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Prioritizing ecosystem services for marine management through stakeholder engagement

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ABSTRACT

When applying the Ecosystem Services (ES) concept for the management of marine activities it is beneficial to involve stakeholders from the start and incorporate their knowledge in the decision-making process. Doing so can help to identify key ES, to prioritize the development of human activities that positively impact those ES, and to identify potential trade-offs and win-win scenarios between sectors. On the Belgian Continental Shelf (BCS), different marine economic activities share a relatively small area where the demand for space continues to grow to accommodate emerging sectors. In order to systematically capture the stakeholders' opinions on key ecosystem services and to make the relation between specific marine economic activities and the anticipated change these bring to the ES, a stakeholder workshop was organized. Participants had to prioritize a list of fourteen marine ES relevant to the BCS and the highest-ranking ES were coastal protection, biodiversity, offshore wind energy, surface for navigation, and habitat maintenance. In addition, a conceptual diagram was co-developed linking marine activities and ES to highlight potential synergies and trade-offs, with a focus on the fastest growing activity in the BCS - offshore wind farming. The approach presented is easily transferable and can help researchers and decision-makers capture stakeholders' perceptions regarding the importance of local ES at specific points in time, thus providing a baseline for establishing priorities during ES modeling and management.

1. Introduction

Marine ecosystems provide a wealth of services that contribute to human health and well-being (Barbier, 2012; Liquete et al., 2013). According to the Common International Classification of Ecosystem Services (CICES), ecosystem services (ES) can be classified into three major types: *provisioning* ES, such as food and raw materials from wild and farmed organisms; *regulating & maintenance* ES, such as coastal protection, climate regulation, and waste remediation; and *cultural* ES, such as recreational and educational opportunities and the expression of symbolic and spiritual values (Haines-Young and Potschin-Young, 2018).

To protect and maintain the flow of these ES to society, the European Union (EU) has taken measures to gradually and explicitly incorporate them into environmental policies (Bouwma et al., 2018). The EU mandates that all member-states quantify and evaluate the state of ecosystems and their services within their national territories, with the ambition to integrate ES into natural capital accounting and reporting schemes (European Commission, 2011; Schröter et al., 2016). ES assessments may also be used to inform decision-making in the context of spatial planning, to ensure their alignment with the ecosystem-based approach. However, within the context of marine spatial planning, ES assessments are not yet formally included in the process (Friess and Grémaud-Colombier, 2019).

Marine spatial planning (MSP) is the process responsible for analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives (UNESCO-IOC & European Commission, 2021), and is of particular relevance in areas of intensive human use. The Belgian

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Continental Shelf (BCS) is one such area, where demand for space is constantly increasing and the allocation of space to the different blue economy sectors is currently defined for the period of 2020–2026 (Federal Public Service Health, Food Chain Safety and Environment, 2016).

To safeguard a sustainable blue economy in the BCS, that allows for the development and integration of the blue economy sectors while protecting the marine ecosystem and its services, future ecosystem-based MSP processes should include ES assessments that use the best available scientific knowledge and monitoring data (Galparsoro et al., 2021; Mulazzani and Malorgio, 2017; UNESCO-IOC & European Commission, 2021). This way, the local/regional effects of human activities on marine ES can be more efficiently and reliably accounted for and used as evidence to prioritize the most sustainable development scenarios (Friedrich et al., 2020; Morf et al., 2019). This will in turn encourage the expansion of activities in the BCS that work with nature rather than against it, following the ecosystem-based approach (Degraer et al., 2020a,b).

Marine spatial planning recognizes that the marine environment is composed of both natural and human elements and that the interrelationships need to be taken into account to ensure a more equitable distribution of access to ES among stakeholders (Haas et al., 2021; Pomeroy and Douvere, 2008). Therefore, stakeholder engagement is an essential step for an inclusive and transparent MSP process (UNESCO-IOC & European Commission, 2021) because it promotes transparency, inclusiveness, knowledge exchange, conflict mitigation, trust, and empowerment among users within the marine social-ecological system (Frederiksen et al., 2021; Newig and Fritsch, 2009; Reed, 2008; Stringer et al., 2006). This is especially relevant in the context of the EU Blue Growth strategy (European Commission, 2012), where the more traditional sectors (e.g. fisheries, shipping, sand extraction) are expected to adapt and cooperate with emerging sectors (e.g. offshore renewable energy, aquaculture). In the context of the German part of the North Sea, for example, stakeholders considered spatial-use conflicts a more pressing issue in the short term than climate change (Hoerterer et al., 2020). This was related to the increased amount of space allocated to new marine activities such as offshore wind farming (OWF), a concern that extends to other exclusive economic zones in the North Sea (Schupp et al., 2021; Steins et al., 2021). The expansion of OWF in the EU is necessary to meet the EU's renewable energy targets and offshore wind power capacity is foreseen to grow from 12 GW in 2020 to 60 GW by 2030 and 300 GW by 2050 (European Commission, 2020). It is, therefore, no surprise that OWF within the BCS is also undergoing significant development, with nine wind farms currently operational and occupying an exclusive area of 225 km^2 and with an additional 221 km^2 to be commissioned, as shown in the current marine spatial plan (Federal Public Service Health, Food Chain Safety and Environment, 2016).

Stakeholder engagement can help gather additional information from marine social-ecological systems and promote healthy relations between science and society and is, therefore, a key element of constructive, legitimate, and influential ES assessments in general (de Juan et al., 2017; Durham et al., 2014; Friedrich et al., 2020; Hölting et al., 2020; Posner et al., 2016; Slater et al., 2020). However, certain stakeholder groups may be skeptical about the relevance and usefulness of the ES concept for MSP. For instance, McKinley et al. (2019) investigated UK stakeholders' perceptions of the concept of ES and its usefulness to marine management and found that industry stakeholders, in particular, were generally less informed and less confident about its usefulness compared to other groups (e.g. consultancies, NGOs, research and government institutions). This mistrust shows that there is a need for more inclusiveness and cross-collaboration with diverse stakeholder groups to promote co-learning and increase trust and adoption of ES assessments for MSP.

Studying stakeholders' perceptions about the ES produced in a particular marine area can provide a better understanding and recognition of their relative importance to a specific group or society at large, to inform ES assessments and marine management (Lamarque et al., 2011; Martín-López et al., 2012; Rey-Valette et al., 2017). This is especially relevant in intensely used areas such as the BCS, where stakeholders use and benefit from the available ES to varying degrees and where ES trade-offs are more likely to occur (Turkelboom et al., 2018). Moreover, potential conflicts among the blue economy sectors might be anticipated and managed accordingly (Koko et al., 2020; McShane et al., 2011). Furthermore, stakeholder engagement could allow researchers and decision-makers to access relevant complementary knowledge (e.g. local ecological knowledge) and fresh perspectives on the state of marine ecosystems and their services that would otherwise be ignored (Bennett et al., 2015; Fulton et al., 2011; Gelcich & O'Keeffe, 2016; Simpson et al., 2016). Participatory conceptual modeling is a useful methodology to capture and integrate stakeholders' knowledge and has been previously used in the context of ES assessments (e.g. Broszeit et al., 2019; Slater et al., 2020). They can serve several concrete objectives, such as focusing attention on specific linkages that should be investigated and providing a first step towards developing dynamic models and tools for evidence-based marine management (Broszeit et al., 2019).

In the context of the SUMES project (Flanders Marine Institute, 2020), whose main goal is to develop a decision-support tool for the BCS to assess the impact of human activities at sea on ES, stakeholders were involved in a participatory workshop to gain insight into their perceptions and knowledge of the ES in the BCS. This study presents the stakeholder engagement process and its outcomes, namely a list of ES priorities and the linkages between those ES and marine activities. These results help to understand the priorities of the blue economy sectors and establish a baseline for ES prioritization in upcoming assessments. It is anticipated that this pragmatic approach can be adapted and applied to other geographical areas to capture stakeholder knowledge quickly and efficiently.

2. Material and methods

The participatory process developed for this study consisted of two activities carried out during a virtual stakeholder workshop to facilitate knowledge exchange and the expression of perceptions related to ES in the BCS by the stakeholders. Before the workshop, a stakeholder mapping process was employed to select the group of stakeholders that would represent the sectoral landscape of the BCS in the workshop (Section 2.1) and a list of the ES relevant to the BCS was created (Section 2.2). During the workshop, a ranking exercise inspired by the method of Rey-Valette et al. (2017) was proposed to the stakeholders. In this first activity, stakeholders were requested to individually select a subset of ES they considered most important and rank them (Section 2.3.1). For the second activity, a diagramming exercise was designed to facilitate the co-creation of a linkage diagram that expressed stakeholders' knowledge on the linkages between the relevant ES and marine activities (Section 2.3.2). The workshop was organized on April 2021 in a virtual setting to conform with COVID-19 restrictions in effect at the time.

2.1. Selection of stakeholders

To facilitate the selection of potential stakeholders for the workshop, we took advantage of the list of nearly 200 members of the De Blauwe Cluster,[1] a Flemish spearhead cluster that supports and unifies its members (mainly companies, but also knowledge centers and government institutes active in the blue economy) to develop and strengthen maritime activities and innovation to achieve sustainable blue growth. All listed members were carefully screened concerning their main activities to make a pre-selection that included all the relevant socio-economic sectors, including those taken up in the Marine Spatial Plan

[1] https://www.blauwecluster.be/leden.

2020–2026 (Federal Public Service Health, Food Chain Safety and Environment, 2016). In consultation with the Compendium for Coast and Sea, sixteen marine-related sectors were considered most relevant in the BCS: aquaculture, cables and pipelines, coastal protection, conservation, consultancy, cultural heritage, dredging, fisheries, information technologies, marine engineering, offshore energy, ports, sand extraction, scientific research, shipping, society, and tourism. After a pre-selection of potential stakeholders across these sectors (n = 76), a series of consultations followed with scientific partners and the strategic advisory board of the SUMES consortium to arrive at a realistic yet representative number of stakeholders to be invited for the workshop. Following the recommendation of Campagne and Roche (2018), we aimed to bring about 15–20 stakeholders to the workshop. The final selection included 30 stakeholders, from which 18 accepted the invitation and participated in the workshop. Although selected amongst the sixteen most important sectors, no representatives of the tourism and information technologies sectors responded positively to our invitations. The sectors are used throughout the document to characterize the stakeholder group, but the identity of the participants and their organizations are kept anonymous.

2.2. Selection of relevant ecosystem services

To create the reference list of relevant ES for the workshop (Rey--Valette et al., 2017), the literature related to ES in the North Sea was consulted using the search string ("ecosystem service*" AND "north sea") in Web of Science. Regional projects webpages and reports focused on ES in the BCS were also consulted. Ecosystem services were added to the reference list following the typology of the Common International Classification of Ecosystem Services (CICES, v5.1) (Haines-Young and Potschin-Young, 2018). The ES were identified either at the Group or the Class levels of CICES. An adapted CICES table that includes references to the consulted sources is available in Supplementary Material (Table S1). Note that dunes and intertidal ecosystems were excluded as we only considered those ES potentially supplied by the biotic and abiotic components within the horizontal boundaries of the BCS (Fig. 1). Fourteen ES were selected as relevant to the BCS (Table 1).

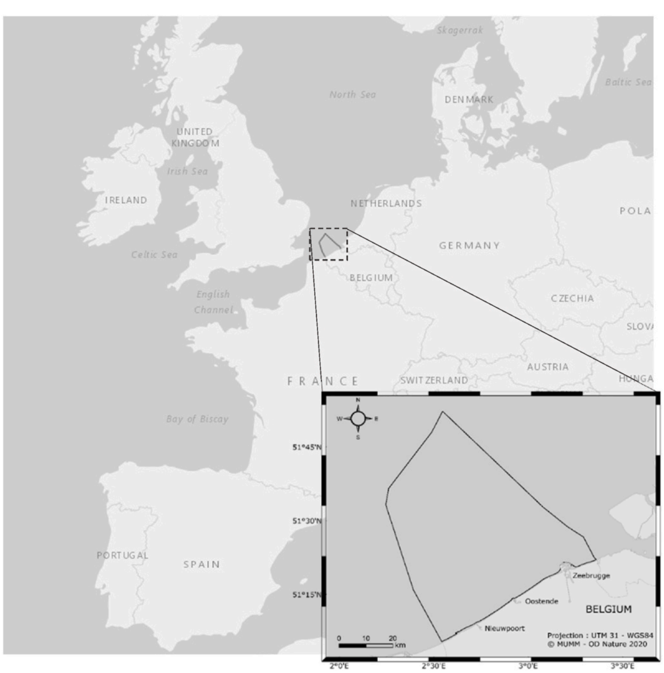

Fig. 1. The Belgian Continental Shelf.

Table 1
List of relevant ecosystem services from the BCS.

CICES section	CICES code	Ecosystem service
Provisioning ES	1.1.2	Farmed plants (for food, materials and energy)
	1.1.4	Farmed animals (for food, materials and energy)
	1.1.6	Wild animals (for food, materials and energy)
	4.2.1.2	Surface for navigation
	4.3.1.2	Sand and other minerals
	4.3.2.3	Offshore wind energy
Regulating & maintenance ES	2.1.1 + 5.1.1	Mediation of wastes
	2.2.1.3 + 5.2.1.2	Coastal protection
	2.2.2.3 + 5.3	Nursery and habitat maintenance
	2.2.6.1 + 5.3	Climate regulation
Cultural ES	3.1.1 + 6.1.1.1	Recreation
	3.1.2.1 + 6.1.2.1	Scientific research
	3.1.2.3 + 6.3	Cultural heritage
	3.1.2.4 + 6.2.1.1	Aesthetic value

2.3. Workshop exercises

The workshop was started with an introductory session to introduce participants to the structure of the workshop and the tools for the participatory exercises. The introductory part also included information on the concept of ES and the presentation of the selected ES (Table 1), to provide all participants with a common knowledge base.

2.3.1. Selection and ranking of ES

To prioritize ES in the BCS according to the stakeholders' opinions and perceptions, the first exercise consisted of three steps. In a first step, participants were first asked which sector they represented so that it would be possible to associate each respondent's responses to their respective sector while keeping their anonymity. This allowed for comparing the relative importance of ES to each sector. In case of an imbalance in the number of representatives per sector, these data will be also used to normalize the responses before determining the final ranking (to balance the contribution of each sector to the final ranking). In a second step, stakeholders were asked to reflect on the fourteen ES selected (Table 1) and determine if they wanted to add additional ES to the list of relevant ES. In the third step, after the additional ES were added to the list, each stakeholder was asked to rank those ES in order of their importance for the BCS from the point of view of the sector he/she represented. Each stakeholder selected the five most important ES and then ranked them in order of priority, from highest (1) to lowest (5). This exercise resulted in a series of ranking scores for each respondent, with the ES in first place receiving 5 points, the second receiving 4 points, the third 3 points, the fourth 2 points, the fifth 1 point, and the non-ranked ES receiving 0 points. Responses were collected using the live polling tool Slido[2] and the anonymized raw dataset is available at Custodio et al. (2022).

Based on the responses, two indicators proposed in Rey-Valette et al. (2017) were calculated: i) *Selection frequency*, which reflected the number of times each ES was selected to be in the top five; and ii) *Sum of ranking scores*, which reflected the overall rank score obtained by each ES. Before calculating the indicators, the responses were normalized by sector. For the *selection frequency,* the mode was used to obtain the most frequent category (*selected*, *not selected*) for each sector regarding each ES; for the *ranking scores,* the mean was used to obtain the average score each sector gave to each ES.

[2] https://www.sli.do/.

Hierarchical clustering was used to determine the similarities between sectors in terms of their ES preferences. Note that in this analysis, we used the individual *ranking scores* from each participant (rather than the normalized values per sector) to have an idea of how participants representing the same sector compared. Hierarchical clustering is an unsupervised clustering method where the different data instances (in this case the *participant*) are grouped in such a way that those clustered together are more closely related than to data instances in another cluster (Rokach and Maimon, 2005). Often dendrograms are used to visualize the results. Hierarchical clustering does not require pre-setting the number of clusters, but the within-cluster-sum-of-squares (WCSS) method was used to help select the optimal number of clusters (Rokach and Maimon, 2005).

A Kruskal-Wallis rank-sum test was used to assess differences in ES ranking between clusters, followed by a Wilcoxon rank-sum test for pairwise comparison. In the cluster analysis, the individual ranking scores from each participant (rather than the normalized values per sector) were used to find out if participants representing the same sector cluster together or not. Differences were considered statistically significant when $p < 0.05$. RStudio (Version 1.4.1717) was used for carrying out the statistical analysis.

2.3.2. *Linking ES and marine activities*

Following the ranking exercise (section 2.3.1.), stakeholders evaluated the perceived effects of certain marine activities on the ES from the previous exercise. To do so, the group was divided into four mixed-sector groups of 4–5 stakeholders, and each group was requested to create a linkage diagram in a breakout room discussion. Each linkage diagram would therefore represent the links between marine activities and ES as perceived by each group. The links were represented by arrows, whose orientation depicts the direction of the effect and the color indicates the type of effect perceived (green = positive effect, red = negative effect, yellow = mixed effect, and grey = unknown effect). Each virtual breakout room was assigned a facilitator knowledgeable in the subject of the workshop and trained in using the diagramming software Diagram.net[3] used in this exercise.

Offshore wind farming (OWF) received special attention in this exercise, given its growing socioeconomic significance in the BCS, and groups were given specific instructions to initiate their linkage diagrams with OWF as a starting point. Other than that, participants were free to pick the ES and additional marine activities they wished to add to the diagram as they progressed through the exercise.

After the breakout discussions, each group presented their diagrams in a plenary session, explaining the links and the reasoning behind them. The four diagrams were then combined into a consensus diagram of all participants, according to the following rules: if a link had the same color across the four diagrams, the original color remained; if a link had at least two different colors across the four diagrams, the effect was considered mixed (yellow color).

The consensus diagram was presented and discussed with an external panel of five scientists with expertise in marine ES (affiliations: AZTI-Tecnalia, Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), National University of Ireland Galway, Royal Belgian Institute of Natural Sciences and University of Liverpool). The final diagram, condensing the inputs from both the stakeholders and the expert group, was developed using the R package DiagrammeR in RStudio (Version 1.4.1717).

3. Results

3.1. *Sectors*

The stakeholder group represented eleven marine-related sectors

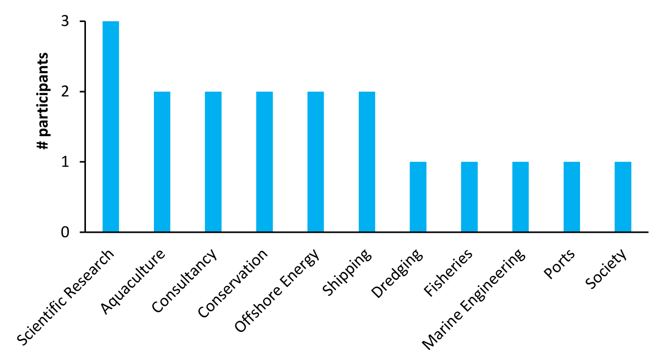

Fig. 2. Sectorial representation.

(Fig. 2). Some of the original sectors (section 2.1) were merged given the considerable overlap in terms of their scope: i) coastal protection was included within marine engineering, ii) cultural heritage was included within tourism, iii) cables & pipelines was included within offshore energy, and iv) sand extraction was included within dredging. The sector with the highest representation was scientific research, with three representatives, followed by conservation, consultancy, aquaculture, offshore energy, and shipping, with two representatives each. fisheries, marine engineering, dredging, ports, and society had one representative. Tourism and information technologies were not represented in the workshop.

3.2. *Ranking*

Participants proposed ten additional ES to the preselected ES (Table 1), namely: *biodiversity, wild plants, intrinsic value, education, birds, minerals, biotic materials, biofuels, water quality,* and *air quality*. From these suggestions and upon consensus only *wild plants* and *biodiversity* ended up being added to the reference list. Eight out of ten proposed ES were left out for three main reasons. Six of the suggested ES were considered similar or analogous to at least one ES from the original reference list or to another one of the newly proposed ES. These were: *minerals* (= *sand and other minerals*), *biotic materials* (= *wild animals, farmed animals, farmed plants, wild plants*), *biofuels* (= *farmed plants, wild plants*), *water quality* (= *mediation of wastes*), *air quality* (= *climate regulation*) and *birds* (= *biodiversity*). The service *intrinsic value* was not included because its compatibility with the concept of ES is debatable (Davidson, 2013). The *education* service, on the other hand, is sometimes combined or used interchangeably with *scientific research* (Mocior and Kruse, 2016; van Oudenhoven et al., 2012) and was not included specifically to avoid confusion.

The stakeholder workshop prioritized ES in the BCS from the perspective of eighteen stakeholder representing eleven marine

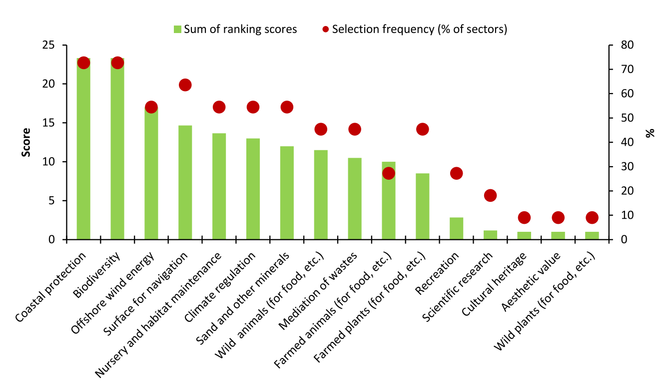

Fig. 3. Ecosystem Services ranking scores and selection frequency.

[3] https://app.diagrams.net/.

socioeconomic sectors (Fig. 3). The top 10 ES according to the ranking scores are (in order): *coastal protection* and *biodiversity* (tie, score = 23.3), *offshore wind energy* (17.0), *surface for navigation* (14.7), and *nursery & habitat maintenance* (13.7), *climate regulation* (13.0), *sand & other minerals* (12.0), *wild animals (for food, etc.)* (11.5), *mediation of wastes* (10.5), and *farmed animals (for food, etc.)* (10.0).

Hierarchical clustering and the resulting dendrogram provided insight into the similarity between sectors regarding ES prioritization (Fig. 4). According to the WCSS method, the optimal number of clusters is three, which appears to make sense following visual inspection of the dendrogram. The red cluster is composed of the sectors of aquaculture, fisheries, and offshore energy; the green cluster includes the sectors of shipping, society, consultancy, offshore energy, conservation, and scientific research; and the blue cluster is composed of marine engineering, dredging, ports, scientific research, consultancy, and conservation. The most important ES to discriminate between the three clusters were *coastal protection, biodiversity, surface for navigation, farmed plants,* and *farmed animals* ($p < 0.05$; Table 2). The red cluster assigned high scores to both *farmed plants* (average ranking score = 3.3) and *farmed animals* (4.3), unlike the other two clusters (<0.4). The green cluster assigned high scores to *surface for navigation* (3.1), a priority not reflected by the other clusters (<0.6). The blue cluster assigned high scores to *coastal protection* (3.6) and *biodiversity* (4.3), contrary to the other clusters (<1.0).

3.3. Diagram

The four breakout groups co-created four linkage diagrams (Fig. S1 in Supplementary Material) that were combined into a consensus diagram depicting fifty different links (Fig. S2), reflecting stakeholders' understandings of how OWF and other marine activities affect ES (and the reverse, how ES affect the activities). The scientific experts validated the stakeholders' diagram and added eight additional links to the final diagram (Fig. 5).

The OWF sector was considered to be dependent on only one ES - *offshore wind energy*. There was general consensus that OWF has direct and indirect effects on thirteen of the relevant ES. Most effects were considered as mixed (i.e. both positive and negative) and were related to *climate regulation, habitat maintenance, wild animals, surface for navigation, recreation, aesthetic value,* and *cultural heritage.* The service of *scientific research* was seen as being always positively affected by OWF, whereas *sand and other minerals* was seen as being always negatively affected. In terms of its direct effects on the other marine activities, OWF was perceived as having a positive impact on Aquaculture (more specifically on shellfish and algae aquaculture, as specified in the diagram) and the passive-type of Fisheries, given the possibility for integration of these activities in a scenario of multi-use of space. OWF was also seen as having a positive impact on Pipes & Cables and Shipping/Ports since it depends on these sectors for its construction and operations. The active-type Fisheries were considered negatively impacted by OWF, given that this type of fishing is excluded from concession areas.

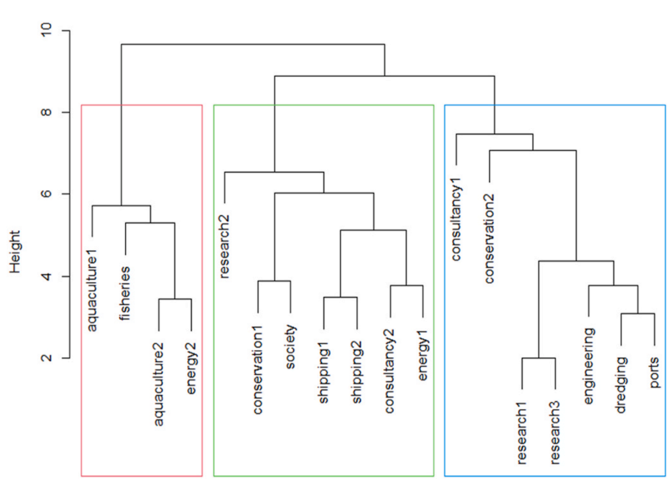

Fig. 4. Hierarchical clustering dendrogram of participants based on ES ranking scores. Labels identify the sector of the participant and the numbers are assigned to labels that are repeated (i.e. sectors with more than one representative). Linkage method: Ward's minimum variance with Euclidean distances.

Table 2
Clusters average ranking scores.

Ranked ecosystem services	Average ranking score		
	Red cluster (n = 4)	Green cluster (n = 7)	Blue cluster (n = 7)
Provisioning ES			
Farmed plants for food, materials and energy*	3.3 ± 1.0 [a]	0.3 ± 0.5 [b]	0 [b]
Farmed animals for food, materials and energy*	4.3 ± 1.0 [a]	0 [b]	0 [b]
Wild animals for food, materials and energy	1.3 ± 2.5	0.3 ± 0.8	1.3 ± 1.4
Wild plants for food, materials and energy	0	0	0.3 ± 0.8
Surface for navigation*	0.5 ± 1.0 [ab]	3.1 ± 2.0 [a]	0.4 ± 0.8 [b]
Sand and other minerals	0	1.4 ± 1.4	1.0 ± 1.5
Offshore wind energy	1.3 ± 2.5	2.7 ± 2.1	0.6 ± 1.5
Regulating and maintenance ES			
Mediation of wastes	0.3 ± 0.5	2.0 ± 2.2	0
Coastal protection*	0.5 ± 0.6 [ab]	0.9 ± 1.5 [a]	3.6 ± 1.7 [b]
Nursery and habitat maintenance	1.8 ± 2.1	1.4 ± 2.1	1.1 ± 1.7
Climate regulation	1.0 ± 1.4	1.6 ± 1.8	1.4 ± 1.6
Cultural ES			
Recreation	0	0.3 ± 0.8	0.6 ± 1.1
Scientific research	0	0.4 ± 0.8	0
Cultural heritage	0.5 ± 1.0	0	0
Aesthetic value	0	0	0.3 ± 0.8
Intermediate ES			
Biodiversity*	0.5 ± 1.0 [a]	0.6 ± 1.5 [a]	4.3 ± 1.3 [b]

* statistically significant differences following Kruskal-Wallis test ($p < 0.05$).
[a,b] different letters represent significant differences between clusters following Wilcoxon test for pairwise comparisons ($p < 0.05$).

4. Discussion

The present study brought together a diverse group of stakeholders from the BCS to understand which marine ES they consider most important in the local context and how the expansion of the OWF sector might affect (and be affected by) those ES and the other marine human activities. The methodology and the results of this study are directly relevant to ecosystem-based marine management in the BCS, by providing a list of ES priorities for the stakeholders, anticipating potential differences in ES valorization, and foreseeing potential ES trade-offs and spatial conflicts associated with the expansion of OWF and other marine activities.

4.1. Prioritizing ecosystem services

The reference list of fourteen ES relevant to the BCS initially compiled (Table 1) was complemented with stakeholders' inputs before the actual ranking exercise. Based on that input, two additional ES were added to the list of relevant ES, namely *wild plants* and *biodiversity*. *Wild plants* was not initially considered a relevant ES because, even though some macroalgae do occur naturally in small patches, information on their use is lacking and angiosperms such as seagrasses are not typically found in the BCS (Belgische Staat, 2012). *Biodiversity* was originally not included because it is considered an intermediate ES and these are not covered under CICES (Haines-Young and Potschin, 2018). The reason why CICES excludes intermediate ES is that they pose a conceptual

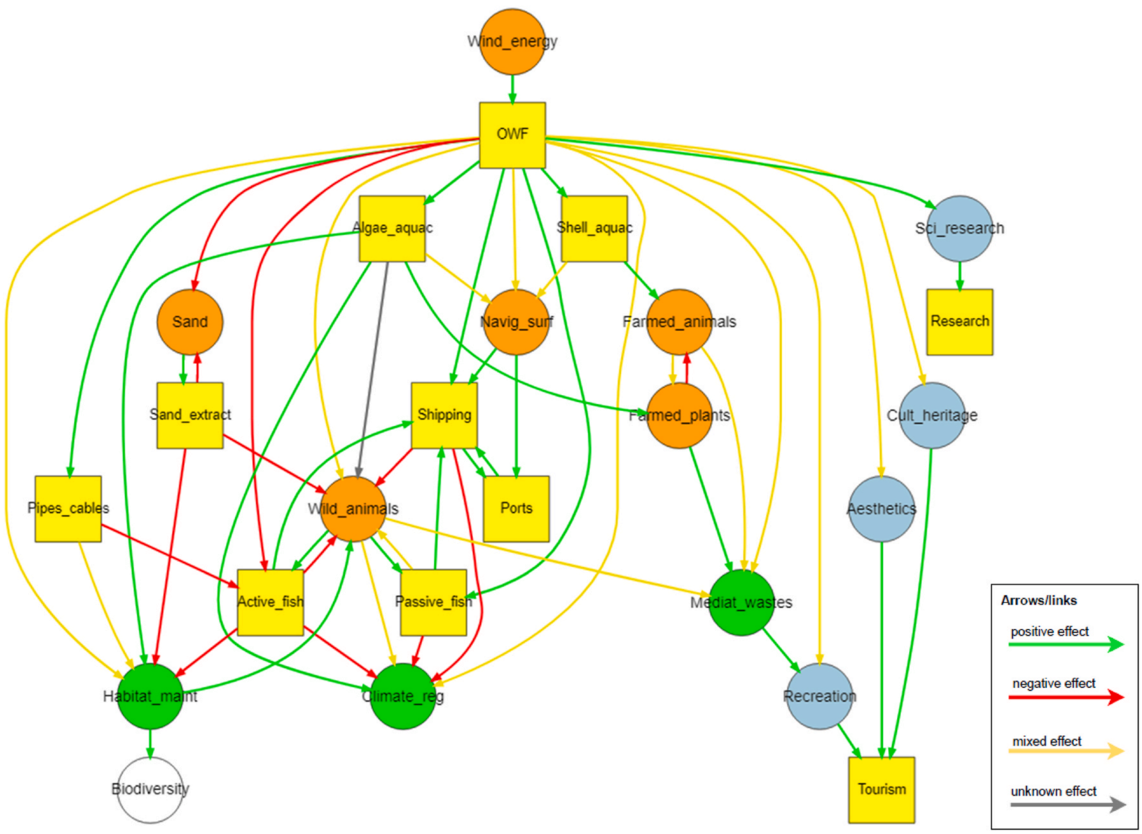

Fig. 5. Linkage diagram of human activities and ES, as perceived by the stakeholders and the scientific experts. Yellow squares - human activities, Orange circles - provisioning ES, Green circles - regulating ES, Blue circles - cultural ES, White circles – intermediate ES.

problem in the context of ES accounting, as they do not describe an ES *per se* but rather represent the ecological functions that underpin final ES (Potschin-Young et al., 2017). Lamothe and Sutherland (2018) also concluded that intermediate ES are in reality ecosystem functions. To avoid this conceptual issue and also prevent potential double-counting, CICES only seeks to classify the final ES that link to the actual goods and benefits that are valued by people. Despite causing some debate regarding its inclusion in the list of relevant ES, *biodiversity* was finally added in order to meet the expectations of the majority of the stakeholders. *Biodiversity* ended up at the top of the rank (Fig. 3), showing that the stakeholders are aware of the importance of biodiversity in the context of ES, notwithstanding the conceptual differences between intermediate and final ES.

Overall, both provisioning and regulating ES were highly valorized by the stakeholder group. *Coastal protection, biodiversity, offshore wind energy, surface for navigation,* and *nursery and habitat maintenance* were the most valued ES, displaying high values for both indicators (selection frequency and ranking score). On the other hand, cultural ES were the least valued, presenting low values for both indicators (e.g. *scientific research*, *cultural heritage*, *aesthetic value*). For a few ES, the position in the ranking changed depending on the indicator used (*offshore wind energy* vs *surface for navigation* and *farmed animals* vs *farmed plants)*. For instance, *farmed animals* had a higher ranking score than *farmed plants,* yet the latter had a comparatively higher selection frequency. This indicates that more stakeholders selected *farmed plants* to be in the top five of their priorities than *farmed animals* but gave it a relatively low ranking score. On the other hand, the fewer stakeholders that selected *farmed animals* as a top ES gave it a relatively high ranking score. It was also evident that certain ES were given high scores by those stakeholders whose activities directly depend on their existence (e.g. *wild animals* to fisheries, *offshore wind energy* to OWF, *coastal protection* to dredging/sand extraction). According to the literature, stakeholders from the fisheries sector tend to prioritize provisioning ES (e.g. *wild animals*), while sectors such as research (e.g. scientists), society (e.g. coastal users and residents), and tourism (e.g. tourists) tend to prioritize regulating and cultural ES more often (Biggs et al., 2016; de Juan et al., 2017; Hicks et al., 2013). Moreover, ES from other marine social-ecological systems and geographical locations might be prioritized differently by the same sectors (e.g. Hicks et al., 2013; Yoskowitz et al., 2016), which highlights the importance of engaging with local stakeholders and avoiding the transfer of results from one location to another.

Cultural ES were ranked the lowest in the present study, a result that was likely associated with the underrepresentation of the sectors that benefit the most from those services, such as tourism (Ruskule et al., 2018; Zamboni et al., 2021). This is arguably a limitation of the stakeholder engagement process of the present research, as not all stakeholder groups and sectors active on the BCS were represented. Hence, some sector-specific opinions and perspectives are not reflected in the ES ranking. In this context, it is important to mention that the communication strategy was the same for all stakeholders invited. Certain stakeholders responded to our inquiry from the first invitation while others responded after a second invitation was sent. Unfortunately, we did not obtain a response from those representing the tourism sector. Some have previously argued that there is a general disconnect of the Tourism community from the ES concept (Pueyo-Ros, 2018), which may suggest that a tailored communication strategy should be adopted when addressing this sector in the context of ES research. Additionally, engaging regular citizens such as coastal residents could also improve the overall ranking outcome of cultural ES such as *aesthetic value* (Gee, 2010; Gee and Burkhard, 2010). All sectors that eventually participated in the stakeholder consultation (Fig. 2) did so enthusiastically and constructively.

Sector-specific priorities are comprehensively illustrated by using clustering methods that, in spite of their simplicity, are not often used in this type of analyses (Mouchet et al., 2014). The hierarchical clustering analysis used in this study identified groups of consistently prioritized ES and thus provided a sense of which stakeholders/sectors are more likely to converge and help identify where conflicts may arise. The red cluster, composed of the aquaculture and fisheries representatives and one from offshore energy, assigned high priority to *farmed animals* and *farmed plants*, contrary to the rest of the stakeholders. Alignment in terms of priorities and challenges is normally expected between aquaculture and fisheries as both sectors belong to the seafood industry and rely on marine living resources (Hoerterer et al., 2020). Joining them is the offshore energy sector, likely reflecting the prospects of an increase in the supply of those ES in the BCS through the integration of aquaculture with OWF (Buck et al., 2017; Federal Public Service Health, Food Chain Safety and Environment, 2016). At the moment, however, those ES are still underdeveloped in the BCS which might explain their low priority to the remaining stakeholders. The stakeholders in the green cluster (shipping, society, consultancy, conservation, research, and offshore energy) prioritized *surface for navigation* and *offshore wind energy*, both vital ES to Belgium's blue economy (Breyer et al., 2017; Lee et al., 2014; Rodrigues et al., 2015) and also *waste remediation*, which was not so important to the other stakeholders (9th position in the overall ranking). This group likely recognizes the issue of eutrophication in the BCS associated with the high nutrient concentration near the coast as the result of inputs from the Atlantic ocean and the river Scheldt (Lenhart et al., 2010). The stakeholders in the blue cluster (marine engineering, dredging, ports, research, consultancy, and conservation) prioritized *coastal protection* and *biodiversity*, reflecting the results of the overall ranking. *Coastal protection* is considered key ES in the BCS that can help mitigate the impacts of storm surges and coastal erosion (Roebeling et al., 2013), but the relatively low supply available from natural components begets the need for human interventions (e.g. seawalls, beach nourishment) (Pranzini et al., 2015). These activities are typically carried out by some of the sectors of this cluster, namely marine engineering and dredging.

The differences outlined above support the view that, in principle, stakeholders will express different priorities towards ES depending on how they engage and connect with them. This has been previously observed in other studies, where the seafood industry tends to prioritize provisioning ES and groups such as researchers, coastal residents and tourists tend to prioritize regulating and cultural ES (Biggs et al., 2016; de Juan et al., 2017; Hicks et al., 2013). This has been previously observed in terrestrial ecosystems as well. Zoderer et al. (2019), for instance, observed that farmers in an Alpine region of Italy expressed a strong preference for provisioning ES, while residents prioritized regulating ES and visitors prioritized cultural ES. Martín-López et al. (2012) observed that, across different Spanish ecosystems, urban people tend to prioritize a different set of ES compared with rural people, giving more importance to cultural ES while the latter group prioritizes provisioning ES. These differences in social preferences towards ES stresses the need to improve sectorial diversity and representativeness in participatory processes, to cover as much as possible the multitude of societal demands for marine ES and mitigate potential biases towards the influential sectors. Identifying stakeholders' perceptions about ES and marine activities will help identify potential conflicts and, thereby, enable targeted measures to stimulate cooperation and create compromise during marine management processes (Blayac et al., 2014; de Juan et al., 2017; Rey-Valette et al., 2017).

4.2. Linking ES and human activities

The linkage diagram co-created with the stakeholders and the scientific experts highlights the potential interactions of OWF with other marine activities and local ES in the BCS, expressing both positive, negative, and mixed effects (Fig. 5). From the stakeholders' point of view, only *scientific research* is positively affected directly by OWF development. This reflects the many research opportunities that the presence of OWF provides, such as studying the impacts of artificial structures on marine life and hydrodynamics (Degraer et al., 2020a,b; Gill et al., 2020), and changes in geophysical and geochemical processes (Dannheim et al., 2020; De Borger et al., 2021). The boost in research opportunities is also supported by the obligation of OWF operators to monitor their environmental impacts as part of their license in the BCS. Additionally, indirect positive effects are also perceived, for instance, in *farmed animals* and *farmed plants,* given the possibilities for developing low-trophic aquaculture (e.g. seaweed, bivalves) in co-location with OWF (Abhinav, 2020; Galparsoro et al., 2020). Increasing these ES by promoting low-trophic aquaculture may, in turn, positively impact regulating ES such as the *mediation of wastes* through the function of filtration/extraction of particulate and dissolved matter that those low-trophic organisms provide (Lindahl et al., 2005; Mavraki et al., 2020).

Most of the highlighted links suggest a mixed effect of OWF on local ES. The extent to which the effect is positive or negative may depend on a variety of factors. For example, *aesthetic value* can be negatively or positively affected by OWF development, as some people may be attracted or repelled by their sight, which highly depends on socio-demographic and psychographic characteristics (Gee, 2010; Smythe et al., 2020). *Recreation* can also be affected both ways, as some recreational opportunities are virtually reduced by their exclusion from OWF areas (e.g. sailing) while others can be potentially increased due to novel habitats being created (e.g. recreational diving). OWF can benefit *biodiversity* and *wild animals* by promoting the proliferation of sessile and benthic species on the hard artificial structures, which in turn promote the aggregation of certain fish species around these new feeding grounds (Slavik et al., 2019). On the other hand, OWF could harm the very same ES, like other animals (e.g. marine mammals) seem to avoid OWF areas during both construction and operation phases (Degraer et al., 2020a,b) and the associated increase of underwater cables and their electromagnetic fields might also disturb some species (Hutchison et al., 2020) as highlighted in the diagram.

The direct negative effects of OWF are mostly associated with the decrease of available space and potential resources for other marine activities. One of the most obvious conflicts is with the fisheries sector, which has been losing fishing grounds to accommodate more OWF areas all across the North Sea. However, it is argued that benefits may also arise from the exclusion of active forms of fisheries, including to fisheries sector itself, as it can potentially increase the supply of *wild animals* and *nursery and habitat maintenance* services locally and consequently generate a spillover effect (Stelzenmüller et al., 2021). The sand within OWF concession areas also becomes inaccessible which, theoretically, diminishes the supply of *sand and other minerals*.

Other studies have previously used participatory conceptual modeling to illustrate the links between local ES and the socioeconomic components of social-ecological systems. Lopes and Videira (2017), for instance, engaged stakeholders of the Arrábida Natural Park, a coastal protected area in Portugal, to conceptualize the feedback processes underlying the local supply of *climate regulation, food provision,* and *recreation* services, where several variables were identified as affecting those ES. They found out, for example, that *food provision* and *recreation* services were perceived to be closely linked through tourism and the attractiveness of the area for living. They concluded that the diagrams provided a holistic perspective on the interrelations among ES, allowing to identify entry points to act in the system to improve ES management. This approach can also be used to create conceptual models that link ecosystem components, processes, and functions to ES, providing a first step towards developing dynamic models of ES supply (Broszeit et al., 2019).

The linkage diagram produced during this engagement process reflects the current understanding of a group of stakeholders and scientific experts of the most salient connections, which were drawn from explicit memory in a time-limited context. Therefore, it is by no means a full representation of all possible links between OWF and the locally relevant ES, but can be seen as a starting point. Moreover, it shows the usefulness of having a heterogeneous group of people (with differing interests) share their mental models and bridge their perspectives into a visual representation of causal links between components of a system. This diagram can be therefore used as a starting point to build towards a more holistic model of the BCS social-ecological system (centered around OWF or not), using additional sources of knowledge such as literature.

4.3. Perspectives and limitations

The stakeholder engagement methodology presented here was developed with a particular objective in mind. The aim was to inform decision-making within the SUMES project regarding which ES are relevant to the BCS and which to prioritize during the ES assessment and development of a sustainability impact model for offshore human activities. Moreover, the linkage diagram was used to inform scientists regarding the potential (positive or negative) effects of human activities on specific ES, particularly regarding the possible causal relationships that exist between OWF and the key relevant ES. This methodology can be repeated to expand the conceptual modelling of ES-related impacts with other human activities and their integration (e.g. multi-use platforms of OWF and aquaculture in the BCS). These results (or the replication of this methodology) enables informed future decision-making (e.g. MSP, ecosystem-based management) in terms of anticipating differences in ES valorization by the stakeholders and mitigating potential spatial conflicts and ES trade-offs.

To engage stakeholders, we had to adapt the traditional physical workshop to the digital age, a need intensified by the COVID-19 crisis where businesses and people were required to telework and communicate using digital tools. In that process of adaptation, what was developed is a methodology that can be easily deployed through videoconferencing platforms, removing the logistics and barrier to participation that physical workshops may entail, providing the opportunity to engage stakeholders in a different way and collect information in a more systematic manner by using the appropriate virtual tools (Tobin et al., 2020). Digital workshops are therefore a valid alternative to physical workshops, which will ultimately depend on the scope and objectives of the participatory process. Besides defining realistic goals for a digital workshop, important for its success is also the accessibility (e.g. having a decent internet connection) and digital literacy of the stakeholders involved. Whenever these conditions cannot be satisfied, physical workshops should be prioritized. This is also true if the goal is to stimulate free-flowing discussion and employ certain types of participatory exercises that are not suitable for digital interactions (e.g. role-playing games, forum theaters).

The stakeholder selection process inherently comes with some limitations. First, defining and identifying who are the relevant stakeholders is often difficult, especially regarding those who are (or will be) indirectly affected by management choices (Buchy and Race, 2001). Stakeholder groups are, therefore, rarely fully heterogeneous and certain socioeconomic factors often dictate whose voice is heard, incurring the risk of biasing results and, in some cases, marginalizing certain groups (Baker-Médard et al., 2021; Flannery et al., 2018). Additionally, some stakeholder categories might be harder to reach or more reluctant to engage, which will result in their perspective not being considered in the outcomes (in the present study we missed the tourism perspective for example), and such limitations should always be acknowledged to put the results in the right context (Glicken, 2000; Voyer et al., 2015). Future workshops could also attempt to select stakeholders based on the proportion of society they represent (e.g. contribution to livelihoods) or input to the economy (e.g. contribution to GDP).

The relatively small group size, despite allowing for better interactions (Campagne and Roche, 2018), could also be considered a limitation in terms of allowing for generalized conclusions to be made to the whole social-ecological system. Performing a series of small-group workshops with different stakeholders could be a way to increase the representativeness of the stakeholder sample. Following up-to-date guidelines for best practices in stakeholder engagement while keeping the process simple and pragmatic is a balance that must be carefully thought through in order to obtain credible and legitimate results that will inform decision-making.

Providing clear definitions of the ES to the stakeholders is key, as well as for deciding if intermediate ES are included (which will also depend on the ES classification system used). Intermediate ES are vaguely defined in the literature (Lamothe and Sutherland, 2018), sometimes considered analogous to ecosystem components or functions, or even to some regulating ES, potentially introducing ambiguity in the process (as observed in this study with the ES *biodiversity*). Concerning the linkage diagram, time is an important factor that determines the level of detail achieved and, therefore, more time would have certainly allowed for a more comprehensive representation of the linkages between local ES and all the marine activities. Moreover, a physical workshop can be a more suitable setting for carrying-out participatory diagramming exercises as it facilitates more open and free-flowing discussions than a virtual setting. Some stakeholders expressed their willingness to further develop the diagram in future interactions that could take place physically to potentially extend the focus from OWF to other marine activities as well.

5. Conclusion

The virtual engagement methodology presented in this study can help researchers and decision-makers capture stakeholders' perceptions regarding the importance of local ES, thus providing a baseline for establishing priorities during ES modeling and management. Although this method does not allow for the same level of interaction and dynamics as physical workshops, this work proves that virtual environments, through the use of appropriate virtual tools, can be an efficient and reliable alternative. The results provide a baseline of Belgian stakeholders' perceptions on the relative importance of marine ES from the BCS. Overall, the final ES of highest priority were *coastal protection*, *offshore wind energy*, *surface for navigation*, *nursery & habitat maintenance* and *climate regulation*, even though some differences in prioritization were observed between the sectors. Stakeholders also provided interesting insights into the possible links between local ES and key marine activities. Understanding the heterogeneity in stakeholders' perceptions and considering the value of their knowledge is essential to support legitimate ecosystem-based management decisions in complex social-ecological systems such as the BCS.

Declaration of competing interest

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

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Appendix A. Supplementary data

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