# Mapping and assessing the marine ecosystem services potential across the Canary Islands: PLASMAR+ approach

Cordero-Penín V., Abramic A., García Mendoza, A., Fernández-Palacios Y., Cecilia Ruano C., Pulido-Santiago, L.M., Haroun R.

IU-ECOAQUA ULPGC

www.plasmar.eu
www.facebook.com/ProyectoPlasmar

To cite this report:

Cordero-Penín V., Abramic A., García Mendoza, A., Fernández-Palacios Y., Cecilia Ruano C., Pulido-Santiago, L.M. Haroun R. 2023. Mapping and assessing the marine ecosystem services potential across the Canary Islands: PLASMAR+ approach. ECOAQUA Institute from the University of Las Palmas de Gran Canaria. Report prepared as part of PLASMAR+ Project (co-financed by ERDF as part of POMAC 2014-2020). 35 pp.

LEGAL NOTICE

This document has been prepared as part of PLASMAR+ Project (MAC2/1.1a/347), however it reflects the views only of the authors, and the Project partners or POMAC 2014-2010 programme cannot be held responsible for any use which may be made of the information contained therein.

## Contents

1. **Brief Summary** 1
1.1. Spanish summary .......... 1
1.2. English Summary .......... 2
2. **Introduction** 3
3. **Methodology** 5
3.1. Study area.......... 6
3.2. Benthic habitats spatial distribution .......... 8
3.3. Ecosystem services identification .......... 9
3.4. Ecosystem services assessment. .......... 9
4. **Results** 10
5. **Discussion** 20
5.1. ES in the Canary Islands .......... 20
5.2. Applicability to marine planning .......... 21
5.3. Approach and data limitations of the study.......... 22
6. **Conclusion** 24
7. **Future steps.** 24
8. **References** 26

# 1. Brief Summary

## 1.1. Spanish summary

Comprender los múltiples beneficios (es decir, Servicios Ecosistémicos, SE) que la biodiversidad y medio marino proporcionan a la sociedad es clave para una toma de decisiones adecuada que mantenga nuestro bienestar a largo plazo. El objetivo principal de esta investigación ha sido el de mapear y evaluar, en el contexto de la planificación espacial marina, el suministro de SE por parte de los hábitats marinos someros y de aguas profundas en las Islas Canarias. Para ello, se desarrolló una matriz de SE a través de una revisión bibliográfica para evaluar el potencial de provisión. La extensión total de los hábitats bentónicos se consideró para evaluar la capacidad de suministro de cada SE resultante. La matriz vinculó 34 hábitats respecto a 42 SE, en aproximadamente 485,000 $km^2$. Así, se observa que los SE culturales son los suministrados por mayor número de hábitats en el archipiélago. En promedio, los hábitats someros suministraron potencialmente 25 SE en comparación con los 17 SE de los hábitats de aguas profundas. Esto se explica probablemente por limitaciones en la información disponible, sugiriendo que tanto los SE de aprovisionamiento como el potencial de suministro de SE de aguas profundas han sido subestimados. El análisis de capacidad de suministro mostró que ciertos servicios de regulación y mantenimiento podrían estar en riesgo frente a la degradación de la relativamente escasa área de los hábitat con potencial de su provisión. Además, los resultados permitieron la extrapolación de la monetización de SE ya existentes como por ejemplo para aquellos contabilizados para la *Cymodocea nodosa* generando 25,633,919 € al año en las Islas Canarias.

La precisión y resolución de los mapas de Potencial de Servicios Ecosistémicos (PSE) dependen de la calidad de los mapas de hábitats utilizados como unidades espaciales. Dado que el PSE tiene su base en la biodiversidad y sus funciones, mejorar la precisión requiere revisiones sistemáticas exhaustivas adaptadas a la zona de estudio e involucrando a un mayor número de expertos locales. Este estudio proporciona una aproximación inicial, con potencial para expandirse mediante la recopilación de información ecológica más detallada. Esta información puede explorar las interconexiones entre las estructuras y el funcionamiento ecológicos, así como sus contribuciones al bienestar humano.

El informe se deriva del estudio publicado realizado por Cordero-Penín et al. (2023)[1], que ofrece acceso a información metodológica y complementaria más detallada.

---

[1] https://doi.org/10.1016/j.ecoser.2023.101517

## 1.2. English Summary

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 km2. 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.

The accuracy and resolution of Ecosystem Service Potential (ESP) maps rely on the quality of habitat maps used as spatial units. Given that ESP is rooted in biodiversity and its functions, enhancing accuracy requires thorough systematic literature reviews tailored to the study area and involving a greater number of local experts. This study provides an initial approximation, with potential for expansion through gathering more detailed ecological information. This information can explore interconnections between ecological structures and functioning, as well as their contributions to human well-being.

The report is derived from the published study by Cordero-Penín et al. (2023) [2], offering access to more detailed methodological and supplementary information.

---

[2] https://doi.org/10.1016/j.ecoser.2023.101517

## 2. Introduction

Since the popularisation of the ecosystem services (ES) concept as the contributions of ecosystems to humans well-being (Millennium Ecosystem Assessment, 2005), this has been gradually integrated into decision making pursuing sustainability, as in mainstream European policies (EC, 2020). Seeking more effective planning and management responses to enhance the natural capital on which the blue economy development and our human well-being depends on (de Groot, 1987), Europe has been fostering the identification and restoration of its Green Infrastructure (GI) (European Commission, 2013). GI has been defined as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission, 2013).

Marine spatial planning (MSP) has been identified as one of the main tools to implement in practice an ecosystem-based management approach (Chalastani et al., 2021; Douvere, 2008), i.e. ensuring a reasonable use of ES that prevents and avoids the deterioration of the GI in the long-term. However, in order to do so, MSP must consider the complexity of marine ecosystems and their functioning as well as the heterogeneity of human uses that depend on them (Crowder & Norse, 2008). Comprising both environmental and socio-economic information, ES can contribute to the transparency of MSP processes by providing a baseline to assess the trade-offs between different economic, ecological and social objectives and measure their success (Michael Elliott & O'Higgins, 2020; García-Onetti et al., 2021; Tallis et al., 2012).

MSP processes depend highly on spatial data leading to the relevance of mapping ES. In practice, spatial-temporal variability of ecosystem functioning is generally disregard by considering benthic marine habitats as management units for ES assessments and mapping (Fletcher et al., 2012; Galparsoro et al., 2014; Potts et al., 2014; Tempera et al., 2016). Nevertheless, unlike in the terrestrial counterpart, the assessment of marine ES is costly and technically more complex (Riera et al., 2014), and is still under development within MSP (Galparsoro et al., 2021; Townsend et al., 2018). The provision of ES is underpinned by the overall functioning of ecosystems (Marion Potschin-Young et al., 2017). However, the recognition that ES is an anthropogenic concept (i.e. only exist in reference to human beneficiaries (Armstrong et al., 2012)) necessarily results in the consideration of cultural values and human-made or built capital (M. Elliott et al., 2017) for their flow from nature to society (Burkhard et al., 2014). In turn, this flow depend on the governance system (Spangenberg et al., 2014), the society's consumption habits, and perceptions and values around ES, all of which may change over time (Hebel, 1999; Klain & Chan, 2012) altering the ES mapping efforts. Thus, to promote the implementation of ES into MSP processes is recommended to clearly differentiate 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) (Tallis et al., 2012). Therefore, the present study is framed in the first step mapping the supply of ES in our study area.

Commonly, ES supply is mapped through the ES-matrix approach, which explores the linkages between ecosystem types as geospatial units and their potential to provide ES (Campagne et al., 2020; Jacobs et al., 2015), or ecosystem service potential (ESP) (Geange et al., 2019a). Most studies map the ESP at a regional scale based on secondary data without validation techniques (Martínez-Harms & Balvanera, 2012) and mainly relaying on expert-based to score the causal relationships (Campagne et al., 2020). The usage of expert-based approaches is generally considered well-suited for ES assessments that are characterized by large uncertainty due to their social-ecological complexity (Jacobs et al., 2015). Therefore, studies may be based exclusively on the perception of stakeholders (Hutchison et al., 2013). However, a combination of empirical evidence and expert knowledge is recommended both for the linking and scoring processes (Geange et al., 2019a), together with a confidence reporting method (Jacobs et al., 2015). Moreover, ES matrices have been applied to MSP developing supply models that link ecosystem components, to ecosystem functions, to ES visually represented by Sankey diagrams flows (Armoškaitė et al., 2020).

Responding to which ecosystems provide which ES is a complex task, which has been identified as a particular need for European Atlantic Ocean archipelagos (Galparsoro et al., 2014). 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 (Bordt & Saner, 2019; M. Potschin-Young et al., 2018). Nonetheless, the work "spatial distribution of marine ecosystem service capacity [i.e. potential] in the

European seas" (Tempera et al., 2016) has cross-referenced the different ES terminologies from various reviews into the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2018) enabling ES mapping in areas where detailed benthic habitats cartography is available. Thus, the aim of this study is to fill the existing knowledge gap in mapping the potential of marine habitats to provide multiple ES in an oceanic archipelago while assessing their implications for MSP processes and GI identification.

## 3. Methodology

Aiming to map the ESP of benthic marine habitats in the Canary Islands, we have adopted the following definition of ESP supply 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). Consequently, ES have been assigned according to their theoretical potential as described by the literature reviewed for the European regional seas (Agardy et al., 2005; Armstrong et al., 2012; Galparsoro et al., 2014; Millennium Ecosystem Assessment, 2005; Potts et al., 2014; Salomidi et al., 2012; Tempera et al., 2016). Figure 1 shows the methodological steps followed, which are explained in more detail in the following sections.

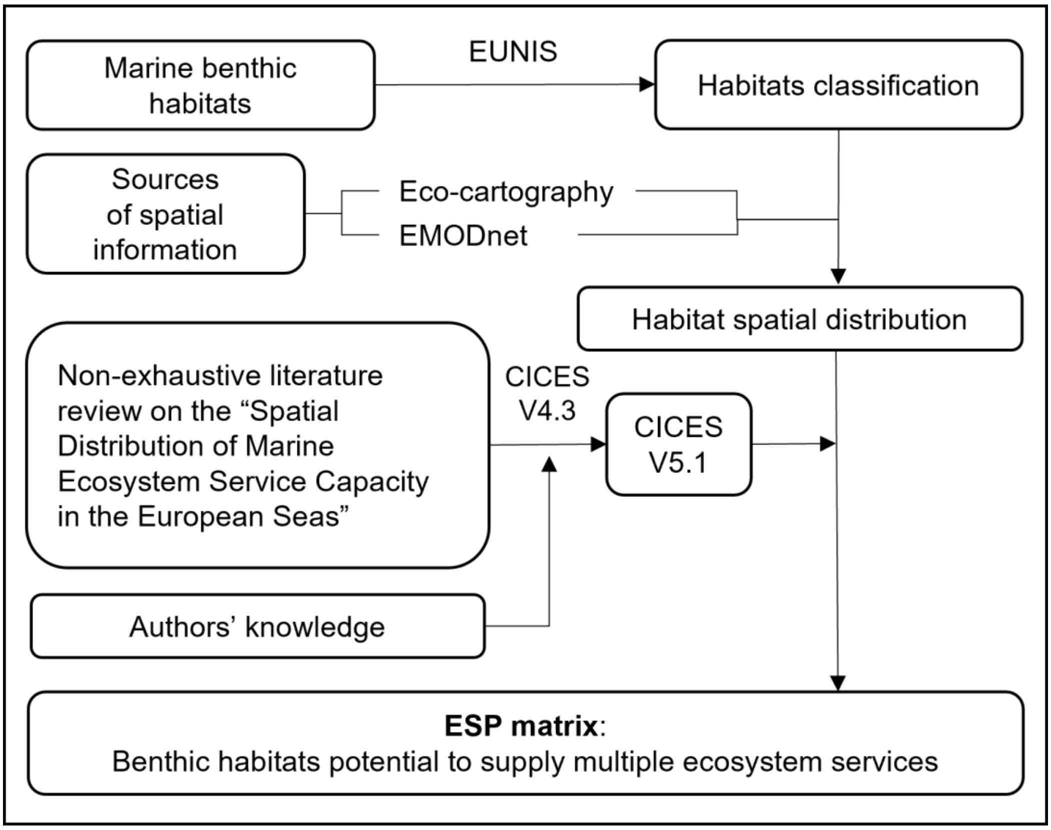

Fig. 1. Methological steps followed to map the ESP of  marine benthic habitats in the study area.

## 3.1. Study area.

The Canary Island archipelago is located off the Northwest African coast at about 28° N (Figure 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).

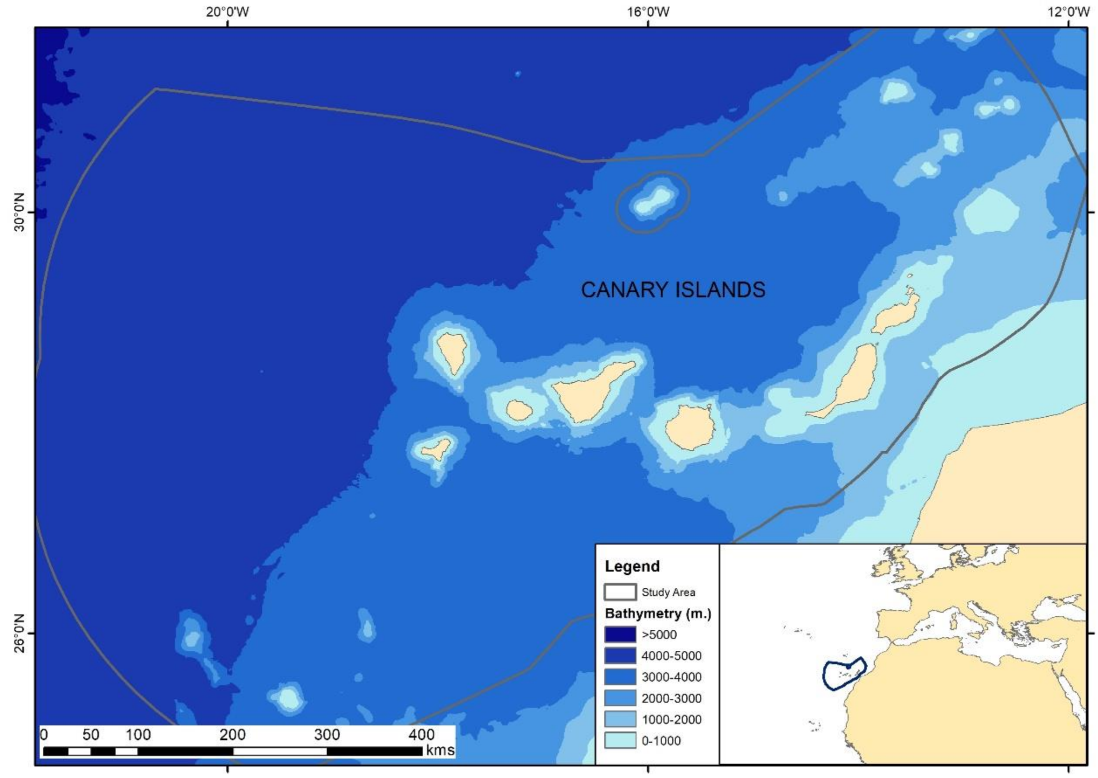

Fig. 2. The Canary Island archipelago located off the northwest African coastal upwelling system. The grey line represents the outer limit of the study area coinciding with the technical application of the Spanish Marine Strategy Framework Directive (2008/56/EC). Source: own elaboration.

Regarding benthic habitats, canopy-forming macroalgae in tidal pools are often found in rocky intertidal 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 (F 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 assemblages 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; Fernando Tuya, Png-Gonzalez, et al., 2014). All the above biological characteristics support the Canary Islands to be considered a marine biodiversity hotspot that, together with the highly developed coastal tourism and traditional community linkages with the sea, convert this area into a social and natural "laboratory" for the study of multiple ES.

## 3.2. 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 metres) and the European Marine Observation and Data Network (EMODnet) for deep habitats up to the outer limit of the study area (see figure 2).

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 without following homogeneously a common standard classification terminology. Thus, this study has 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 crosswalk tables, a cartography based on the 2012 revision of the pan-European EUNIS habitat classification was produced (PLASMAR Consortium, 2020).

According to EUNIS available description of marine habitats, these were categorized by their littoral zone (intertidal, infralittoral, circalittoral, deep circalittoral and deep-sea), and their substrate type (rock, coarse, sand, mud, mixed and biogenic). For their spatial analysis, habitats were separated by the two data set up to 50 metres of depth and beyond to deeper habitats. Separated analysis was decided due to the differences in the geospatial data used: habitats from the eco-cartography were mapped with high level of detail (1m resolution) but with restricted extension, whereas deeper habitats from EMODnet cover wider areas but were mapped with less precision (200m resolution).

## 3.3. Ecosystem services identification

The linkage of the multiple ES provided by the marine habitats has been done based on Tempera et al. (Tempera et al., 2016). This study compiles much of the scientific evidence linking marine benthic habitats to their potential to provide ES in the European Seas and harmonize the different ES terminologies into CICES standard, version 4.3. Subsequently, we have cross walked from CICES V4.3 to its latest current version 5.1. following the guidance on the application of the revised structure and its corresponding equivalence table (Haines-Young & Potschin, 2018) (see Table A.2 for more details).

For the ESP of those benthic habitats in our study area not assessed by Tempera et al. (Tempera et al., 2016) (e.g. intertidal habitats, EUNIS coded as #A1 and #A2), we have followed their same methodology to assign ESP (i.e. applying qualitative categories of presence, absence or no data) through their reviewed literature (see Table A.3 (Agardy et al., 2005; Armstrong et al., 2012; Galparsoro et al., 2014; Millennium Ecosystem Assessment, 2005; Potts et al., 2014; Salomidi et al., 2012)). Finally, for the habitats not assessed in any of the previous mentioned literature, i.e. the *Cystoseira spp.* habitat (EUNIS code A3.151) and the habitat associated with "faunal communities on low energy infralittoral rock" (EUNIS code A3.35), their ESP have been assigned according to local scientific literature and the authors' knowledge on the Canary Islands similarly to [37, 30] (see ESP assignment explanation in section A.4).

## 3.4. Ecosystem services assessment.

To map and compare ESP supply between ES aggregated by section level (i.e., provisioning, regulation and maintenance (hereafter both referee to as regulating), and cultural), five classes of Jenks natural breaks classification were applied through a geographic information system (GIS). For this, the ES abundance for each habitat was calculated similarly to (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).

To analyse patterns in the spatial distribution of ESP supply, we have considered similarly to (Galparsoro et al., 2014), the total area of each habitat and its relative extension to the total marine study area mapped. The ESP contributing area was calculated in a similar simplified way to (Geange et al., 2019b) as:

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

(1)

where $a$ is the area, $h$ is habitat type, $i$ is the service. Note that this study has not considered whether the ESP is supplied at a low, moderate, or high level (i.e., $j$) given 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.

Similarly to (Galparsoro et al., 2014), Friedman test, followed by *post-hoc* Wilcoxon tests, were done to explore statistical differences between ESP aggregated at a section level (i.e. provision, regulating, and cultural). Besides, Kruskal-Wallis non-parametric tests and *post-hoc* tests between pairs corrected through the Bonferroni test were applied to analyse the influenced of the hierarchical classification levels, the littoral zones and substrate type on the ESP. 3.

## 4. Results

The harmonized eco-cartography for the Canary Islands resulted in 23 shallow marine benthic, which together with the 11 deeper habitats from EMODnet were characterized for the ESP analysis of this study (see Table A.5). The literature reviewed together with the author's knowledge resulted in a matrix analysing the ESP of 34 habitats regarding 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 (Table 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 regulating ES (56% of cells, n=612) and provisioning ES (47% of cells, n=374). Besides, 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 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). Opposite, 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 littoral 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 latter 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, deep 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).

Table 1. Ecosystem services aggregated at section level potentially provided by shallow benthic habitats in the Canary Islands.

| **Intertidal, 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$^2$ | % | Nº | % | Nº | % | Nº | % | Nº | % |
| 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/average** | **2834.5** | **100** | **5** | **16** | **10** | **37** | **11** | **61** | **25** | **35** |

Table 2. Ecosystem services aggregated at section level potentially provided by deep benthic habitats in the Canary Islands.

| **Deep 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$^2$ | % | Nº | % | Nº | % | Nº | % | Nº | % |
| 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/average** | **481858.31** | **100** | **4** | **14** | **6** | **22** | **7** | **38** | **17** | **23** |

Similarly, reading the ESP-matrix vertically (Table 3), the number of benthic habitats with an ESP of a particular ES vary significantly across the levels of CICES classification (Kruskal-Wallis $H = 14.115, p < 0.003$) for both shallower habitats ($H = 15.521, p < 0.001$) and deeper habitats ($H = 13.964\ p < 0.003$). Thus, 100% of the habitats supply ES at their aggregated section level and decreases towards more specific ES at lower levels in CICES. This is observed across all littoral zones (all $p < 0.015$).

Besides, significant differences are 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) (Figures 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 significantly more than provisioning ES (z =−5.023, p < 0.001).

Collectively, marine benthic habitats present ESP for a wide range of different ES in the Canary Islands (Figure 6). However, the ESP area vary greatly across ES depending on the spatial extent of the habitats underpinning these ES. For example, for shallow habitats (see Table 3), ca. 16 Km$^2$ (i.e. 1 %) of our study area presents the potential to provide regulating ES such as "regulation of soil quality" (code 2.2.4),

Table 3. Cumulative extension (Km$^2$) and relative area values (%) across littoral zones of the benthic habitats (Nº) that potentially provide a particular ES. Empty cells indicate cero value. Ecosystem service codes are translated in Table A.2.

| **Ecosystem service** | **Shallow habitats (Eco-cartography)** | | | | | | | | | **Deep habitats (EMODnet)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Intertidal | | | Infralittoral | | | Circalittoral | | | Deep circalittoral | | | Deep-sea | | |
| CICES | Nº | Area | | Nº | Area | | Nº | Area | | Nº | Area | | Nº | 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 | 480521 | 100 |
| 1.1 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 3 | 475072 | 99 |
| 1.1.5 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 3 | 475072 | 99 |
| 1.1.6 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 3 | 475072 | 99 |
| 1.1.5.2 | | | | 6 | 933 | 34 | | | | | | | | | |
| 1.1.6.1 | | | | | | | | | | | | | 3 | 475072 | 99 |
| 1.1.6.2 | | | | 6 | 933 | 34 | | | | | | | | | |
| 2 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 4 | 480521 | 100 |
| 2 | 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 | 480521 | 100 |
| 2.2.1 | 5 | 4.25 | 100 | 14 | 2248 | 83 | 1 | 109 | 100 | 2 | 1133 | 87 | 3 | 475072 | 99 |
| 2.2.2 | 3 | 0.43 | 10 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 4 | 480521 | 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 | 475072 | 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 | 475072 | 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 | 475072 | 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 | 480521 | 100 |
| 3.1 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 1 | 407 | 31 | 4 | 480521 | 100 |
| 3.2 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 1 | 468989 | 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 | 480521 | 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 | 480521 | 100 |
| 3.1.2.2 | 3 | 0.43 | 10 | 13 | 2087 | 77 | 2 | 109 | 100 | 1 | 407 | 31 | 3 | 475072 | 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 | 480521 | 100 |
| 3.2.2.2 | 5 | 4.25 | 100 | 16 | 2721 | 100 | 2 | 109 | 100 | 7 | 1296 | 100 | 4 | 480521 | 100 |

"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). Similarly, 89 and 105 $Km^2$ potentially underpins, respectively, the provision of "control of erosion rates" (code 2.2.1.1), and "maintaining nursery populations and habitats (Including gene pool protection)" (code 2.2.2.3). As the eco-cartography were 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 depend (Figure 7).

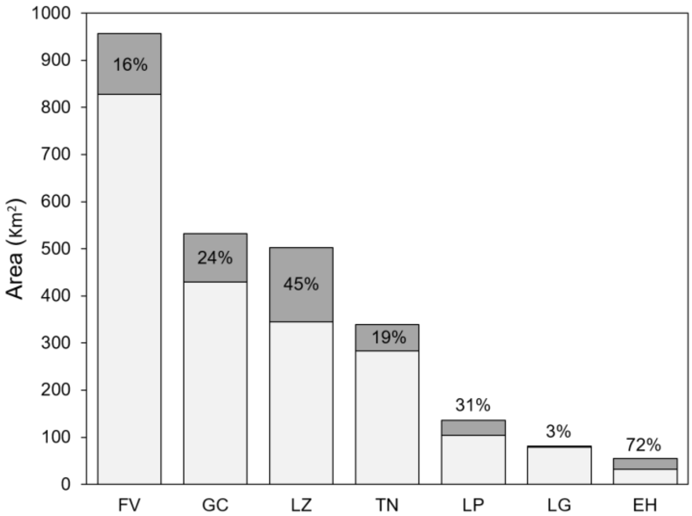

Fig. 7. Total area of marine benthic habitats (light grey) of each of the Canary Islands sorted from the highest to the lowest extension. Sum of areas with a high or very high ESP, i.e. with the potential to supply more than 26 ES (dark grey). Relative area with high to very high ESP values (%) are denoted inside bars. Island's abbreviations mean: FV= Fuerteventura, GC= Gran Canaria, LZ= Lanzarote, TN= Tenerife, LP= La Palma, LG= La Gomera, EH= El Hierro.

Besides, having calculated the spatial extent of the habitats underpinning different ES enable us to extrapolate already existing monetization of some ES, e.g. those accounted for *Cymodocea nodosa* regarding the island of Gran Canaria (Bañolas et al., 2020; Fernando Tuya, Haroun, et al., 2014) to the whole archipelago (ca. 8260 ha, corresponding to A5.5311 in Table 1). Thus, *C. nodosa* could be marketable (for three ES out of all those potentially provided) into ca. 17,689,864 € for its role to reduce carbon emissions (using the maximum market carbon price (Bañolas et al., 2020)), and 7,944,055 € $y^{-1}$ for coastal fisheries (through fish biomass generation for human consumption and as nursery grounds, (Fernando Tuya, Haroun, et al., 2014).

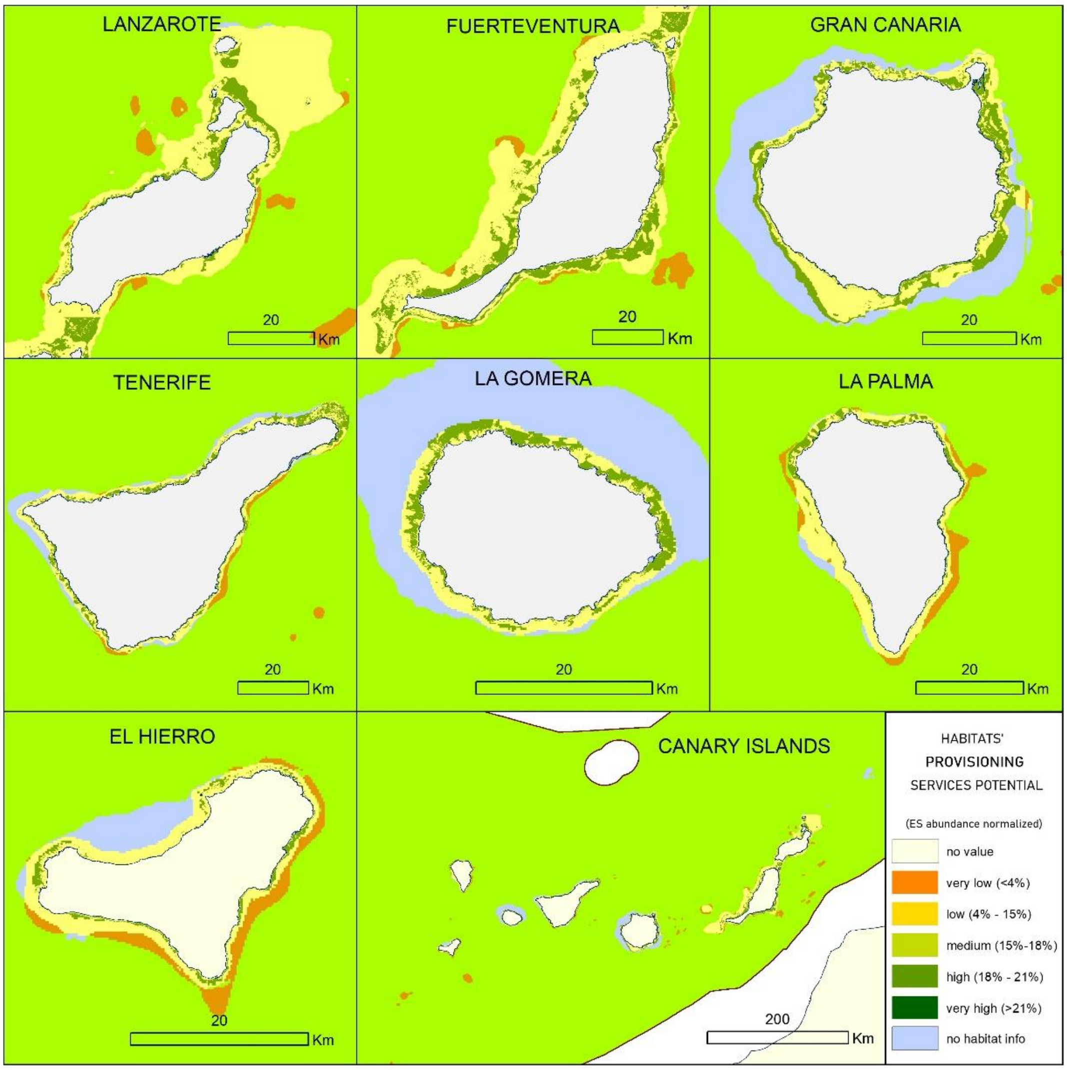

Fig. 3. Illustrates the provisioning ESP of marine benthic habitats of the Canary Islands.

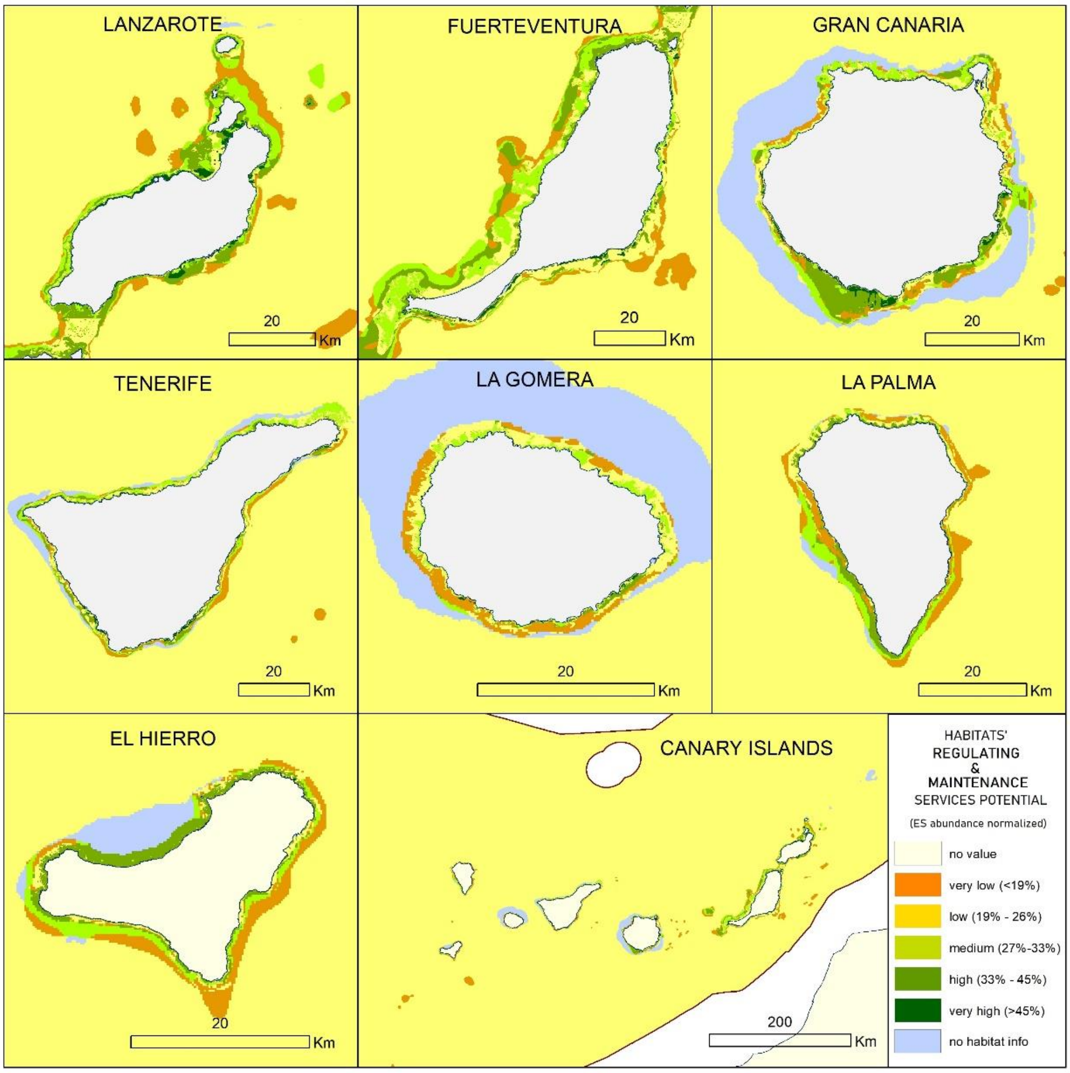

Fig. 4. Illustrates the regulation and maintenance ESP of marine benthic habitats of the Canary Islands.

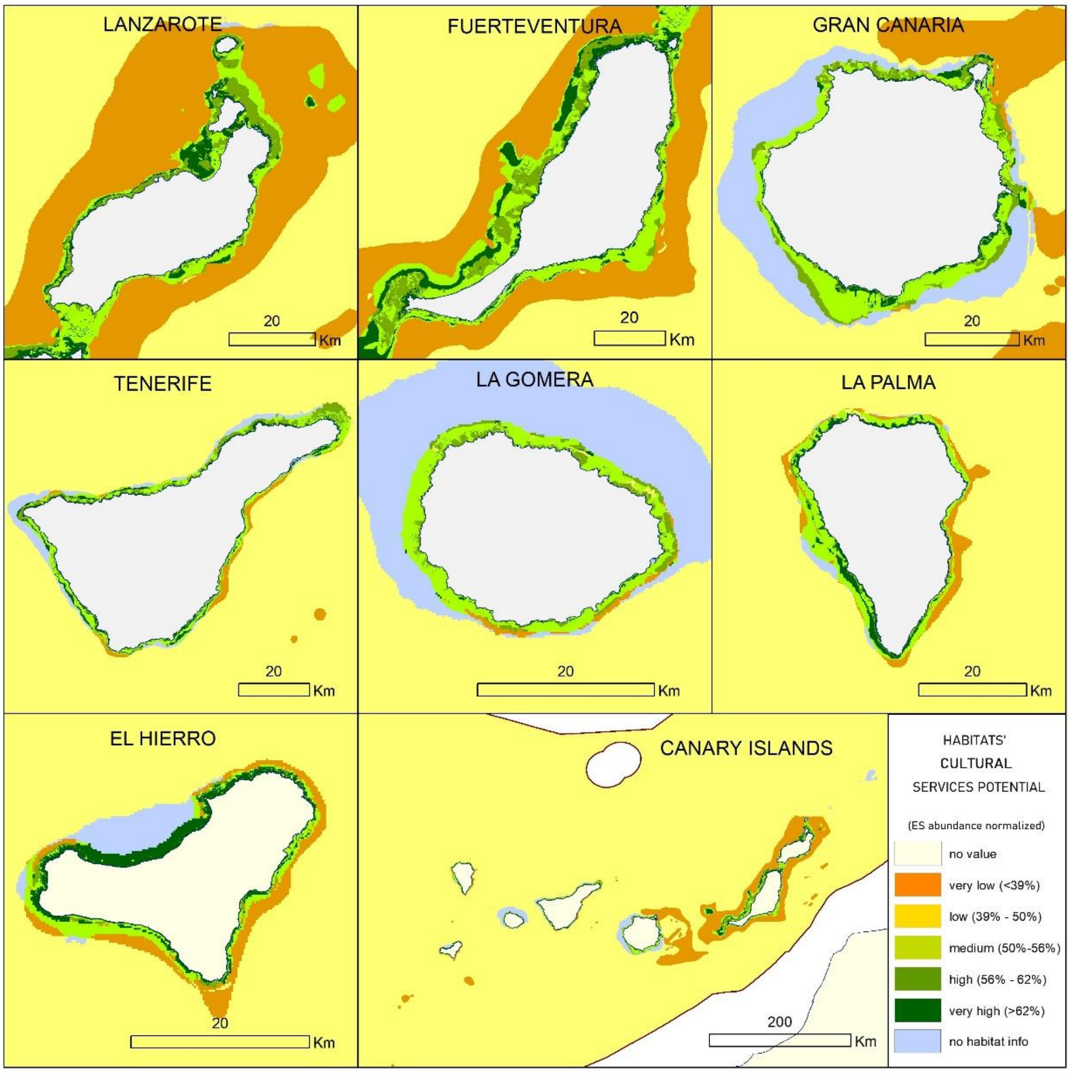

Fig. 5. Illustrates the cultural ESP of marine benthic habitats of the Canary Islands.

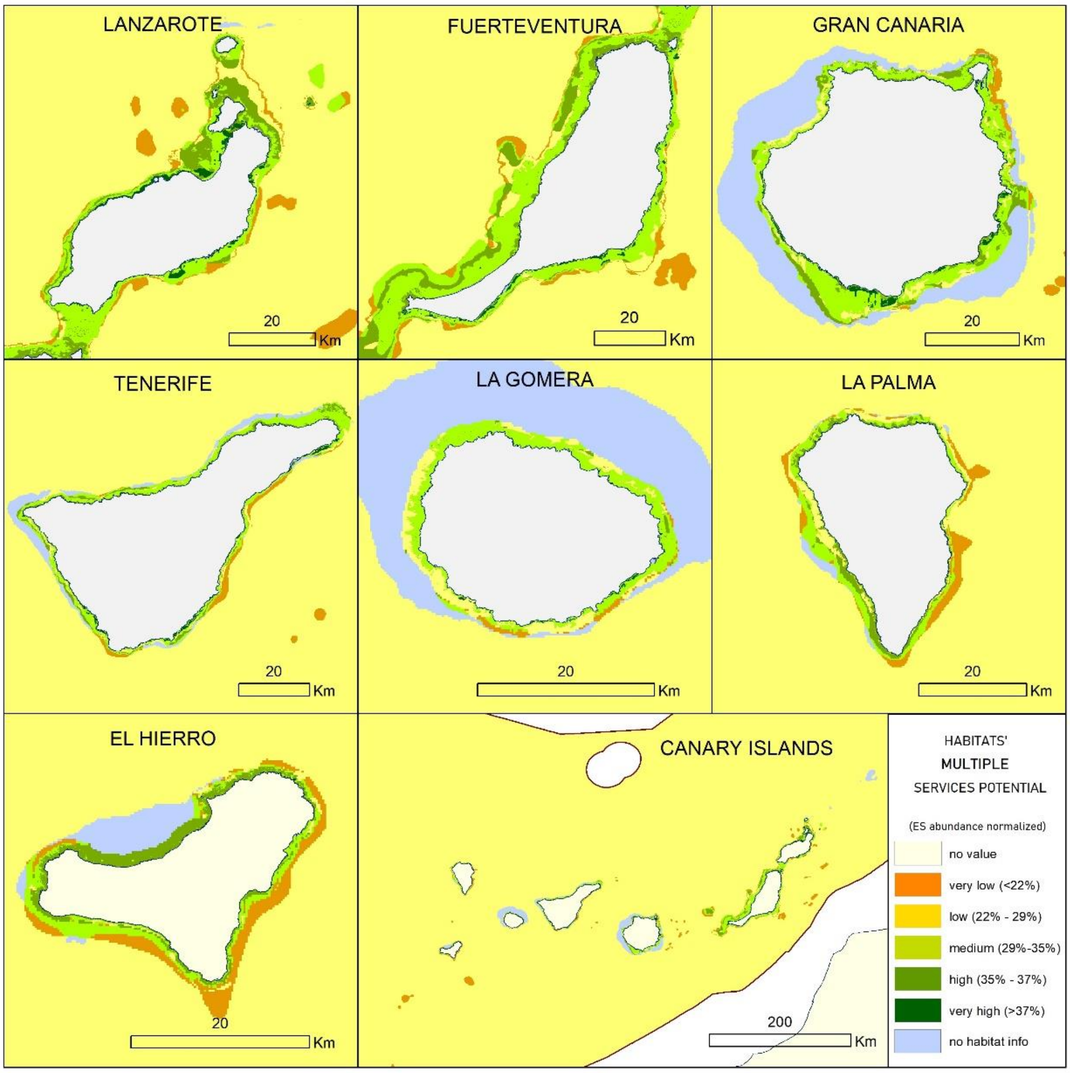

Fig. 6. Illustrates the overall ESP of marine benthic habitats of the Canary.

# 5. Discussion

## 5.1. ES in the Canary Islands

This study provides the first comprehensive spatial assessment of the ESP of the benthic habitats of the Canary Islands filling this knowledge gap noted at a regional scale (Galparsoro et al., 2014). The followed approach, based on the literature reviews gathered for the European Seas (Tempera et al., 2016), has resulted in a flexible and easy-to-apply method to cross-reference different ES terminologies and approximate to the ESP of marine habitats.

Cultural ES are the most widely supplied in the Canary islands in contrast to the European Seas which were provisioning ES (Galparsoro et al., 2014). This result is in line with literature reviews in ES for small islands where most studies have looked at cultural ES, e.g. recreation and eco-tourism (Balzan et al., 2018). Besides, cultural ES are easier to identify in the absence of scientific literature than other types of services (Caro et al., 2020), which has been the case during the discussion rounds undertook in this study to include the authors knowledge on the ESP assessment.

Statistically significant ESP decreasing gradient towards seawards and deeper habitats have not been noted for the Canary Islands as reported for the European Seas (Galparsoro et al., 2014). Although higher ESP near the coastline is visually appreciable in the ESP maps as expected in volcanic archipelagos with limited and abrupt continental platform. We argue this is due to other factors such as more limited information on ESP for deeper habitats compared to shallower (Thiele, 2019; Tyler et al., 2016). The deep-sea is generally considered out of reach for direct or in-situ interactions compared to more accessible shallower habitats, especially for cultural ES (Galparsoro et al., 2014; Milcu et al., 2013), but is recognized their fundamental role in providing habitat for great diversity of commercial species (Armstrong et al., 2012). However, provisioning ESP have been the less assessed ES (i.e. 53 % left unassessed), suggesting 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). Besides, local studies have modelled biological species of commercial interest using spatial units through ranges of depth (including both benthic and pelagic habitats) (Couce-Montero et al., 2015;

Couce Montero et al., 2021). This may suggest that both provisioning ES and deep-sea ESP have been underestimated in this study, partially likely to be explained by the use of benefits rather than biophysical functions and processes as a proxy for ESP (La Notte et al., 2017).

## 5.2. Applicability to marine planning

ES assessments can promote understanding of human activity-ecosystem interactions informing MSP processes and favouring of stakeholder's engagement (Friedrich et al., 2020). While broad ES terms (e.g. CICES division or group levels) may help bringing together political will and transdisciplinary efforts (van Oudenhoven et al., 2018), depicting marine benthic habitats and ES to their upper levels in our study favour the generation of nuance maps and promoting further assignment of ecosystem goods and benefits (Schaafsma & Turner, 2015).

Our results 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). This could be particularly useful while analysing the existing conditions or evaluating the outputs in MSP processes (Ehler & Douvere, 2009). Furthermore, our results can be interpreted as a mapping exercise of the marine green infrastructure of the Canary Islands based on the ecosystem service-based approach (Estreguil et al., 2019). For example, given the bioengineer ecological role of seagrasses and *Cystoseira* communities (Cheminée et al., 2013; Salomidi et al., 2012), comparing the area of these habitats and other high ESP associated habitats in relation to the total extent of shallow habitats (see Figure 7), we can analyse the equivalent area to the ecological structures of which the provision of most ES depend. This may suggest the susceptibility, in spatial terms, to lose ESP (and thus benefits for human well-being) in case of habitat degradation (Geange et al., 2019b). In the case of the Canary Islands, for example, massive decline of *Cystoseira abies-marina* have been reported (Valdazo et al., 2017). This habitats state changes will result on a decrease of their ESP or ES flow, which could reinforce decision-making arguments to improve marine protected areas (MPA) design (Schill et al., 2021) or track the expected benefits provided by existing MPAs (Geange et al., 2019b).

Our study may also serve as an ecosystem extent account, the first step of the System of Environmental-Economic Accounting (SEEA) methodology proposed by United Nations (United Nations, 2021). Following the example of *Cymodocea nodosa* accounted in our results for generating ca. 25,633,919 € $y^{-1}$ in the Canary Islands, similar studies could be built upon our results. However, we highlight, as noted by SEEA, that monetary valuation is not a necessary feature of all accounts (United Nations, 2021). Thus, we recommend acknowledging for cost-benefit analysis in decision-making that price is an approximation of value (Vatn & Bromley, 1994) and the need of supplementary approaches to avoid unintended social inequity, potentially resulting in ecological degradation (see e.g. (Pascual et al., 2014; Spash & Aslaksen, 2015)). Moreover, this work entails a practical example of the utility of standardised classification systems (e.g. EUNIS and CICES) applicability to MSP processes and more particular, to the regional planning process of the Canary Islands. The benthic habitat harmonisation done for our case study following the principles of the INSPIRE Directive (PLASMAR Consortium, 2020) enabled assembling the national (i.e. Spanish) benthic habitat mapping efforts with the 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.

## 5.3. Approach and data limitations of the study

If changes in the environment's condition depend upon our perception to be considered worth manageable environmental problems (Downs, 1972), benefits derived from the ocean may as well depend on our ability to perceive them. Besides, provisioning, regulation and maintenance ES are better explained by quantifiable natural-physical processes (La Notte et al., 2017), whereas cultural ES are mainly underpinned by social meaning (Irvine & Herrett, 2018). Being cultural ES the most widely assessed in the present study and generally in small islands (Balzan et al., 2018), we agree with other ES studies (Caro et al., 2020) indicating that decisions are being made based more on socio-cultural arguments than ecological characteristics and requirements.

The EUNIS habitats classification generally includes information regarding oceanographic conditions, species distribution and abiotic characteristics of the environment. However, habitats do not support the provision of ES directly, but ultimately are the numerous interactions of biodiversity within these habitats that accounts for the structures and functions underpinning ESP (Culhane et al., 2019; de Groot et al., 2002). Our 2D mapping disregards pelagic habitats and their dynamic spatial-temporal variability. We acknowledge the need of incorporating more holistic approaches to the ocean, e.g. the “cells of ecosystem functioning” (Boero et al., 2019) through identifying the significant ecological connected units explaining the main biogeochemical cycles, life cycles and food webs interactions covering the instability of marine systems. Progressing in the understanding the habitat’s ESP is, thus, progressing in the holistic understanding of such ecological processes and interactions. This was defined in 2010 as one of the main pending tasks regarding ES assessments for the past decade (Perrings et al., 2010), and we believe it is still pending for the current 2030 decade.

Assuming the good environmental status of the assessed benthic habitats enabled us to consider their total area as a proxy of their total ESP (Millennium Ecosystem Assessment, 2005). Although is recognized that ESP do not increase linearly with the spatial size of habitats (Barbier et al., 2008; Koch et al., 2009), this has been a necessary simplification to provide an approximation to the ESP in the Canary Islands.

Other data limitations derived from the reliability and quality of benthic habitats maps (Galparsoro et al., 2014) used as spatial units for this study. The eco-cartography, the most recent available data, has more than 16 years, which implies that habitat extensions most likely differ nowadays, e.g. as reported for *Cystoseira spp.* (Valdazo et al., 2017). Besides, is noticeable the usage of broad categories within EMODnet for deep-sea habitats, underestimating, for example, the extension of seamounts (and thus their ESP (Agardy et al., 2005)) located in the North-eastern part of the Canaries. Nevertheless, these datasets represent the most comprehensive, updated and a legitimate geospatial source for both shallow and deeper habitats (Tempera et al., 2016). Furthermore, as new remote sensing techniques are being developed, more accurate ES-supply assessments of regulating ES of deep circalittoral black coral habitats could soon be included (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.

## 6. Conclusion

The ESP-matrix approach based on the compilation of existing reviews for the European Seas has provided an easy and flexible tool to get a first snapshot of the overall habitats' ESP. Producing (to our knowledge) the first ESP maps for the Canary Islands, enables accounting for ES previously overlooked in the region and reinforce the recognition that coastal communities' well-being in small islands depend on their marine ecosystems. By adding the spatial extent and distribution of the habitats with the potential to provide multiple ES, we hope to inform existing regional MSP processes on the potentially large societal benefits that may be at risk by allocating maritime activities, while also serve to support marine protected areas design. As ESP maps quality and resolution depend on the features of the habitat maps used as spatial units, and ESP is actually underpinned by biodiversity and its functions, accuracy of both the employed data and approach can be increased successively, e.g. through deeper systematic literature reviews specifically for the study area and involving a larger number of local experts. Thus, this study serves as a useful first approximation that can be further expanded by gathering more detailed ecological information that explore interconnections between the ecological structures and functioning and between these and their contributions to our human well-being.

## 7. Future steps.

As explored during the PLASMAR+ project, marine ecosystems (as benthic habitats) are able to provide a wide variety of ES. Future assessments should aim to explore the other sides of the ES 'production chain', i.e. how the ecological provision 'flows' into society through the different complementary capital (e.g. human, built or technological capital), and how the multiple benefits from these flows are valued economically (i.e. instrumental value), but also socially (i.e. relational value), as it stands as a crucial challenge that we must address in order to ensure a sustainable usage of our environment (Pascual et al., 2023).

Regarding economic valuations, some ES have a directly use-value quantifiable in the national economic accountability of the Blue Economy. In this sense, having more precise and disaggregated socio-economic data by economic activities (see the PLASMAR+ report on the socio-economic analysis of maritime activities considered in the blue economy of the Canary Islands for more details in this regard) will allow for a more detailed monetization of ecosystem services.

## 8. References

Agardy, T., Alder, J., Dayton, P., Curran, S., Kitchingman, A., Wilson, M., Catenazzi, A., Restrepo, J., Birkeland, C., Blaber, S. J. M., Saifullah, S., Branch, G. M., Boersma, D., Nixon, S., Dugan, P., Davidson, N., & Vorosmarty, C. (2005). Coastal systems. In R. Bos (Ed.), *Ecosystems and human well-being: current state and trends* (pp. 513–550). Island Press. https://doi.org/http://hdl.handle.net/102.100.100/179272?index=1

Arístegui, J., Sangrá, P., Hernández-León, S., Cantón, M., Hernández-Guerra, A., & Kerling, J. L. (1994). Island-induced eddies in the Canary islands. *Deep-Sea Research Part I*, *41*(10), 1509–1525. https://doi.org/10.1016/0967-0637(94)90058-2

Armoškaitė, A., Puriņa, I., Aigars, J., Strāķe, S., Pakalniete, K., Frederiksen, P., Schrøder, L., & Hansen, H. S. S. (2020). Establishing the links between marine ecosystem components, functions and services: An ecosystem service assessment tool. *Ocean and Coastal Management*, *193*(October 2019). https://doi.org/10.1016/j.ocecoaman.2020.105229

Armstrong, C. W., Foley, N. S., Tinch, R., & van den Hove, S. (2012). Services from the deep: Steps towards valuation of deep sea goods and services. In *Ecosystem Services* (Vol. 2, pp. 2–13). Elsevier. https://doi.org/10.1016/j.ecoser.2012.07.001

Balzan, M. V., Potschin-Young, M., & Haines-Young, R. (2018). Island ecosystem services: Insights from a literature review on case-study island ecosystem services and future prospects. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *14*(1), 71–90. https://doi.org/10.1080/21513732.2018.1439103

Bañolas, G., Fernández, S., Espino, F., Haroun, R., & Tuya, F. (2020). Evaluation of carbon sinks by the seagrass Cymodocea nodosa at an oceanic island: Spatial variation and economic valuation. *Ocean & Coastal Management*, *187*, 105112. https://doi.org/10.1016/j.ocecoaman.2020.105112

Barbier, E. B., Koch, E. W., Silliman, B. R., Hacker, S. D., Wolanski, E., Primavera, J., Granek, E. F., Polasky, S., Aswani, S., Cramer, L. A., Stoms, D. M., Kennedy, C. J., Bael, D., Kappel, C. V., Perillo, G. M. E., & Reed, D. J. (2008). Coastal ecosystem-based management with nonlinear ecological functions and values. *Science*, *319*(5861), 321–323. https://doi.org/10.1126/SCIENCE.1150349/SUPPL_FILE/BARBIER.SOM.PDF

Barton, E. D., Aristegui, J., Tett, P., Canton, M., García-Braun, J., Hernández-León, S., Nykjaer, L., Almeida, C., Almunia, J., Ballesteros, S., Basterretxea, G., Escanez, J., García-Weill, L., Hernández-Guerra, A., López-Laatzen, F., Molina, R., Montero, M. F., Navarro-Peréz, E., Rodríguez, J. M., … Wild, K. (1998). The transition zone of the Canary Current upwelling region. *Progress in Oceanography*, *41*(4), 455–504. https://doi.org/10.1016/S0079-6611(98)00023-8

Boero, F., De Leo, F., Fraschetti, S., & Ingrosso, G. (2019). The Cells of Ecosystem Functioning: Towards a holistic vision of marine space. In *Advances in Marine Biology* (1st ed., Vol. 82). Elsevier Ltd. https://doi.org/10.1016/bs.amb.2019.03.001

Bordt, M., & Saner, M. A. (2019). Which ecosystems provide which services? A meta-analysis of nine selected ecosystem services assessments. *One Ecosystem*, *4*. https://doi.org/10.3897/oneeco.4.e31420

Burkhard, B., Kandziora, M., Hou, Y., & Müller, F. (2014). Ecosystem service potentials, flows and demands-concepts for spatial localisation, indication and quantification. *Landscape Online*, *34*(1), 1–32. https://doi.org/10.3097/LO.201434

Campagne, C. S., Roche, P., Müller, F., & Burkhard, B. (2020). Ten years of ecosystem services matrix: Review of a (r)evolution. *One Ecosystem*, *5*. https://doi.org/10.3897/oneeco.5.e51103

Caro, C., Cunha, P. P., Marques, J. C., & Teixeira, Z. (2020). Identifying ecosystem services research hotspots to illustrate the importance of site-specific research: An Atlantic coastal region case study. *Environmental and*

*Sustainability Indicators*, *6*, 100031. https://doi.org/10.1016/j.indic.2020.100031

Chalastani, V. I., Tsoukala, V. K., Coccossis, H., & Duarte, C. M. (2021). A bibliometric assessment of progress in marine spatial planning. *Marine Policy*, *127*, 104329. https://doi.org/10.1016/j.marpol.2020.104329

Cheminée, A., Sala, E., Pastor, J., Bodilis, P., Thiriet, P., Mangialajo, L., Cottalorda, J. M., & Francour, P. (2013). Nursery value of Cystoseira forests for Mediterranean rocky reef fishes. *Journal of Experimental Marine Biology and Ecology*, *442*, 70–79. https://doi.org/10.1016/J.JEMBE.2013.02.003

Cordero-Penín, V., Abramic, A., García-Mendoza, A., Otero-Ferrer, F., & Haroun, R. (2023). Mapping marine ecosystem services potential across an oceanic archipelago: Applicability and limitations for decision-making. *Ecosystem Services*, *60*(April), 101517. https://doi.org/10.1016/j.ecoser.2023.101517

Couce-Montero, L., Christensen, V., & Castro, J. J. (2015). Effects of small-scale and recreational fisheries on the Gran Canaria ecosystem. *Ecological Modelling*, *312*, 61–76. https://doi.org/10.1016/J.ECOLMODEL.2015.05.021

Couce Montero, L., Christensen, V., & Castro Hernández, J. J. (2021). Simulating trophic impacts of fishing scenarios on two oceanic islands using Ecopath with Ecosim. *Marine Environmental Research*, *169*, 105341. https://doi.org/10.1016/j.marenvres.2021.105341

Crowder, L., & Norse, E. (2008). Essential ecological insights for marine ecosystem-based management and marine spatial planning. *Marine Policy*, *32*(5), 772–778. https://doi.org/10.1016/j.marpol.2008.03.012

Culhane, F., Frid, C., Royo Gelabert, E., & Robinson, L. (2019). *EU Policy-Based Assessment of the Capacity of Marine Ecosystems to Supply Ecosystem Services. ETC/ICM Technical Report 2/2019*. https://www.eionet.europa.eu/etcs/etc-icm

Czechowska, K., Feldens, P., Tuya, F., Cosme de Esteban, M., Espino, F., Haroun, R., Schönke, M., & Otero-Ferrer, F. (2020). Testing Side-Scan Sonar and

Multibeam Echosounder to Study Black Coral Gardens: A Case Study from Macaronesia. *Remote Sensing*, *12*(19), 3244. https://doi.org/10.3390/rs12193244

de Groot, R. S. (1987). Environmental functions as a unifying concept for ecology and economics. *The Environmentalist*, *7*(2), 105–109. https://doi.org/10.1007/BF02240292

de Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, *41*(3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. *Marine Policy*, *32*(5), 762–771. https://doi.org/10.1016/j.marpol.2008.03.021

Downs, A. (1972). Up and Down with Ecology–The "issue-attention cycle." *Public Interest*, *28*(Summer), 38–50. http://www.unc.edu/~fbaum/teaching/articles/Downs_Public_Interest_1972.pdf

EC. (2020). EU Biodiversity Strategy for 2030 - Bringing nature back into our lives. *Official Journal of the European Communities*, *380 final*.

Ehler, C., & Douvere, F. (2009). *Marine spatial planning: a step-by-step approach toward ecosystem-based management*. http://unesdoc.unesco.org/images/0018/001865/186559e.pdf

Elliott, M., Burdon, D., Atkins, J. P., Borja, A., Cormier, R., de Jonge, V. N., & Turner, R. K. (2017). "And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management. *Marine Pollution Bulletin*, *118*(1–2), 27–40. https://doi.org/10.1016/j.marpolbul.2017.03.049

Elliott, Michael, & O'Higgins, T. G. (2020). From DPSIR the DAPSI(W)R(M) Emerges… a Butterfly – 'protecting the natural stuff and delivering the human stuff.' In *Ecosystem-Based Management, Ecosystem Services and Aquatic*

*Biodiversity* (pp. 61–86). Springer International Publishing. https://doi.org/10.1007/978-3-030-45843-0_4

Estreguil, C., Dige, G., Kleeschulte, S., Carrao, H., Raynal, J., & Teller, A. (2019). *Strategic Green Infrastructure and Ecosystem Restoration: geospatial methods, data and tools* (Issue February). https://doi.org/10.2760/36800

European Commission. (2013). *COM(2013) 249 final. Green Infrastructure (GI) — Enhancing Europe’s Natural Capital*.

Fletcher, S., Saunders, J., Herbert, R., Roberts, C., & Dawson, K. (2012). *Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area* (Issue 088). https://doi.org/10.1007/978-3-319-60156-4_3

Friedrich, L. A., Glegg, G., Fletcher, S., Dodds, W., Philippe, M., & Bailly, D. (2020). Using ecosystem service assessments to support participatory marine spatial planning. *Ocean & Coastal Management*, *188*, 105121. https://doi.org/10.1016/J.OCECOAMAN.2020.105121

Galparsoro, I., Borja, A., & Uyarra, M. C. M. C. (2014). Mapping ecosystem services provided by benthic habitats in the European North Atlantic Ocean. *Frontiers in Marine Science*, *1*(JUL). https://doi.org/10.3389/fmars.2014.00023

Galparsoro, I., Pınarbaşı, K., Gissi, E., Culhane, F., Gacutan, J., Kotta, J., Cabana, D., Wanke, S., Aps, R., Bazzucchi, D., Cozzolino, G., Custodio, M., Fetissov, M., Inácio, M., Jernberg, S., Piazzi, A., Paudel, K. P., Ziemba, A., & Depellegrin, D. (2021). Operationalisation of ecosystem services in support of ecosystem-based marine spatial planning: insights into needs and recommendations. *Marine Policy*, *131*, 104609. https://doi.org/10.1016/j.marpol.2021.104609

García-Onetti, J., Scherer, M. E. G., Asmus, M. L., García Sanabria, J., & Barragán, J. M. (2021). Integrating ecosystem services for the socio-ecological management of ports. *Ocean and Coastal Management*, *206*(February). https://doi.org/10.1016/j.ocecoaman.2021.105583

Geange, S., Townsend, M., Clark, D., Ellis, J. I., & Lohrer, A. M. (2019a). Communicating the value of marine conservation using an ecosystem service matrix approach. *Ecosystem Services*, *35*, 150–163. https://doi.org/10.1016/j.ecoser.2018.12.004

Geange, S., Townsend, M., Clark, D., Ellis, J. I., & Lohrer, A. M. (2019b). Communicating the value of marine conservation using an ecosystem service matrix approach. *Ecosystem Services*, *35*, 150–163. https://doi.org/10.1016/j.ecoser.2018.12.004

Haines-Young, R., & Potschin, M. B. (2018). *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure*.

Haroun, R., Gil-Rodríguez, M. C., Neto, A. I., Machín-Sánchez, M., & Viera-Rodríguez, M. A. (2019). A review of current uses and potential biotechnological applications of seaweeds from the Macaronesian region (Central-East Atlantic Ocean). *Journal of Applied Phycology*, *31*(6), 3777–3790. https://doi.org/https://doi.org/10.1007/s10811-019-01889-4

Hebel, M. (1999). World-Views as the Emergent Property of Human Value Systems. *Systems Research and Behavioral Science*, *16*, 253–261. https://doi.org/10.1002/(SICI)1099-1743(199905/06)16:3

Hutchison, L., Montagna, P., Yoskowitz, D., Scholz, D., & Tunnell, J. (2013). Stakeholder Perceptions of Coastal Habitat Ecosystem Services. *Estuaries and Coasts*, *38*(1), 67–80. https://doi.org/10.1007/S12237-013-9647-7

Irvine, K. N., & Herrett, S. (2018). Does ecosystem quality matter for cultural ecosystem services? *Journal for Nature Conservation*, *46*, 1–5. https://doi.org/10.1016/J.JNC.2018.08.010

Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., & Schneiders, A. (2015). 'The Matrix Reloaded': A review of expert knowledge use for mapping ecosystem services. *Ecological Modelling*, *295*, 21–30. https://doi.org/10.1016/J.ECOLMODEL.2014.08.024

Klain, S. C., & Chan, K. M. A. (2012). Navigating coastal values: Participatory mapping of ecosystem services for spatial planning. *Ecological Economics*, *82*, 104–113. https://doi.org/10.1016/j.ecolecon.2012.07.008

Koch, E. W., Barbier, E. B., Silliman, B. R., Reed, D. J., Perillo, G. M. E., Hacker, S. D., Granek, E. F., Primavera, J. H., Muthiga, N., Polasky, S., Halpern, B. S., Kennedy, C. J., Kappel, C. V., & Wolanski, E. (2009). Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment*, *7*(1), 29–37. https://doi.org/10.1890/080126

La Notte, A., D'Amato, D., Mäkinen, H., Paracchini, M. L., Liquete, C., Egoh, B., Geneletti, D., & Crossman, N. D. (2017). Ecosystem services classification: A systems ecology perspective of the cascade framework. *Ecological Indicators*, *74*, 392–402. https://doi.org/10.1016/j.ecolind.2016.11.030

Martínez-Harms, M. J., & Balvanera, P. (2012). Methods for mapping ecosystem service supply: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1–2), 17–25. https://doi.org/10.1080/21513732.2012.663792

Milcu, A. I., Hanspach, J., Abson, D., & Fischer, J. (2013). Cultural Ecosystem Services: A Literature Review and Prospects for Future Research. *Ecology and Society*, *18*(3), art44. https://doi.org/10.5751/ES-05790-180344

Millennium Ecosystem Assessment. (2005). *Ecosystem and Human Well-being: Wetlands and Water Synthesis*. World Resources Institute. https://doi.org/https://www.millenniumassessment.org/documents/document.358.aspx.pdf

Otero-Ferrer, F., Cosme, M., Tuya, F., Espino, F., & Haroun, R. (2020). Effect of depth and seasonality on the functioning of rhodolith seabeds. *Estuarine, Coastal and Shelf Science*, *235*, 106579. https://doi.org/10.1016/j.ecss.2019.106579

Pascual, U., Balvanera, P., Anderson, C. B., Chaplin-Kramer, R., Christie, M., González-Jiménez, D., Martin, A., Raymond, C. M., Termansen, M., Vatn, A., Athayde, S., Baptiste, B., Barton, D. N., Jacobs, S., Kelemen, E., Kumar, R., Lazos, E., Mwampamba, T. H., Nakangu, B., … Zent, E. (2023). Diverse values of nature for sustainability. *Nature*, *620*(7975), 813–823. https://doi.org/10.1038/s41586-023-06406-9

Pascual, U., Phelps, J., Garmendia, E., Brown, K., Corbera, E., Martin, A., Gomez-Baggethun, E., & Muradian, R. (2014). Social Equity Matters in Payments for Ecosystem Services. *BioScience*, *64*(11), 1027–1036. https://doi.org/10.1093/biosci/biu146

Perrings, C., Naeem, S., Ahrestani, F., Bunker, D. E., Burkill, P., Canziani, G., Elmqvist, T., Ferrati, R., Fuhrman, J., Jaksic, F., Kawabata, Z., Kinzig, A., Mace, G. M., Milano, F., Mooney, H., Prieur-Richard, A.-H., Tschirhart, J., & Weisser, W. (2010). Ecosystem Services for 2020. *Science*, *330*(6002), 323–324. https://doi.org/10.1126/science.1196431

PLASMAR Consortium. (2020). *Marine monitoring methods needed to apply MSP ecosystem approach*. https://doi.org/http://hdl.handle.net/10553/107120

Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., & Schleyer, C. (2018). Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. *Ecosystem Services*, *29*, 428–440. https://doi.org/10.1016/j.ecoser.2017.05.015

Potschin-Young, Marion, Czúcz, B., Liquete, C., Maes, J., Rusch, G. M., & Haines-Young, R. (2017). Intermediate ecosystem services: An empty concept? *Ecosystem Services*, *27*, 124–126. https://doi.org/10.1016/j.ecoser.2017.09.001

Potts, T., Burdon, D., Jackson, E., Atkins, J., Saunders, J., Hastings, E., & Langmead, O. (2014). Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy*, *44*, 139–148. https://doi.org/10.1016/j.marpol.2013.08.011

Riera, R., Becerro, M. A., Stuart-Smith, R. D., Delgado, J. D., & Edgar, G. J. (2014). Out of sight, out of mind: Threats to the marine biodiversity of the Canary Islands (NE Atlantic Ocean). *MARINE POLLUTION BULLETIN*, *86*(1–2), 9–18.

https://doi.org/10.1016/j.marpolbul.2014.07.014

Salomidi, M., Katsanevakis, S., Borja, A., Braeckman, U., Damalas, D., Galparsoro, I., Mifsud, R., Mirto, S., Pascual, M., Pipitone, C., Rabaut, M., Todorova, V., Vassilopoulou, V., & Vega Fernandez, T. (2012). Assessment of goods and services, vulnerability, and conservation status of European seabed biotopes: a stepping stone towards ecosystem-based marine spatial management. *Mediterranean Marine Science*, *13*(1), 49–88. https://doi.org/https://doi.org/10.12681/mms.23

Sangil, C., Sansón, M., & Afonso-Carrillo, J. (2011). Spatial variation patterns of subtidal seaweed assemblages along a subtropical oceanic archipelago: Thermal gradient vs herbivore pressure. *Estuarine, Coastal and Shelf Science*, *94*(4), 322–333. https://doi.org/10.1016/j.ecss.2011.07.004

Schaafsma, M., & Turner, R. K. (2015). Coastal Zones Ecosystem Services. In *Coastal Zones Ecosystem Services. From Science to Values and Decision Making* (Vol. 9, pp. 103–125). Springer. https://doi.org/10.1007/978-3-319-17214-9

Schill, S. R., McNulty, V. P., Pollock, F. J., Lüthje, F., Li, J., Knapp, D. E., Kington, J. D., McDonald, T., Raber, G. T., Escovar-Fadul, X., & Asner, G. P. (2021). Regional High-Resolution Benthic Habitat Data from Planet Dove Imagery for Conservation Decision-Making and Marine Planning. *Remote Sensing*, *13*(21), 4215. https://doi.org/10.3390/rs13214215

Sousa, L. P., Sousa, A. I., Alves, F. L., & Lillebø, A. I. (2016). Ecosystem services provided by a complex coastal region: Challenges of classification and mapping. *Scientific Reports*, *6*, 1–14. https://doi.org/10.1038/srep22782

Spangenberg, J. H., Görg, C., Truong, D. T., Tekken, V., Bustamante, J. V., & Settele, J. (2014). Provision of ecosystem services is determined by human agency, not ecosystem functions. Four case studies. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *10*(1), 40–53. https://doi.org/10.1080/21513732.2014.884166

Spash, C. L., & Aslaksen, I. (2015). Re-establishing an ecological discourse in the policy debate over how to value ecosystems and biodiversity. *Journal of Environmental Management*, *159*, 245–253. https://doi.org/10.1016/j.jenvman.2015.04.049

Tallis, H., Lester, S. E., Ruckelshaus, M., Plummer, M., McLeod, K., Guerry, A., Andelman, S., Caldwell, M. R., Conte, M., Copps, S., Fox, D., Fujita, R., Gaines, S. D., Gelfenbaum, G., Gold, B., Kareiva, P., Kim, C., Lee, K., Papenfus, M., … White, C. (2012). New metrics for managing and sustaining the ocean's bounty. *Marine Policy*, *36*(1), 303–306. https://doi.org/10.1016/j.marpol.2011.03.013

Tempera, F., Liquete, C., & Cardoso, A. C. (2016). Spatial Distribution of Marine Ecosystem Service Capacity in the European Seas. In P. O. of the E. Union (Ed.), *JRC Technical Report* (Technical). https://doi.org/10.2788/753996

Thiele, T. (2019). Deep-Sea Natural Capital: Putting Deep-Sea Economic Activities into an Environmental Context. In R. Sharma (Ed.), *Environmental Issues of Deep-Sea Mining* (pp. 507–518). Springer, Cham. https://doi.org/10.1007/978-3-030-12696-4_18

Townsend, M., Davies, K., Hanley, N., Hewitt, J. E., Lundquist, C. J., & Lohrer, A. M. (2018). The challenge of implementing the marine ecosystem service concept. *Frontiers in Marine Science*, *5*(359). https://doi.org/10.3389/fmars.2018.00359

Tuya, F, Ramirez, R., Sanchez-Jerez, P., Haroun, R. J., Gonzalez-Ramos, A., & Coca, J. (2006). Coastal resources exploitation can mask bottom-up mesoscale regulation of intertidal populations. *HYDROBIOLOGIA*, *553*, 337–344. https://doi.org/10.1007/s10750-005-1246-6

Tuya, Fernando, Haroun, R., & Espino, F. (2014). Economic assessment of ecosystem services: Monetary value of seagrass meadows for coastal fisheries. *Ocean & Coastal Management*, *96*, 181–187. https://doi.org/10.1016/J.OCECOAMAN.2014.04.032

Tuya, Fernando, Png-Gonzalez, L., Riera, R., Haroun, R., & Espino, F. (2014). Ecological structure and function differs between habitats dominated by seagrasses and green seaweeds. *MARINE ENVIRONMENTAL RESEARCH*, *98*, 1–13. https://doi.org/10.1016/j.marenvres.2014.03.015

Tyler, P. A., Baker, M., & Ramirez-Llodra, E. (2016). Deep-sea Benthic Habitats. In M. R. Clark, M. Consalvey, & A. A. Rowden (Eds.), *Biological Sampling in the Deep Sea* (pp. 1–15). Wiley. https://doi.org/10.1002/9781118332535

UNESCO-IOC/European Commission. (2021). International Guide on Marine/Maritime Spatial Planning. In A. Iglesias-Campos, J. Rubeck, D. Sanmiguel-Esteban, & G. Schwarz (Eds.), *Maritime Spatial Planning* (IOC Manual). UNESCO/European Commission. https://doi.org/10.1007/978-3-319-98696-8

United Nations. (2021). System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). In *White cover publication, pre-edited text subject to official editing*. https://seea.un.org/ecosystem-accounting

Valdazo, J., Ascension Viera-Rodriguez, M., Espino, F., Haroun, R., & Tuya, F. (2017). Massive decline of Cystoseira abies-marina forests in Gran Canaria Island (Canary Islands, eastern Atlantic). *SCIENTIA MARINA*, *81*(4), 499–507. https://doi.org/10.3989/scimar.04655.23A

van Oudenhoven, A. P. E., Aukes, E., Bontje, L. E., Vikolainen, V., van Bodegom, P. M., & Slinger, J. H. (2018). 'Mind the Gap' between ecosystem services classification and strategic decision making. *Ecosystem Services*, *33*(September), 77–88. https://doi.org/10.1016/j.ecoser.2018.09.003

Vatn, A., & Bromley, D. W. (1994). Choices without Prices without Apologies. *Journal of Environmental Economics and Management*, *26*(2), 129–148. https://doi.org/10.1006/jeem.1994.1008