regulating and maintenance classes (over six ES classes).

Concerning cultural services, 9 of the 11 ES CICES' classes were identified and 7 were mapped (**Figure 6c**). The higher number of cultural services is mostly present in the water courses, walking, and cycling pathways in the BVL as well as in the Aveiro city's channels.
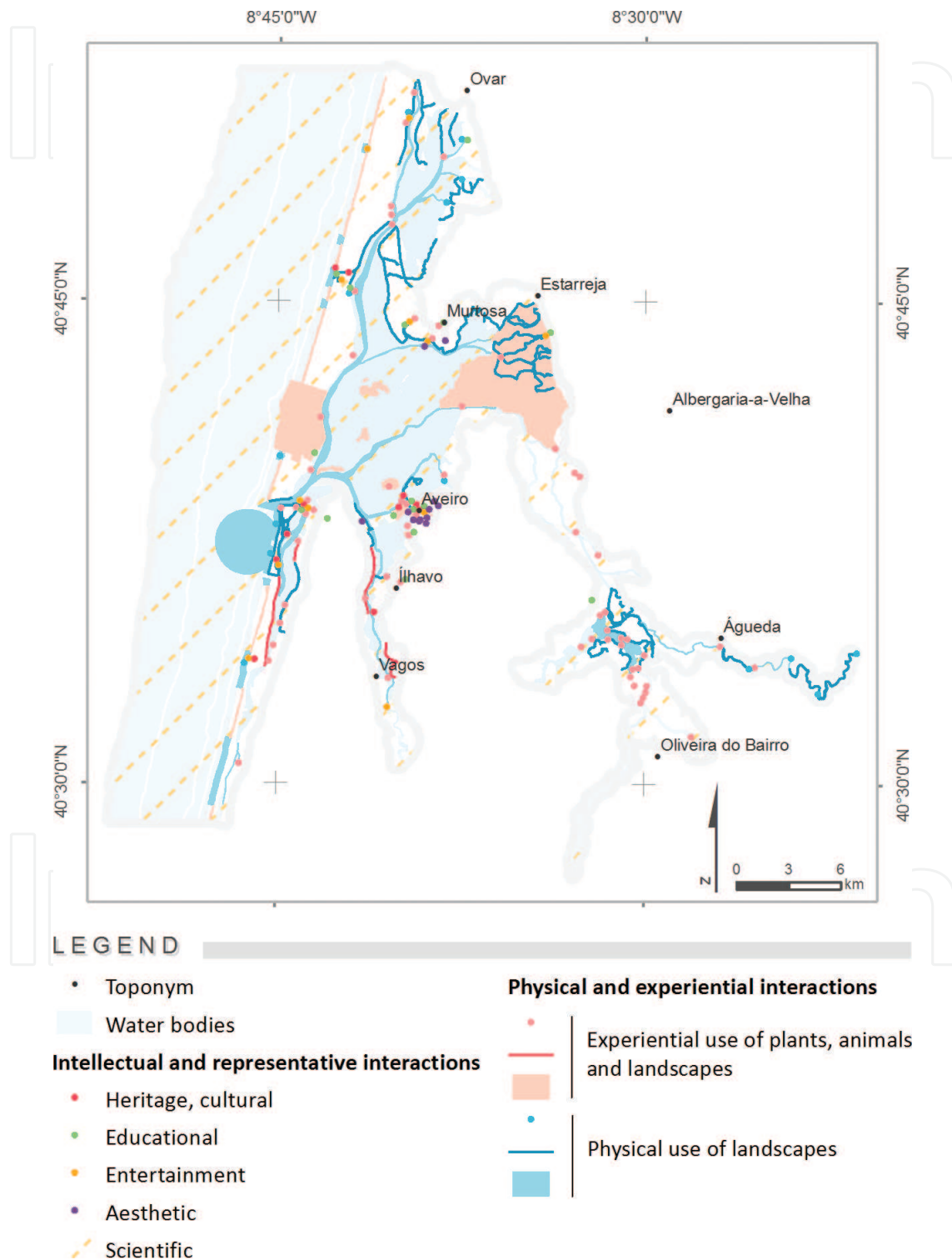

Figure 5. Spatial distribution of cultural services in Ria de Aveiro coastal region.

The synthesis map (**Figure 6d**) reveals that a significant part of the case study (approximately 80%) has the ability to provide a high number of ES (seven or more ES classes identified and mapped). *Bocage*, *Zostera noltei* beds, riparian areas, salt marshes, coastal waters, and freshwater lakes are among the ecosystems present in the case study that provide the higher number of ES, namely maintaining good water quality, reducing patterns of erosion, flood protection,
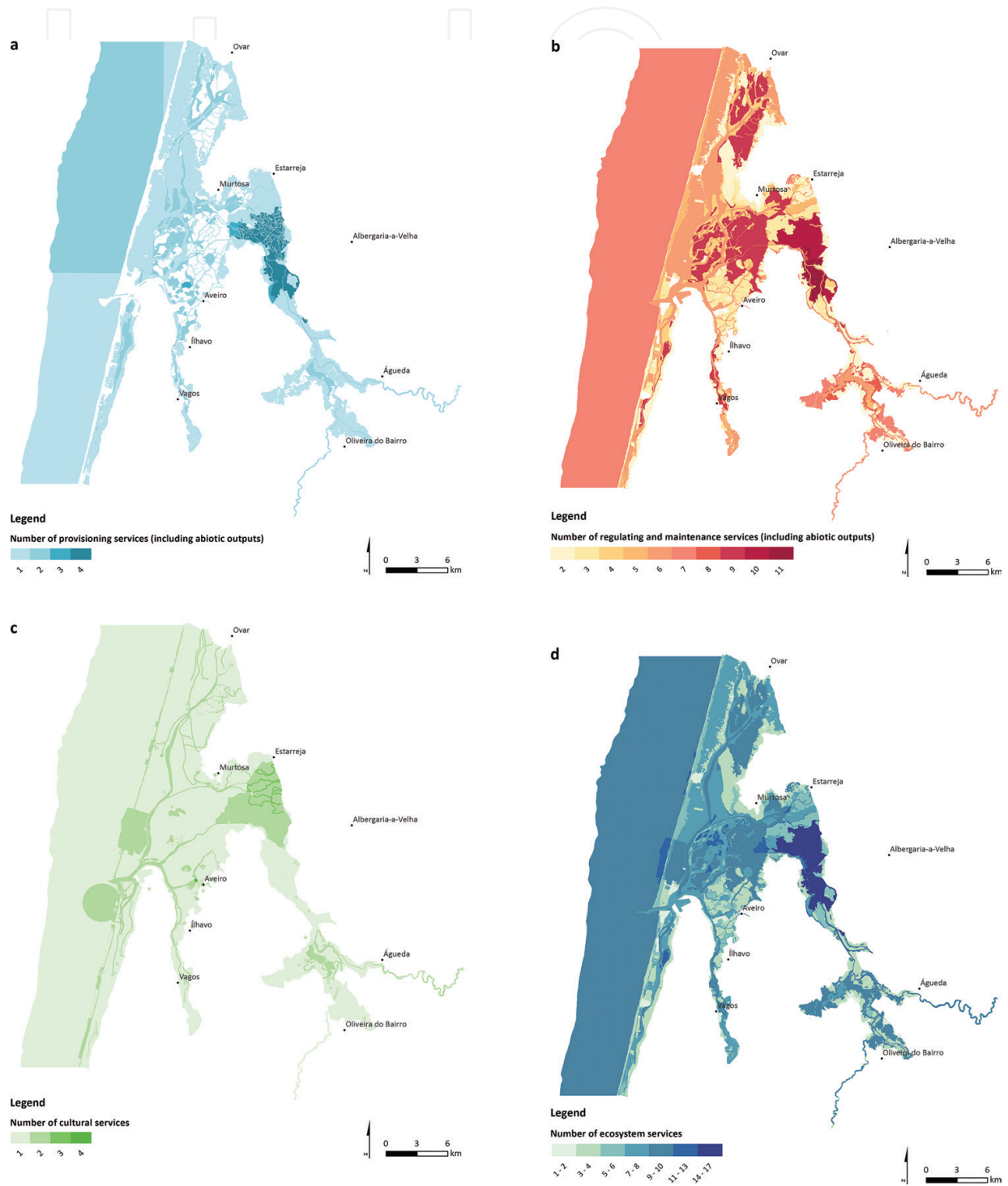

Figure 6. Multifunctional areas by ES section: (a) provisioning, (b) regulating and maintenance, (c) cultural; and a synthesis map combining all the ES classes (d).

maintaining nursery populations and habitats, landscape and scenic quality, recreation, education, and research.

3. Discussion

In this research, an effort was made to bridge science and decision-making, more specifically ES research and environmental planning processes. Therefore, it used existing and available data, as well as mainstream software with the aim of enabling the uptake of the produced information, as well as the approach itself, by spatial planners and technicians. Additionally, it provided:

- an integrated and comprehensive view of the ecosystems services present in the case study, that is, acknowledged the diversity of ecosystems, uses, and activities, and sought to identify and map a wide range of ESs and abiotic outputs rather than focusing on a single or a small set of ESs;

- spatially explicit information relevant to the spatial scale at which decisions regarding the management of social-ecological systems are made;

- an approach that deals with the lack of quantitative and systematic data, particularly at the land use/land cover level.

Being an interface system, Ria de Aveiro coastal region holds a diversity of ecosystems: from marine to seagrass meadows, saltmarshes, freshwater, extensive areas of agriculture, and so on. This brought out the differences in quality, scale, and accuracy of the available data. Marine and coastal lagoon ecosystems, and related uses and activities, have considerably less public and available information, with lower spatial detail than terrestrial ones. Availability of quantitative and systematic data at the ecosystem or land use/cover level rather than administrative is scarce, posing a constraint in the assessment of certain ESs at this scale of analysis.

We argue that ES characterization and mapping, as well as the identification of multifunctional areas, is only the beginning of the integration of ES in the environmental planning process. The analysis and diagnosis of a social-ecological system—which most often correspond to the first stages of any spatial planning process—should incorporate other layers of information, for instance, identify the main pressures resulting from human activities, management options, and/or climate change threatening multifunctional areas and identify their impacts on ecosystems and on their ability to provide ESs, as well as the effects on human well-being. This type of analysis is considered valuable to inform the design of local strategies to adapt communities to current and future challenges; to minimize the impact of pressures on the ecosystems; to identify priority areas for intervention; and to guide public investment. The incorporation of stakeholders' perceptions on significant ESs and concerns regarding the main pressures is also seen as an opportunity to improve the degree of policy and social relevance of the analysis, as it helps meeting the real needs of local population and potentially improving the acceptability of future decisions by communities.

4. Conclusion

The process of identifying multiple services delivered by coastal ecosystems together with their spatial representation, even without any subsequent valuation, is crucial for informing environmental planning process and decision-making. Notwithstanding its limitations, the applied framework proved to be valuable in providing relevant information on ES provision and spatial distribution. We consider that the use of tools and approaches that are familiar to planners or similar to those habitually used is an opportunity for bridging these two spheres and promoting ES integration in planning and decision processes. This must be an adaptive process so it can assimilate new information as methods become standardized or technical capacity is developed.

The authors argue that ES maps and characterization should be used as a foundation—along with other layers of information typically analyzed in the first stages of the spatial planning process—in the design of strategies for socioeconomic development and nature conservation, either at terrestrial or marine ecosystems. Moreover, the combined analysis of ES distribution (including multifunctional areas) and the most vulnerable areas to certain pressures has the potential to better inform planners in the design of local strategies, promoting a more transparent decision, and planning processes.

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Conflict of interest

The authors declare no competing financial interests.

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