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Mapping marine ecosystem services potential across an oceanic archipelago: Applicability and limitations for decision-making

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ABSTRACT

Understanding the multiple benefits (i.e. Ecosystem Services, ES) that marine habitats provide to society is key for adequate decision-making that maintains our well-being in the long-term. The main objective of this research was to map and assess, in the context of marine spatial planning, the ES supply of shallow and deep-sea habitats in the Canary Islands across biological zones and substrate types. An ES-matrix was developed through a literature review to evaluate the supply potential, complemented with the habitats' total extension to assess the supply capacity of each resulting ES. The matrix linked 34 habitats in relation to 42 ES, over ca. 485,000 km^2. Cultural ES were the most abundant in the archipelago. On average, shallow habitats supplied potentially 25 ES compared to 17 ES by deep-sea habitats. This is likely to be explained by limitations regarding the available information suggesting that both provisioning ES and ES supply potential of the deep-sea were underestimated. The supply capacity analysis showed that particularly certain regulating and maintenance services may be at risk in the face of habitat degradation. Results enabled the extrapolation of already existing ES monetization, e.g. for those accounted for *Cymodocea nodosa* generating 25,633,919 € y^{-1} in the Canary Islands. This study provided the first comprehensive spatial assessment of ES supply potential in the Canary Islands, filling a regional knowledge gap. This enables accounting for previously overlooked ES in the region, strengthening the idea that coastal communities' well-being in small islands depends on their marine ecosystems. Finally, results were discussed in relation to their applicability and limitations to marine spatial planning and protected area design informing on the potentially large societal benefits that may be at risk when allocating maritime activities spatially.

1. Introduction

Ecosystem services (ES) concept was popularized as the contributions of ecosystems to human well-being (Millennium Ecosystem Assessment, 2005). To equate the growing interest in the development of a blue economy improving human welfare, and the conservation of nature (de Groot, 1987), ES was thus gradually integrated into the decision-making process.

The ES concept is embedded in the ecosystem-based approach (EBA), which aims "to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need" (McLeod et al., 2005). For the marine environment, marine spatial planning (MSP) has been identified as one of the main tools to implement the EBA (Chalastani et al., 2021; Douvere, 2008). In other words, MSP should ensure a reasonable use of the marine space to prevent the deterioration of the ecological components that underpins the provision of ES (i.e. the "service providing units"; Kremen, 2005; Luck et al., 2009). Therefore, maintaining ES supply in the long-term. Additionally, ES assessments, comprising both environmental and socio-economic information, can contribute to the transparency of MSP processes. They may provide a baseline to evaluate existing trade-offs between different economic, ecological and social objectives while measuring their success (Elliott and O'Higgins, 2020; García-Onetti et al., 2021; Tallis et al., 2012).

The provision of ES is underpinned by the overall functioning of ecosystems (Potschin-Young et al., 2017). However, ES is an anthropogenic concept, i.e. only exists in reference to human beneficiaries (Armstrong et al., 2012a; Armstrong et al., 2012b). This makes it necessary to consider cultural values and human-made or built capital (Elliott et al., 2017) that mediates the ES 'flow' from nature to society (Burkhard et al., 2014). In turn, this flow depends (positively or negatively) on the governance system (Spangenberg et al., 2014), and the society's consumption habits, perceptions, and values around ES, all of which may change over time

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(Hebel, 1999; Klain & Chan, 2012). All these make integrated ecosystem services assessments challenging, being still under development within MSP (Galparsoro et al., 2021; Townsend et al., 2018).

Tallis et al. (2012) proposes a way to structure and promote the implementation of ES into MSP processes by clearly differentiating between (1) the potential and further capacity of ecosystems to provide ES (i.e. supply metrics), (2) the flow of ES used or enjoyed by users (i.e. service metrics), and (3) the benefits that are perceived by society (i.e. value metrics). In this sense, the present study is framed within the first supply-side step.

Commonly, ES supply is assessed through the ES-matrix approach, which explores the linkages between the service providing units (SPU; Kremen, 2005; Luck et al., 2009) and the different ES they provide (Campagne et al., 2020; Jacobs et al., 2015). Then, from all possible SPU with the potential to provide ES, critical ones are identified based on their supply capacity (Culhane et al., 2020a; Culhane et al., 2020b), which in turn will depend on their ecological state or condition. For example, Teixeira et al. (2019) score the overall ecosystem services supply of the SPU by distinguishing between three dimensions: (1) the supply potential, (2) the supply capacity and (3) the supply condition. The idea of potential refers to the theoretical ability of a certain SPU to provide particular ES (Tallis et al., 2012). Whereas the ideas of capacity and condition refer to the ecosystem functions of the SPU that underpins a particular ES and the general descriptors of the status of the SPU, respectively (Potschin-Young et al., 2017).

Responding to which ecosystems provide which ES is a complex task, which was identified as a particular need for European Atlantic Ocean archipelagos (Galparsoro et al., 2014). Most studies map and assess the ES supply at a regional scale, based on secondary data without validation techniques to test the accuracy of the developed model (Martínez-Harms & Balvanera, 2012), while relaying on expert-based knowledge to link and weight the SPU-ES associations through the ES-matrix approach (Campagne et al., 2020). ES are context-dependent and their analysis has not always followed a uniform terminology across literature hindering the compilation of empirical data about their supply potential and capacity (Bordt & Saner, 2019; Potschin-Young et al., 2018). Nonetheless, Tempera et al. (2016) have consulted a number of corresponding authors from various literature reviews to build cross-reference tables between the different ES terminologies into the Common International Classification of Ecosystem Services (CICES; Haines-Young & Potschin, 2018) enabling ES potential supply assessments and mapping in areas where detailed benthic habitats cartography is available.

Moreover, the supply capacity of each SPU may be weighted by a series of criteria including their relative importance in providing a given ES (Galparsoro et al., 2014; Potts et al., 2014), their efficiency in performing the ecological processes or functions leading to the supply of ES (Culhane et al., 2020), their spatial extent (Teixeira et al., 2019), or a combination of the above (Geange et al., 2019). Here, despite recognizing that ES do not increase linearly with habitats size (Barbier et al., 2008; Koch et al., 2009), the community/habitat extension has been directly related to the magnitude or capacity of ecosystem services supply (Harrison et al., 2014). Additionally, the supply condition of each SPU may be determined by field measurements of biophysical processes and functions (Geange et al., 2019) or derived from their conservation status or state assessed by environmental policies such as European Directives related to Habitats, Water and Marine Strategy (Culhane et al., 2020a; Culhane et al., 2020b; Teixeira et al., 2019).

Thus, the aim of this study is to map and assess the ES supply, undertaken for the first time with this level of detail in a European North-Atlantic outermost region, while assessing their implications for decision-making and undergoing MSP processes. This study also intends to strengthen the basis paving the way for other similar oceanic archipelagos that will be required to advance in ES assessments encouraged by the European legislation.

2. Methodology

MSP processes depend highly on spatial data, leading to the usage of benthic marine habitats as the SPU for ES assessment and mapping (Fletcher et al., 2012; Galparsoro et al., 2014; Potts et al., 2014; Tempera et al., 2016). The ES supply potential of benthic marine habitats in the Canary Islands was mapped and assessed through a literature review carried out for the European regional seas (Agardy et al., 2005; Armstrong et al., 2012a; Armstrong et al., 2012b; Galparsoro et al., 2014; Millennium Ecosystem Assessment, 2005; Potts et al., 2014; Salomidi et al., 2012; Tempera et al., 2016). The total extension of the habitats was used to assess the supply capacity of each resulting ES. Fig. 1 shows the

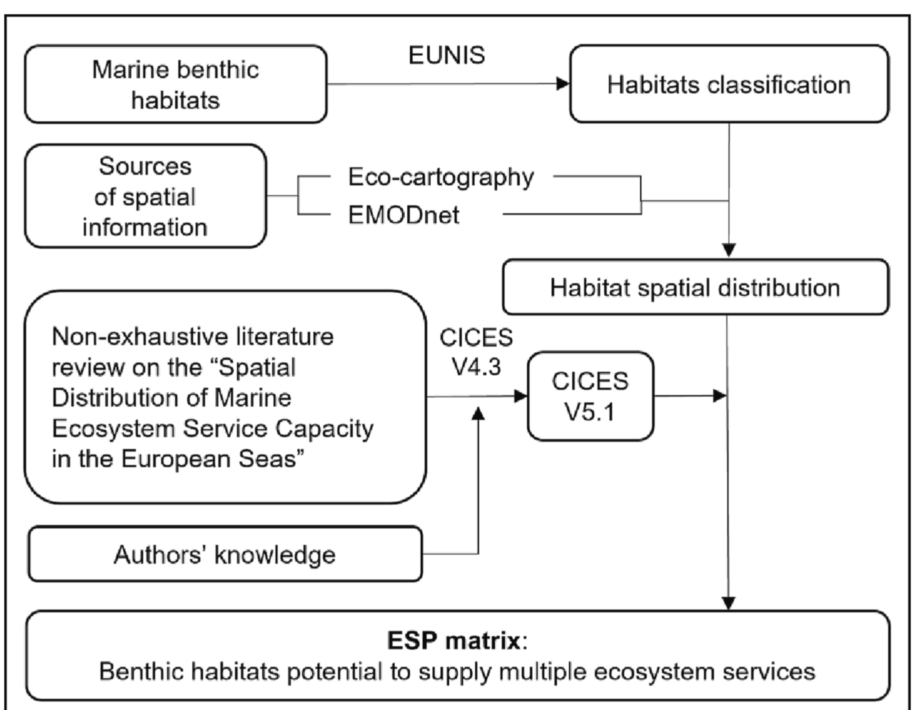

Fig. 1. Methological steps followed to map the ecosystem service potential (ESP) of marine benthic habitats in the study area.

methodological steps taken, which are further explained in the following sections.

2.1. Study area

The Canary Island archipelago is located off the Northwest African coast at about 28° N (Fig. 2). Rising steeply from the seabed, they represent a natural barrier to the southward flow of the Trade Winds and the Canary Current, generating large mesoscale eddies south of the islands (Arístegui et al., 1994). Besides, the archipelago is regularly influenced by cold water upwelling filaments derived from the NW African coastal upwelling system locating the islands in the so-called Canaries-African Coastal Transition Zone (Barton et al., 1998).

Regarding benthic habitats, canopy-forming macroalgae in tidal pools are often found in rocky littoral platforms which, in general, are dominated by turf-forming macroalgae, cirriped and scattered cyanobacterial colonies or mats in their lower, intermediate and upper bands, respectively (Tuya et al., 2006). Subtidal benthic landscapes are constituted by volcanic rocky bottoms presenting a variety of forms, e.g. marine caves, canyons or large boulders, surrounded by coarse, sandy and muddy sediment plains. Subtidal macroalgal assemblages structure varies across islands together with the thermal gradient ranging from *Fucales* dominated assemblages towards the eastern islands to ones dominated by *Dictyotales* in the western islands. However, this natural pattern is diffused by the pressure of the main herbivore *Diadema africanum* (Sangil et al., 2011), which creates extensive urchin barrens in rocky subtidal bottoms. The archipelago also hosts other important 'ecological engineer' species, such as extensive, but fragmented seasonal seagrass meadows of *Cymodocea nodosa* on soft bottoms and maerl beds (Otero-Ferrer et al., 2020; Tuya et al., 2014a). All of the above biological characteristics support the idea that the Canary Islands are a marine biodiversity hotspot. Furthermore, due to the highly developed coastal tourism and the existing traditional community linkages with the marine environment, this area is thought of as a social and natural "laboratory" for the study of multiple ES.

2.2. Benthic habitats spatial distribution

The spatial distributions of marine habitats were gathered from two spatial data set (see Table A.1 for more detail and links to the sources): the so-called eco-cartography for shallow habitats (up to a depth of 50 m), and for deep habitats up to the outer limit of the study area (see Fig. 2) obtained from the European Marine Observation and Data Network (EMODnet).

The eco-cartographies of the Canary Islands were individually mapped by islands through public tenders during 2000–2006. These produced various maps with high spatial resolution, but that did not follow a standardized classification terminology. Thus, this study used the harmonized eco-cartography for the Canary Islands done through a local expert group following the Spanish Inventory of marine species and habitats (IEHEM). Subsequently, applying the IEHEM own cross-walk tables, a cartography based on the 2012 revision of the pan-European EUNIS habitat classification was produced (PLASMAR Consortium, 2020).

According to the EUNIS available description of marine habitats, these were categorized by their biological zone related to depth (littoral, infralittoral, circalittoral, offshore circalittoral and deep-sea), and substrate type (rock, coarse sediment, sand, mud, mixed sediment and biogenic substrate). The spatial distribution analysis of benthic habitats was done separately due to differences between the two data sets employed in the assessment. Habitats from the eco-cartography were mapped with a high level of detail (1 m resolution) up to 50 m of depth. Whereas deeper habitats from EMODnet, although covering wider areas, were mapped with less precision (200 m resolution).

2.3. Ecosystem services supply potential, capacity and condition

We adopted the following definition of ES supply potential (ESP) as the "full potential of ecological functions or biophysical elements in an ecosystem to provide a potential ecosystem service, irrespective of whether humans actually use or value that function or element currently" (Tallis et al., 2012), similarly to (Caro et al., 2020). The

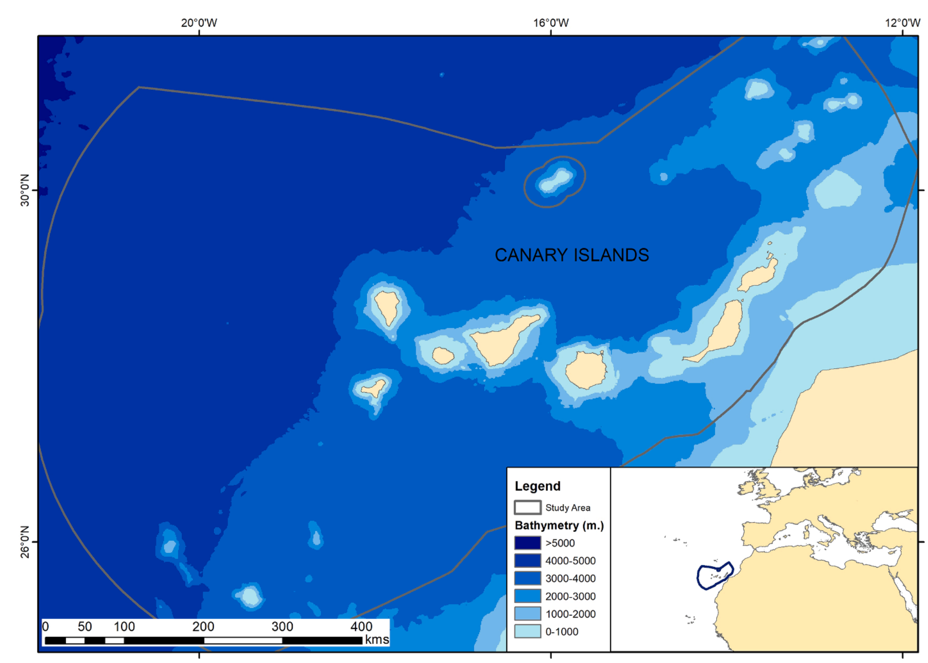

Fig. 2. The Canary Island archipelago located off the northwest African coastal upwelling system. The grey line represents the outer limit of the study area coinciding with the technical application of the Spanish Marine Strategy Framework Directive (2008/56/EC).

identification of the multiple ES potentially provided by the marine habitats was done based on Tempera et al. (2016). Their cross-reference tables were used to translate the ES terminology presented by the consulted literature reviews (see Table A.2 for more details) into the latest CICES version 5.1. following the guidance on the application of the revised structure and its corresponding equivalence table (Haines-Young & Potschin, 2018).

The CICES (and EUNIS) classification is hierarchical, gaining in detail towards lower levels, i.e. from section, division, group to class. Meaning that a given section, includes all its corresponding divisions, and the latter their groups, and these their classes (i.e. higher levels include the lower levels). Similarly to Tempera et al. (2016), in the present study, 'parents' were considered to inherit the ESP from their 'children' (see Tables A6 to A8). Terminology around specific ES tend to be translated or broadened to facilitate dialogue and consensus among actors (van Oudenhoven et al., 2018). Given the difficulty of translating ESP evidence into ES at a class level, all ES across the hierarchy were considered equally. In line with Potschin-Young et al. (2017), we argued that the ES-related 'double counting' issue should be confined to the accounting of the usage/enjoyed services and derived values, while preventing the screening of the ecological functional characteristics that the ES supply assessments aim to explain. This was a necessary approach to avoid falling into "all ecosystems provide all ES".

For the ESP of those benthic habitats in our study area not assessed by Tempera et al. (2016) (e.g. littoral habitats, EUNIS coded as #A1 and #A2), we followed their same methodology to assign ESP (i.e. applying qualitative categories of presence, absence or no data) through the reviewed literature (see Table A.3). Finally, for the habitats not assessed in any of the previously mentioned literature, i.e. the *Cystoseira* spp. habitat (EUNIS code A3.151) and "faunal communities on low energy infralittoral rock" (EUNIS code A3.35), their ESP was assigned according to local scientific literature and the authors' knowledge on the Canary Islands, as in Galparsoro et al. (2014) and Potts et al. (2014) (see ESP assignment explanation in section A.4).

The services supply capacity (ESC) was considered as the habitats' "true spatial representativeness" (Teixeira et al., 2019) meaning the contributing area to a given ES, which was calculated resembling Geange et al. (2019)'s approach:

$$aESP_{ijk} = \sum_{h=1}^{n} a_{ijk} \tag{1}$$

where a is the area, h is habitat type, i is the service. Note that this study did not weight the ESC through a ranking scale (i.e., j), due to the difficulty in harmonizing these semi-quantitative scores from the various literature sources. Besides, providing habitat quality information (i.e., k) at a regional scale for the Canary Islands was out of the scope of this study. Moreover, using environmental policies to assess the condition of the evaluated habitats was not possible considering that the Good Environmental Status (EU Directive 2008/56/EC) for the seafloor integrity and benthic habitats was only partially assessed for the Canary Islands (Abramic et al., 2020).

2.4. Ecosystem services assessment

To map and compare ESP supply between ES aggregated by section level (i.e., provisioning, regulation and maintenance (hereafter both referred to as regulating), and cultural), five classes of Jenks natural breaks classification were applied through a geographic information system (GIS) approach. For this, the ES abundance for each habitat was calculated as in Caro et al. (2020), based on the number of ES provided by that habitat in relation to the maximum number of ES within CICES, i.e. provisioning (n = 28), regulating (n = 27); and cultural (n = 18). Finally, to analyse patterns in the spatial distribution of ESP supply, like Galparsoro et al. (2014), the total area of each habitat and its relative extension to the total marine study area were mapped.

2.5. Statistical analysis

A Friedman test, followed by *post-hoc* Wilcoxon tests, as in the just aforementioned study, were done to explore statistical differences between ESP aggregated at a section level (i.e. provision, regulating, and cultural). Then, Kruskal-Wallis non-parametric tests and *post-hoc* tests between pairs, corrected through the Bonferroni test, were applied to analyse the influenced of the biological zones and substrate type on the ESP.

3. Results

The harmonized eco-cartography for the Canary Islands resulted in 23 shallow marine benthic habitats. These were characterized for the ESP analysis of this study together with the 11 deeper habitats from EMODnet (see Table A.5). The literature reviewed supplemented with the authors' knowledge, resulted in a matrix summarizing the ESP of 34 habitats in relation to 43 ES (see Tables A.6, A.7 and A.8) over a marine extension of approximately 485,000 km^2. The ESP matrix can be read both horizontally to see all ES potentially provided by a particular habitat (Tables 1 and 2), and vertically to see all habitats with the potential to provide a particular service (Table 3). In general, 57.6 % of the cells within the matrix were assessed confirming either the presence or absence of ESP (see Table A.9 for more details). Particularly, there is greater scientific knowledge about the ESP of cultural ES (69 % of cells, n = 476) than of regulating ES (56 % of cells, n = 612) or provisioning ES (47 % of cells, n = 374). Moreover, shallower habitats were more extensively assessed (64 % of cells, n = 989) than deeper habitats (45 % of cells, n = 473).

Reading the ESP-matrix horizontally, none of the 34 habitats identified in the Canary Islands provide all the 43 ES considered in this study (Table 1 and 2). Shallower habitats supply on average a total of 25 ES, i.e. an ES abundance of 35 %. The habitats better covered by the literature and, thus, presenting very high ESP are the *Cymodocea* and *Halophila* seagrass beds, and "*Cystoseira* spp. on exposed infralittoral bedrock and boulders" (i.e. supplying 31, 31 and 30 ES respectively). Conversely, the habitats with the lowest ESP were infralittoral fine sand and faunal communities on low energy infralittoral rock (i.e. supplying 19 and 21 ES respectively). In turn, deeper habitats present significantly lower ESP than shallower habitats ($H = 20.401, p < 0.001$), supplying on average 17 ES (an ES abundance of 23 % of the 73 possible ES included in CICES). "Sponge communities on deep circalittoral rock" and broad "deep-sea bed" are the deeper habitats with the highest ESP, i.e. associated with 22 and 21 different ES, respectively.

Overall, for all aggregated ES at the section level (i.e. provisioning, regulating, and cultural ES), the habitats' ESP differ significantly across the hierarchical levels of the EUNIS habitat classification (Kruskal-Wallis $H = 15.673, p < 0.003$), and across biological zones ($H = 20.972$, $p < 0.001$). Although rock and biogenic types of seafloor substrate show the highest abundances of ES (Table 1), there were no significant ESP differences among substrate types. The just presented significant differences were seen for both regulating, and cultural ES, but not for provisioning ES.

Particularly for regulating and cultural ES, benthic habitats informing on the dominant communities (i.e. EUNIS level 4) are significantly associated with less ESP than those habitats characterized for specific marine species (i.e. EUNIS 6) (*post-hoc* tests between pairs $p < 0.033$ in all cases). Besides, offshore circalittoral habitats show significant lower ESP than infralittoral habitats (*post-hoc* tests between pairs $p < 0.038$ and $p < 0.001$, respectively for regulating and cultural ES).

Significant differences are also observed regarding the spatial distribution of ESP aggregated by sections (i.e. provisioning, regulating and cultural) (Friedman test $\chi^2 = 54.672$, $p < 0.001$) (Figs. 3, 4, 5). Cultural ES are significantly more abundant than both regulating and provisioning ES (Wilcoxon *post-hoc* test $z = -2.984$, $p < 0.003$; and $z = -5.108$, $p < 0.001$, respectively). In turn, regulating ES are supplied

Table 1
Ecosystem services supply potential, aggregated at section level, of shallow benthic habitats in the Canary Islands.

Littoral, infralittoral and circalittoral habitats from the Eco-cartography (EUNIS)				Ecosystem Services (CICES V5.1)							
				Provision (n=28)		Regulation (n=27)		Cultural (n=18)		Total (n=73)	
Code	Name	km^2	%	N°	%	N°	%	N°	%	N°	%
A1	Littoral rock and other hard substrata	0.07	0.002	4	14	12	44	11	61	27	37
A3	Infralittoral rock and other hard substrata	575.6	19.52	4	14	11	41	12	67	27	37
A4	Circalittoral rock and other hard substrata	109.25	3.76	4	14	11	41	10	56	25	34
A1.2	Moderate energy littoral rock	0.002	0.0001	4	14	12	44	11	61	27	37
A1.4	Features of littoral rock	3.05	0.11	4	14	10	37	9	50	23	32
A2.2	Littoral sand and muddy sand	0.36	0.01	4	14	12	44	11	61	27	37
A3.1	Atlantic and Mediterranean high energy infralittoral rock	0.012	0.0004	4	14	9	33	10	56	23	32
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	484.7	16.63	4	14	9	33	11	61	24	33
A3.3	Atlantic and Mediterranean low energy infralittoral rock	5.32	0.18	4	14	9	33	11	61	24	33
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	0.01	0.0003	4	14	9	33	10	56	23	32
A5.1	Sublittoral coarse sediment	4.2	0.14	6	21	9	33	11	61	26	36
A5.2	Sublittoral sand	730.7	24.64	6	21	7	26	10	56	23	32
A5.3	Sublittoral mud	0.39	0.01	6	21	7	26	10	56	23	32
A2.11	Shingle (pebble) and gravel shores	0.74	0.03	4	14	10	37	9	50	23	32
A3.24	Faunal communities on moderate energy infralittoral rock	10.27	0.35	4	14	8	30	8	44	20	27
A3.35	Faunal communities on low energy infralittoral rock	3.85	0.13	1	4	1	4	9	50	11	15
A5.13	Infralittoral coarse sediment	62.9	2.16	6	21	6	22	11	61	23	32
A5.23	Infralittoral fine sand	410.5	16.77	4	14	5	19	10	56	19	26
A5.51	Maerl beds	118.8	4.12	6	21	9	33	11	61	26	36
A5.52	Kelp and seaweed communities on sublittoral sediment	212.7	7.98	4	14	11	41	10	56	25	34
A3.151	*Cystoseira spp*. on exposed infralittoral bedrock and boulders	15.95	0.55	6	21	13	48	10	56	29	40
A5.5311	Macaronesian *Cymodocea* beds	82.6	2.82	4	14	14	52	13	72	31	42
A5.5321	Canary Island *Halophila* beds	2.48	0.09	4	14	12	44	13	72	29	40
Total area/average ES		**2834.5**	**100**	**5**	**16**	**10**	**37**	**11**	**61**	**25**	**35**

Table 2
Ecosystem services supply potential, aggregated at section level, of deep-sea benthic habitats in the Canary Islands.

Offshore circalittoral and deep-sea habitats from EMODnet (EUNIS)				Ecosystem Services (CICES V5.1)							
				Provision (n=28)		Regulation (n=27)		Cultural (n=18)		Total (n=73)	
Code	Name	km^2	%	N°	%	N°	%	N°	%	N°	%
A6	Deep-sea bed	472959.5	98.15	5	18	7	26	9	50	21	29
A6.3	Deep-sea sand	1975.71	0.41	5	18	7	26	7	39	19	26
A6.4	Deep-sea muddy sand	4107.15	0.85	5	18	7	26	7	39	19	26
A6.11	Deep-sea bedrock	1619.79	0.34	1	4	3	11	5	28	9	12
A4.12	Sponge communities on deep circalittoral rock	386.38	0.08	4	14	8	30	10	56	22	30
A5.14	Circalittoral coarse sediment	18.63	0.004	4	14	5	19	5	28	14	19
A5.15	Deep circalittoral coarse sediment	54.71	0.01	4	14	5	19	5	28	14	19
A5.27	Deep circalittoral sand	726.28	0.15	4	14	7	26	5	28	16	22
A5.35	Circalittoral sandy mud	0.41	0.0001	4	14	6	22	5	28	15	21
A5.37	Deep circalittoral mud	9.78	0.002	4	14	6	22	5	28	15	21
A	Marine (unknown) habitats	1402.87	0.29								
Total area/average ES		**481858.31**	**100**	**4**	**14**	**6**	**22**	**7**	**38**	**17**	**23**

Note: Habitat code "A", which is classified as "unknown habitats", is not summing to the total extension of the study area, nor to the percentage of the relative area of each habitat type. Unknown habitats correspond to the category "not habitat info" in to 6.

significantly more than provisioning ES ($z = -5.023$, $p < 0.001$).

Collectively, marine benthic habitats in the Canary Islands present ESP for a wide range of different ES (Fig. 6). However, the supply capacity of benthic habitats, as their spatial representativeness to an ES, varies greatly across ES (see Table 3). For example, only infralittoral shallow habitats presented the supply potential of regulating ES such as "regulation of soil quality" (code 2.2.4), "filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals" (code 2.1.1.2), or "decomposition and fixing processes and their effect on soil quality" (code 2.2.4.2). In turn, the latter habitats only presented a capacity to supply these ES in ca. 16 km^2 (i.e. 0.003 %) of our study area. Another example would be the 89 km^2 and 105 km^2 that underpins the capacity to supply the ES "control of erosion rates" (code 2.2.1.1), and "maintaining nursery populations and habitats (Including gene pool protection)" (code 2.2.2.3), respectively. The latter examples of the total area capable to contribute to each ES may indicate the susceptibility to lose their supply capacity in case of habitat degradation.

The eco-cartography data was harmonized from individual mapping for each island (see Table A.5). Thus, considering all habitats with a high or very high ESP (see Table 1), we can analyse the relative area per island upon which the provision of most ES depends upon (Fig. 7).

4. Discussion

4.1. Ecosystem services supply in the Canary Islands

Cultural ES are the most widely supplied in the Canary Islands in line with ES literature reviews for other small islands (Balzan et al., 2018). However, this contrast with the European North Atlantic Ocean where provisioning ES were dominant (Galparsoro et al., 2014). Cultural ES are easier to identify in the absence of scientific literature than other types of services (Caro et al., 2020), which was also noted during the

Table 3
Supply capacity of each ES summarized by the cumulative extension (km^2) and relative area values (%) across biological zones of the benthic habitats (N°) that potentially provide each ES in particular. Empty cells indicate cero value. Ecosystem service codes are translated in Table A.2.

Ecosystem service	Shallow habitats (Eco-cartography)									Deep habitats (EMODnet)					
	Littoral			Infralittoral			Circalittoral			Offshore circalittoral			Deep-sea		
CICES	N°	Area		N°	Area		N°	Area		N°	Area		N°	Area	
V5.1		km^2	%		km^2	%		km^2	%		km^2	%		km^2	%
1	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
1.1	5	4.25	100	16	2721	100	2	109	100	7	1296	100	3	475,072	99
1.1.5	5	4.25	100	16	2721	100	2	109	100	7	1296	100	3	475,072	99
1.1.6	5	4.25	100	16	2721	100	2	109	100	7	1296	100	3	475,072	99
1.1.5.2				6	933	34									
1.1.6.1													3	475,072	99
1.1.6.2				6	933	34									
2	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
2.1	5	4.25	100	14	2192	81	2	109	100	4	1143	88			
2.2	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
2.2.1	5	4.25	100	14	2248	83	1	109	100	2	1133	87	3	475,072	99
2.2.2	3	0.43	10	16	2721	100	2	109	100	7	1296	100	4	480,521	100
2.2.3	5	4.25	100	6	996	37	1	109	100	1	407	31			
2.2.4				1	16	1									
2.2.5	5	4.25	100	16	2721	100	2	109	100	7	1296	100	3	475,072	99
2.2.6	5	4.25	100	11	1512	56	2	109	100						
2.1.1.2				1	16	1									
2.2.1.1				3	89	3									
2.2.1.2				1	4										
2.2.1.3	5	4.25	100	9	1486	55	2	109	100				3	475,072	99
2.2.2.3				4	105	4									
2.2.3.2	5	4.25	100	3	661	24	1	109	100						
2.2.4.2				1	16	1									
2.2.5.2	5	4.25	100	16	2721	100	2	109	100	7	1296	100	3	475,072	99
2.2.6.1	3	0.43	10	4	314	12									
3	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
3.1	5	4.25	100	16	2721	100	2	109	100	1	407	31	4	480,521	100
3.2	5	4.25	100	16	2721	100	2	109	100	7	1296	100	1	468,989	98
3.1.1	5	4.25	100	16	2721	100	2	109	100	1	407	31			
3.1.2	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
3.2.1				3	661	24	1	109	100						
3.2.2				10	1632	60	2	109	100	1	407	31	1		
3.1.1.1				16	2721	100	2	109	100						
3.1.1.2	5	4.25	100												
3.1.2.1	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
3.1.2.2	3	0.43	10	13	2087	77	2	109	100	1	407	31	3	475,072	99
3.1.2.4	5	4.25	100	5	433	16									
3.2.2.1	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100
3.2.2.2	5	4.25	100	16	2721	100	2	109	100	7	1296	100	4	480,521	100

discussion rounds undertaken in this study to include the authors knowledge on the ESP assessment. This may influence the results of studies which are solely based on expert knowledge, reason why ES supply assessments would greatly benefit from the incorporation of empirical evidence (Geange et al., 2019).

The statistically significant ESP decreasing gradient towards seawards and deeper habitats were not noted for the Canary Islands, although it has been reported for the European North Atlantic Ocean (Galparsoro et al., 2014). Despite that, higher ESP near the coastline is visually appreciable in the ESP maps as expected in volcanic archipelagos with limited and abrupt continental platforms. We argue this is due to other factors such as more limited information on ESP for deeper habitats as compared to shallower ones (Thiele, 2019; Tyler et al., 2016).

The deep-sea is generally considered out of reach for direct or in-situ interactions in contrast to more accessible shallower habitats, especially regarding cultural ES (Galparsoro et al., 2014; Milcu et al., 2013). Its fundamental role in providing habitat for a great diversity of commercial species is nonetheless recognized (Armstrong et al., 2012a; Armstrong et al., 2012b). Additionally, provisioning ESP was the less assessed, followed by regulating ESP (i.e. 53 % and 47 % left unassessed, respectively). This suggests that they would particularly benefit from a local extensive literature review, e.g. on ES related to biotechnological applications of seaweeds (Haroun et al., 2019). This may suggest that both provisioning and regulating ES, and deep-sea ESP were underestimated in this study. This is likely due to the use of derived goods and services (i.e. services metrics) rather than biophysical functions and processes (i.e. supply metrics) as a proxy for ESP (La Notte et al., 2017).

Assuming the good environmental status of the assessed benthic habitats enabled us to consider their total area as a proxy of their ES supply capacity in the Canary Islands. Although ES capacity is recognized not to increase linearly with the size of habitats (Barbier et al., 2008; Koch et al., 2009), this simplification was necessary to provide an approximation to the ES supply. However, habitats do not support the provision of ES directly. It is the numerous biodiversity interactions within these habitats that ultimately account for the structures and functions underpinning ES supply (Culhane et al., 2019; de Groot et al., 2002). Besides, ES capacity depends on the condition and attributes of the considered SPUs, which may vary across places. For example, seagrass meadows' carbon sequestration capacity was found different across various locations even at a local scale for the island of Gran Canaria (Bañolas et al., 2020).

The EUNIS habitats classification generally includes information regarding oceanographic conditions, species distribution and abiotic characteristics of the environment. But our 2D maps disregard pelagic habitats and their dynamic spatial–temporal variability. The inclusion of

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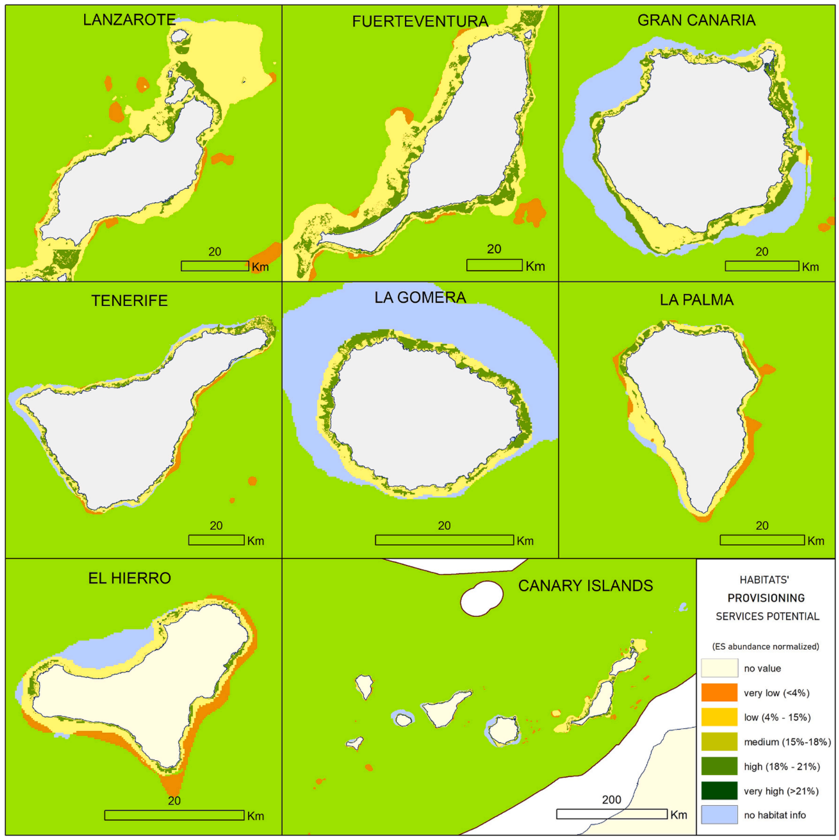

Fig. 3. Illustrates the potential of marine benthic habitats to provide provisioning services in the Canaries.

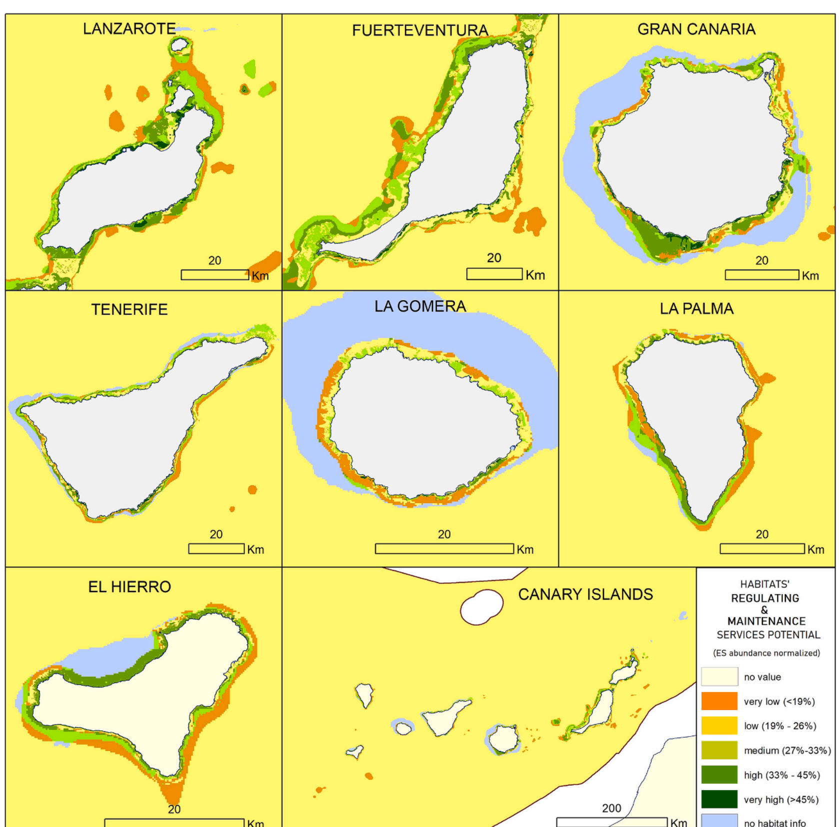

Fig. 4. Illustrates the potential of marine benthic habitats to provide regulation and maintenance services in the Canaries.

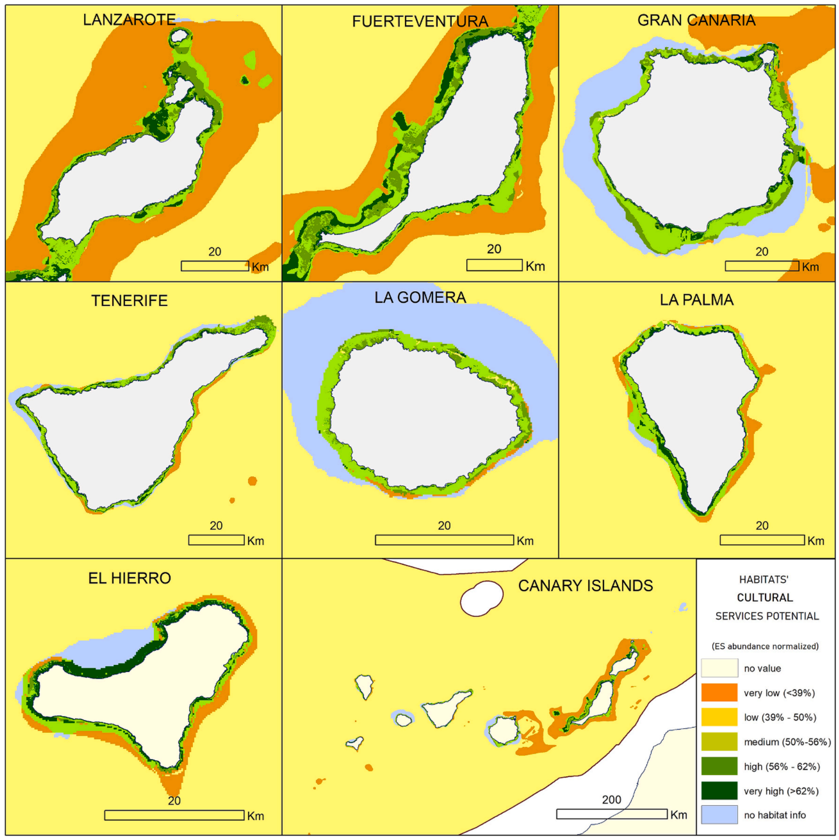

Fig. 5. Illustrates the potential of marine benthic habitats to provide cultural services in the Canaries.

mobile biotic groups and their association to multiple habitats in ES supply assessments would be a step forward (Armoškaitė et al., 2020; Culhane et al., 2018, 2020). This would additionally reinforce the intrinsic value of shared ES, and enable consideration of new bundles of ES resulting from their interrelations (Tempera et al., 2016). In the Canaries, for instance, local studies modelling species of commercial interest could be incorporated in future ES supply studies, e.g. using spatial units through different depth ranges including both benthic and pelagic habitats (Couce-Montero et al., 2015; Couce Montero et al., 2021).

We acknowledge the need to incorporate more holistic approaches to marine ES supply studies, e.g. system dynamics based on the "cells of ecosystem functioning" (Boero et al., 2019). For example, through the identification of significant ecological interconnected units that explain the main biogeochemical cycles, life cycles and food webs interactions covering the instability of marine systems. To advance in the understanding of habitat's ES supply is, thus, improving our knowledge on such ecological interactions and processes. This was defined in 2010 as one of the main pending tasks regarding ES assessments of the decade (Perrings et al., 2010), and we believe it is still pending in the current 2020 to 2030 decade.

4.2. Applicability and limitations to marine planning

ES assessments can promote understanding of human activity-ecosystem interactions informing MSP processes while favouring stakeholder's engagement (Friedrich et al., 2020). In turn, broad ambiguous ES terms may help bringing political will and transdisciplinary efforts together (van Oudenhoven et al., 2018), depicting marine benthic habitats and ES to their lowest possible level in our study favour promoting further assessments of ES goods and benefits (Schaafsma & Turner, 2015). Thus, this study may also serve to pave the way for similar ES mapping and assessment in other insular regions.

Degradation of ecosystems depends upon public attention to be considered environmental problems worth managing (Downs, 1972). This suggests that the connection to our oceans (i.e. nature), and thus also their management, may depend on our ability to perceive the benefits derived from them. Therefore, reinforcing the role of society in the co-production of ES alongside nature. For example, shark observation through snorkelling or scuba diving tended to favour positive attitudes towards them, which in turn promoted conservation management responses (Acuña-Marrero et al., 2018).

Greater biodiversity and more complex habitat structures (i.e. "good" condition) are positively related with ES of all types (Harrison et al., 2014) including, for example, greater species abundance for wildlife watching. However, this connection is stronger across provisioning and regulating ES, which are associated with tangible benefits than for cultural ES, which tend to produce intangible benefits (La Notte et al., 2017) and are mainly assessed through social-cultural dimensions and world-views (Jefferson et al., 2021; Jobstvogt et al., 2014; Klain & Chan, 2012; Tonge et al., 2013).

Through the analysis of the main factors underpinning cultural ES associated with woodlands in the UK and Ireland, Irvine & Herrett (2018) found that the enhancement of elements with social meaning, rather than ecological characteristics, guided conservation initiatives. This may be due to the fact that the concept of 'naturalness' varies with public perception (Nawaz & Satterfield, 2022). Due to the findings of Irvine & Herrett (2018), Caro et al. (2020) suggested that decision-makers may be undervaluing ecosystem characteristics in the management of a Portuguese estuary where cultural ES were the most observed. If we assume the same for this case study in the Canary Islands, MSP processes in the region may risk pursuing socio-cultural enhancement

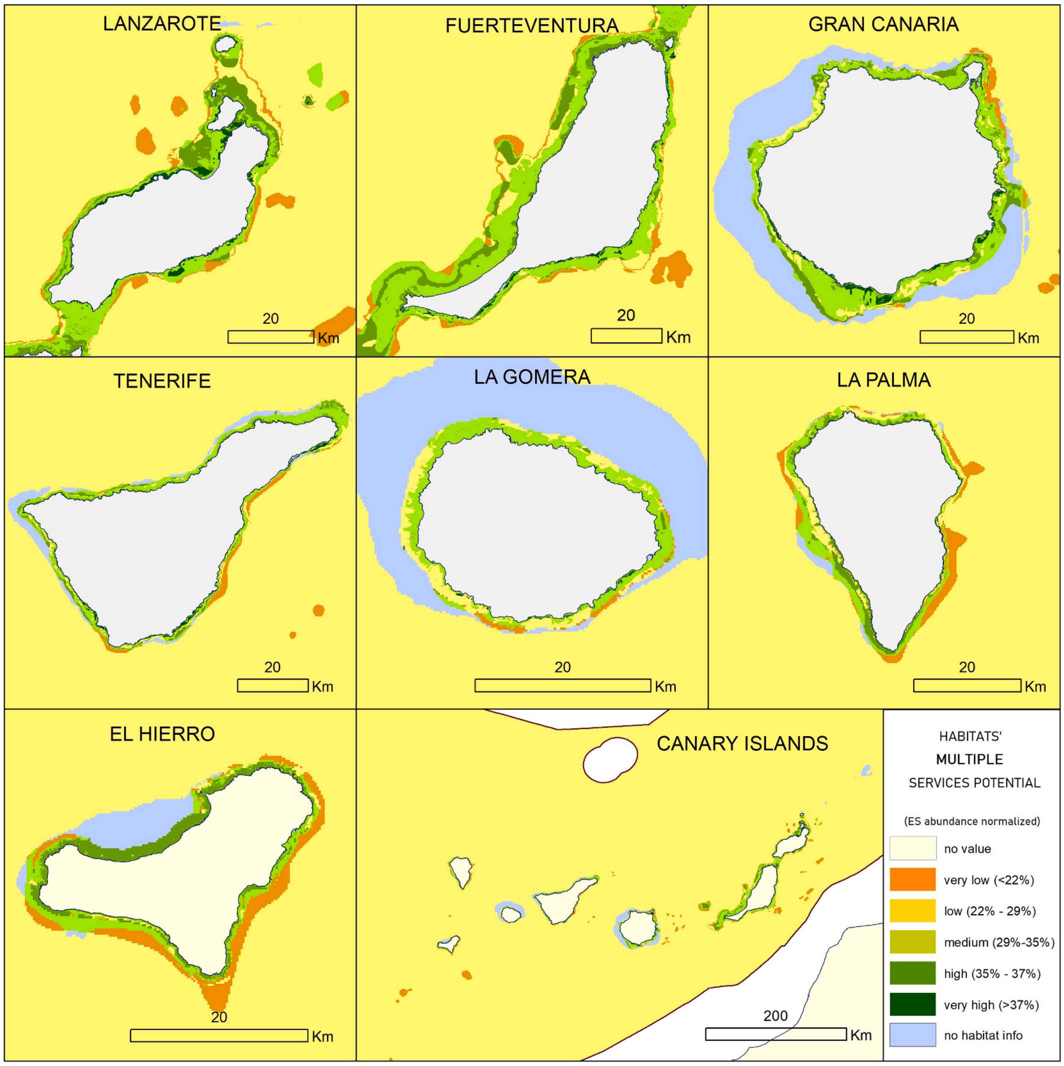

Fig. 6. Illustrates the overall potential of marine benthic habitats to provide multiple ecosystem services in the Canaries.

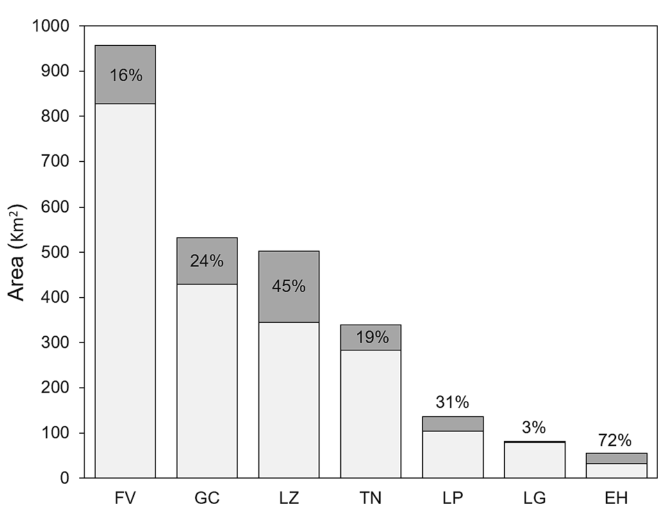

Fig. 7. Represents, in spatial terms, the sum of shallower benthic habitats contributing to supply 26 ES or more in relation with the total area extension. Sum of the area of habitats presenting high or very high ESP (dark grey) is showed on top of the total area of marine shallower benthic habitats (light grey) of each of the Canary Islands sorted from the highest to the lowest extension. The relative habitat's area with high to very high ESP values (%) are denoted inside bars. Islands' abbreviations mean: FV = Fuerteventura, GC = Gran Canaria, LZ = Lanzarote, TN = Tenerife, LP = La Palma, LG = La Gomera, EH = El Hierro.

rather than ecosystem health.

Incorporating littoral habitats and improving the spatial resolution (i.e. up to 1 m) of benthic habitats enabled to produce nuanced ESP maps that can be used as new communication tools for policy guidance accounting for ES previously overlooked in the archipelago. This can reinforce the recognition that coastal communities' well-being in small islands depends on their marine ecosystems.

However, it is understood that the reliability of the obtained ES supply maps depends on the quality of the benthic habitats' available spatial data (Galparsoro et al., 2014; Tempera et al., 2016). Accordingly, the eco-cartographies are more than 16 years old, which implies that habitat extensions most likely differ nowadays, e.g. as reported for *Cystoseira* spp. (Valdazo et al., 2017). Besides, the usage of broad categories within EMODnet was noticed to underestimate deep-sea habitats, e.g. the extension of seamounts located in the North-eastern part of the Canaries, and thus their ESP (Agardy et al., 2005). Nevertheless, these datasets represent the most comprehensive, updated and a legitimate geospatial source for both shallow and deeper habitats (Tempera et al., 2016). In the future, as new spatial data become available, more accurate ES-supply mapping and assessments could be done, e.g. to incorporate regulating ES of offshore circalittoral black coral habitats (Czechowska et al., 2020). The above mentioned limitations coincided with what other ES studies have named as sources of uncertainty (Sousa et al., 2016), which must be considered when communicating and applying the results.

Furthermore, our findings could inform existing regional MSP processes on the potentially large societal benefits that may be at risk by allocating maritime activities and, thus, transparently favour outcomes that benefit more people (Tallis et al., 2012). Spatially overlapping the resulting ES supply hotspots with the areas where maritime activities (and derived pressures) concentrate could inform on the area and on the percentage of ES that are being demanded and may be at risk (Tempera et al., 2016). This type of assessments could be particularly of interest while analysing the existing conditions or evaluating future scenarios for MSP (Ehler & Douvere, 2009).

In this sense, the present ES supply assessment may also suggest the risk of losing supply capacity, e.g. particularly of certain regulating ES (Table 3), and thus the related potential benefits for human well-being in case of habitat degradation. For example, Valdazo et al. (2017) reported a "massive decline" of *Cystoseira abies-marina*, passing from 9.28 km^2 in 1987–1989 to 0.077 km^2 in 2016 in the island of Gran Canaria. This habitat loss, only protected regionally within Nature 2000 sites (Law 4/2010, of June 4, 2010, of the Canary Islands Catalogue of Protected Species), will result in a supply decrease of its associated ES, e.g. as nursery grounds for fishes of commercial interest (Cheminée et al., 2013). Translating ecological information in social terms (e.g. losses for fishermen) can foster stakeholder engagement to promote the levelling of power relationships. Thus, fostering a more equitable distribution of benefits derived from marine ecosystems in regional/national MSP processes (von Thenen et al., 2021). Additionally, the presented ES capacity results could improve marine protected areas (MPAs) design (Schill et al., 2021) or help track the expected benefits provided by existing MPAs (Geange et al., 2019).

This study may also serve to meet the first step (i.e. the ecosystem extent account) of the System of Environmental-Economic Accounting (SEEA) methodology proposed by United Nations (United Nations, 2021). For example, based on our results, the ca. 8260 ha corresponding to the extension of *Cymodocea nodosa* beds in the present study (EUNIS #A5.5311 in Table 1) can be used to extrapolate existing monetization of ES done for the island of Gran Canaria. Thus, *C. nodosa* accounts, in instrumental terms, for 25,633,919 € y^{-1} in the Canary Islands. This resulted by adding 17,689,864 € derived from estimations of organic carbon sequestration (i.e. regulating chemical composition of oceans CICES code #2.2.6.1) using maximum market carbon prices (Bañolas et al., 2020); and 7,944,055 € y^{-1} derived from estimations of biomasses of adult fish (i.e. wild animals for nutrition CICES code #1.1.6.1) and juvenile fish (i.e. nursery grounds CICES code #2.2.2.3) of those species of interest for coastal fisheries (Tuya et al., 2014b). Note the usage of CICES class level for the monetization of the ES to avoid double counting. In this sense, similar future extrapolations could be devised from our results.

However, we highlight, as noted by SEEA, that monetary valuation is not a necessary feature of ES accounting (United Nations, 2021). Thus, we recommend acknowledging within cost-benefit analysis that price is an approximation of value (Vatn & Bromley, 1994), e.g. part of the above monetization refer to the instrumental value for local artisanal fisheries and do not cover all species to which seagrass meadows offer nursery and feeding grounds. This statement implies that the understanding, measuring, and leveraging of the diverse values of nature should be embedded into the decision-making process (IPBES, 2022). Particularly, in the establishment of social objectives within MSP process, which tend to lag behind blue economic objectives (Jones et al., 2016). Socio-economic evaluations within MSP should aim to recognize the different world-views and the intrinsic and relational values of nature apart from instrumental values (see IPBES, 2022). Otherwise, unintended social inequity and ecological degradation may occur (see e.g. Pascual et al., 2014; Spash & Aslaksen, 2015).

Moreover, this study entails a practical example of the utility of standardised classification systems (e.g. EUNIS and CICES) applicability to MSP processes, and more in particular, to the planning process of regional applicability to the Canary Islands. The benthic habitat harmonisation done for our case study following the principles of the INSPIRE Directive (PLASMAR Consortium, 2020) enabled the combination of the national (i.e. Spanish) benthic habitat mapping efforts with the European EMODnet products. This, as highlighted by the international guide on MSP (UNESCO-IOC/European Commission, 2021), is an example of the importance of data harmonisation within national MSP processes as well as for cross-border cooperation initiatives.

5. Conclusion

This study provided the first comprehensive spatial assessment of the ES supply of the benthic habitats in the Canary Islands, filling a regional knowledge gap (Galparsoro et al., 2014). The followed ESP approach and the cross-reference tables of Tempera et al. (2016) resulted in a flexible, easy-to-apply and updatable method to assess ESP from multiple literature sources. The ES-matrix resulted in a useful tool to synthesize the available knowledge, and thus to map and assess the ES supply. However, it might promote falling into a mechanistic approach that fails to inform on the ecological characteristics of the SPUs, and how they interrelate to originate the ES supply. Therefore, this study serves as a useful first approximation that can be further expanded by gathering more detailed ecological information that explores the interconnections between the SPUs, as well as between these and their contributions to our human well-being.

This study produced nuanced ESP maps that can be used as new communication tools for policy guidance accounting for previously overlooked ES in the Canary Islands. This can reinforce the recognition that coastal communities' well-being in small islands depends on their marine ecosystems. Moreover, this study intends to inform existing MSP processes on the potentially large societal benefits that may be at risk when allocating maritime activities spatially. Finally, the present results may be used to include another nature dimension to the planning processes beyond existing and future planned MPAs.

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.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2023.101517.

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