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Participatory coastal management through elicitation of ecosystem service preferences and modelling driven by “coastal squeeze”

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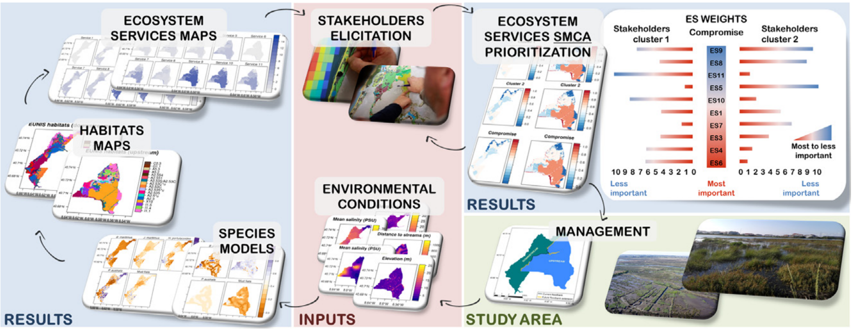
HIGHLIGHTS

- Ecosystem Based Management solutions were co-developed with stakeholders.
- Coastal squeeze was the focus of a coastal area adaptive management cycle.
- Saltmarsh plant species and habitats under coastal squeeze were modelled.
- Ecosystem services were prioritized by stakeholder's elicitation.
- Spatial multi-criteria analysis identified the key areas to be preserved.

GRAPHICAL ABSTRACT



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ABSTRACT

The Baixo Vouga Lagunar (BVL) is part of Ria de Aveiro coastal lagoon in Portugal, which is classified as a Special Protection Area under the European Habitats and Birds Directives. This part of the system, corresponding to the confluence of the Vouga River with the lagoon, is very important culturally and socioeconomically for the local communities, taking place several human activities, especially agriculture. To prevent salt water intrusion from the Ria de Aveiro into agriculture fields, a floodbank was initiated in the 90's. In frame of ongoing changes in Ria de Aveiro hydrodynamics, the existing floodbank will be now extended, introducing further changes in the ecological dynamics of the BVL and its adjacent area. As a consequence, the water level in the floodbank downstream side is expected to rise, increasing the submersion period in tidal wetlands, and leading to coastal squeeze. The aim of this study is to apply an ecosystem based-management approach to mitigate the impacts on biodiversity resulting from the management plan. To do so, we have modelled the implications of the changes in several hydrological and environmental variables on four saltmarsh species and habitats distribution, as well as on their associated ecosystem services, both upstream and downstream of the floodbank. The ecosystem services of interest were prioritized by stakeholders' elicitation, which were then used as an input to a spatial multi-criteria analysis aimed to find the best management actions to compensate for the unintended loss of biodiversity and ecosystem services in the BVL. According to our results, the main areas to be preserved in the BVL were the

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traditional agricultural mosaic fields; the freshwater courses and the subtidal estuarine channels. By combining ecology with the analysis of social preferences, this study shows how co-developed solutions can support adaptive management and the conservation of coastal ecosystems.

1. Introduction

Due to the complex nature of human activity in coastal areas (e.g. Lillebø et al., 2019) Ecosystem Based Management (EBM) planning process appears as a framework supporting integrated coastal management. EBM involves the coordination of policies, institutions and practices (Drakou et al., 2017; Piet et al., 2017; Rouillard et al., 2018), following a set of principles that can be summarized as follows: i) ecological integrity, biodiversity, resilience and ecosystem services; ii) appropriate spatial scales; iii) multi-disciplinary knowledge; iv) social–ecological interactions, stakeholder participation and transparency; v) policy coordination; and vi) adaptive management (Rouillard et al., 2018). One of the main challenges in coastal areas results from tidal wetlands fragmentation and loss due to coastal squeeze (e.g. Borchert et al., 2018). Coastal squeeze is caused by the combined effects of sea level rise (SLR) or water level rise due to hydromorphological changes and human artificial barriers driven by coastal defense or urban and rural development (Pontee, 2013; Mills et al., 2016). Saltmarsh habitats, which are among the most vulnerable coastal habitats in Europe (Janssen et al., 2016), are being particularly targeted by management actions for preventing coastal flooding and salt water intrusion on inland habitats, either favoring or compromising saltmarsh preservation in complex ecological and socio-economic contexts (Doody, 2013; de la Vega-Leinert et al., 2018; Farinós-Celdrán et al., 2017). In this regard, coastal areas are naturally heterogeneous areas prone to host a large number of species and habitats adapted to specific ranges of soil salinity and flooding duration, for which hydrological perturbations represent a major threat (Martínez-López et al., 2014a, 2014b).

In line with EBM planning process, ecosystem services (ES) are becoming a mainstream tool in conservation ecology and management at international, national and regional/local scales (Burkhard et al., 2014; Mononen et al., 2016; Willcock et al., 2018). Assessments of landscape management alternatives at the appropriate spatial scale often involve the modelling of different ES in order to quantify ES trade-offs and hotspots (Martínez-Fernández et al., 2014; Coccoli et al., 2018). Stakeholder participation and transparency is of paramount importance as different sectoral interests, such as conservationists, local users and from the business sector, like tourism, will probably have different priorities in relation to a set of ES of interest. Stakeholders' options can then be used as inputs of a Spatial Multi-Criteria Analysis (SMCA) in order to find best management actions (Villa et al., 2002). Furthermore, stakeholders' preferences on ES can be incorporated into prospective scenarios of ES provision while preventing biodiversity loss following an adaptive management approach (e.g., Vargas et al., 2017; Villa et al., 2002). Thus, a participatory valuation of ES offers a more comprehensive, fair and integrative perspective for Ecosystem Based Management (EBM).

The Baixo Vouga Lagunar (BVL) is a traditional agricultural area located in the inner area of a southern European coastal lagoon (Ria de Aveiro, Portugal), at the confluence of the river Vouga with the lagoon (Lillebø et al., 2019; O'Higgins et al., 2019). In the last decades, this Nature 2000 territory has been suffering from salinization, from surface saltwater intrusion due to changes in the lagoon's hydrodynamics, and land degradation. Together these pressures have led to a reduction in yields over the years and therefore caused rural abandonment (ADAPT-MED, 2015). Within this socio-ecological context, coastal interventions took place for preventing surface saltwater intrusion into these freshwater wetlands and agriculture fields by means of a floodbank (Lillebø et al., 2015a; Luís et al., 2018). The extension of the floodbank, which represents the primary system of defense of BVL against surface saltwater intrusion and management of freshwater from Vouga River is expected to improve accessibility, to foster agricultural and livestock activities and protect the upstream wildlife and other economic activities in the area. This management option has been under public consultation and has passed institutional fitness check (Lillebø et al., 2019). However, unintended impacts on biodiversity are expected, namely at the downstream area of the floodbank, by a coastal squeeze effect fostered by changes in the lagoon's hydrodynamics (Lillebø et al., 2019). In an adaptive management perspective, the aim of this study is to apply an ecosystem based-management approach to mitigate the unintended impacts on biodiversity in BVL resulting from the conclusion of the floodbank. To support the adaptive management approach this study builds upon previous initiatives involving participatory methods and policy characterization (Lillebø et al., 2015b, 2016, 2019; Dolbeth et al., 2016; Luís et al., 2017, 2018; O'Higgins et al., 2019) being structured into main three steps: 1) characterize the spatial and temporal gradients of several hydrological and related environmental variables (e.g. immersion period and water salinity) that influence saltmarshes; 2) improve the existing saltmarsh habitats maps developing new distribution models of four key species and 3) establish critical areas for ES provision in the BVL area, i.e. both upstream (freshwater) and downstream (lagoon transitional water body) the floodbank, through a combination of ES expert judgement valuation (H. Teixeira et al., 2018-this issue) and aggregated preferences on ES of key stakeholders using SMCA. Results show that BVL socio-ecological context illustrates the importance of considering an EBM approach for an effective biodiversity conservation strategy of priority habitats in a Nature 2000 protected area, while reducing conflicts with human uses.

2. Methods

2.1. Study area

The BVL is part of Ria de Aveiro coastal lagoon, hosting a significant area of Atlantic coastal saltmarsh habitats (Lillebø et al., 2015a; Sousa et al., 2017) and integrating the Special Protection Area (SPA – with the Natura 2000 code PTZPE0004; ICNF, 2014; Lillebø et al., this issue, O'Higgins et al., 2019). The transitional biogeographic character of this lagoon area confers it a singular floristic richness, integrating plant communities typical of the Eurosiberian, as well as of the Mediterranean Region (Almagro Bonmatí et al., 2006). The BVL territory is very important culturally and socioeconomically for the local communities, being characterized by a strong and balanced relationship between humans, land and water. Some of the most relevant activities are related with traditional practices that have evolved in equilibrium with the natural environment and are highly dependent on the integrity of this ecosystem (Sumares and Fidelis, 2015). The intricate network of intertidal channels, the reticular saltpan habitats, and the unique BVL 'Bocage' landscape with its water channels and treelines riparian corridors, are a few examples of how human activities contributed to shape and enrich the Ria de Aveiro and BVL natural habitats for centuries (ADAPT-MED, 2015; Lillebø et al., 2015a; Sousa et al., 2015). The BVL area is also home to several important species, in particular migratory bird species (Leão, 2011a, 2011b; ICNF, 2014). Many of these species are targeted for special conservation measures regarding their habitats, under the

EU Nature Directives, in order to ensure their survival and reproduction in their distribution area. The Natura 2000 SPA hosts 60% of the national breeding population of the purple heron (*Ardea purpurea*) and over 1% of the biogeographic populations of several four targeted bird species: (*Recurvirostra avosetta*, *Melanitta nigra*, *Charadrius hiaticula*, and *Charadrius alexandrinus* (ICNF, 2014; ADAPT-MED, 2015).

The study area covers approximately 5000 ha (downstream 2080 ha; upstream 2980 ha) and has a population of 23,556 inhabitants (INE, 2011), stabilized over the recent years based on regional scale yearly trends (PORDATA, 2018). The BVL region is characterized by a temperate climate with a strong Atlantic influence (Costa et al., 1998; Almagro Bonmatí et al., 2006). The annual temperature averages 14.6 °C (Hesse et al., 2015). The maximum daily temperature in summer unusually exceeds 25 °C and in winter rarely negative values are recorded. The annual precipitation averages 1000 mm and it is mainly concentrated in the autumn and spring months (Hesse et al., 2015). Due to its proximity to the Atlantic Ocean and the Ria de Aveiro, air relative humidity values are very high throughout the year, with an average air relative humidity of 80%, with minimum daily oscillation.

The landscape is a mosaic of natural, semi-natural and human-shaped habitats (Mendes et al., 2014), which can be divided into three landscape units: 1) ‘Bocage’, 2) open fields and 3) wetlands (Andresen and Curado, 2001). The traditional form of agriculture, represented by the ‘Bocage’, is a unique habitat, composed of small and irregular patches of farmlands and meadows, intersected by small freshwater courses and living hedgerows of autochthonous trees (e.g. *Alnus glutinosa*, *Salix atrocinerea*, *Quercus robur*), shrubs and grasses (e.g. *Hedera* spp., *Rubus* spp.). This type of agricultural practice is limited to the BVL region in Portugal, but it is also typical of other Atlantic regions of Europe in southern France, northern England and northern Spain (Brito et al., 2010). Beside agriculture, ‘Bocage’ landscape is also relevant for birds of prey, considering the high nests density of black kite *Milvus migrans* and common buzzard *Buteo buteo*, and prey abundance of reptiles (the Iberian emerald lizard *Lacerta schreiberi*), amphibians (the Iberian painted frog *Discoglossus galganoi* and the European tree frog *Hyla arborea*) and mammals (the least weasel *Mustela nivalis*, the common genet *Genetta genetta*, the otter *Lutra lutra* and the polecat *Mustela putorius*) (ICNF, 2014; Lillebø et al., 2015a; Torres et al., 2016). Freshwater ditches and watercourses are also commonly inhabited by amphibians and fishes (e.g. lampreys such as the *Petromyzon marinus* and *Lampetra planeri*, shad *Alosa alosa* and eels *Anguilla anguilla*) (Pombo et al., 2002; García-Seoane et al., 2016). The remaining arable lands correspond to open fields, which are characterized by large agricultural plots with no arboreal vegetation and the production of annual forages (silage maize and hay) or permanent pastures, and to a lesser extent, to the production of rice (*Oryza* sp.) (Mendes et al., 2014).

Wetlands are semi-permanent flooded areas or water-saturated soil areas, wherein a zonation in the vegetation species composition occurs following a salinity gradient. Namely, at BVL wetlands include rice fields and rushes (*Juncus maritimus*) or reeds (*Phragmites australis*) tidal marshes (Almagro Bonmatí et al., 2006). Livestock producers frequently use marsh vegetation as cattle beds. Woodlands around the BVL are fragmented, and mostly composed by plantations of non-deciduous tree species such as *Eucalyptus globulus*, to a greater extent, and *Pinus pinaster* (Lillebø et al., 2015a).

From the geological point of view, it is located in the sedimentary basin of Aveiro, where mainly Quaternary formations appear deposited on a substrate of clay schists before the Ordovician. It belongs to the Vouga river basin and one of the important features of the BVL area is the confluence of freshwater rivers and streams (Vouga, Antuã, Fontão and Jardim rivers) and brackish water courses (Esteiro de Canelas, Esteiro de Salreu, Esteiro do Barbosa, Esteiro da Linha and Esteiro de Estarreja), which together with the estuary constitute the main drainage system. The natural conditions of the BVL - flatness of the land, convergence zone and discharge of several channels, infiltration difficulties as a result of the tide effects on the lagoon - explain its susceptibility to flooding and drainage problems, presenting a large surface area subject to permanent or prolonged waterlogging (Andresen and Curado, 2001). The soils, mostly classified as modern Aluvisols (Michéli et al., 2006), are therefore subject to intense hydromorphism and in some cases to halomorphism (Rogado and Perdigão, 1986).

2.1.1. Coastal management interventions in the area - brief retrospective

In BVL territory the water management for agricultural purposes is based on an ancient network of water channels and ditches, to prevent upstream river flood events and downstream surface saltwater intrusion. However, changes in the lagoon system hydrology have led to the increase of the lagoon water body tidal prism and consequently an increase of surface saltwater intrusion at BVL territory. Past and planned interventions in the BVL territory are summarized in Supplementary online material (SOM1) and aim at regulating the upstream freshwater and the coastal lagoon transitional water regime upstream and downstream the floodbank. The main goal is to prevent freshwater habitats and agriculture fields from being progressively salinized. As a consequence, the water level downstream the floodbank is expected to rise, increasing the submergence period in tidal wetlands, while flood events in the upstream area will continue to contribute to freshwater drain into the coastal lagoon, managed through tidal sluices during ebbing (Lopes et al., 2017).

The main measure consisted of a floodbank built (1995–1999) in the area to prevent the surface salt water intrusion from the coastal lagoon during periods of high tide, as well as to allow the storage of water for irrigation in the dry season and the infiltration of water from drainage in the rainy season (Fig. 1). During the three following years, a program of soil and vegetation monitoring was carried out in order to evaluate its effects on the soil-plant system (DGADR, 2017). In 2004, to comply with the Birds Directive (79/409/EEC), Habitats (92/43/EEC) and Environmental Impact Assessment (85/337/EEC), additional monitoring programs for flora, fauna and water quality were imposed, until the spring of 2007. In parallel several other measures were implemented, which included: construction of a new floodbank, reinforcement works and improvements of the old one, primary drainage systems, as well as secondary roads, irrigation and drainage infrastructures, which implied land restructuring (Andresen and Curado, 2001). However, nowadays the BVL territory is still threatened, as the ecological and the agricultural infrastructures have been subdued by heavy winter upstream floods, downstream surface saltwater intrusion, combined with insufficient maintenance of the hydraulic infrastructures (ditches, dikes, water-gates) (ADAPT-MED, 2015; Lillebø et al., 2015a; Sousa et al., 2015).

2.2. Species distribution models

The saltmarsh habitats of this coastal lagoon and particularly of BVL are well studied and their spatial distribution partially mapped (Sousa et al., 2017). The four more representative species of mid-high marsh halophyte communities were selected for modelling due to their structuring role on community succession from mean high water level until the upper reaches of spring tides in the study area; namely *Halimione portulacoides* (L.) Aellen (sea purslane), *Juncus maritimus* Lam. (sea rush), *Bolboschoenus maritimus* (L.) Palla (saltmarsh tuber-bulrush), and *Phragmites australis* (Cav.) Trin. ex Steud. (common reed). The potential abundance of representative saltmarsh species was modelled based on species abundance data collected in the field (measured as % coverage) over time and on relevant environmental variables. Models were trained using general linear models (betareg family; (Cribari-Neto and Zeileis, 2010; Grün et al., 2012) separately for the downstream and upstream area of the floodbank. Final models were selected automatically following a procedure based on the Akaike Information Criterion (Calcagno, 2013).

The training dataset for the plant species distribution models used coverage data (%) for each species from five field campaigns conducted

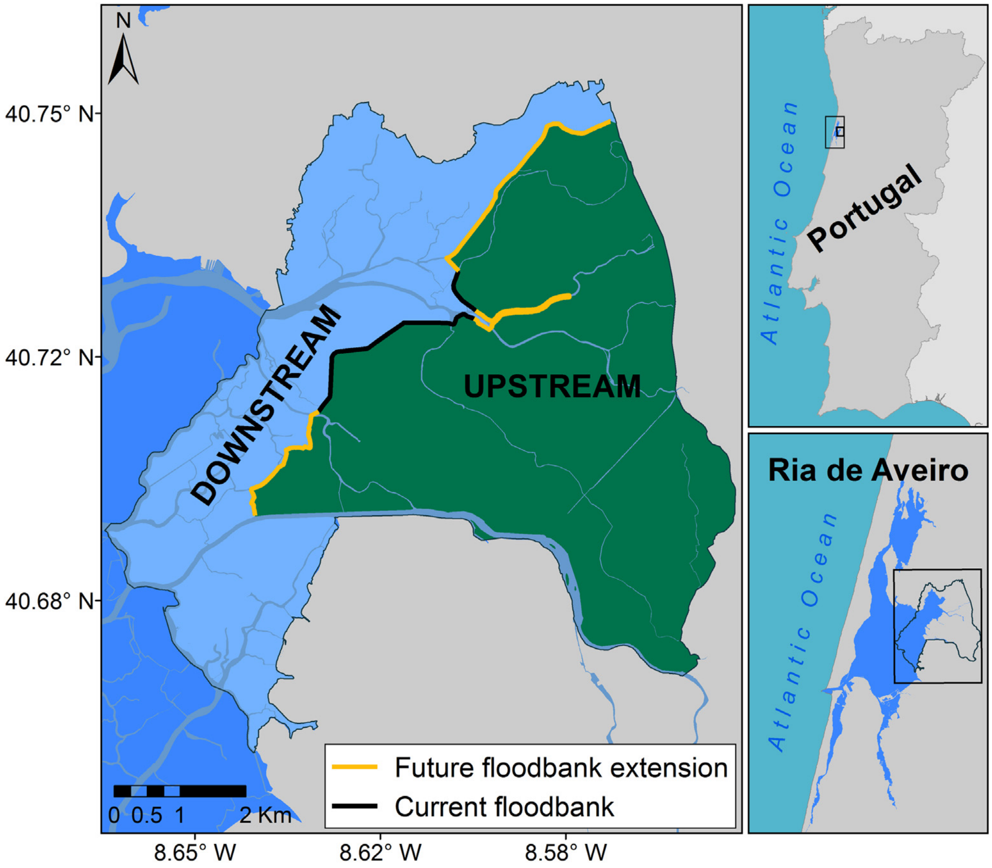

Fig. 1. Map of the Baixo Vouga Lagunar area (BVL) with the current and future floodbank extension.

in 2004 (Autumn/Winter), 2005 (Spring and Autumn), 2006 (Spring), and 2015 (Spring). The sampling sites were located in the BVL area, at an average distance of 150 m, upstream and downstream, from the floodbank (see SOM2). Early years campaigns were part of a monitoring program designed for detecting changes in the spatio-temporal vegetation patterns in the BVL area, while 2015 campaign was part of a research project (MARSH-C-LEVEL) on the effect of sea-level rise on BVL salt marshes carbon storage as an ecosystem service. Between 2004 and 2015 plant species were identified and their coverage was assessed using a simplified version of the Braun-Blanquet scale (Braun-Blanquet, 1979). Overall 13 transects (100 m long) were selected and distributed across four representative areas which were chosen in relation to the floodbank: i) downstream of the existing partial floodbank, subjected to two daily floods by tidal flow, where the most halophilic plant communities are located (T4, T6, T8, T10); ii) upstream adjacent to the floodbank, where the tidal flow is restricted (T3, T5, T7, T9); iii) an area in which the entrance of salt water was strongly increasing and had invaded the agricultural fields, permanently flooded and colonized by halophilic species (T1, T2); and iv) an area in which salt water intake increased, colonized by brackish water communities (T11, T12, T13). In the first campaign (Autumn-Winter of 2004) a more detailed characterization was undertaken by using 520 sampling points (all quadrats) in the 13 transects. In the following years (2005–06), 106 sampling points in the 13 transects were taken per campaign (only at predefined permanent quadrats). In 2015, only 32 points were sampled in three transects (permanent quadrats of T4, T6 and T8) located downstream of the floodbank. For more details on the methodology and quadrats selection criteria see (Almagro Bonmatí et al., 2006; IDAD, 2008; Pinho, 2010).

A set of three environmental predictors were selected for each model, after collinearity check, to avoid the inclusion of highly collinear variables (maximum linear correlation coefficient observed was Pearson $r = -0.66$). Common explanatory variables used in both upstream and downstream models were 1) 'mean salinity' and 2) 'elevation' (m). In addition, for the downstream BVL models, the 'percentage of tides above critical level', related to submersion period, was used; while for the upstream BVL models, i.e. upstream the existing floodbank, the 'distance to streams' (m) was also included as a predictive variable (Fig. 2). The determination of each environmental covariate used in the models is detailed below.

'Mean salinity' for the earlier surveys (2004 to 2006), was taken from field measurements at high tide conditions, at sampling points corresponding to BVL transects (IDAD, 2008). For 2015, a salinity raster, covering the whole study area, was interpolated from field data sampled across the BVL and modelled data from Vargas et al. (2017). For this an ordinal spherical kriging interpolation was used with a raster cell size of 30 m, a variable search radius of minimum 8 points and no maximum distance (Li et al., 2010). The geoprocessing was performed using ArcMap v10.4 and R 3.4.4 (R Core Team, 2018).

'Elevation' was assumed constant for the study period and was obtained from two datasets: a bathymetry point shapefile built on survey information from the hydrographic surveying in Ria de Aveiro (Instituto Hidrográfico, 2013) and an elevation raster of Portugal, previously derived from an ASTER image (Advanced Spaceborne Thermal Emission and Reflection Radiometer; METI/NASA, 2009). The bathymetry shapefile (originally of 100 m cell size) was converted into a raster of 30 m cell size and the values were inverted in order to match the elevation dataset. Then, both rasters were patched. When both files overlapped (bathymetry and elevation) we decided to give priority to the bathymetry because it was surveyed in the field whereas the elevation model was obtained through a satellite sensor.

The 'percentage of tides above critical level' was used as a proxy of immersion stress due to tidal flooding (table in SOM3). Tidal heights above a certain level become critical because saltmarsh species have tolerance limits to submergence in terms of the submersion periods they

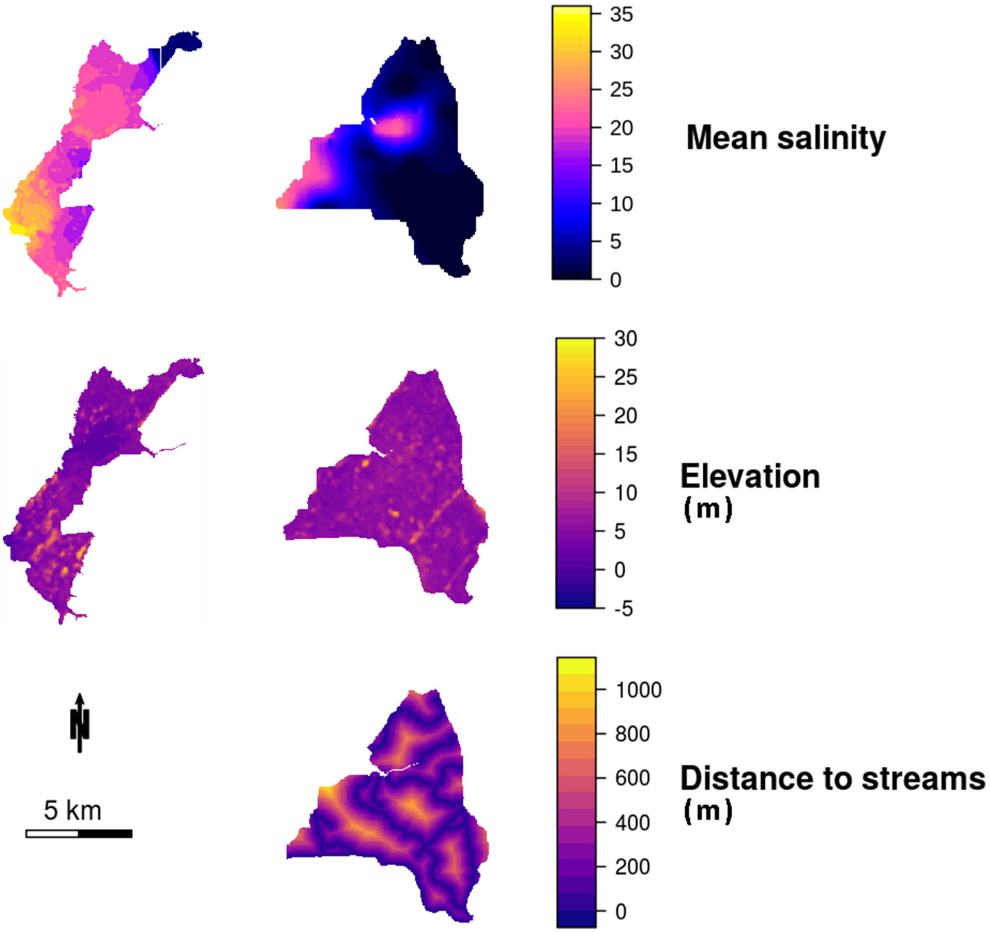

Fig. 2. Input spatial variables used in models for predicting species distribution in 2015, downstream (left) and upstream (right) of the floodbank: salinity, elevation (m; includes bathymetry); and distance to streams (m; only in upstream models).

can sustain (Batriu et al., 2015; Guan et al., 2017). The species' distribution is thus expected to be affected by changes in the hydrodynamics of the system. In this coastal lagoon, a combination of SLR and periodic dredging events are causing an increase of tidal prism and interfering with the lagoon hydrodynamics (Lopes et al., 2013). Critical tide levels (height (m)) were calculated for saltmarsh species in the past and present conditions in BVL territory. For that, we set the current critical tide height at 3 m in 2016, based on authors' personal observations of local saltmarsh distribution in relation to the current mean high tide value of 3 m (SOM3). We then used the mean accretion rate of approximately 0.6 mm$*$year^{-1}, assumed as average considering all saltmarsh species (Sousa et al., 2017), for correcting the critical tide level from 3 m in 2016 for the past years. Finally, daily tidal values were retrieved for the 12 months' period before each vegetation sampling event and the number of high tides above the respective critical height was registered. The percentage of tides above critical level per year was derived to ensure comparison across years (see SOM3). The tidal data was provided by the Instituto Hidrográfico, an agency of the Portuguese Navy.

2.3. Habitat classification and ecosystem service proxies

The BVL main habitats were identified and mapped based on different sources (AMBIECO report on the Ria de Aveiro environmental status; spatial data on Natura 2000 habitats from the National Institute for Nature Conservation and Forests; data from the research projects LAGOONS, ADAPT-MED and MARSH-C-LEVEL). Correspondence of the available habitat maps was established with the EUNIS habitats classification (Table 1).

For the targeted saltmarsh habitats (EUNIS A2.5), the predicted species abundances were used to derive a map of different saltmarsh sub-habitats based on their characteristic relative composition of species (Table 1; A2.5 sub-habitats). The species modelled information was translated into habitat categories by means of ordination and classification analysis, improving the previous saltmarsh information available for the BVL. These saltmarsh sub-habitat classes were predefined based on data from the MARSH-C-LEVEL project,[2] where a combination of ground-truth surveys and vertical aerial images from an unmanned aerial vehicle (UAV) were used to identify and map the most relevant plant species in partial areas upstream and downstream of the BVL floodbank at a resolution of 1 m^2. Finally, the saltmarsh vegetation (including unvegetated mudflat areas) was classified in different classes according to dominant and co-dominant species at each class.

Predicted abundances of species lower than 25% were discarded from the ordination and classification analysis since probability of occurrence was considered too low. The taxa-abundance matrix was first transformed into a dissimilarity matrix using the Bray-Curtis dissimilarity index. Hierarchical clustering was then performed and the resulting classification tree was cut in six groups, to allow best correspondence to the six predefined saltmarsh sub-habitats. Modelled relative abundance of species in each plant community type was analyzed using the indicator value analysis (IndVal; Roberts, 2016). Finally, a mask was created including the areas of previously undifferentiated saltmarsh habitats (EUNIS A2.5), the agricultural (EUNIS I1) and the

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[2] http://www.cesam.ua.pt/.

Table 1
Description of the main habitats occurring in the BVL study area (original data from MARSH-C-LEVEL project). For the saltmarsh habitats (A2.5 at EUNIS level 3), the key species dominating (100%) or co-dominating (25% to 50%) in a given marsh sub-habitat are indicated. Marsh sub-habitat types occurring specifically upstream (u) or downstream (d) of the floodbank are signaled*. EEA EUNIS[a] 2012 habitats classification adapted.

EUNIS code or adaptation	Habitat description (EUNIS original name or adaptation)
A2.3	Littoral mud
A2.5*d	Adapted from original habitat A2.5 (Coastal saltmarshes and saline reedbeds): *Halimione portulacoides* (50%) + *Bolboschoenus maritimus* (50%)
A2.5*u	Adapted from original habitat A2.5 (Coastal saltmarshes and saline reedbeds): *Bolboschoenus maritimus* (100%)
A2.535	*Juncus maritimus* mid-upper saltmarshes
A2.535*d	Adapted from original habitat A2.535 (*Juncus maritimus* mid-upper saltmarshes): *Juncus maritimus* (50%) + *Halimione portulacoides* (25%) + *Bolboschoenus maritimus* (25%)
A2.535*u	Adapted from original habitat A2.535 (*Juncus maritimus* mid-upper saltmarshes): *Juncus maritimus* (50%) + *Bolboschoenus maritimus* (50%)
A2.535/A2.53C	Adapted from original habitats A2.535 (*Juncus maritimus* mid-upper saltmarshes) and A2.53C (Marine saline beds of *Phragmites australis*): *Juncus maritimus* (50%) + *Phragmites australis* (50%)
A2.53C	Marine saline beds of *Phragmites australis*
A2.53C*d	Adapted from original habitat A2.53C (Marine saline beds of *Phragmites australis*): *Phragmites australis* (50%) + *Halimione portulacoides* (25%) + *Bolboschoenus maritimus* (25%)
A2.53C*u	Adapted from original habitat A2.53C (Marine saline beds of *Phragmites australis*): *Phragmites australis* (50%) + *Bolboschoenus maritimus* (50%)
A2.551	*Salicornia*, *Suaeda* and *Salsola* pioneer saltmarshes
A2.554	Flat-leaved *Spartina* swards
A5.2	Sublittoral sand
A5.3	Sublittoral mud
C2.3	Permanent non-tidal, smooth-flowing watercourses
G1.1	Riparian and gallery woodland, with dominant *Alnus*, *Betula*, *Populus* or *Salix*
I1.1	Intensive unmixed crops
I1.4	Inundated or inundatable croplands, including rice fields
I1.5	Bare tilled, fallow or recently abandoned arable land
X10	Mosaic landscapes with a woodland element ('Bocage')

[a] https://eunis.eea.europa.eu/.

terrestrial natural habitats (EUNIS G1), in order to restrain the area of potential expansion of saltmarshes sub-habitats in 2015.

Maps of ES potential supply were then obtained by using a lookup table (see SOM4) on the contribution of each EUNIS habitat to a given ES provision, compiled based on expert judgement (after H. Teixeira et al., 2018-this issue). The ES valuation was weighted as 0, 1 or 2, i.e. from no contribution of habitat to ES (0) to high contribution (2), and made at CICES equivalent ES group level (for more details on the experts' elicitation process see H. Teixeira et al., 2018-this issue). Potential to supply ES by highly mobile biotic groups such as fish and cephalopods, mammals, reptiles, amphibian and insects, which are potentially associated with several habitats, were valuated apart (also weighted 0, 1, or 2). Their contribution to ES was then added to the different habitats that those biotic groups use during their lifecycle. Finally, ES were aggregated into 11 types (see ES type in Table 2), by adding up the values of ES to be aggregated according to correspondence in Table 2. These reduce ES list was used for the stakeholders' preferences elicitation exercise (Table 2). The final list of ES used for the analysis contained only 10 ES types, since 'Abiotic energy sources' (ES 2) was not reported for any habitat in the case study area.

2.4. Stakeholder participation and spatial multicriteria analysis

SMCA was performed using an approach developed by (Villa et al., 2002, 2014), which builds on the Evaluation of Mixed Data (EVAMIX) approach developed by Voogd (1983) and integrates quantitative and semi-quantitative measures into a single score. We applied it to optimize the selection of areas based on the preferences on ES expressed by the stakeholders.

SMCA uses concordance/discordance analysis, where a set of observations with measured variables (in this case, the potential supply of several ES) is ordered according to a concordance or discordance score computed for each different 'evaluation unit'. Each 'evaluation unit' is described by values for each variable considered. First, a 0 to 1 score is computed using sets of weights that express the importance of each variable from a particular stakeholder's perspective. Each perspective is defined by a 'priority vector' containing the weights assigned to each variable, e.g. by a specific stakeholder group. The scores for all units constitute an 'evaluation matrix.' Since this is too computationally intensive to calculate on a pixel basis, it is aggregated by variable values and discretized into a number of intervals (by default the system uses 10 intervals but this parameter can be customized). As a final output, a map of the concordance values ranging from 0 to 1 is produced for each stakeholders' perspective, distributing the computed scores to each pixel. This map represents how concordant the configuration of the landscape is with an optimal landscape, based on a given stakeholder's perspective.

Inputs to the SMCA model included the list of variables (i.e., ES potential) to be considered and a set of importance weights characterizing each criterion. Since different stakeholder or ES beneficiary groups can have diverse perspectives on the importance weights, an active stakeholder participatory process took place in Aveiro in April 27th 2018 (Lillebø et al., 2019). The analytic hierarchy process (AHP) technique was applied to elicit numerical priorities among ES. First, a questionnaire was prepared as an online Google form to be filled in by each participant anonymously using their mobile phones, tablets or PCs in order to make pairwise comparisons of the ES to derive a ranking of criteria for the different stakeholder groups. Six stakeholder categories were defined a priori and included in the questionnaire (Table 3), for each participant to select the stakeholder group that better reflected his/her role in the study area. The scaling method for ranking ES preferences was based on a Likert-type scale, using a five levels bidirectional ordinal scale, with an equivalent number of negative and positive statements: much less important (1/4); less important (1/2); equally important (1); more important (2); and much more important (4). Each participant should qualitatively rank the importance of each ES against the others. A consistency ratio of individual judgments (ICR; Dargahi, 2016) was also computed for each individual answering the questionnaire. From the answers of each participant an anti-symmetric matrix was produced containing the pairwise comparison weights for each ES. Then, their eigenvalues and vectors were calculated and the absolute of the scores of the eigenvector with the highest eigenvalue were selected and used as weights of this participant for each ES after normalization (from 1 to 10). The analysis was performed using R 3.4.4 and the scripts are openly available (Martinez-Lopez, 2018; Team, 2018).

All individual answers were converted into a dissimilarity matrix using Euclidean distance and further classified in groups by means of hierarchical clustering analysis ("Ward" method). The ES ranking of the resulting clusters were compared using Spearman Rank correlation to check for significant differences that would support considering stakeholders´ alternative perspectives, i.e. ES rankings. Initially pre-defined groups were then compared with the resulting clusters of the analysis, checking if the same individuals were grouped together in the a priori identified stakeholder groups. Finally, the average value of the weights for each ES in each cluster was calculated and used into the SMCA, including a compromise group based on the average values across all stakeholders.

3. Results

3.1. Species, habitats and ecosystem services

Overall, based on the results of the species distribution models (Fig. 3; see SOM5 for models' estimated parameters), *P. australis* showed higher abundance on areas with lower salinity, *B. maritimus* was more abundant in areas with lower elevation but negatively affected by higher immersion periods, *J. maritimus* showed a more widespread distribution across the BVL being able to cope with intermediate conditions of elevation and salinity, and *H. portulacoides* was more abundant in areas with higher elevation and higher salinity.

The resulting hierarchical classification tree was cut in six clusters and the relative contribution of the species in each cluster was checked (Table 4). Vegetation clusters obtained were consistent with saltmarsh sub-habitats (A2.5 and derivatives in Table 1). Upstream (Fig. 4), cluster 1 was dominated by *J. maritimus* and *P. australis* (habitat A2.535/A2.53C); cluster 2 by *P. australis* (habitat A2.53C); cluster 3 by *B. maritimus* and *J. maritimus* (habitat A2.535*u); cluster 4 by *B. maritimus* and *P. australis* (habitat A2.53C*u); cluster 5 by *J. maritimus* (habitat A2.535) and cluster 6 by *B. maritimus* (habitat A2.5*u). Downstream (Fig. 4), cluster 1 was dominated by *P. australis* (habitat A2.53C); cluster 2 by *P. australis* and *J. maritimus* (habitat A2.535/A2.53C); cluster 3 by *J. maritimus* (habitat A2.535); cluster 4 by *B. maritimus*, *H. portulacoides* and *J. maritimus* (habitat A2.535*d); cluster 5 by *P. australis*, *H. portulacoides* and *B. maritimus* (habitat A2.53C*d); and cluster 6 by *H. portulacoides* and *B. maritimus* (habitat A2.5*d).

Based on the habitats and associated biota distribution, the resulting maps of aggregated ES valuation using expert knowledge can be seen in Figs. 5 and 6. Following this methodology, provisioning services, such as ES 1 (Biotic-based energy sources) and ES 6 (Nutritional abiotic substances) were likely underrepresented, while regulating and cultural, such as ES 9 (Maintenance of physical chemical biological conditions) and ES 10 (Physical and intellectual interactions with biota, ecosystems, land and seascapes environmental settings) were very important in the BVL.

3.2. Stakeholder participation and spatial multicriteria analysis

The stakeholder meeting gathered 17 people corresponding to 6 stakeholder groups (Table 3). Public administration is the better represented stakeholder group, while business and other interest groups were the least represented. All original answered questionnaires filled in by each participant can be found in SOM6. For the majority of the individuals, the consistency ratio of the judgments (ICR) was low (Fig. 7), indicating coherent answers. However, individual number 2 showed absolute consistency since it gave equal weights to all services, so it was discarded from the analysis as no differences could be possibly derived. Also, individuals number 6 and 7 were excluded since they showed a very high ICR values, much higher than the recommended 0.1 threshold (both above 0.15), indicating that these two individuals very often contradicted themselves when weighing the services, so their opinion was not considered informative.

Two main clusters, representing different opinion groups that share only 25% of relative similarity in their rankings, were selected based on the final list of individuals whose scores were considered meaningful (Fig. 8). Cluster 1 grouped 8 individuals from 4 groups (see Table 3 for

Table 2
Aggregation of 26 ecosystem services (ES) into 10 types for stakeholders' elicitation purposes. ES classification was adapted from CICES.[a]

ES type no.	**ES type (code)**	**CICES ES section**	**Biologically mediated/abiotic outputs of the system**	**ES division**	**ES group**
ES1	Biotic based energy sources	Provisioning	Biotic	Energy	Mechanical energy
			Biotic		Biomass based energy sources
ES3	Biotic materials		Biotic	Materials	Biomass
ES4	Abiotic materials		Abiotic	Abiotic Materials	Non-metallic
			Abiotic		Water
ES5	Nutritional biotic substances		Biotic	Nutrition	Biomass
ES6	Nutritional abiotic substances		Abiotic	Nutritional abiotic substances	Mineral
			Abiotic		Water

Table 2 (*continued*)

ES type no.	ES type (code)	CICES ES section	Biologically mediated/abiotic outputs of the system	ES division	ES group
ES7	Mediation of flows	Regulation & Maintenance	Abiotic	Mediation of flows by natural abiotic structures	By solid liquid gaseous flows
			Biotic	Mediation of flows	Gaseous air flows
			Biotic		Liquid flows
			Biotic		Mass flows
ES8	Mediation of waste toxics and other nuisances		Abiotic	Mediation of waste toxics and other nuisances	By natural chemical physical processes
			Biotic		Mediation biota
			Biotic		Mediation ecosystems
ES9	Maintenance of physical chemical biological conditions		Biotic	Maintenance of physical chemical biological conditions	Atmospheric composition climate regulation
			Biotic		Life cycle maint habitat gene pool protection
			Biotic		Pest disease control
			Biotic		Soil formation composition
			Biotic		Water conditions
ES10	Physical and intellectual interactions with biota,	Cultural	Abiotic	Physical and intellectual interactions with land seascapes	Intellectual representative

Table 2 (*continued*)

ES type no.	ES type (code)	CICES ES section	Biologically mediated/abiotic outputs of the system	ES division	ES group
	ecosystems, land and seascapes environmental settings			physical settings	interactions
			Abiotic		Physical experiential interactions
			Biotic	Physical and intellectual interactions with biota ecosystems and land seascapes environmental settings	Intellectual representative interactions
			Biotic		Physical experiential interactions
ES11	Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings		Biotic	Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings	Other cultural outputs
			Biotic		Spiritual emblematic

[a] https://cices.eu/.

the list of abbreviations): PubAdm (4), PolGov (2), Busi (1) and Scien (1). Cluster 2 grouped 6 individuals from 4 groups: Citiz (2), Scien (2), GrpInt (1) and PubAdm (1).

The mean of the ES scores given by individuals belonging to the same cluster was computed and used as the final weights for the ES in the SMCA. ES with contrasting results among the clusters that were less valued by group 1 were: (4) *Abiotic materials*, (6) *Nutritional abiotic substances*, (10) *Physical and intellectual interactions with biota*, *ecosystems*, *land and seascapes environmental settings* and (11) *Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings*; and for group 2: (5) *Nutritional biotic substances*, (7) *Mediation of flows* and (8) *Mediation of waste toxics and other nuisances*. Service 9 (*Maintenance of physical chemical biological conditions*) was equally low valued by both groups, whereas services, such as (1) *Biotic-based energy sources* and (3) *Biotic materials* were equally medium valued. Highest valued ES were provisioning services 5 (*Nutritional biotic substances*) and 6 (*Nutritional abiotic substances*) for groups 1 and 2, respectively. A moderate negative Spearman rank correlation was found between the rankings of the two clusters ($r_s = -0.57$, $p = 0.087$), but since significance levels were higher than 5%, a third

Table 3
Stakeholder representativeness in the meeting.

Abbreviation	Name	Nr. of participants	Description
PolGov	Policy/governance	2	Environment governance, fisheries and agriculture governance, marine governance and national agencies.
PubAdm	Public administration	8	Regional administration, municipality and parish.
Citiz	Citizens	2	Residents, homeowners, interested individuals, underrepresented and vulnerable groups.
Scien	Environmental sciences background	3	Faculty at local colleges and universities, employees at local research institutions, scientists from state and federal agencies and independent researchers.
GrpInt	Interest groups	1	Local associations, non-governmental organizations (NGO's) and professional organizations.
Busi	Business	1	Tourism, agriculture, fisheries, small businesses, national and multinational corporations with local branches or interests.

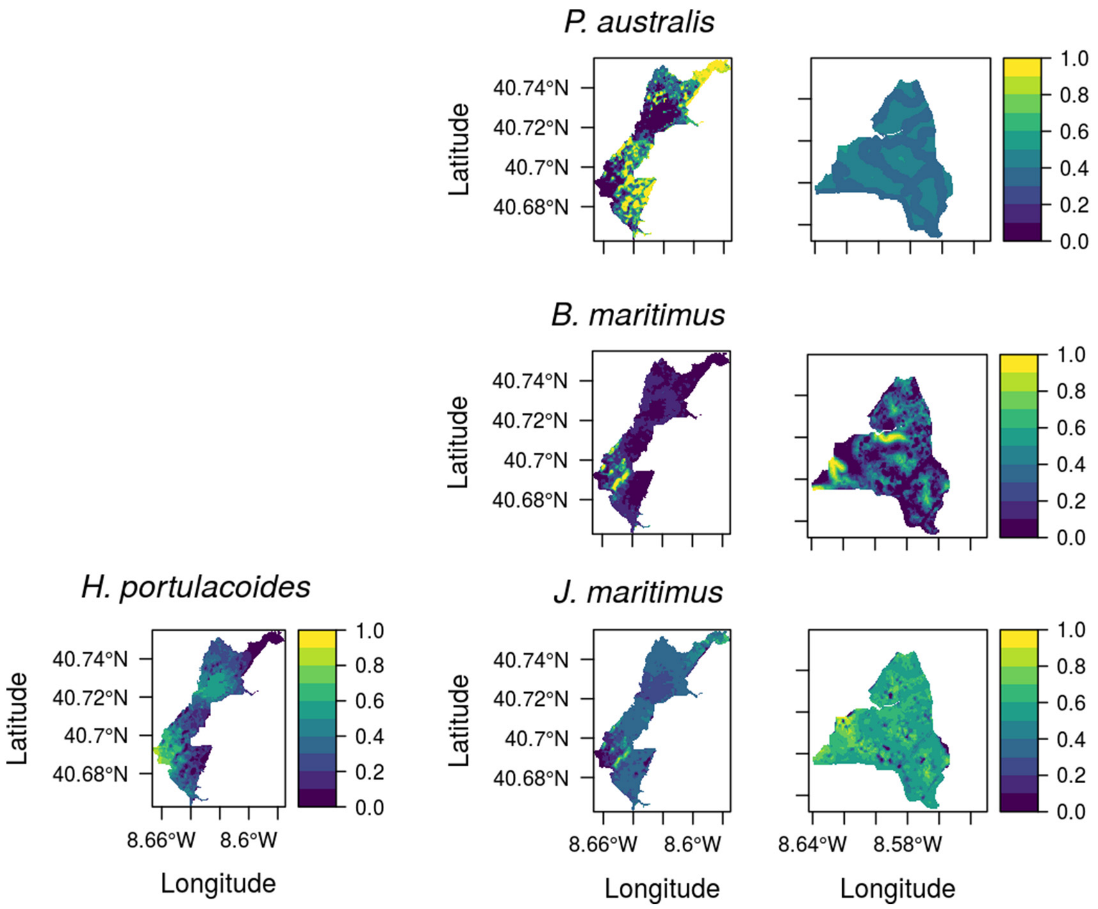

Fig. 3. Species distribution models downstream (left) and upstream (right) of the floodbank. The species *H. portulacoides* occurs only downstream the floodbank. Values represent predicted relative coverage from 0 to 1.

"compromise" group was also taken into account by averaging the scores of both groups (Table 5).

The prioritization maps (Fig. 9) resulting from the application of the spatial multi-criteria analysis in the BVL context, based on the results of the criteria assigned to the ES by different stakeholders' clusters (Table 5), did not differ significantly visually. Hence, a compromise map between the two clusters' views was presented as an alternative, in the absence of significant differentiation between stakeholders' valuations.

Table 4
Modelled relative contribution of species in each cluster downstream and upstream of the floodbank based on the IndVal analysis.

Species/habitat	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Upstream						
Bolboschoenus maritimus	0	0	0.29	0.21	0	0.48
Juncus maritimus	0.16	0	0.2	0.2	0.22	0.2
Phragmites australis	0.16	0.18	0.17	0.17	0.18	0.15
Unvegetated mudflats	0	0.1	0.34	0	0	0.57
Downstream						
Bolboschoenus maritimus	0	0	0	0	0.79	0.21
Juncus maritimus	0.2	0.2	0.19	0.1	0.28	0
Halimione portulacoides	0	0.14	0.17	0.26	0.13	0.29
Phragmites australis	0.41	0.22	0	0	0.37	0
Unvegetated mudflats	0.22	0.18	0.15	0	0.3	0.16

4. Discussion

The management of a socio-ecological system necessarily requires compromises between conservationist and local activities interests following and active and participatory interaction (Lillebø et al., 2016). This is particularly important in complex systems, as demonstrated in other studies (e.g. Lepetu, 2012; Villamor et al., 2014; Z. Teixeira et al., 2018). Furthermore, ecosystems and society are dynamic and adaptive, therefore an EBM approach entails a set of feedback cycles, named as *adaptive-management cycles*, that enables revisiting the EBM principles and mitigate unintended impacts. To support the adaptive management approach for the BVL this study was structured into three main steps, which are now discussed in the following sub-sections. We also discuss the relevance of ES modelling tools in face of some of the foreseen challenges that require further EBM *adaptive-management cycles*.

4.1. Species models, environmental variables and habitat classification

The previous existing habitat map for the BVL, based on field sampling, was very precise in the area downstream next to the floodbank, coarser upstream in the rest of the BVL, and very coarse in downstream areas distant from the floodbank. By means of the species distribution models and the classification of plant communities we obtained a more consistent map of the habitats across the BVL, which improved the assessment of ES and supported spatial planning. The species distribution models did not take into account interspecific interactions and therefore show only potential probability of presence. However, the method used for translating species probability of occurrence into habitats favors those more likely to occur at a given point, which can be

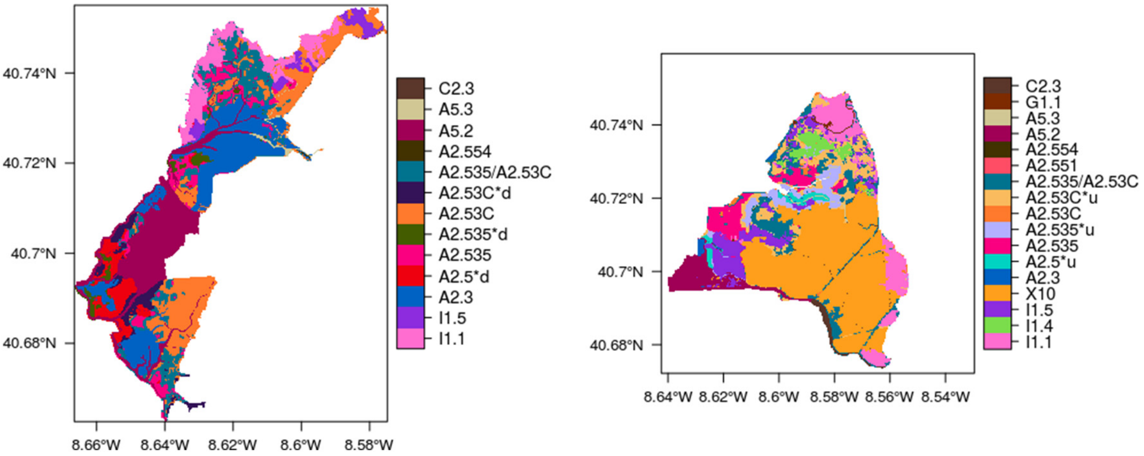

Fig. 4. Resulting BVL upstream (right) and downstream (left) habitats map in 2015. See Table 1 for clarification of the habitat codes.

considered as an indirect accountability of dominance and co-dominance patterns.

Different tolerances of the species to salinity and to immersion were shown to be important factors structuring the saltmarsh community composition in this coastal lagoon area and ultimately determining the loss or recovery of saltmarsh habitats. Thus, potential species predicted distribution in the BVL based on our models was consistent with observations in the literature, as discussed hereafter.

From the four species modelled, *P. australis* is the less tolerant to salinity, with a physiological optimum value below 10 psu (Achenbach et al., 2013; Schenck et al., 2017), concurrent with model predictions of higher abundances at lower salinity in most areas. Above such salinity value, *B. maritimus* has competitive advantages over *P. australis*; and above 15 psu both of them are outcompeted by *J. maritimus* or *H. portulacoides* (Lissner and Schierup, 1997; Lillebø et al., 2003; Achenbach and Brix, 2014; Hroudová et al., 2014; Holmes et al., 2016). These patterns were also observed in our projections (Fig. 3), where *B. maritimus* replaces *P. australis* towards more downstream areas, co-occurring with high probabilities of *J. maritimus*, which are in turn replaced by *H. portulacoides* further downstream.

The common reed *P. australis* is also affected by water table levels (Adnitt et al., 2007; Guan et al., 2017). However, as a perennial species, it easily outcompetes the annual *B. maritimus* under immersion stress conditions, as the later produces no shoots if submerged long, supporting only very occasional tidal inundation. Similarly, *P. australis* was shown to outcompete other *Juncus* species under waterlogged non-saline conditions (Batriu et al., 2015), as *J. maritimus* also die back if submerged long (Adnitt et al., 2007). Our models captured also how stress by immersion affects the species competitive ability. Competitive exclusion between *J. maritimus* and *H. portulacoides*, the two species most tolerant to salinity, has been demonstrated to be decided by the elevation at which species can occur, with *H. portulacoides* usually constrained to higher elevation areas (Talavera et al., 1999). Thus, *H. portulacoides* models showed a higher probability of occurrence in areas with higher salinity with a positive effect of elevation, while *J. maritimus* showed decreasing probabilities of occurrence with

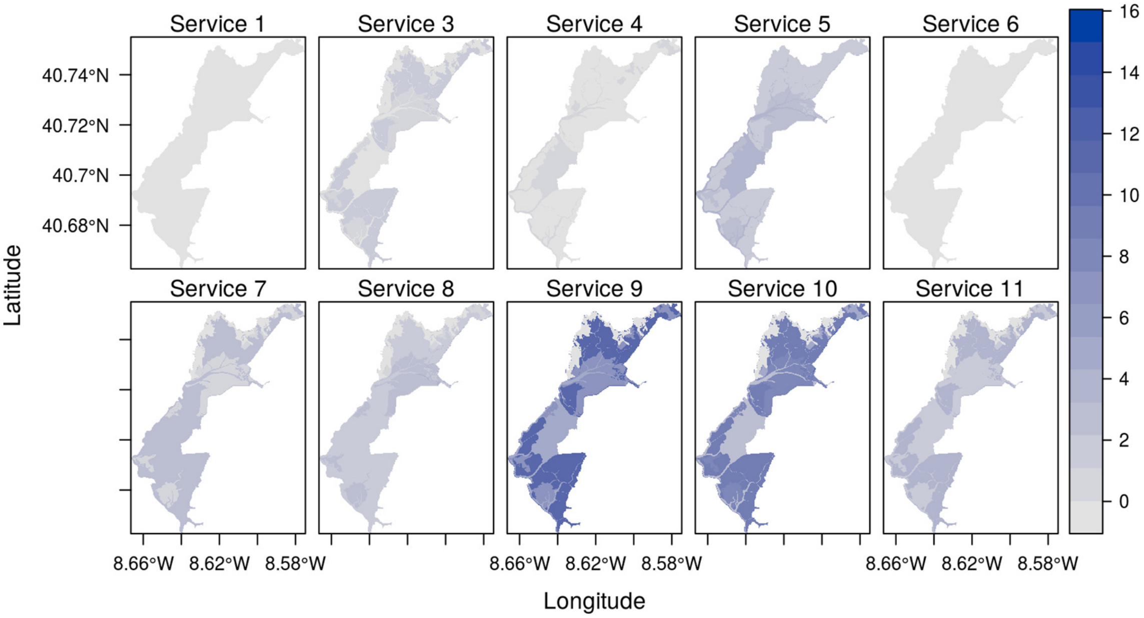

Fig. 5. Resulting maps representing the total contribution of habitats to each aggregated service downstream, following ES valuation using expert knowledge, with the color scale representing the degree of aggregated services overlap in each habitat. Legend: Provisioning Service 1 - Biotic based energy sources; Service 3 - Biotic materials; Service 4 - Abiotic materials; Service 5 - Nutritional biotic substances; Service 6 - Nutritional abiotic substances; Regulation and Maintenance Service 7 - Mediation of flows; Service 8 - Mediation of waste toxics and other nuisances; Service 9 - Maintenance of physical chemical biological conditions; Cultural Service 10 - Physical and intellectual interactions with biota, ecosystems, land and seascapes environmental settings; Service 11 - Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings (see SOM4 for the source look-up table).

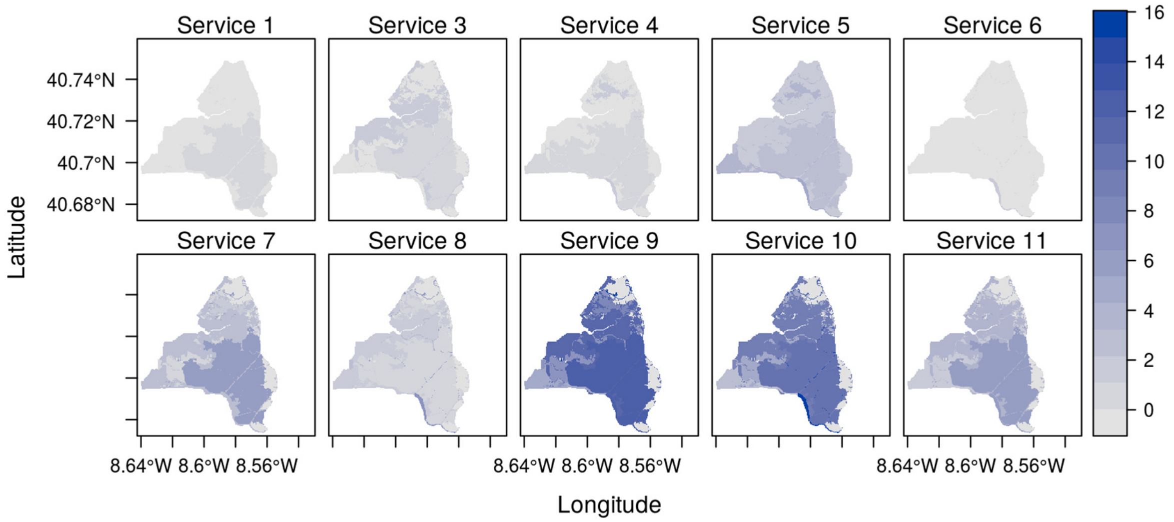

Fig. 6. Resulting maps representing the total contribution of habitats to each aggregated service upstream, following ES valuation using expert knowledge, with the color scale representing the degree of aggregated services overlap in each habitat. Legend: Provisioning Service 1 - Biotic based energy sources; Service 3 - Biotic materials; Service 4 - Abiotic materials; Service 5 - Nutritional biotic substances; Service 6 - Nutritional abiotic substances; Regulation and Maintenance Service 7 - Mediation of flows; Service 8 - Mediation of waste toxics and other nuisances; Service 9 - Maintenance of physical chemical biological conditions; Cultural Service 10 - Physical and intellectual interactions with biota, ecosystems, land and seascapes environmental settings; Service 11 - Spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings (see SOM4 for the source look-up table).

increasing elevation and also more vulnerable to increasing tidal exposure. Models for *B. maritimus* predicted higher abundances in areas with lower elevation, but pointing also to vulnerability to increasing tidal stress, since the species probability of occurrence was negatively affected by higher immersion periods as the percentage of tides above critical level increased. The mudflat intertidal areas in the BVL occurred essentially in lower elevation areas with no saltmarsh vegetation due to the increased tidal prism.

4.2. Ecosystem services mapping

The proxies used in this study for linking habitats and ES (see methodological details in H. Teixeira et al., 2018-this issue) allowed to quantify the importance of specific habitats in relation to several services, which are relevant for different stakeholder groups in the region. However, there were uncertainties in this process that had an influence on the final outcome, mainly a) the method to account for the ES provided by mobile biotic groups and b) the aggregation of multiple ES into reduced ES types, as explained hereafter.

The services provided directly by mobile biotic groups are relevant but difficult to assign to specific habitats (Kremen et al., 2007; Goedhart et al., 2018). In this sense they were valued separately by experts and later added to the habitats they are associated to. The weight of mobile biota ES might have introduced some bias as well, since those

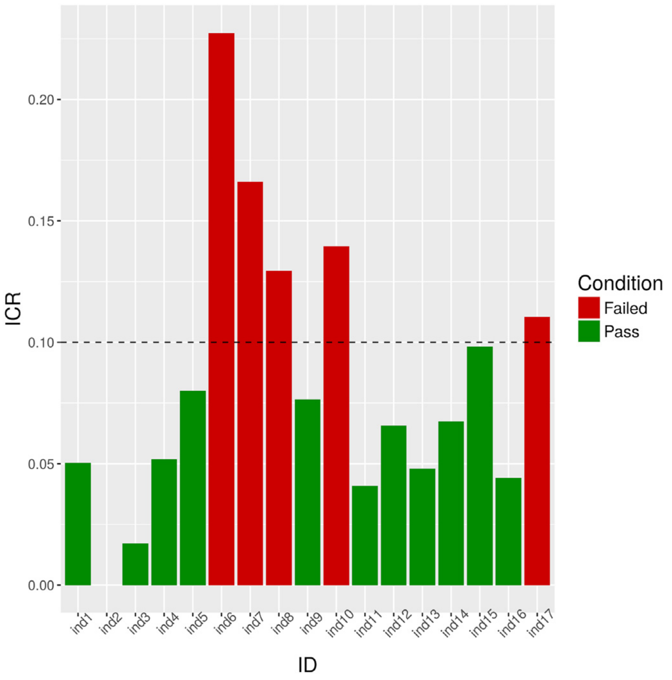

Fig. 7. Consistency ratio of individual judgments (ICR) plot.

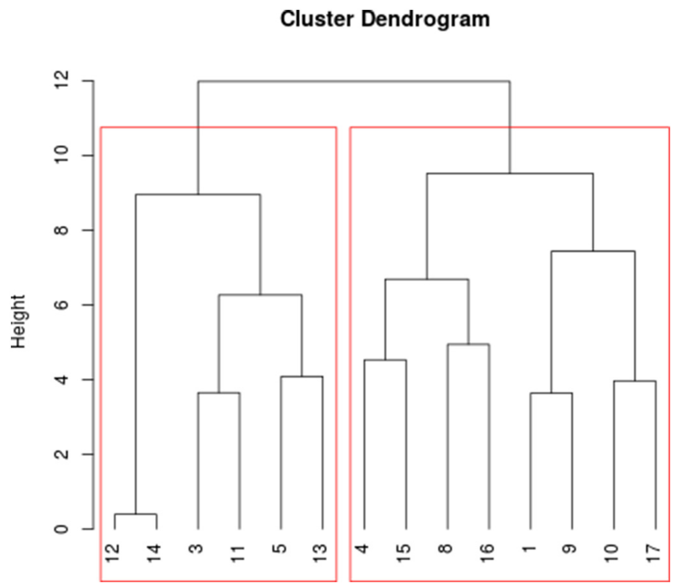

Fig. 8. Cluster dendrogram out of the distance matrix based on the individual preferences highlighting final clusters (red boxes). Numbers at the bottom correspond to the different individuals. Right red box corresponds to group 1 and left one to group 2.

Table 5
Final mean weights of each Ecosystem Service (ES) for the two stakeholder clusters. Values from 1 (most important) to 10 (less important).

Ecosystem service	Cluster 1	Cluster 2	Compromise
ES1	4	5.2	4.6
ES3	4.1	3.7	3.9
ES4	5.9	1.6	3.7
ES5	1	10	5.5
ES6	6	1	3.5
ES7	1.4	6.6	4
ES8	4.2	8.5	6.3
ES9	7.1	9.3	8.2
ES10	8	2.1	5.1
ES11	10	1.3	5.7

habitats with more associated biotic fauna may end up with an overestimated ES provision capacity. This issue should be further tested in future studies to assess the true dimension of this effect.

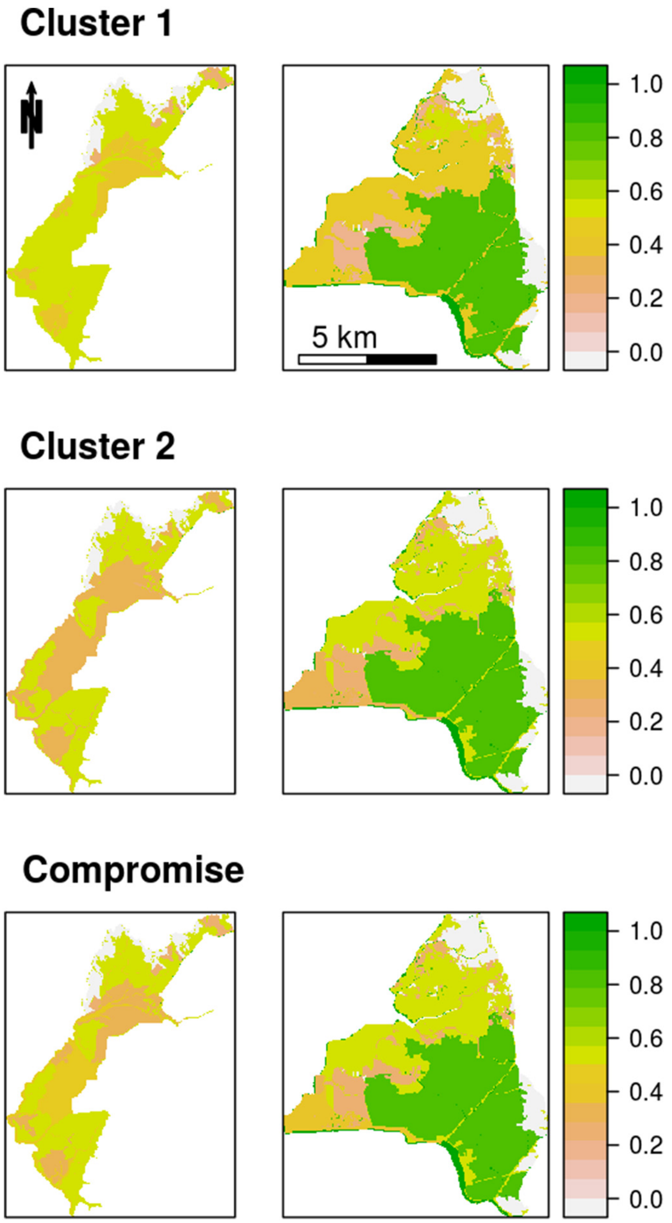

Fig. 9. Downstream (left) and upstream (right) maps of the SMCA output (concordance values ranging from 0, representing no concordance, to 1, representing maximum concordance) for each stakeholder cluster plus the compromise.

On the other hand, in order to facilitate the participatory process of the stakeholders while stating their preferences on ES, the list of 26 ES evaluated by expert judgement, was reduced and presented at broader classes (equivalent to CICES Division Level). This aggregation introduced an artifact between the ES types relative value, because some ES types aggregated more groups ES than others. As a consequence, the habitats identified as providing more of such lumped ES types will come out as more relevant in the priority maps. Despite that the aggregation method adopted in this study overestimates slightly the valuation of ES aggregating more services, there is still a very high correlation with a method, such as using the maximum observed value across the ES to be aggregated that tries to control for that additive effect (minimum observed $r = 0.8$; SOM7). The method for aggregating different ES groups needs to ensure that a balanced weight is kept and differences reflect only expert valuation instead of aggregation artifacts (Willcock et al., 2016; Bennett, 2017; Zulian et al., 2018). On the other hand, the ES types that aggregate more services do reflect the higher diversity and complexity of services provided by habitats providing them, according to the CICES classification.

4.3. Stakeholder participation and spatial multicriteria analysis

The elicitation of priorities by different stakeholder groups in relation to the ES present in the BVL showed contrasting views based on their preferences. This is in line with the diversity of activities and uses of the study area, and hence diversity of stakeholders and respective expectations (Fidélis and Carvalho, 2015; Sumares and Fidelis, 2015).

The spatial multicriteria analysis reflected the different preferences of the two main groups obtained through multivariate classification, thus highlighting several habitats across the BVL that should be preserved in order to meet their expectations. According to our results, the main areas to be preserved in the BVL were the traditional agricultural mosaic fields with a woodland element (X10); the freshwater courses (C2.3) and the subtidal estuarine channels (A5.2). These are the habitats that maximize the delivery of ES as valued by the stakeholders. In this case, the priority habitats were well aligned with the latest interventions recently implemented and planned for the near future in this BVL area, e.g.: floodbank extension to prevent salinization of agricultural fields; dredging of the estuarine channels to maintain navigability; or channel desanding and margins reinforcement for preventing flooding (Lillebø et al. this issue). This study shows therefore that the local communities most immediate concerns (being tackled by management measures in the BVL), match quite well their ES preferences.

These results support the use of the ecosystem services concept as a valid and unbiased approach for capturing stakeholders' preferences and promote participatory approaches to decision-making (Sumares and Fidelis, 2015). Moreover, the AHP method applied for aggregating opinions is able to filter out individuals with highly incoherent preferences and allows furthermore the comparison between individual opinions anonymously. These properties contribute greatly for reducing conflicts between stakeholders by warrantying robustness of the results, transparency along the process, and promote inclusion of very different types of stakeholders in an equal opportunity for expressing their views (Lepetu, 2012; Villamor et al., 2014).

There was, however, an overall similarity among the priority maps generated after each of the two stakeholder clusters, partially due to the fact that most of the ES higher ranked by each group (Table 5) are less supported by the habitats in the area (Figs. 5 and 6). Therefore, the maps used as input were not so different from each other, which did not allow making great distinctions among the groups final priority maps. Therefore, and considering also the low number of participants in this exercise, the compromise group seemed to be a good alternative for management in this case since it very much reflected the priorities of both groups. Improving the participation dimension (Sumares and Fidelis, 2015) is another crucial aspect for ensuring that the expressed preferences are representative for entering the decision-making process. Our study shows clearly that for increasing the homogeneity of the cluster of opinions, the number of individuals in a cluster would be too low and would not legitimate the establishment of management alternatives and measures based on such reduced number of preferences. While the participants were highly engaged, the effort must be however placed in increasing the number of stakeholders participating in order to obtain more representative results that can be used by managers (Langemeyer et al., 2018).For the reasons stated above, the methodology here tested is robust, provides clear and consistent results, and is easy to replicate. This exercise focused of services valuation, as the mapping of the services itself may be a more challenging task for stakeholders (Reilly et al., 2018). However such step is better complemented by habitat modelling and expert-knowledge based maps of ES, as showed in our study. By combining ecology with the analysis of social preferences, management could be informed to improve the conservation of coastal ecosystems (Martínez-Fernández et al., 2014).

4.4. Challenges for further EBM adaptive-management cycles

The models developed in this study should be further used to monitor the evolution of the saltmarsh and predict potential new threats under local SLR projections due to climate change (0.42 m to 0.64 m) until the end of the century (Lopes et al., 2013). With an expected increase of 20% to 35% of the submerged areas in the lagoon, salt marshes might be at risk. The current average salt marsh habitats accretion rate in the area (Sousa et al., 2017), which could compensate for the local SLR effects, is also likely to decrease in the future due to reduced transport of sediments into the lagoon (Lopes et al., 2001), associated to global evidences that unstable marsh conditions favor sediment export (Ganju et al., 2015). In addition, the foreseen capital dredging for the near future is expected to further increase the current tidal prism in a short time frame (Lillebø et al., 2019). Conditions with which most saltmarsh areas in the BVL are unlikely to cope, as demonstrated by our results. These scenarios anticipate a loss of the ES that these habitats provide, namely provisioning of nutritional biotic substances (ES 5); regulation and maintenance of physical chemical biological conditions (ES 9), such as pest disease control and water conditions; cultural services such as physical and intellectual interactions with biota, ecosystems, land and seascapes environmental settings (ES 10); and spiritual symbolic and other interactions with biota ecosystems and land seascapes environmental settings (ES 11). Supported by the models here developed, predicted maps of habitats and ES loss scenarios can be derived and coupled with re-assessed stakeholders' preferences, as demonstrated in the present study. This information would aid managers seeking for compensatory non-conflictive measures at the scale of the whole coastal lagoon (Lillebø et al. this issue) in an adaptive EBM approach for future scenarios.

More dynamic approaches for modelling saltmarsh species distribution, that take into account interspecific interactions and dispersal events, could improve the current models, together with a large scale field sampling campaign that would allow model validation (Martínez-López et al., 2015; Qi et al., 2018). Moreover, using the output of detailed ES models instead of look-up tables based on expert valuations would avoid typical artifacts of those (Bagstad et al., 2013), providing better estimates of services provision and a better accountability of their relative importance.

5. Conclusions

The EBM approach used in this study to mitigate the unintended impacts on biodiversity in the BVL comprised both fundamental and applied research. The proposed methodology to support adaptive management allowed for the co-development of solutions by combining results based on species models, the presence of habitats and the mapping of ES, as well as stakeholders' preferences. The ES elicitation approach followed by a structured analytic hierarchy process showed the advantage of capturing reliable preferences of the stakeholders regarding conservation and management goals. The proposed methodology can be further updated and support decision making in face of new adaptive management challenges for the BVL, namely driven by policies (e.g., environmental status), directly driven by human activities (e.g., land use) or by the need for climate change adaptation (e.g., mean sea level rise). The proposed stepwise methodology clearly illustrates a feedback adaptive management cycle within an EBM approach.

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