



HAL
open science

Multidimensional assessment of supporting ecosystem services for marine spatial planning of the Adriatic Sea

Elisabetta Manea, Davide Di Carlo, D. Depellegrin, T. Agardy, E. Gissi

► To cite this version:

Elisabetta Manea, Davide Di Carlo, D. Depellegrin, T. Agardy, E. Gissi. Multidimensional assessment of supporting ecosystem services for marine spatial planning of the Adriatic Sea. *Ecological Indicators*, 2021, 101, pp.821-837. 10.1016/j.ecolind.2018.12.017 . hal-04422476

HAL Id: hal-04422476

<https://hal.science/hal-04422476v1>

Submitted on 28 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Multidimensional assessment of supporting ecosystem services for marine spatial** 2 **planning of the Adriatic Sea**

3 E. Manea^{1*}, D. Di Carlo¹, D. Depellegrin², T. Agardy³, E. Gissi¹

4

5 ¹ Università Iuav di Venezia, Tolentini, 191, 30135, Venice, Italy, email: emanea@iuav.it.

6 ² National Institute of Marine Science, National Research Council, Arsenale, Tesa 104, Castello 2737/F,
7 30122 Venice, Italy.

8 ³ Sound Seas, Bethesda, Maryland, United States.

9 *Correspondence and requests for materials should be addressed to E. Manea (email: emanea@iuav.it)

10

11

Abstract

12 The assessment and mapping of ecosystem services (ES) has become an increasingly important instrument for
13 environmental management and conservation priority-setting. As such, this practice can be used in ecosystem-
14 based Marine Spatial Planning (MSP). MSP is recognized as an opportunity to achieve socio-economic and
15 ecological goals simultaneously, to suggest solutions for sustainable management of marine environment and
16 its resources. In this study, we propose an operational approach that includes novel spatial analysis in the
17 marine field to quantify and map supporting ecosystem services. Such approach spans the 3D-dimension of
18 the marine environment, considering all marine domains (sea surface, water column, seabed) separately. Our
19 approach is focused on mapping supporting ES of the Adriatic Sea, to grant their preservation in order to
20 guarantee the delivery of all other ES. Supporting ES provision in the Adriatic was quantified through the use
21 of indicators that denote ES delivery and that are specifically related to the three marine domains. We identified
22 areas of elevated provisioning levels of multiple supporting ES in the Adriatic, which is hypothesized to be
23 priority areas of conservation. Our results confirm the importance of explicitly including the pelagic domain
24 in planning and conservation processes. Areas that provide the lowest levels of supporting ES delivery were
25 also mapped, to indicate possible ‘sacrificial areas’ for industrial or intensive use. The spatial coincidence of
26 the determined hotspots areas of ES delivery associated with particular marine areas that are and are not under
27 conservation regimes was analysed. This approach led us to test the applicability of the method for identifying

28 marine areas for conservation purposes. Our methodological approach aims at producing relevant scientific
29 knowledge for prioritizing marine conservation and sustainable management actions, to be used in MSP and
30 marine management.

31

32 **Keywords:** supporting ecosystem services; 3-dimensionality; ecosystem services mapping, hotspot analysis;
33 Adriatic Sea, marine spatial planning

34

35 **1. Introduction**

36 The assessment and mapping of ecosystem services (ES) has become an important instrument for
37 environmental management and conservation priority-setting (Egoh et al. 2007, Fisher et al. 2009, Verhagen
38 et al. 2017). In fact, since ES are the benefits people obtain from nature (MA 2005), upon which both socio-
39 economic development and human well-being depend, their consideration is fundamental for an efficient and
40 lasting management of the environment and its resources. Moreover, recent studies have demonstrated the
41 existence of strict linkages between nature, ES delivery, and human well-being, not only in terms of socio-
42 economic value but also in favouring human health from a physical and mental perspective (Sandifer et al.
43 2015, Gascon et al. 2015, Frumkin et al. 2017).

44 Despite the recognized importance of ES for maintaining human well-being, most of the decisions related to
45 environmental management and resource exploitation neglect ES (Laurans et al. 2013, Ruckelshaus et al.
46 2015). Going back to the ES classification of MA (MA, 2005), which categorizes ES in four groups
47 (provisioning, supporting, regulating, and cultural), the supporting ES are often omitted in conservation
48 planning. However, supporting ES represent the basic ecological processes and functions that are fundamental
49 for the supply of all other ES (MA 2005, Costanza et al. 2017). Supporting ES are not recognized as providers
50 of direct economic benefits since they act indirectly on human well-being (MA, 2005). This aspect has
51 exacerbated the difficulty in assigning them a market value to be taken into account in decision-making
52 processes (Costanza et al. 2017). For this reason, they are commonly the last benefits to be assessed (Egoh et
53 al. 2007, Martínez-Harms & Balvanera 2012), especially in the marine field. This omission easily allows

54 decision makers to avoid consideration related to those services that are of outmost importance for establishing
55 sustainable management priorities, because of their role in ensuring the existence of all other benefits (Böhnke-
56 Henrichs et al. 2013).

57 While marine supporting ES provide numerous key benefits underpinning several economic activities and
58 human prosperity in coastal regions (EC, 2012), their assessment is challenging because it is difficult to find
59 appropriate indicators to represent them (Hauck et al. 2013). Moreover, the dynamic and complex nature of
60 marine ecosystems, their high connectivity, the truly widespread dispersal of species, the wide spatial
61 distribution of any ecological processes that lead supporting ES delivery, including the interactions among
62 biotic and abiotic components (Maxwell et al. 2015, Smith et al. 2017, Carr et al. 2003), are all aspects that
63 complicate supporting ES assessment. Marine ES assessment is still far from being exhaustive, especially
64 because of the difficulty to incorporate the marine vertical component and its spatio-temporal dynamics and
65 ecological processes (Lavorel et al. 2017, Tempera et al. 2016, Caro et al. 2018). Furthermore, the speculated
66 amount of unknown marine biodiversity (Costello et al. 2010) limits our knowledge on organisms' relations
67 and their role in marine ecosystem functioning. Such complexity needs to be overpassed since supporting ES
68 assessment and preservation can be widely beneficial to numerous services and benefits at once. Supporting
69 ES need urgent protection to endure in the wake of increasing direct and indirect threats due to the
70 anthropogenic pressures that lead to ecosystem degradation (Halpern et al. 2015, Borja et al. 2016).

71 The necessity to integrate supporting ES information in a multi-benefits sustainable management calls for
72 Marine or Maritime Spatial Planning (MSP) that is rooted in an ecosystem-based (EB) approach. MSP
73 represents an opportunity for planners and decision makers to spatially assign human uses at sea to favour
74 socio-economic development, preserving the good status of the marine environment and the sustainable use of
75 its resources, meeting both ecological, economic and social objectives (Douvere 2008, Outeiro et al. 2015).
76 MSP provides the occasion to adopt an integrated approach to look at and anticipate conflicts among uses and
77 the environment, and it is the mean through which EB can be implemented and operationalized (Douvere,
78 2008, Ansong et al. 2017). Incorporating ES assessment and mapping in MSP is not a common practice yet,
79 but it is recognized as a practice that allows more easy communications with politicians in decision-making
80 processes (Maes et al. 2012, Portman 2013). It is also indicated as a valid method in achieving different

81 management goals in multisector contexts (White et al. 2012, Arkema et al. 2015), especially when goals
82 include environmental conservation. Ecosystem-based Marine Spatial Planning (EB-MSP) is acknowledged
83 to be a powerful way to offer solutions to the excessive pressures the marine environment is facing (Foley et
84 al. 2010, Buhl-Mortensen et al. 2016, Ansong et al. 2017). When ES information is incorporated in MSP, this
85 moves EB approach principles from theory to practice (Guerry et al. 2012).

86 A systematic and science-based approach such as EB-MSP is fundamental in places where there are not yet
87 approved marine spatial plans, but where they are on track for implementation (Maes 2008). This is the case
88 of the Adriatic Sea, where the need for MSP is urgent in order to address transboundary conservation
89 challenges at regional and national level (Gissi et al. 2018) while meeting the requirements of the MSP
90 Directive (2014/89/EEA). This process is complementary to the forward-looking scenario that the European
91 Union articulated in its Strategy for the Adriatic Ionian Region (EUSAIR, COM(2014)357). EUSAIR
92 establishes strategic objectives of major concern for the area. In particular, Pillar 3 – Environmental quality –
93 addresses the marine environment, with special regard to the sustainable management of marine resources and
94 to marine ecosystems and biodiversity protection for their multiple ES.

95 In this study, we adopted an EB approach (Long et al. 2015, Borja et al. 2016, Ansong et al. 2017), synthesizing
96 information on the ecological linkages that allow benefits flows in the Adriatic. We focused on supporting ES
97 information, according to the MA classification (MA, 2005). We developed an innovative and operational
98 methodology for assessing and mapping ES delivery capacity in the Adriatic Sea. We explored how marine
99 ES mapping can inform MSP, by identifying areas of high and low delivery levels of supporting ES. Such
100 methodological approach spans the 3-dimensions of the marine environment, thus including sea surface, water
101 column, and seabed domains. The methodology is structured in six steps. In the first four steps, we quantified
102 supporting ES delivered in the Adriatic Sea by associating them with specific marine components, already
103 characterized by geospatial information, representing ES delivery indicators and specifically related to the
104 three marine domains. The fifth step includes the application of two spatial analyses. We used the obtained ES
105 delivery values to apply the hotspot analysis, identifying “areas which provide large proportions of a particular
106 service” (Egoh et al. 2008, Schröter & Remme 2016). This analytical approach has been recognized as key
107 tool for favouring cost-effective strategies for conservation purposes (O’Donnel et al. 2012, Marchese 2015)

108 and was already used in land-based studies (Bagstad et al. 2013, Timilsina et al. 2013, Schröter & Remme
109 2016, Bagstad et al. 2017, Schröter et al. 2017). Secondly, we developed the richness analysis by mapping
110 areas where the most and least numbers of ES are simultaneously delivered. Both these analyses identified the
111 most important areas in the Adriatic Sea of supporting ES supply. Areas that provide low levels of ES delivery
112 (coldspots) were also mapped. Finally, in step six, through the application of the spatial coincidence, we
113 verified the applicability of our approach to identify new marine areas for conservation purposes.

114

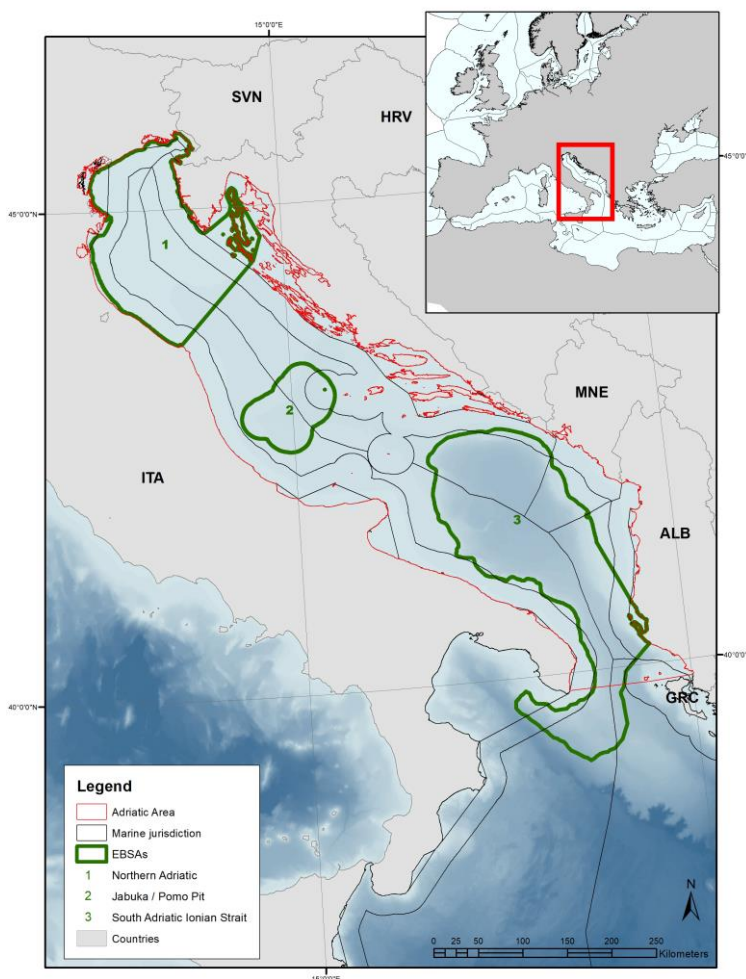
115 **2. Methods**

116 *2.1 Study area*

117 The Adriatic Sea is a heavily used, and highly valued marine region. It is recognized as a particularly
118 productive portion of the Mediterranean Sea, highly contributing to global biodiversity while providing
119 essential natural resources to people. Yet the Adriatic, and especially its Northern part, is one of the most
120 threatened and impacted regions of the Mediterranean Sea (Micheli et al. 2013, Bastari et al. 2017, Gissi et al.
121 2017). The semi-enclosed Adriatic basin is characterized by shallow depths in its northern area (Cattaneo et
122 al. 2003, Tesi et al. 2007), and by deeper waters in its southern extent, where depths exceed 1000 m. Even
123 though the Adriatic comprises only 5% of the Mediterranean Sea area, it is characterized by highly
124 differentiated habitat. It hosts important regional biodiversity, including several endemic species, as well as
125 species of relevant economic value (Bastari et al. 2016). Especially, the northern Adriatic Sea is characterized
126 by the existence of major river inputs and unusual oceanographic conditions, which underlie a decreasing
127 gradient in nutrient concentration southward and eastward (Coll et al. 2007). This peculiarity amplifies the
128 already mentioned ecological heterogeneity of the Adriatic and contributes to its delivery of many kinds of
129 ES.

130 The Adriatic ecoregion contains numerous and scattered marine protected areas (MPAs), significantly limited
131 in size (average size corresponding to 63 km²) with respect to the MPAs in other parts of the Mediterranean
132 (Rodríguez-Rodríguez et al. 2016). In the study area, of about 139160 km², 32 MPAs were designated (Med-
133 PAN, MAPAMED GIS database; www.medpan.org). In particular, the Italian territorial waters count 4 MPAs,

134 with an average area of 17,8 km², while the remaining ones belong to Slovenia, counting 2 MPAs (average
135 area 0,18 km²), Croatia (17 MPAs with an average size of 51,7 km²), Montenegro (only 1 MPA, 110 km² in
136 size), and Albania (8 MPAs, with average size 114,7 km²) (Fig. 1). Despite this seemingly high number of
137 MPAs, these protected areas cover only around 1% of the Adriatic, contributing only slightly to the 10% target
138 of MPAs coverage requested by the Convention of the Biological Diversity (CBD) for all ecoregions. Within
139 the Adriatic, three Ecologically or Biologically Significant Marine Areas (EBSA) were also identified: the
140 Northern Adriatic, the Pomo Pit in the Central Adriatic, and the South Adriatic Ionian Strait that crosses
141 towards the Ionian (www.cbd.it, Fig. 1).
142



143

144 Fig. 1 Map of the study area with the administrative delimitations and delimited at the south by the Adriatic-Ionian
145 boundary, which meets the Otranto Strait. All Marine Protected Areas (MPAs) and Ecologically or Biologically
146 Significant Marine Areas (EBSAs) included in the area are mapped (sources: www.medpan.org for MPAs; sources:

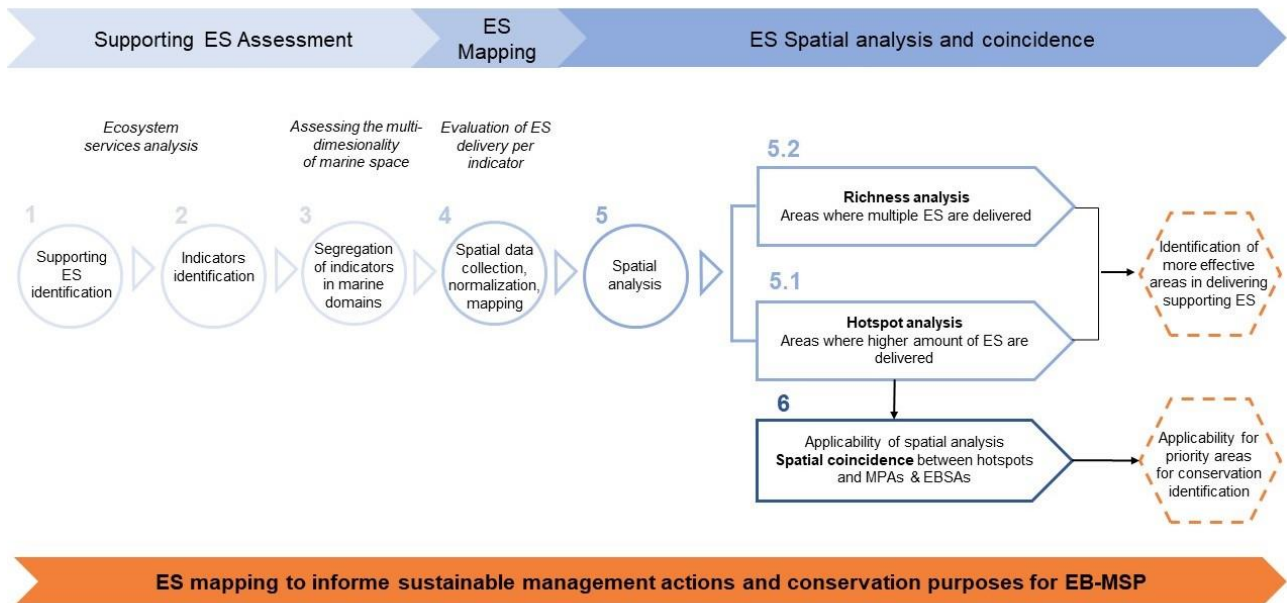
147 www.cbd.int for EBSAs). ITA = Italy; SVN = Slovenia; HRV = Croatia; BIH = Bosnia-Herzegovina; MNE =
 148 Montenegro; ALB = Albania; GRC = Greece.

149

150 *2.2 Operational approach for mapping supporting ES for MSP processes*

151 In order to map supporting ES, we propose a methodological framework consisting in six steps. We identified
 152 supporting ES and we associated marine components as indicators (steps 1 and 2). In step 3, these marine
 153 components, characteristic of the Adriatic Sea, were related to specific marine domains. Then, we quantified
 154 and mapped ES delivery in the study area in step 4. We applied two spatial analyses to recognise marine areas
 155 potentially more effective in ES supply and we tested the applicability of our methodological approach to
 156 support conservation priorities (Steps 5 and 6, Fig. 2). The steps are described one by one in the following
 157 sections.

158



159

160 Fig. 2 Methodological framework for mapping supporting ES delivered from the marine environment. Steps 1, 2, 3 and
 161 4 indicate the stages to carry out before step 5 that consists in applying the spatial analyses 5.1 and 5.2, and before step 6
 162 to reach the main outputs.

163

164 *2.2.1. Step 1: Supporting ES identification*

165 We selected four supporting ES (Step 1, Fig. 2) in the framework of the MA classification (MA, 2005). Such
166 ES provide the foundation for life and human well-being in the Adriatic. Their delivery depends on interlinked
167 ecological interactions between biotic and abiotic attributes (Smith et al. 2017) which make them
168 complementary. The selected four services were: i) primary production, ii) nutrient cycling, iii) biodiversity
169 maintenance, and iv) habitat provisioning.

170 -Primary production (PP) is fundamental for the support of marine communities in both pelagic and benthic
171 realms, in which they receive vertical nutrient flux from the surface (Lutz et al. 2007, Laufkötter et al. 2015)
172 other than support *in situ* production, both of photosynthetic and chemosynthetic origin.

173 -Nutrient cycling (NC) is defined as “the movement within and between the various biotic or abiotic entities
174 in which nutrients occur in the global environment” (MA 2005). It describes the cycle of nutrients production
175 and consumption and their flow in nature, and it is supported by a wide diversity of organisms.

176 -Biodiversity maintenance (BM). Biodiversity was defined in different ways in ES context. For instance, it
177 was identified as the core element affecting and enhancing several ecological processes thus leading to multiple
178 ES delivery (Palumbi et al. 2009, Soliveres et al. 2016) therefore not being considered as a service. Mace et
179 al. (2012) recognized biodiversity as a function, not framed within a defined classification but potentially
180 linkable to ES concept at different levels (e.g. as regulatory service for ecosystem processes, or even at the
181 level of final ecosystem service). Biodiversity was also defined as supporting ES in terms of “maintenance of
182 genetic diversity”, i.e., the variety of genes within and between species (TEEB, 2010). Despite the multiple
183 understanding of biodiversity in current ES classifications, in this study biodiversity maintenance was
184 considered as a service that support key ecosystem processes, directly affecting the maintenance of ecosystem
185 functioning and the delivery of multiple ES.

186 -Habitat provision (HP) is intended as a supporting ES, because the availability of habitats as well as their
187 quality status is the base for communities’ life and for the support and maintenance of biodiversity and to
188 ensure high delivery of multiple ES (Dobson et al.2006, Maes et al. 2012).

189 2.2.2. Step 2: Indicators identification

190 In order to map the marine areas delivering the supporting services described in section 2.2.1, we identified
191 and selected several indicators. These indicators represent marine components that ensure and support the

192 supply of these four ES and play key roles in Adriatic Sea functioning (Step 2, Fig. 2). Table 1 summarizes
 193 the choice of the indicators and their relation with the ES.

194 Summing up, the indicators selected to map the four ES delivery and included in this study are: i) 4 different
 195 megafauna components, in particular marine mammals, loggerhead turtles, giant devil rays and seabirds, ii)
 196 chlorophyll a (Chl-a) concentration as proxy representing primary producers, iii) the 28 seabed habitat types
 197 that characterize the Adriatic seafloor, and iv) 33 areas suitable to provide nursery habitats. Table 1 summarizes
 198 the indicators and their relation with the related ES.

199 Table 1. List and description of the selected ES indicators and their relation with the four supporting ES

Indicators	Description	Delivered supporting services	References
Marine mammals	Fundamental for the equilibrium and functioning of marine ecosystems in Adriatic Sea, ensure the supply of essential habitats along the water column and are recognized as flagship species.	-Nutrient cycling -Biodiversity maintenance -Habitat provision	Lotze et al. 2011, Lewison et al. 2014, di Sciara et al. 2016, Frazier 2005, O’Leary & Roberts 2017
Seabirds	Keystone species, fundamental for the equilibrium and functioning of marine ecosystems in Adriatic Sea.	-Nutrient cycling -Biodiversity maintenance	Lotze et al. 2011, Wenny et al. 2011, Lewison et al. 2014
Giant devil ray	Vulnerable species, fundamental predator regulating the trophic chain, it contributes to ensure the supply of essential habitats along the water column	-Nutrient cycling -Biodiversity maintenance -Habitat provision	Holcer et al. 2013, Dulvy et al. 2017, di Sciara et al. 2015, Croll et al. 2016, Lawson et al. 2017, O’Leary & Roberts 2017
Loggerhead turtles	Fundamental for the equilibrium and functioning of marine ecosystems in Adriatic Sea, ensure the supply of essential habitats along the water column and are recognized as flagship species.	-Nutrient cycling -Biodiversity maintenance -Habitat provision	Lotze et al. 2011, Casale et al. 2014, Lewison et al. 2014, di Sciara et al. 2016, Frazier 2005, O’Leary & Roberts 2017
Primary producers	Key role of primary production in ensuring the conditions for all organisms’ life.	-Primary production -Nutrient cycling -Biodiversity maintenance -Habitat provision	MA 2005 Costanza et al. 2007
Seabed habitats	Different seabed habitats characterizing the Adriatic and ensuring all organisms’ life.	-Primary production -Nutrient cycling -Biodiversity maintenance	MA 2005 De Groot et al. 2002
Areas suitable to provide nursery habitats	Fundamental in sustaining diverse communities and the production of important species of ecological and commercial value. Their status relies on the connection between seabed and water column, from which they receive juvenile individuals	-Biodiversity maintenance -Habitat provision	Liquete et al. 2016, Colloca et al. 2015, Sheaves et al. 2006

200

201 2.2.3. Step 3: Segregation of indicators in marine domains

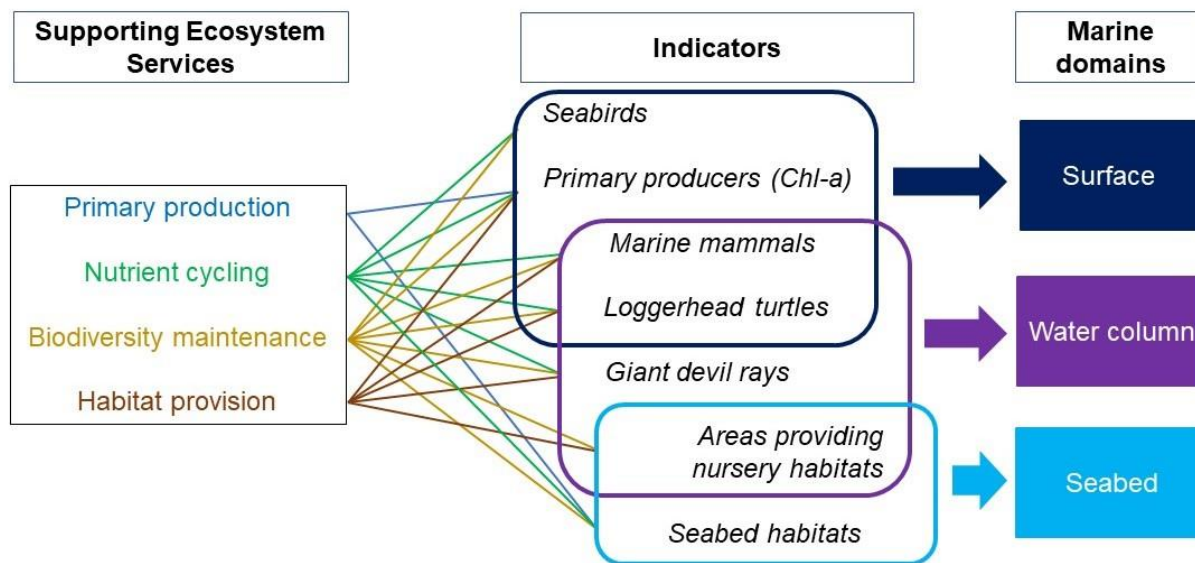
202 In step 3, each of the indicators were associated to a specific marine domain (surface, water column, seabed).
 203 Segregation among domains was based on life behaviour and spatial distribution of the marine components,
 204 as described in Table 2.

205 Table 2. Correspondence between ES indicators and marine domains.
 206

Indicators	Segregation of indicators in marine domains	Domains
Marine mammals	Primarily in water column coming to the surface to breathe, associated with both water column and sea surface domains.	Water Column; Surface
Seabirds	Seabirds feed at the surface and are associated with this domain.	Surface
Giant devil ray	Mainly inhabits deep sea pelagic waters, associated solely with the water column domain.	Water Column
Loggerhead turtles	Lifetime spent mainly swimming in water column, coming to the surface to breathe, associated with both water column and sea surface domains.	Water Column; Surface
Primary producers	Data originated from satellite-based optical sensor (MODIS-A) for the Adriatic, provided by EMIS – Environmental Marine Information System (EU-JRC). These data are defined to be related to near surface chlorophyll signal.	Surface
Seabed habitats (EUNIS classification)	Ecological processes related to specific seabed habitats	Seabed
Areas suitable to provide nursery habitats	Nursery grounds are associated with both seabed and water column since they receive and deliver juveniles from this second domain	Water column; Seabed

207
 208 Correspondence between ES, indicators, and the segregation within the three domains is summarized in Fig.
 209 3.

210



211

212 Fig. 3 Synthesis of the 3-dimensionality assessment of supporting ecosystem services delivery. Description of the link
 213 between the selected supporting ES and the indicators, and their segregation among the three marine domains.
 214

215 2.2.4. Step 4: Spatial data collection, normalization, mapping

216 We created a 1x1 km vector grid of the Adriatic basin using the EEA’s reference grid for Europe and selecting
 217 the marine areas (EEA 2013). Then, we quantified the delivery of each ES as the quantitative value of each
 218 indicator for each grid cell according to the different units of measure (see Table 3).

219 For the seabed habitats, the capacity to deliver the three supporting ES of primary production, nutrient cycling,
 220 and biodiversity maintenance was calculated differently. Firstly, for each seabed habitat, the ES delivery was
 221 scored according to Salomidi et al. (2012). This was possible because Salomidi et al. 2012 valued the
 222 effectiveness in delivering certain ES (negligible/irrelevant/unknown, low and high) for each EUNIS seabed
 223 habitat, the same classification adopted by this study (see Table 3). The few seabed habitats not covered by
 224 Salomidi et al. (2012) but present in the Adriatic, were associated to the most similar seabed habitats included
 225 in the EUNIS classification, based on the similarity of abiotic and biotic characteristics. Finally, based on the
 226 presence of seabed habitats, for each grid cell we assigned values 0 (negligible/irrelevant/unknow), 1 (low),
 227 and 2 (high) to quantify the delivery capacity of each of the three ES (PP, NC and BM).

228 The value related to the quantity of each indicator in each grid cell, as well as the values related to the seabed
 229 habitats delivery capacity, were normalized and a value ranging from 0 to 1 was assigned to each of them, on
 230 the base of the highest value.

231 Data related to the 33 areas suitable to provide nursery habitats were initially normalized and then were
 232 summed together in one unique value, which then represented the value of the overall indicator “areas suitable
 233 to provide nursery habitats”. Information related to the datasets is summarized in Table 3. All these normalized
 234 values were used for the hotspot spatial analysis (see paragraph 5.1).

235

236 Table 3 The unit of measure and the format of the spatial data used to quantify and map the ES indicators are reported.

Indicators	Unit of measure used to quantify the indicators	References format
Marine mammals	Number of individuals/20 km ²	EMODnet
Seabirds	Number of individuals/20 km ²	Adriplan dataportal
Giant devil ray	Number of individuals/20 km ²	Adriplan dataportal
Loggerhead turtles	Number of individuals/20 km ²	Adriplan dataportal
Primary producers	Chlorophyll-a, average annual value mg m ⁻³	OGS-NODC Adriplan dataportal
Seabed habitats (EUNIS classification)	Score ranged from 0 to 2 on the base of the capacity of each seabed habitat to deliver the associated services	EMODNET Salomidi et al. 2012
Areas suitable to provide nursery Habitats	% of presence probability of nursery habitat for 18 species	Mediseh-Marea project, Adriplan dataportal

237

238 2.2.5. Step 5: ES spatial analysis

239 5.1 Hotspot analysis

240 The hotspot analysis aims at identifying “areas which provide large proportions of a particular service” (Egoh
 241 et al. 2008, Schröter & Remme 2016). The spatial analysis proposed here allows the identification of both ES
 242 hotspot and coldspot areas, where maximum or minimum values, respectively, of single or multiple services
 243 of interest cluster together (Mitchel 2005, Timilsina et al. 2013). The spatially explicit identification of hotspot
 244 and coldspot areas of ES delivery helps to inform conservation and management decisions (Li et al. 2017). In
 245 order to perform the hotspot analysis, the normalized values calculated for the indicators in each grid cell, and
 246 related to the delivery of the four supporting ES were used for spatial clustering, using the Getis-Ord (Getis &
 247 Ord 1992) in ArcGIS 10.5 (ESRI, 2016). The analysis was carried out using all the normalized values of all
 248 the indicators contemporarily and thus mapping the delivery of all ES together. The hotspot and coldspot areas
 249 were mapped in the three marine domains (sea surface, water column, seabed) both independently in three

250 distinct analyses (one for each domain), and jointly. To carry out the analyses on the single domain, only the
251 indicators related to the considered domain were used. The joint hotspot and coldspot analysis and mapping
252 were applied not distinguished the marine domains and considering all the indicators and their services delivery
253 values together. In this case, the indicators were only counted once, even when they were associated to more
254 than one domain, in order to avoid double counting.

255 This analysis identifies the concentration of grid cells with highest (or lowest) ES delivery values within a
256 distance, which in the case of this study was fixed and determined by the 1x1 km vector grid. Spatial
257 relationships among grid cells were defined by applying the Rook Contiguity (Getis & Aldstadt 2004). The
258 G_i^* statistic was calculated according to Mitchel (2005; see Eq. A, Appendix).

259 Aggregations of cells with higher and lower values of G_i^* statistic indicates clusters of higher and lower ES
260 values (respectively hotspot and coldspot) (Timilsina et al. 2013).

261 To test the significance of the results, the Getis-Ord- G_i^* value was used. This test combines both the z-scores
262 and p-values resulting from the hotspot analysis (Fig. A, Appendix). Getis-Ord- G_i^* values were considered
263 statistically significant if corresponding to $p = 0.05$ (95%).

264 Hotspot and coldspot area percentage coverage was calculated on the base of the areas where Getis-Ord- G_i^*
265 value corresponded to $p = 0.05$ ($\geq 95\%$, Timilsina et al. 2013; Table A, Appendix).

266 Afterwards, we also discriminated among hotspot areas with Getis-Ord- G_i^* values corresponding to $p = 0.01$
267 and $p = 0.05$, by defining the first as “core” hotspots, statistically more significative in terms of high ES
268 delivery, and the second as “buffer zones”.

269 5.2: Richness analysis

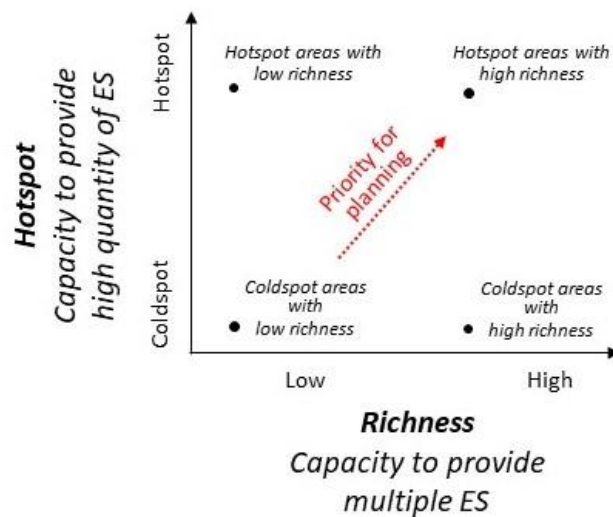
270 The richness method (Schröter & Remme 2016) was applied to map the distribution of the selected indicators
271 in the study area and their overlap. It was used to identify the areas where multiple ES are simultaneously
272 delivered. This was termed ‘multifunctionality’, a measurement of the ability of an ecosystem of
273 contemporarily delivering more than one ES (Manning et al. 2018). Since the definition of both hotspot and
274 richness methods is not definitively established, they can even correspond (Schröter and Remme). In this study,
275 we intended the richness analysis as a method to support and confirm the hotspot analysis and its results, in

276 order to identify the marine areas with the highest delivery capacity of multiple ES together. The conceptual
277 relationship between hotspot and richness analysis is presented in figure 4. A new dataset was created for the
278 richness analysis, by considering only the presence/absence (respectively 1 and 0) of the indicators delivering
279 the supporting ES in each grid cell. The absence (0) was given to those indicators that were either absent
280 because investigated and found having value equal to 0 or considered absent for lack of data. The presence (1)
281 was given to those indicators presenting values higher than 0. In the case of the indicator “seabed habitat”, the
282 values 0/1 were assigned to the presence/absence of the delivery capacity of the three ES associated to this
283 indicator (primary production, nutrient cycling and biodiversity maintenance). Therefore, “low” and “high”
284 corresponded to 1/presence, while “negligible/irrelevant/unknow” corresponded to 0/absence. Considering
285 each indicator, and for the indicator “seabed habitat” the three related ES (primary production, nutrient cycling
286 and biodiversity maintenance), the maximum value of richness resulted from the analysis could be 9.
287 The analysis was performed in ArcGIS 10.5 (ESRI, 2016), firstly converting all the presence/absence values
288 in raster. To calculate the richness value of the entire basin, the rasters were summed through Raster calculator
289 tool obtaining the number of indicators per pixel, which was a value ranged from 0 to 9. The richness values
290 for each pixel was calculated as follows:

$$291 \quad r = \sum x_i \quad (2)$$

292 where r is the richness value (number of indicators contemporarily present in a pixel), x corresponds to 1 or 0
293 on the base of the presence/absence of each indicator, and i is the indicator.

295 The results of richness, representing the multifunctionality, were then compared with those of the hotspot
296 analysis searching for areas with higher value of ES delivered (with Getis-Ord-Gi* values corresponding to p
297 = 0.05) and higher number of indicators simultaneously present. Since in literature there is no pre-established
298 criteria to define thresholds for richness levels (Schröter & Remme 2016), we divided the richness values in
299 three tertiles as follows: tertile “low” with values ranged from 0 to 2, tertile “medium” with values ranged
300 from 3 to 5, and tertile “high” with values ranged from 6 to 8 (the maximum value 9 was never reached in the
301 Adriatic, so was not considered). The highest tertile corresponds to the highest 30% of the richness values.



302

303 Fig. 4 Conceptual relationship between Hotspot and Richness analyses. The application of both the analyses allow the
 304 identification of marine areas with the highest delivery capacity of multiple ES

305

306 *2.2.6. Step 6: Spatial coincidence*

307 The area of all the resulted hotspots within the MPAs and the EBSAs in the Adriatic was calculated. This
 308 analysis represented the spatial coincidence between areas identified as highly efficient in ES delivery and
 309 existing areas recognized of major ecological and conservation interest, as MPA and EBSAs.

310

311 **3. Results**

312 *3.1 ES Hotspot areas distribution*

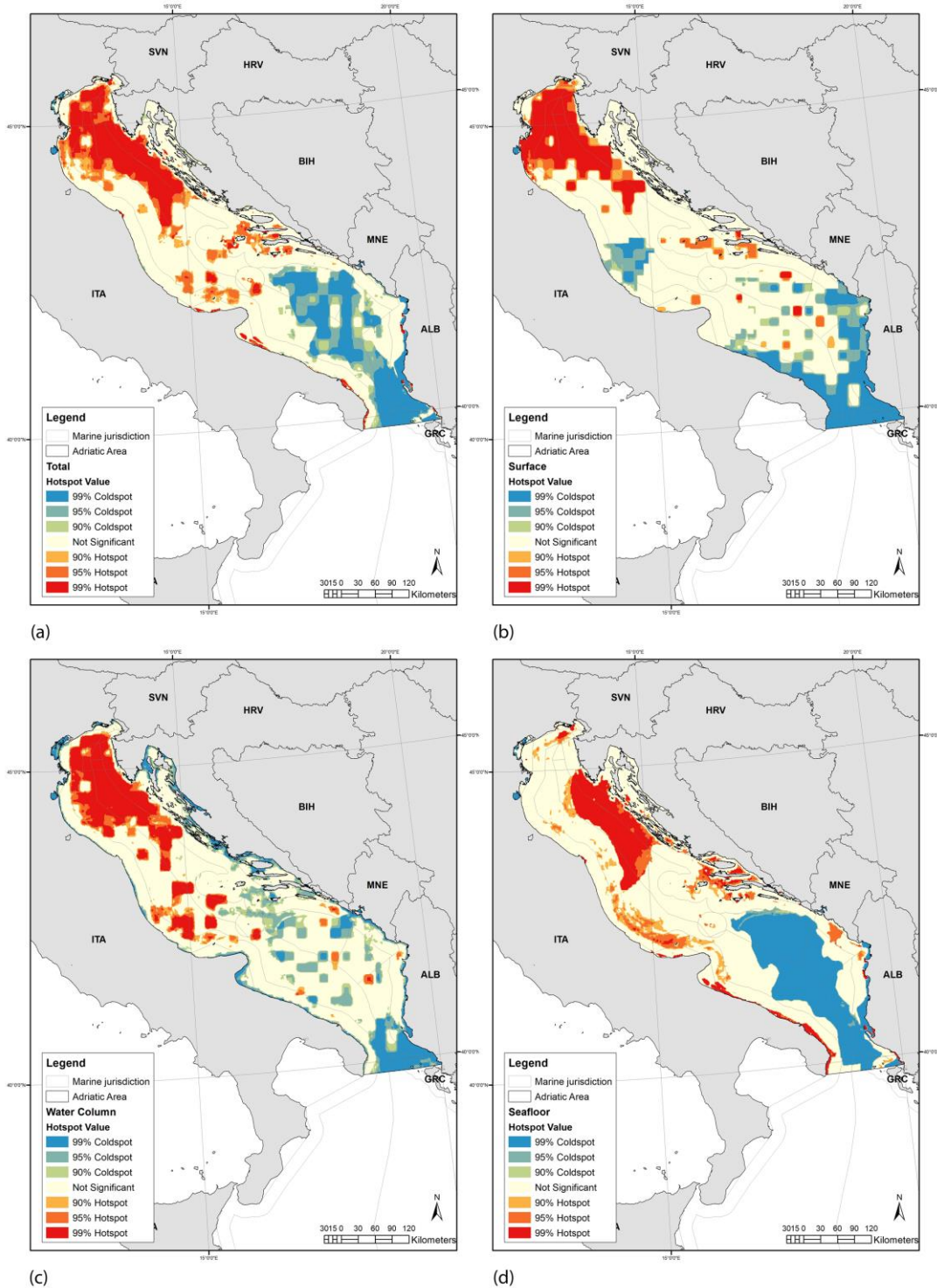
313 The hotspot analysis in the Adriatic Sea revealed a scattered distribution of areas delivering ES. With respect
 314 to the joint analysis for the three marine domains (sea surface, water column and seabed), hotspots covered the
 315 18.6% of the entire Adriatic Sea (Table A Appendix, Fig. 5a). Hotspots were mainly found in the Northern
 316 Adriatic, with a vast and homogeneous area of high ES delivery. This area extends to the eastern side of the
 317 Adriatic and far from the coast (Fig. 5a). Coldspot areas, on the contrary, were primarily localized in the
 318 southern open sea and along the south-eastern margin of the Adriatic, covering a percentage area of 19.3% of
 319 the entire Adriatic. Similar results were found when considering the sea surface domain separately (15.6% for

320 hotspots and 18.9% for coldspots, Fig. 5b), with the difference that coldspots shifted towards more coastal
321 areas, and for the presence of a coldspot in Central Adriatic (Italian side). Among the three marine domains,
322 the highest percentage of hotspots coverage was found in the water column, while the lowest one was related
323 to the seabed domain (18.2% and 14.9%, Fig. 5c and 5d respectively). Moreover, seabed hotspots showed a
324 different distribution if compared to the other domains, not reaching the northernmost part of the basin (with
325 the exception of two spots in the Gulf of Trieste), and in part covering the Southernmost Italian coastline. In
326 the water column the coldspots were mainly located along coastal areas (16.8%, Fig. 5c), while in seabed
327 domain, where the highest coldspot coverage occurred, they were primarily concentrated in deep-sea habitats
328 for a 20.3% of the Adriatic.

329 When considering only the core hotspots (Getis-Ord-Gi* values equal to $p = 0.01$), the percentage coverage
330 of marine areas highly delivering ES decreased by approximately 4-6% compared to the previous results (Table
331 A, Appendices). Such core hotspots presented a percentage coverage area corresponding to 12.1% of the entire
332 Adriatic basin when all the marine domains were jointly considered.

333 The area with no statistical significance (Getis-Ord-Gi* values equal to $p > 0.05$), both in terms of hotspot and
334 coldspot among all the marine domains, ranged between 54 and 60% ca., with the highest percentages related
335 with water column and seafloor (59.6% and 60%, respectively).

336



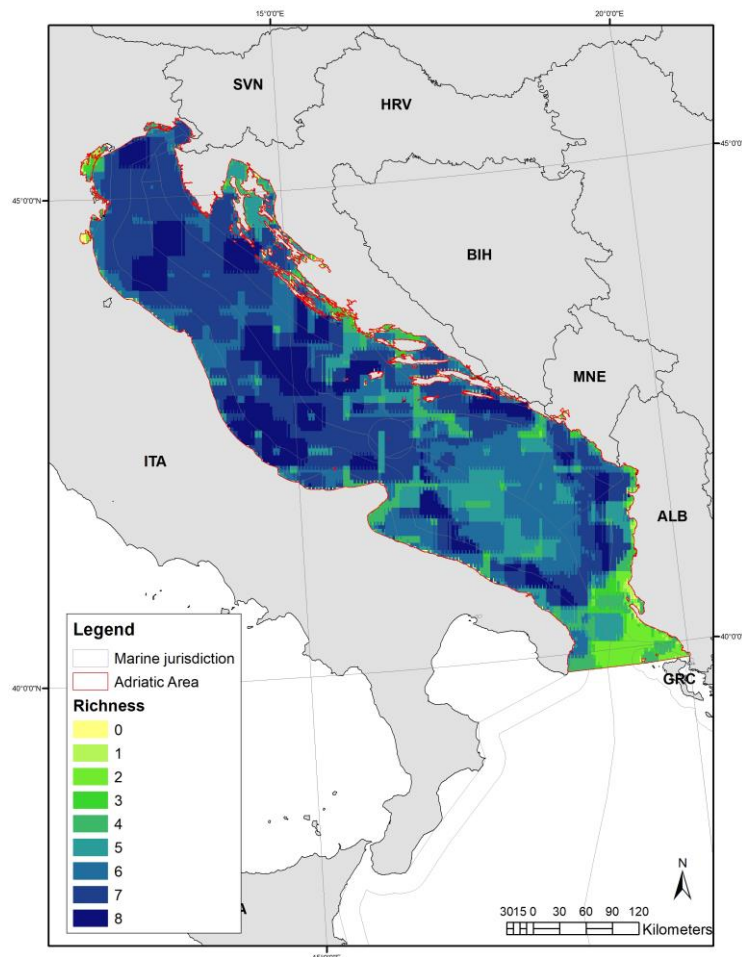
337

338 Fig.5 Identified hotspot and coldspot areas. Map (a) Total hot and cold spot areas not distinguishing the marine domains;
 339 map (b) Surface hot and cold spot areas; map (c) Water Column hot and cold spot areas; map (d) Seabed hot and cold
 340 spot areas. Red areas (core hotspots) represent distribution values corresponding to Getis-Ord-Gi* values equal to $p=0.01$,
 341 light red areas (buffer zones) equal to $p=0.05$, and orange areas equal to $p=0.1$. For the coldspots, dark blue areas represent
 342 distribution values corresponding to Getis-Ord-Gi* values equal to $p=0.01$, blue areas equal to $p=0.05$, and light blue
 343 areas equal to $p=0.1$.

344

345 3.2 Richness distribution

346 Richness analysis revealed that marine components and seabed habitat-related ES are never present all together
347 in one location at once (richness values never exceeded the value of 8 in the same grid cell). Higher values of
348 richness are found especially in North and Central Adriatic (Fig. 6)



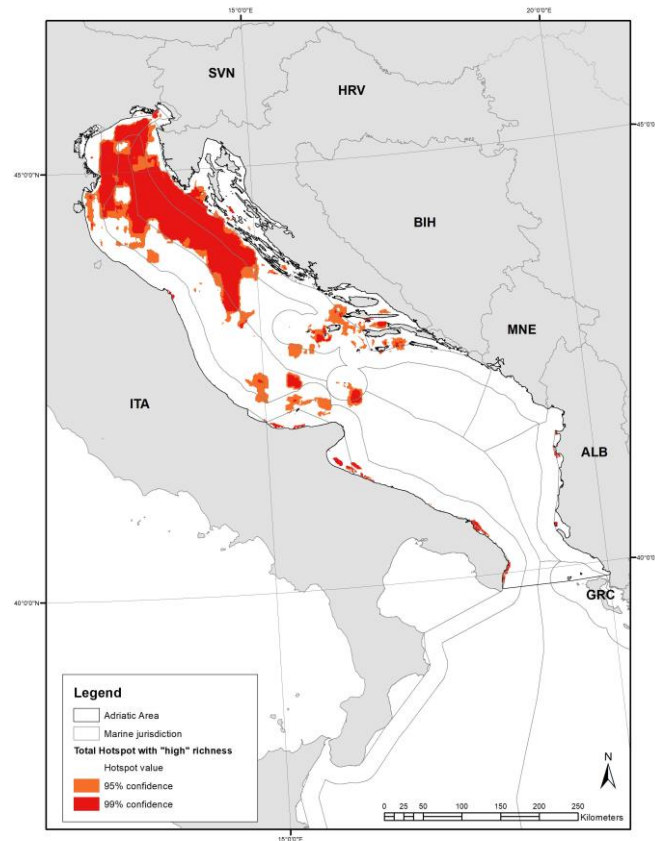
349

350 Fig.6 Richness map. It allows the identification of areas with different overlapping scores, which are related to the
351 simultaneous presence in the same area of the indicators delivering supporting ES and of the seabed habitats ES-related.
352 The map reveals the areas with the highest overlap and where multiple ecosystem services are simultaneously delivered.
353 The scoring ranged from 0 to 8, which was the maximum value obtained from the analysis.

354 3.3 Areas of higher and lower effectiveness in supporting ecosystem services delivery

355 The results of richness values confirm those obtained by the hotspot analysis. In fact, higher values of richness
356 are found highly correspondent to hotspot areas (Fig. 7).

359



361

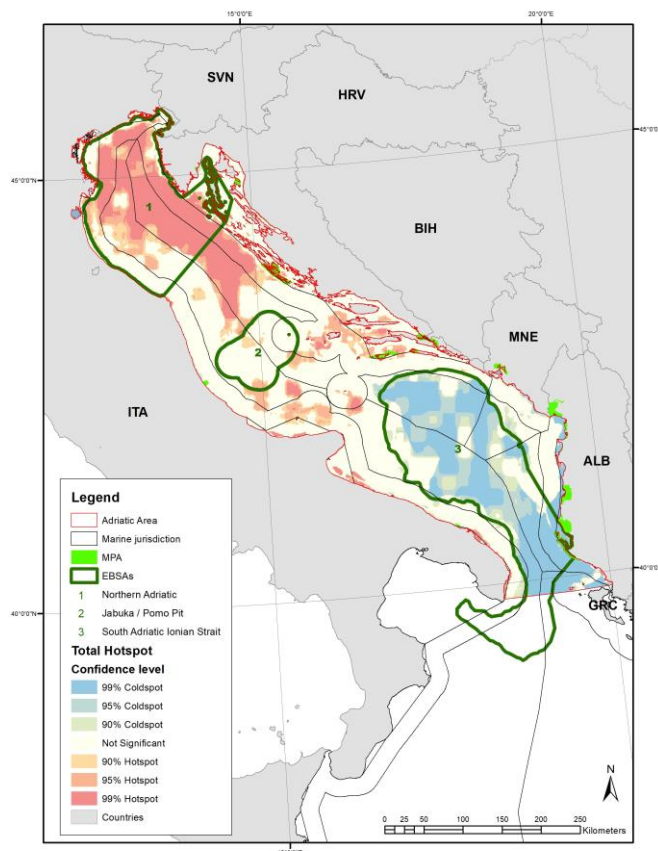
362 Fig. 7 The overlap between ES delivery hotspot areas, not distinguishing the marine domains, and areas with “high”
 363 richness (third tertile of richness scores) reveals the most productive and efficient areas in terms of supporting ES delivery.

364

365 3.4 Spatial coincidence between hotspots and areas managed for environmental conservation

366 The percentage coverage area of the resulting hotspots that correlate with the MPAs and the EBSAs in the
 367 study area was calculated (Fig. 8), to compare the ES supply capacity of areas associated with different
 368 conservation values.

369 Supporting ES hotspots overlapped with MPAs for 0.33% of their total surface, which corresponds to roughly
 370 about 84 km². When considering the three domains separately, MPAs overlapped with hotspots for 0.13% at
 371 sea surface, 0.00% in the water column, and 0.66% of seabed (Table 4). Considering the three EBSAs, hotspots
 372 spatially coincided for a percentage of coverage of 58.35% with the Northern Adriatic EBSA, 1.14% with the
 373 Pomo Pit one, and 0.21% with the Southern Adriatic one (Table 4).



375

376 Fig. 8 Spatial coincidence between hot and cold spot areas, not distinguishing the marine domains, and MPAs and
 377 EBSAs in the study area.

378

379 Table 4 Percentage of spatial coincidence between hotspot areas and MPAs and EBSAs in Adriatic Sea

	MPAs			EBSA North Adriatic			EBSA Jabuka Pomo Pit			EBSA South Adriatic		
	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %
Hotspot total												
Hotspot ≥ 95%	93	84	0.33%	15073	15073	58.35%	295	295	1.14%	74	54	0.21%
Coldspot ≥ 95%	436	285	1.06%	0	0	0.00%	0	0	0.00%	23059	23014	85.87%
Hotspot surface												
Hotspot ≥ 95%	31	27	0.13%	15935	15931	73.24%	48	48	0.22%	980	980	4.51%
Coldspot ≥ 95%	413	309	1.18%	0	0	0.00%	2586	2586	9.85%	8784	8714	33.19%

Hotspot water column												
	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %
Hotspot ≥ 95%	0	0	0.00%	15843	15842	62.50%	1927	1927	7.60%	627	627	2.47%
Coldspot ≥ 95%	790	531	2.27%	695	599	2.56%	0	0	0.00%	9758	9692	41.43%
Hotspot seabed												
	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %	Cells n°	Area (km ²)	Spatial coincidence %
Hotspot ≥ 95%	155	136	0.66%	5990	5989	28.95%	149	149	0.72%	120	94	0.46%
Coldspot ≥ 95%	368	223	0.79%	2	0.4	0.00%	0	0	0.00%	25606	25566	90.33%

380

381 4. Discussion

382 Incorporating ES assessments in planning procedures is gaining increasing importance in decision making
383 processes, including those driven by MSP. Despite the recognition of its importance and the several
384 environmental European directives and strategies that support this integrated approach (e.g. Water Framework
385 Directive, Marine Strategy Framework Directive, Common Fishery Policy), ES integration in MSP and
386 management is still in its infancy (Boulton et al. 2016; Drakou et al. 2017). In this study, a methodological
387 approach to assess and map ES favouring scientifically oriented decisions for the sustainable use of the marine
388 environment through MSP is presented.

389 4.1 Including supporting services in planning the marine space

390 We addressed the analysis of multiple ES supply capacity by selecting and mapping supporting ES, in order
391 to operationalize an EB approach. Identification of supporting ES allowed us to populate a relatively
392 manageable dataset for ES mapping. This method responds to the need to consider a vast range of marine ES,
393 both direct and indirect, within a planning process. This is true starting from the assumption that supporting
394 ES delivery makes possible the supply of all other ES categories (MA, 2005). Therefore, while supporting ES
395 are assessed and mapped, information regarding all other services is indirectly embedded within the analysis.
396 Our method is meant to overcome the difficulties in mapping provisioning, regulating, and cultural services
397 individually. Maes et al. (2016) proposed a list of indicators and proxies to map marine ES. However, only the
398 8.4% of the proposed indicators were selected, and 42% of this percentage could be actually populated for the
399 European marine regions due to high quality data availability (Maes et al. 2016). Our method can overcome

400 these data gaps focusing the data need only on supporting ES indicators and facilitating a comprehensive ES
401 analysis at wider scale. This approach gives place to a rapid assessment while working for more accurate data
402 and for ES models' refinement for the marine realm. Thus, planners can use our methodology to integrate the
403 assessment of a limited number of key ES within the planning process, but whose maintenance can provide a
404 broad range of other ES. This approach even leads to avoid ES classification problems and evaluation
405 inconsistencies due to the different ES categorization frameworks, which complicate and make not practicable
406 ES assessment within planning and decision systems (Wallace 2007, Fu et al. 2011).

407 From the hotspot analysis, areas characterized by high delivery capacity of the ES analysed in this study were
408 mainly found in the northern part of the Adriatic Sea across the three marine domains. The Northern Adriatic
409 was shown to be the most productive in ES supply efficiency and high richness levels, results that confirm the
410 ecological value of this marine area (Micheli et al. 2013, Bastari et al. 2017). Previous studies recognized the
411 upper area of the Adriatic basin as one of the most affected by human activities in the Mediterranean, with
412 high biodiversity and habitats threatened by anthropogenic impacts (Coll et al. 2012; Gissi et al. 2017). These
413 results can be used to increase awareness about the urgent need to introduce mitigation measures in future
414 marine plans. The obtained results can support further studies addressed to spatially identify areas where higher
415 impacts occur due to the maritime uses that are in place and that overlap with ES delivery hotspots. Moreover,
416 such approach can be adopted in a highly transboundary contexts as the Adriatic Sea is, especially in its
417 northern part. Thus its adoption can be of help for neighbouring countries to concentrate on concerns that
418 overpassed multiple jurisdictional boundaries to be more focused in achieving shared sustainability objectives
419 at regional level (Gissi et al. 2018).

420 We created a methodological workflow for operationally considering and characterizing the 3-dimensionality
421 of the marine environment in the study area, leading to the identification of hotspots in the three marine
422 domains (sea surface, water column, seabed). Hotspot identification within the pelagic realm, beside the
423 benthic one, was already suggested as a winning approach for conservation and resources management
424 purposes even if difficult to apply (Marchese 2015). Though our subdivision was rather coarse, we were able
425 to include it in our analysis and we found that hotspot area footprints in the Adriatic differed in the three
426 domains, both in extent and distribution. We found the high ES delivery capacity of the pelagic domain in both

427 open and deep-sea areas. These results confirm that MSP and conservation actions should address failures to
428 incorporate the open sea and pelagic realms in planning (O’Leary et al. 2012, Ban et al. 2014), explicitly
429 considering the 3-dimensionality of the marine environment and both horizontal and vertical zoning when
430 needed. Furthermore, our results suggest that MSP should consider spatial and non-spatial management
431 measures to control potential negative effects of activities on environmental components that can stretch over
432 specific or multiple vertical marine zones. Well-defined spatial management and conservation strategies
433 addressing the pelagic realm are difficult to apply, but there is an urgent need to explicitly include such
434 management measures in planning and conservation processes (Foley et al. 2010, Briscoe et al. 2016, Levin et
435 al. 2017, Venegas-Li et al. 2017). The water column is home for pelagic marine animals of high ecological
436 value, and it supports many fundamental ecological processes (e.g., biomass production, carbon sequestration,
437 nutrient transfer). Therefore, MSP should consider management targeted specifically at this domain, alongside
438 management of uses impacting benthos.

439 Ever increasing numbers of studies focus attention on identifying priority areas for conservation (Knight et al.
440 2008, Ruiz-Frau et al. 2015, Lascelles et al. 2016, Venegas-Li et al. 2018, Gissi et al. 2018, da Luz Fernandes
441 et al. 2018) to orient conservation actions. Our method allows the identification of areas that provide high
442 levels of selected ES, as well as those areas that are less important for ES delivery across the Adriatic Sea.
443 Identified coldspot areas could potentially be considered for the allocation of new marine uses. However,
444 excluding coldspots from conservation perspective could put at risk areas that, on the contrary, need
445 consideration (Kareiva and Marvier 2003, Marchese 2015). It may be necessary to produce an analysis at local
446 scale in order to detect environmental components that deserve additional management measures, but which
447 could not be included in the present analysis (such as areas of high localized endemism). Moreover, coldspots
448 could aggregate few or even just one of the analysed ES that could be exclusively delivered in those areas thus
449 gaining relevant importance in terms of ecosystem functioning support and becoming areas of conservation
450 priority. Nevertheless, it is worthy of attention that almost half of the Adriatic (57% on average) resulted to be
451 neither hotspots nor coldspots due to data-gap or high heterogeneity and different spatial resolution of the
452 available data. This result supports the request for more extensive and detailed research and monitoring data
453 to facilitate the EB-MSP approach that is needed at different spatial scales, even at the finest one.

454 *4.2 Orienting the establishment of conservation areas*

455 Within the scope of conservation, the ES mapping approach can be the foundation for supporting the zoning
456 of new marine protected areas on the basis of the Getis-Ord-Gi* values that identify hotspot. The analysis of
457 the core hotspots allows the definition of areas of conservation concern or where uses have to be strictly
458 limited. It was also possible to identify potential buffer zones around the core ones, where different levels of
459 restrictions upon the exploitation of resources and activities located there could be put in place. Such approach
460 can guarantee the preservation of core sites and their connectivity with external areas. This distinction could
461 support more focused conservation and management strategies in the future.

462 In this study, a very small percentage of ES hotspot areas overlap with existing Marine Protected Areas. MPAs
463 in Mediterranean Sea were established on the basis of socio-political priorities instead of scientific and
464 environmental evaluations (Francour et al. 2001; Fraschetti et al. 2005, García-Charton et al. 2008; Coll et al.
465 2012). Briscoe et al. (2016) already suggested that conservation actions should be guided not only by the
466 evaluation of species richness in a specific area, but also by estimating the capacity of marine environment to
467 provide benefits that humans need. Thus, protecting areas that deliver multiple ES can be considered as an
468 additional criterion for establishing spatial priorities for conservation action. On the other hand, our results
469 showed the hotspot area in the Northern Adriatic coincides spatially with one of the Ecological or Biological
470 Significant Areas (EBSAs) designated by the CBD. These areas are intended to contribute to the sustainable
471 management of marine resources (Dunstan et al. 2016, Johnson et al. 2018). EBSAs are defined by seven
472 criteria that describe marine areas highly capable of providing habitats, high level of biodiversity including
473 endemism and sensitive species, and of ensuring the functioning of marine ecosystems (Johnson et al. 2018).
474 These aspects coincide with the supporting services considered in this study. Our results suggest that the
475 application of our methodology for spatial conservation actions could offer greater benefits on larger
476 geographical scales than the smaller scale of the existing MPAs.

477 *4.3 Limitations and opportunities*

478 The higher percentage coverage of coldspots in deep-sea areas of the southern part of the Adriatic basin,
479 observed in all the three marine domains, are most likely related to knowledge gaps (Gissi et al. 2017). For

480 this reason, it is necessary to be aware of the uncertainty in data quality and available knowledge. For instance,
481 ES values related to seabed domain rely on knowledge about primary production, nutrient cycling, and
482 biodiversity, which are likely underestimated in deep-sea areas due to limited information (Danovaro et al.
483 2014, Corinaldesi 2015, Danovaro et al. 2017). Moreover, we could not consider primary production delivered
484 by the water column due to the fact that Chl-a data are limited to surface water. Despite the limitations of the
485 approach, for instance having to do with temporal variability, data limitations, and paucity of information on
486 status of habitats vis a vis their ecological health, we were able to produce relevant spatial information on
487 hotspot and coldspot areas delivering multiple supporting ES in Adriatic Sea. This methodology will build
488 more robust and informed planning processes for EB-MSP. As already highlighted in recent studies, there is
489 the urgency to prioritize the vertical zoning within the 3-D marine environment for conservation and resources
490 management objectives (Levin et al. 2017, Venegas-Li et al. 2017). As human activities are expanding, also
491 at greater marine depths, planning and management strategies must reflect on the different spatial footprint of
492 such activities and impact on marine components and ES delivery, adding considerations related with the
493 pelagic domain. We suggest there is great potential to refine existing mapping approaches given advances that
494 present more detailed data available on a global scale (Cord et al. 2017, Roberson et al. 2017). With the
495 incorporation of the vertical marine component, as well as even more advanced ecosystem-based management
496 techniques that are coming forward (Venegas-Li et al. 2017), EB-MSP and conservation planning can widely
497 improve and be even more comprehensive. Our methodology supports the integration of the ecosystem
498 services into MSP tools and approaches.

499

500 **5. Conclusions**

501 Our methodological approach incorporates different spatial analyses to map and evaluate ecosystem services
502 delivery in the Adriatic marine environment. This approach is based on a user-friendly method consisting on
503 six steps that represents the foundation of the multidimensional analyses we proposed. In fact, the method
504 embeds the 3-dimensionality of the sea by assessing and mapping supporting ES delivery associated with each
505 of the three marine domains through the adoption of representative indicators. Focusing on supporting ES
506 allows us to be more efficient in integrating and preserving the highest number of ES within marine planning

507 processes. This approach aims at simplify the analysis of a highly complex framework constituted by an
508 outstanding number of ecological processes on which marine ecosystem functioning and ES delivery rely. We
509 spatially identified the ES hotspots and coldspots, areas more and less effective in providing multiple ES
510 supply in the Adriatic Ionian Region. We found these hotspots overlapping only 0.33% with the existing MPAs
511 in this marine region, suggesting the need to integrate ES information in identifying spatial conservation
512 priorities. The obtained results inform optimal zoning plans for sustainable management and conservation
513 actions on a large geographical scale. This study highlights the paramount importance of incorporating the
514 pelagic realm in MSP, and the need to deepen our understanding of ecological processes and functioning that
515 span the whole multidimensional marine system, with special regard to deep-sea environments. Better
516 identification and definition of the ES on which human wellbeing depends will allow an ecosystem-based
517 approach that recognizes the central role of conservation as a basis for development. The EB approach is the
518 path through which conservation is assured while sustainable economic development is fostered. Therefore, in
519 the Adriatic Sea, where regional high-level strategic objectives in line with EUSAIR and the Blue Growth
520 Strategy are a stated goal for the countries of the region, this approach is an imperative and not an alternative.
521 Presenting a way to identify priority areas for conservation due to their delivery of high levels of supporting
522 ES is an essential step to move from theory to action in sustainable development.

523

524 **Acknowledgments**

525 EM, DDC, and EG acknowledge the support of the European Maritime and Fisheries Fund of the European
526 Union through the projects SUPREME “Supporting maritime spatial Planning in the Eastern
527 Mediterranean”, grant no. EASME/EMFF/2015/1.2.1.3/01/S12.742087; this study reflects only the authors’
528 views and not those of the European Union.

529

530

References

531

- 532 1. Ansong, J., Gissi, E., & Calado, H., 2017. An approach to ecosystem-based management in maritime
533 spatial planning process. *Ocean & Coastal Management*, 141, 65-81. [doi:
534 10.1016/j.ocecoaman.2017.03.005](https://doi.org/10.1016/j.ocecoaman.2017.03.005)
- 535 2. Arkema, K. K., Verutes, G. M., Wood, S. A., Clarke-Samuels, C., Rosado, S., Canto, M., Rosenthal,
536 A., Ruckelshaus, M., Guannel, G., Toft, J., Faries, J., Silver, J. M., Griffin, R., & Guerry, A. D., 2015.
537 Embedding ecosystem services in coastal planning leads to better outcomes for people and
538 nature. *Proceedings of the National Academy of Sciences*, 112(24), 7390-7395. [doi:
539 10.1073/pnas.1406483112](https://doi.org/10.1073/pnas.1406483112)
- 540 3. Bagstad, K. J., Semmens, D. J., Waage, S., & Winthrop, R., 2013. A comparative assessment of
541 decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services*, 5, 27-
542 39. [doi: 10.1016/j.ecoser.2013.07.004](https://doi.org/10.1016/j.ecoser.2013.07.004)
- 543 4. Bagstad, K. J., Semmens, D. J., Ancona, Z. H., & Sherrouse, B. C., 2017. Evaluating alternative
544 methods for biophysical and cultural ecosystem services hotspot mapping in natural resource
545 planning. *Landscape ecology*, 32(1), 77-97. [doi: 10.1007/s10980-016-0430-6](https://doi.org/10.1007/s10980-016-0430-6)
- 546 5. Ban, N. C., Maxwell, S. M., Dunn, D. C., Hobday, A. J., Bax, N. J., Ardron, J., Gjerder K. M., Game,
547 E. T., Devillers, R., Kaplan, D. M., Dunstan, P. K., Halpin, P. N., & Pressey, R. L., 2014. Better
548 integration of sectoral planning and management approaches for the interlinked ecology of the open
549 oceans. *Marine Policy*, 49, 127-136. [doi: 10.1016/j.marpol.2013.11.024](https://doi.org/10.1016/j.marpol.2013.11.024)
- 550 6. Bastari, A., Micheli, F., Ferretti, F., Pusceddu, A., & Cerrano, C., 2016. Large marine protected areas
551 (LMPAs) in the Mediterranean Sea: the opportunity of the Adriatic Sea. *Marine Policy*, 68, 165-177.
552 [doi: 10.1016/j.marpol.2016.03.010](https://doi.org/10.1016/j.marpol.2016.03.010)
- 553 7. Bastari, A., Beccacece, J., Ferretti, F., Micheli, F., & Cerrano, C., 2017. Local ecological knowledge
554 indicates temporal trends of benthic invertebrates species of the Adriatic Sea. *Frontiers in Marine
555 Science*, 4, 157. [doi: 10.3389/fmars.2017.00157](https://doi.org/10.3389/fmars.2017.00157)
- 556 8. Böhnke-Henrichs, A., Baulcomb, C., Koss, R., Hussain, S. S., & de Groot, R. S., 2013. Typology and
557 indicators of ecosystem services for marine spatial planning and management. *Journal of
558 Environmental Management*, 130, 135-145. [doi: 10.1016/j.jenvman.2013.08.027](https://doi.org/10.1016/j.jenvman.2013.08.027)

- 559 9. Borja, A., Elliott, M., Andersen, J. H., Berg, T., Carstensen, J., Halpern, B. S., Heiskanen, A-S.,
560 Korpinen, S., Stewart Lowndes, J. S., Martin, G., & Rodriguez-Ezpeleta, N., 2016. Overview of
561 integrative assessment of marine systems: the ecosystem approach in practice. *Frontiers in Marine*
562 *Science*, 3, 20. [doi: 10.3389/fmars.2016.00020](https://doi.org/10.3389/fmars.2016.00020)
- 563 10. Boulton, A. J., & Ekebom, J., 2016. Integrating ecosystem services into conservation strategies for
564 freshwater and marine habitats: a review. *Aquatic Conservation: Marine and Freshwater Ecosystems*.
565 [doi: 10.1002/aqc.2703](https://doi.org/10.1002/aqc.2703)
- 566 11. Briscoe, D. K., Maxwell, S. M., Kudela, R., & Crowder, L. B., 2016. Are we missing important areas
567 in pelagic marine conservation? Redefining conservation hotspots in the ocean. *Endangered Species*
568 *Research*, 29(3). [doi: 10.3354/esr00710](https://doi.org/10.3354/esr00710)
- 569 12. Buhl-Mortensen, L., Galparsoro, I., Fernández, T. V., Johnson, K., D'Anna, G., Badalamenti, F.,
570 Garofalo, G., Carlström, J., Piwowarczyk, J., Rabaut, M., Vanaverbeke, J., Schipper, C., Dalfsen, J.,
571 Vassilopoulou, V., Issaris, Y., van Hoof, L., Pecceu, E., Hostens, K., Pace, M. L., Knittweis, L.,
572 Stelzenmüller, V., Todorova, V., & Doncheva, V., 2016. Maritime ecosystem-based management in
573 practice: Lessons learned from the application of a generic spatial planning framework in
574 Europe. *Marine Policy*, 75, 174-186. [doi: 10.1016/j.marpol.2016.01.024](https://doi.org/10.1016/j.marpol.2016.01.024)
- 575 13. Caro, C., Pinto, R. Marques, J.C., 2018. Use and usefulness of open source spatial databases for the
576 assessment and management of European coastal and marine ecosystem services. *Ecological*
577 *Indicators* 95, 41–52. doi.org/10.1016/j.ecolind.2018.06.070
- 578 14. Carr, M. H., Neigel, J. E., Estes, J. A., Andelman, S., Warner, R. R., & Largier, J. L., 2003. Comparing
579 marine and terrestrial ecosystems: implications for the design of coastal marine reserves. *Ecological*
580 *Applications*, S90-S107. [doi: 10.1890/1051-0761\(2003\)013\[0090:CMATEI\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2003)013[0090:CMATEI]2.0.CO;2)
- 581 15. Casale, P., Freggi, D., Furi, G., Vallini, C., Salvemini, P., Deflorio, M., Totaro, G., Raimondi, S.,
582 Fortuna, C., & Godley, B. J., 2014. Annual survival probabilities of juvenile loggerhead sea turtles
583 indicate high anthropogenic impact on Mediterranean populations. *Aquatic Conservation: Marine and*
584 *Freshwater Ecosystems*, 25(5), 690-700. [doi: 10.1002/aqc.2467](https://doi.org/10.1002/aqc.2467)

- 585 16. Cattaneo, A., Correggiari, A., Langone, L., & Trincardi, F., 2003. The late-Holocene Gargano
586 subaqueous delta, Adriatic shelf: sediment pathways and supply fluctuations. *Marine Geology*, 193(1-
587 2), 61-91. [doi: 10.1016/S0025-3227\(02\)00614-X](https://doi.org/10.1016/S0025-3227(02)00614-X)
- 588 17. Coll, M., Santojanni, A., Palomera, I., Tudela, S., & Arneri, E., 2007. An ecological model of the
589 Northern and Central Adriatic Sea: analysis of ecosystem structure and fishing impacts. *Journal of*
590 *Marine Systems*, 67(1), 119-154. [doi: 10.1016/j.jmarsys.2006.10.002](https://doi.org/10.1016/j.jmarsys.2006.10.002)
- 591 18. Coll, M., Piroddi, C., Albouy, C., Ben Rais Lasram, F., Cheung, W. W., Christensen, V., Karpouzi,
592 V. S., Guilhaumon, F., Mouillot, D., Paleczny, M., Palomares, M. L., Steenbeek, J., Trujillo, P.,
593 Watson, R., & Pauly, D., 2012. The Mediterranean Sea under siege: spatial overlap between marine
594 biodiversity, cumulative threats and marine reserves. *Global Ecology and Biogeography*, 21(4), 465-
595 480. [doi: 10.1111/j.1466-8238.2011.00697.x](https://doi.org/10.1111/j.1466-8238.2011.00697.x)
- 596 19. Colloca, F., Garofalo, G., Bitetto, I., Facchini, M. T., Grati, F., Martiradonna, A., Mastrantonio, G.,
597 Nikolioudakis, N., Ordinas, F., Scarcella, G., Tserpes, G., Tugores, M. P., Valavanis, V., Carlucci, R.,
598 Fiorentino, F., Follesa, M. C., Iglesias, M., Knittweis, L., Lefkaditou, E., Lembo, G., Manfredi, C.,
599 Massutí, E., Pace, M. L., Papadopoulou, N., Sartor, P., Smith, C. J., & Spedicato, M. T., 2015. The
600 seascape of demersal fish nursery areas in the North Mediterranean Sea, a first step towards the
601 implementation of spatial planning for trawl fisheries. *PloS one*, 10(3), e0119590. [doi:](https://doi.org/10.1371/journal.pone.0119590)
602 [10.1371/journal.pone.0119590](https://doi.org/10.1371/journal.pone.0119590)
- 603 20. Cord, A. F., Brauman, K. A., Chaplin-Kramer, R., Huth, A., Ziv, G., Seppelt, R., 2017. Priorities to
604 advance monitoring of ecosystem services using earth observation. *Trends in ecology &*
605 *evolution*, 32(6), 416-428. doi.org/10.1016/j.tree.2017.03.003
- 606 21. Corinaldesi, C., 2015. New perspectives in benthic deep-sea microbial ecology. *Frontiers in Marine*
607 *Science*, 2, 17. [doi: 10.3389/fmars.2015.00017](https://doi.org/10.3389/fmars.2015.00017)
- 608 22. Costanza, R., Fisher, B., Mulder, K., Liu, S., & Christopher, T., 2007. Biodiversity and ecosystem
609 services: A multi-scale empirical study of the relationship between species richness and net primary
610 production. *Ecological economics*, 61(2-3), 478-491. doi.org/10.1016/j.ecolecon.2006.03.021

- 611 23. Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso,
612 M., 2017. Twenty years of ecosystem services: How far have we come and how far do we still need
613 to go?. *Ecosystem Services*, 28, 1-16. doi: [10.1016/j.ecoser.2017.09.008](https://doi.org/10.1016/j.ecoser.2017.09.008)
- 614 24. Costello, M. J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., & Miloslavich, P., 2010. A census of
615 marine biodiversity knowledge, resources, and future challenges. *PloS one*, 5(8), e12110. doi:
616 [10.1371/journal.pone.0012110](https://doi.org/10.1371/journal.pone.0012110)
- 617 25. Croll, D. A., Dewar, H., Dulvy, N. K., Fernando, D., Francis, M. P., Galván-Magaña, F., Hall, M.,
618 Heinrichs, S., Marshall, A., McCauley, D., Newton, K. M., di Sciara, G. N., O'Malley, M., O'Sullivan,
619 J., Poortvliet, M., Roman, M., Stevens, G., Tershy, B. R., & White, W. T., 2016. Vulnerabilities and
620 fisheries impacts: the uncertain future of manta and devil rays. *Aquatic Conservation: Marine and*
621 *Freshwater Ecosystems*, 26(3), 562-575. doi: [10.1002/aqc.2591](https://doi.org/10.1002/aqc.2591)
- 622 26. da Luz Fernandes, M., Quintela, A., & Alves, F. L., 2018. Identifying conservation priority areas to
623 inform maritime spatial planning: A new approach. *Science of The Total Environment*, 639, 1088-
624 1098.
- 625 27. Danovaro, R., Snelgrove, P. V., & Tyler, P., 2014. Challenging the paradigms of deep-sea
626 ecology. *Trends in ecology & evolution*, 29(8), 465-475. doi: [10.1016/j.tree.2014.06.002](https://doi.org/10.1016/j.tree.2014.06.002)
- 627 28. Danovaro, R., Corinaldesi, C., Dell'Anno, A., & Snelgrove, P. V., 2017. The deep-sea under global
628 change. *Current Biology*, 27(11), R461-R465. doi: [10.1016/j.cub.2017.02.046](https://doi.org/10.1016/j.cub.2017.02.046)
- 629 29. De Groot, R. S., Wilson, M. A., & Boumans, R. M., 2002. A typology for the classification, description
630 and valuation of ecosystem functions, goods and services. *Ecological economics*, 41(3), 393-408.
631 [doi.org/10.1016/S0921-8009\(02\)00089-7](https://doi.org/10.1016/S0921-8009(02)00089-7)
- 632 30. Dobson, A., Lodge, D., Alder, J., Cumming, G. S., Keymer, J., McGlade, J., Mooney, H., Rusak, J.
633 A., Sala, O., Wolters, V., Wall, D., Winfree, R., & Xenopoulos, M. A., 2006. Habitat loss, trophic
634 collapse, and the decline of ecosystem services. *Ecology*, 87(8), 1915-1924. doi: [10.1890/0012-9658\(2006\)87\[1915:HLTCAT\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2006)87[1915:HLTCAT]2.0.CO;2)
- 635
636 31. Drakou, E. G., Kermagoret, C., Liquete, C., Ruiz-Frau, A., Burkhard, K., Lillebø, A. I., van
637 Oudenhoven, A. P. E., Ballé-Béganton, J., Rodrigues, J. G., Nieminen, E., Oinonen, S., Ziemba, A.,
638 Gissi, E., Depellegrin, D., Veidemane, K., Ruskule, A., Delangue, J., Böhnke-Henrichs, A., Boon, A.,

- 639 Wenning, R., Martino, S., Hasler, B., Termansen, M., Rockel, M., Hummel, H., El Serafy, G., & Peey,
640 P. 2017. Marine and coastal ecosystem services on the science–policy–practice nexus: challenges and
641 opportunities from 11 European case studies. *International Journal of Biodiversity Science, Ecosystem*
642 *Services & Management*, 13(3), 51-67. [doi: 10.1080/21513732.2017.1417330](https://doi.org/10.1080/21513732.2017.1417330)
- 643 32. Douvère, F., 2008. The importance of marine spatial planning in advancing ecosystem-based sea use
644 management. *Marine policy*, 32(5), 762-771.
- 645 33. Dulvy, N. K., Simpfendorfer, C. A., Davidson, L. N., Fordham, S. V., Bräutigam, A., Sant, G., &
646 Welch, D. J., 2017. Challenges and priorities in shark and ray conservation. *Current Biology*, 27(11),
647 R565-R572. [doi: 10.1016/j.cub.2017.04.038](https://doi.org/10.1016/j.cub.2017.04.038)
- 648 34. Dunstan, P. K., Bax, N. J., Dambacher, J. M., Hayes, K. R., Hedge, P. T., Smith, D. C., & Smith, A.
649 D., 2016. Using ecologically or biologically significant marine areas (EBSAs) to implement marine
650 spatial planning. *Ocean & Coastal Management*, 121, 116-127. [doi:](https://doi.org/10.1016/j.ocecoaman.2015.11.021)
651 [10.1016/j.ocecoaman.2015.11.021](https://doi.org/10.1016/j.ocecoaman.2015.11.021)
- 652 35. EEA, 2013. European Environmental Agency Reference Grid. [http://www.eea.europa.eu/data-and-](http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2)
653 [maps/data/eea-reference-grids-2](http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2) (accessed 23/04/2017).
- 654 36. Egoh, B., Rouget, M., Reyers, B., Knight, A. T., Cowling, R. M., van Jaarsveld, A. S., & Welz, A.,
655 2007. Integrating ecosystem services into conservation assessments: a review. *Ecological*
656 *Economics*, 63(4), 714-721. [doi: 10.1016/j.ecolecon.2007.04.007](https://doi.org/10.1016/j.ecolecon.2007.04.007)
- 657 37. Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le Maitre, D. C., & van Jaarsveld, A. S., 2008.
658 Mapping ecosystem services for planning and management. *Agriculture, Ecosystems &*
659 *Environment*, 127(1), 135-140. [doi: 10.1016/j.agee.2008.03.013](https://doi.org/10.1016/j.agee.2008.03.013)
- 660 38. ESRI, 2016. Works Smarter with ArcGIS. <http://www.esri.com/arcgis/about-arcgis> (accessed
661 23/04/2017).
- 662 39. European Commission, 2000. Directive 2000/60/EC of the European Parliament and of the Council
663 of 23 October 2000 establishing a framework for Community action in the field of water policy.
- 664 40. European Commission, 2008. Directive 2008/56/EC of the European Parliament of the Council of 17
665 June 2008 establishing a framework for community action in the field of marine environmental policy
666 (Marine Strategy Framework Directive). Official Journal of the European Union L164: 19±40.

- 667 41. European Commission, 2012. Communication from the Commission to the European Parliament, the
668 Council, the European Economic and Social Committee and the Committee of the Regions, Blue
669 Growth opportunities for marine and maritime sustainable growth. Brussels, 13.09.2012 COM(2012)
670 494 final.
- 671 42. European Commission, 2014a. Directive 2014/89/EC of the European Parliament of the Council of 23
672 July 2014 establishing a framework for maritime spatial planning. Official Journal of the European
673 Union L257: 135±145.
- 674 43. European Commission, 2014b. Communication from the Commission to the European Parliament, the
675 Council, the European Economic and Social Committee of the Regions concerning the European
676 Union Strategy for the Adriatic and Ionian Region. COM (2014) 357 final.
- 677 44. Fisher, B., Turner, R. K., & Morling, P., 2009. Defining and classifying ecosystem services for
678 decision making. *Ecological economics*, 68(3), 643-653. [doi: 10.1016/j.ecolecon.2008.09.014](https://doi.org/10.1016/j.ecolecon.2008.09.014)
- 679 45. Foley, M. M., Halpern, B. S., Micheli, F., Armsby, M. H., Caldwell, M. R., Crain, C. M., Prahler, E.,
680 Rohr, N., Sivas, D., Beck, M. W., Carr, M. H., Crowder, L. B., Duffy, J. E., Hacker, S. D., McLeod,
681 K. L., Palumbi, S. R., Peterson, C. H., Regan, H. M., Ruckelshaus, M. H., Sandifer, P. A., & Steneck,
682 R. S., 2010. Guiding ecological principles for marine spatial planning. *Marine Policy*, 34(5), 955-966.
683 [doi: 10.1016/j.marpol.2010.02.001](https://doi.org/10.1016/j.marpol.2010.02.001)
- 684 46. Francour, P., Harmelin, J. G., Pollard, D., & Sartoretto, S., 2001. A review of marine protected areas
685 in the northwestern Mediterranean region: siting, usage, zonation and management. *Aquatic
686 conservation: marine and freshwater ecosystems*, 11(3), 155-188. [doi: 10.1002/aqc.442](https://doi.org/10.1002/aqc.442)
- 687 47. Fraschetti, S., Terlizzi, A., Bussotti, S., Guarnieri, G., D'Ambrosio, P., & Boero, F., 2005.
688 Conservation of Mediterranean seascapes: analyses of existing protection schemes. *Marine
689 Environmental Research*, 59(4), 309-332. [doi: 10.1016/j.marenvres.2004.05.007](https://doi.org/10.1016/j.marenvres.2004.05.007)
- 690 48. Frazier, J. G., 2005. Marine turtles: the role of flagship species in interactions between people and the
691 sea.
- 692 49. Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Lawler, J. J., Levin, P. S.,
693 Tandon, P. S., Varanasi, U., Wolf, K. L., & Wood, S. A., 2017. Nature contact and human health: A
694 research agenda. *Environmental health perspectives*, 125(7), 075001-1. [doi: 10.1289/EHP1663](https://doi.org/10.1289/EHP1663)

- 695 50. Fu, B. J., Su, C. H., Wei, Y. P., Willett, I. R., Lü, Y. H., & Liu, G. H., 2011. Double counting in
696 ecosystem services valuation: causes and countermeasures. *Ecological research*, 26(1), 1-14.
697 doi.org/10.1007/s11284-010-0766-3
- 698 51. García-Charton, J. A., Pérez-Ruzafa, A., Marcos, C., Claudet, J., Badalamenti, F., Benedetti-Cecchi,
699 L., Falcón, J. M., Milazzo, M., Schembri, P. J., Stobart, B., Vandeperre, F., Brito, A., Chemello, R.,
700 Dimech, M., Domenici, P., Guala, I., Le Diréach, L., Maggi, E., & Planes, S., 2008. Effectiveness of
701 European Atlanto-Mediterranean MPAs: Do they accomplish the expected effects on populations,
702 communities and ecosystems? *Journal for Nature Conservation*, 16(4), 193-221. [doi:](https://doi.org/10.1016/j.jnc.2008.09.007)
703 [10.1016/j.jnc.2008.09.007](https://doi.org/10.1016/j.jnc.2008.09.007)
- 704 52. Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forn, J., Plasència, A., & Nieuwenhuijsen,
705 M. J., 2015. Mental health benefits of long-term exposure to residential green and blue spaces: a
706 systematic review. *International journal of environmental research and public health*, 12(4), 4354-
707 4379. [doi: 10.3390/ijerph120404354](https://doi.org/10.3390/ijerph120404354)
- 708 53. Getis, A., & Ord, J. K., 1992. The analysis of spatial association by use of distance statistics.
709 *Geographical analysis*, 24(3), 189-206. [doi: 10.1111/j.1538-4632.1992.tb00261.x](https://doi.org/10.1111/j.1538-4632.1992.tb00261.x)
- 710 54. Getis, A., & Aldstadt, J., 2004. Constructing the Spatial Weights Matrix Using a Local Statistic.
711 *Geographical analysis*, 36(2), 90-104. [doi: 10.1111/j.1538-4632.2004.tb01127.x](https://doi.org/10.1111/j.1538-4632.2004.tb01127.x)
- 712 55. Gissi, E., Menegon, S., Sarretta, A., Appiotti, F., Maragno, D., Vianello, A., Depellegrin, D., Venier,
713 C., & Barbanti, A., 2017. Addressing uncertainty in modelling cumulative impacts within maritime
714 spatial planning in the Adriatic and Ionian region. *PloS one*, 12(7), e0180501. [doi:](https://doi.org/10.1371/journal.pone.0180501)
715 [10.1371/journal.pone.0180501](https://doi.org/10.1371/journal.pone.0180501)
- 716 56. Gissi, E., McGowan, J., Venier, C., Di Carlo, D., Musco, F., Menegon, S., Mackelworth, P., Agardy,
717 T., & Possingham, H., 2018. Addressing transboundary conservation challenges through marine
718 spatial prioritization. *Conservation Biology*. [doi: 10.1111/cobi.13134](https://doi.org/10.1111/cobi.13134)
- 719 57. Guerry, A. D., Ruckelshaus, M. H., Arkema, K. K., Bernhardt, J. R., Guannel, G., Kim, C.-K., Marsik,
720 M., Papenfus, M., Toft, J. E., Verutes, G., Wood, S. A., Beck, M., Chan, F., Chan, K. M.A.,
721 Gelfenbaum, G., Gold, B. D., Halpern, B. S., Labiosa, W. B., Lester, S. E., Levin, P. S., McField, M.,
722 Pinsky, M. L., Plummer, M., Polasky, S., Ruggiero, P., Sutherland, D. A., Tallis, H., Day, A. &

- 723 Spencer, J., 2012. Modeling benefits from nature: using ecosystem services to inform coastal and
724 marine spatial planning. *International Journal of Biodiversity Science, Ecosystem Services &*
725 *Management*, 8(1-2), 107-121. doi.org/10.1080/21523732.2011.647835
- 726 58. Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., Stewart Lowndes, J.,
727 Cotton Rockwood, R., Selig, E. R., Selkoe, K. A., & Walbridge, S., 2015. Spatial and temporal
728 changes in cumulative human impacts on the world's ocean. *Nature communications*, 6. [doi:](https://doi.org/10.1038/ncomms8615)
729 [10.1038/ncomms8615](https://doi.org/10.1038/ncomms8615)
- 730 59. Hauck, J., Görg, C., Varjopuro, R., Ratamáki, O., Maes, J., Wittmer, H., Jax, K., 2013. “Maps have
731 an air of authority” : potential benefits and challenges of ecosystem service maps at different levels
732 of decision making. *Ecosyst. Serv.* 4, 25-32. doi.org/10.1016/j.ecoser.2012.11.003
- 733 60. Holcer, D., Lazar, B., Mackelworth, P., & Fortuna, C. M., 2013. Rare or just unknown? The occurrence
734 of the giant devil ray (*Mobula mobular*) in the Adriatic Sea. *Journal of Applied Ichthyology*, 29(1),
735 139-144. [doi: 10.1111/jai.12034](https://doi.org/10.1111/jai.12034)
- 736 61. Johnson, D. E., Froján, C. B., Turner, P. J., Weaver, P., Gunn, V., Dunn, D. C., Halpin, P., Bax, N. J.,
737 & Dunstan, P. K., 2018. Reviewing the EBSA process: Improving on success. *Marine Policy*, 88, 75-
738 85. [doi: 10.1016/j.marpol.2017.11.014](https://doi.org/10.1016/j.marpol.2017.11.014)
- 739 62. Kareiva, P., & Marvier, M., 2003. Conserving biodiversity coldspots: Recent calls to direct
740 conservation funding to the world's biodiversity hotspots may be bad investment advice. *American*
741 *Scientist*, 91(4), 344-351. [doi: 10.1511/2003.4.344](https://doi.org/10.1511/2003.4.344)
- 742 63. Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T., & Campbell, B. M., 2008.
743 Knowing but not doing: selecting priority conservation areas and the research–implementation gap.
744 *Conservation biology*, 22(3), 610-617. [doi: 10.1111/j.1523-1739.2008.00914.x](https://doi.org/10.1111/j.1523-1739.2008.00914.x)
- 745 64. Lascelles, B. G., Taylor, P. R., Miller, M. G. R., Dias, M. P., Opper, S., Torres, L., Hedd, A., Le Corre,
746 M., Phillips, R. A., Shaffer, S. A., Weimerskirch, H., & Small, C., 2016. Applying global criteria to
747 tracking data to define important areas for marine conservation. *Diversity and Distributions*, 22(4),
748 422-431. [doi: 10.1111/ddi.12411](https://doi.org/10.1111/ddi.12411)

- 749 65. Laufkötter, C., Vogt, M., Gruber, N., Aita-Noguchi, M., Aumont, O., Bopp, L., Buitenhuis, E. T.,
750 Doney, S. C., Dunne, J. P., Hashioka, T., Hauck, J., Hirata, T., John, J. G., Le Quere, C., Lima, I. D.,
751 Nakano, H., Seferian, R., Totterdell, I. J., Vichi, M., & Volker, C., 2015. Drivers and uncertainties of
752 future global marine primary production in marine ecosystem models. *Biogeosciences*, 12, 6955-6984.
753 [doi: 10.5194/bg-12-6955-2015](https://doi.org/10.5194/bg-12-6955-2015)
- 754 66. Laurans, Y., Rankovic, A., Billé, R., Pirard, R., & Mermet, L., 2013. Use of ecosystem services
755 economic valuation for decision making: Questioning a literature blindspot. *Journal of environmental*
756 *management*, 119, 208-219. [doi: 10.1016/j.jenvman.2013.01.008](https://doi.org/10.1016/j.jenvman.2013.01.008)
- 757 67. Lavorel, S., Bayer, A., Bondeau, A., Lautenbach, S., Ruiz-Frau, A., Schulp, N., Seppelt, R., Verburg,
758 P., van Teeffelen, A., Vannier, C., Arneith, A., Cramer, W., Marba, N., 2017. Pathways to bridge the
759 biophysical realism gap in ecosystem services mapping approaches. *Ecol. Ind.* 74, 241-260.
760 doi.org/10.1016/j.ecolind.2016.11.015
- 761 68. Lawson, J. M., Fordham, S. V., O'Malley, M. P., Davidson, L. N., Walls, R. H., Heupel, M. R.,
762 Stevens, G., Fernando, D., Budziak, A., Simpfendorfer, C. A., Ender, I., Francis, M. P., di Sciara, N.,
763 & Dulvy, N. K., 2017. Sympathy for the devil: a conservation strategy for devil and manta
764 rays. *PeerJ*, 5, e3027. [doi: 10.7717/peerj.3027](https://doi.org/10.7717/peerj.3027)
- 765 69. Levin, N., Kark, S., & Danovaro, R., 2017. Adding the Third Dimension to Marine
766 Conservation. *Conservation Letters*. [doi: 10.1111/conl.12408](https://doi.org/10.1111/conl.12408)
- 767 70. Lewison, R. L., Crowder, L. B., Wallace, B. P., Moore, J. E., Cox, T., Zydalis, R., McDonald, S., Di
768 Matteo, A., Dunn, D. C., Kot, C. Y., Bjorkland, R., Kelez, S., Soykan, C., Stewart, K. R., Sims, M.,
769 Boustany, A., Read, A. J., Halpin, P., Nichols, W. J., & Safina, C., 2014. Global patterns of marine
770 mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna
771 hotspots. *Proceedings of the National Academy of Sciences*, 111(14), 5271-5276. [doi:](https://doi.org/10.1073/pnas.1318960111)
772 [10.1073/pnas.1318960111](https://doi.org/10.1073/pnas.1318960111)
- 773 71. Li, Y., Zhang, L., Yan, J., Wang, P., Hu, N., Cheng, W., & Fu, B., 2017. Mapping the hotspots and
774 coldspots of ecosystem services in conservation priority setting. *Journal of Geographical*
775 *Sciences*, 27(6), 681-696. [doi: 10.1007/s11442-017-1400-x](https://doi.org/10.1007/s11442-017-1400-x)

- 776 72. Liqueste, C., Cid, N., Lanzanova, D., Grizzetti, B., & Reynaud, A., 2016. Perspectives on the link
777 between ecosystem services and biodiversity: The assessment of the nursery function. *Ecological*
778 *Indicators*, 63, 249-257. doi: [10.1016/j.ecolind.2015.11.058](https://doi.org/10.1016/j.ecolind.2015.11.058)
- 779 73. Long, R. D., Charles, A., & Stephenson, R. L., 2015. Key principles of marine ecosystem-based
780 management. *Marine Policy*, 57, 53-60. doi.org/[10.1016/j.marpol.2015.01.013](https://doi.org/10.1016/j.marpol.2015.01.013)
- 781 74. Lotze, H. K., Coll, M., & Dunne, J. A.. 2011. Historical changes in marine resources, food-web
782 structure and ecosystem functioning in the Adriatic Sea, Mediterranean. *Ecosystems*, 14(2), 198-222.
783 doi: [10.1007/s10021-010-9404-8](https://doi.org/10.1007/s10021-010-9404-8)
- 784 75. Lutz, M. J., Caldeira, K., Dunbar, R. B., & Behrenfeld, M. J., 2007. Seasonal rhythms of net primary
785 production and particulate organic carbon flux to depth describe the efficiency of biological pump in
786 the global ocean. *Journal of Geophysical Research: Oceans*, 112(C10). doi: [10.1029/2006JC003706](https://doi.org/10.1029/2006JC003706)
- 787 76. Mace, G. M., Norris, K., & Fitter, A. H., 2012. Biodiversity and ecosystem services: a multilayered
788 relationship. *Trends in ecology & evolution*, 27(1), 19-26. doi: [10.1016/j.tree.2011.08.006](https://doi.org/10.1016/j.tree.2011.08.006)
- 789 77. Maes, F., 2008. The international legal framework for marine spatial planning. *Marine Policy*, 32(5),
790 797-810. doi.org/[10.1016/j.marpol.2008.03.013](https://doi.org/10.1016/j.marpol.2008.03.013)
- 791 78. Maes, J., Egoh, B., Willemsen, L., Liqueste, C., Vihervaara, P., Schägner, J. P., Grizzetti, B., Drakou,
792 E. G., La Notte, A., Zulian, G., Bouraoui, F., Paracchini, M. L., Braat, L., & Bidoglio, G., 2012.
793 Mapping ecosystem services for policy support and decision making in the European
794 Union. *Ecosystem Services*, 1(1), 31-39. doi: [10.1016/j.ecoser.2012.06.004](https://doi.org/10.1016/j.ecoser.2012.06.004)
- 795 79. Maes, J., Paracchini, M. L., Zulian, G., Dunbar, M. B., & Alkemade, R., 2012. Synergies and trade-
796 offs between ecosystem service supply, biodiversity, and habitat conservation status in
797 Europe. *Biological conservation*, 155, 1-12. doi: [10.1016/j.biocon.2012.06.016](https://doi.org/10.1016/j.biocon.2012.06.016)
- 798 80. Maes, J., Liqueste, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., Grizzetti, B., Cardoso,
799 A., Somma, F., Petersen, J-E., Meiner, A., Gelabert, E., Zal, N., Kristensen, P., Bastrup-Birk, A., Biala,
800 K., Piroddi, C., Egoh, B., Degeorges, P., Fiorina, C., Santos-Martin, F., Naruševičius, V., Verboven,
801 J., Pereira, H. M., Bengtsson, J., Gocheva, K., Marta-Pedroso, C., Snäll, T., Estreguil, C., San-Miguel-
802 Ayanz, J., Pérez-Soba, M., Grêt-Regamey, A., Lillebø, A. I., Malak, D. A., Condé, S., Moen, J.,
803 Czúcz, B., Drakou, E. G., Zulian, G., & Lavalle, C., 2016. An indicator framework for assessing

- 804 ecosystem services in support of the EU Biodiversity Strategy to 2020. *Ecosystem services*, 17, 14-23.
805 [doi: 10.1016/j.ecoser.2015.10.023](https://doi.org/10.1016/j.ecoser.2015.10.023)
- 806 81. Manning, P., Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., Whittingham, M. J., & Fischer,
807 M., 2018. Redefining ecosystem multifunctionality. *Nature ecology & evolution*, 2(3), 427. [doi:](https://doi.org/10.1038/s41559-017-0461-7)
808 [10.1038/s41559-017-0461-7](https://doi.org/10.1038/s41559-017-0461-7)
- 809 82. Marchese, C., 2015. Biodiversity hotspots: A shortcut for a more complicated concept. *Global Ecology*
810 *and Conservation*, 3, 297-309. [doi: 10.1016/j.gecco.2014.12.008](https://doi.org/10.1016/j.gecco.2014.12.008)
- 811 83. Martínez-Harms, M. J., & Balvanera, P., 2012. Methods for mapping ecosystem service supply: a
812 review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8(1-2), 17-
813 25. [doi: 10.1080/21513732.2012.663792](https://doi.org/10.1080/21513732.2012.663792)
- 814 84. Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., Briscoe, D. K.,
815 Fossette, S., Hobday, A. J., Bennet, M., Benson, S., Caldwell, M. R., Costa, D. P., Dewar, H., Eguchi,
816 T., Hazen, L., Kohin, S., Sippel, T., & Crowder, L. B., 2015. Dynamic ocean management: Defining
817 and conceptualizing real-time management of the ocean. *Marine Policy*, 58, 42-50. [doi:](https://doi.org/10.1016/j.marpol.2015.03.014)
818 [10.1016/j.marpol.2015.03.014](https://doi.org/10.1016/j.marpol.2015.03.014)
- 819 85. Micheli, F., Levin, N., Giakoumi, S., Katsanevakis, S., Abdulla, A., Coll, M., Fraschetti, S., Kark, S.,
820 Koutsoubas, D., Mackelworth, P., Maiorano, L., & Possingham, H. P., 2013. Setting priorities for
821 regional conservation planning in the Mediterranean Sea. *PLoS One*, 8(4), e59038. [doi:](https://doi.org/10.1371/journal.pone.0059038)
822 [10.1371/journal.pone.0059038](https://doi.org/10.1371/journal.pone.0059038)
- 823 86. Millennium Ecosystem Assessment (MA), 2005 Biodiversity synthesis report. World Resources
824 Institute, Washington, DC
- 825 87. Mitchel, A., 2005. The ESRI Guide to GIS analysis, Volume 2: Spatial measurements and
826 statistics. *ESRI Guide to GIS analysis*.
- 827 88. O'donnell, J., Gallagher, R. V., Wilson, P. D., Downey, P. O., Hughes, L., & Leishman, M. R., 2012.
828 Invasion hotspots for non-native plants in Australia under current and future climates. *Global Change*
829 *Biology*, 18(2), 617-629. doi.org/10.1111/j.1365-2486.2011.02537.x

- 830 89. O'Leary, B. C., Brown, R. L., Johnson, D. E., Von Nordheim, H., Ardron, J., Packeiser, T., & Roberts,
831 C. M., 2012. The first network of marine protected areas (MPAs) in the high seas: the process, the
832 challenges and where next. *Marine Policy*, 36(3), 598-605. [doi: 10.1016/j.marpol.2011.11.003](https://doi.org/10.1016/j.marpol.2011.11.003)
- 833 90. O'Leary, B. C., & Roberts, C. M., 2017. The Structuring Role of Marine Life in Open Ocean Habitat:
834 Importance to International Policy. *Frontiers in Marine Science*, 4, 268. [doi:](https://doi.org/10.3389/fmars.2017.00268)
835 [10.3389/fmars.2017.00268](https://doi.org/10.3389/fmars.2017.00268)
- 836 91. Outeiro, L., Häussermann, V., Viddi, F., Hucke-Gaete, R., Försterra, G., Oyarzo, H., Kosiel, K.,
837 Villasante, S., 2015. Using ecosystem services mapping for marine spatial planning in southern Chile
838 under scenario assessment. *Ecosystem services*, 16, 341-353. [doi: 10.1016/j.ecoser.2015.03.004](https://doi.org/10.1016/j.ecoser.2015.03.004)
- 839 92. Palumbi, S. R., Sandifer, P. A., Allan, J. D., Beck, M. W., Fautin, D. G., Fogarty, M. J., Halpern, B.
840 S., Incze, L. S., Leong, J-A., Norse, E., Stachowicz, J. J., & Wall, D. H., 2009. Managing for ocean
841 biodiversity to sustain marine ecosystem services. *Frontiers in Ecology and the Environment*, 7(4),
842 204-211. [doi: 10.1890/070135](https://doi.org/10.1890/070135)
- 843 93. Portman, M. E., 2013. Ecosystem services in practice: challenges to real world implementation of
844 ecosystem services across multiple landscapes—a critical review. *Applied Geography*, 45, 185-192.
845 [doi: 10.1016/j.apgeog.2013.09.011](https://doi.org/10.1016/j.apgeog.2013.09.011)
- 846 94. Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013
847 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No
848 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council
849 Decision 2004/585/EC.
- 850 95. Roberson, L. A., Lagabrielle, E., Lombard, A. T., Sink, K., Livingstone, T., Grantham, H., & Harris,
851 J. M., 2017. Pelagic bioregionalisation using open-access data for better planning of marine protected
852 area networks. *Ocean & coastal management*, 148, 214-230.
853 doi.org/10.1016/j.ocecoaman.2017.08.017
- 854 96. Rodríguez-Rodríguez, D., Rodríguez, J., Blanco, J. M., & Malak, D. A., 2016. Marine protected area
855 design patterns in the Mediterranean Sea: Implications for conservation. *Marine pollution*
856 *bulletin*, 110(1), 335-342. [doi: 10.1016/j.marpolbul.2016.06.044](https://doi.org/10.1016/j.marpolbul.2016.06.044)

- 857 97. Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., ... & Bernhardt, J., 2015.
858 Notes from the field: lessons learned from using ecosystem service approaches to inform real-world
859 decisions. *Ecological Economics*, 115, 11-21. doi: [10.1016/j.ecolecon.2013.07.009](https://doi.org/10.1016/j.ecolecon.2013.07.009)
- 860 98. Ruiz-Frau, A., Possingham, H. P., Edwards-Jones, G., Klein, C. J., Segan, D., & Kaiser, M. J., 2015.
861 A multidisciplinary approach in the design of marine protected areas: Integration of science and
862 stakeholder based methods. *Ocean & Coastal Management*, 103, 86-93. doi:
863 [10.1016/j.ocecoaman.2014.11.012](https://doi.org/10.1016/j.ocecoaman.2014.11.012)
- 864 99. Salomidi, M., Katsanevakis, S., Borja, Á., Braeckman, U., Damalas, D., Galparsoro, I., Mifsud, R.,
865 Mirto, S., Pascual, M., Pipitone, C., Rabaut, M., Todorova, V., Vassilopoulou, V., & Vega Fernández,
866 T., 2012. Assessment of goods and services, vulnerability, and conservation status of European seabed
867 biotopes: a stepping stone towards ecosystem-based marine spatial management. *Mediterranean*
868 *Marine Science*, 13: 49-88.
- 869 100. Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P., 2015. Exploring connections among
870 nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance
871 health and biodiversity conservation. *Ecosystem Services*, 12, 1-15. doi: [10.1016/j.ecoser.2014.12.007](https://doi.org/10.1016/j.ecoser.2014.12.007)
- 872 101. Schröter, M., & Remme, R. P., 2016. Spatial prioritisation for conserving ecosystem services:
873 comparing hotspots with heuristic optimisation. *Landscape ecology*, 31(2), 431-450. doi:
874 [10.1007/s10980-015-0258-5](https://doi.org/10.1007/s10980-015-0258-5)
- 875 102. Schröter, M., Kraemer, R., Ceaușu, S., & Rusch, G. M., 2017. Incorporating threat in hotspots
876 and coldspots of biodiversity and ecosystem services. *Ambio*, 1-13. doi: [10.1007/s13280-017-0922-x](https://doi.org/10.1007/s13280-017-0922-x)
- 877 103. di Sciara, G. N., Lauriano, G., Pierantonio, N., Cañadas, A., Donovan, G., & Panigada, S.,
878 2015. The Devil We Don't Know: Investigating Habitat and Abundance of Endangered Giant Devil
879 Rays in the North-Western Mediterranean Sea. *PloS one*, 10(11), e0141189. doi:
880 [10.1371/journal.pone.0141189](https://doi.org/10.1371/journal.pone.0141189)
- 881 104. di Sciara, G. N., Hoyt, E., Reeves, R., Ardron, J., Marsh, H., Vongraven, D., & Barr, B., 2016.
882 Place-based approaches to marine mammal conservation. *Aquatic Conservation: Marine and*
883 *Freshwater Ecosystems*, 26(S2), 85-100. doi: [10.1002/aqc.2642](https://doi.org/10.1002/aqc.2642)

- 884 105. Sheaves, M., Baker, R., & Johnston, R., 2006. Marine nurseries and effective juvenile
885 habitats. *Marine Ecology Progress Series*, 318, 303-306. doi: [10.3354/meps312291](https://doi.org/10.3354/meps312291)
- 886 106. Smith, A. C., Harrison, P. A., Soba, M. P., Archaux, F., Blicharska, M., Egoh, B. N., Erös, T.,
887 Domenech, N., F., György, A. I., Haines-Young, R., Li, S., Lommelen, E., Meiresonne, L., Ayala, L.
888 M., Mononen, L., Simpson, G., Stange, E., Turkelboom, F., Uiterwijk, M., Veerkamp, C. J., & Wyllie
889 de Echeverria, V., 2017. How natural capital delivers ecosystem services: a typology derived from a
890 systematic review. *Ecosystem Services*, 26, 111-126. doi: [10.1016/j.ecoser.2017.06.006](https://doi.org/10.1016/j.ecoser.2017.06.006)
- 891 107. Soliveres, S., Van Der Plas, F., Manning, P., Prati, D., Gossner, M. M., Renner, S. C., Alt, F.,
892 Arndt, H., Baumgartner, V., Binkenstein, J., Birkhofer, K., Blaser, S., Blüthgen, N., Boch, S., Böhm,
893 S., Börschig, C., Buscot, F., Diekötter, T., Heinze, J., Hölzel, N., Jung, K., Klaus, V. H., Kleinebecker,
894 T., Klemmer, S., Krauss, J., Lange, M., Morris, E. K., Müller, J., Oelmann, Y., Overmann, J., Pašalić,
895 E., Rillig, M. C., Schaefer, H. M., Schlöter, M., Schmitt, B., Schöning, I., Schrumpf, M., Sikorski, J.,
896 Socher, S. A., Solly, E. F., Sonnemann, I., Sorkau, E., Steckel, J., Steffan-Dewenter, I., Stempfhuber,
897 B., Tschapka, M., Türke, M., Venter, P. C., Weiner, C. N., Weisser, W. W., Werner, M., Westphal,
898 C., Wilcke, W., Wolters, V., Wubet, T., Wurst, S., Fischer, M., & Allan, E. 2016. Biodiversity at
899 multiple trophic levels is needed for ecosystem multifunctionality. *Nature*, 536(7617), 456. doi:
900 [10.1038/nature19092](https://doi.org/10.1038/nature19092)
- 901 108. TEEB, 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic
902 Foundation. Earthscan, Cambridge.
- 903 109. Tempera, F., Liqueste, C., Cardoso, A.C., 2016. Spatial Distribution of Marine Ecosystem
904 Service Capacity in the European seas. Technical Report, EUR Scientific and Technical Research
905 Series. Publications Office of the European Union, Luxembourg
- 906 110. Tesi, T., Miserocchi, S., Goni, M. E. A., Langone, L., Boldrin, A., & Turchetto, M., 2007.
907 Organic matter origin and distribution in suspended particulate materials and surficial sediments from
908 the western Adriatic Sea (Italy). *Estuarine, Coastal and Shelf Science*, 73(3-4), 431-446. doi:
909 [10.1016/j.ecss.2007.02.008](https://doi.org/10.1016/j.ecss.2007.02.008)

- 910 111. Timilsina, N., Escobedo, F. J., Cropper, W. P., Abd-Elrahman, A., Brandeis, T. J., Delphin,
 911 S., & Lambert, S., 2013. A framework for identifying carbon hotspots and forest management
 912 drivers. *Journal of environmental management*, 114, 293-302. doi: [10.1016/j.jenvman.2012.10.020](https://doi.org/10.1016/j.jenvman.2012.10.020)
- 913 112. Venegas-Li, R., Levin, N., Possingham, H., & Kark, S., 2017. 3D spatial conservation
 914 prioritisation: Accounting for depth in marine environments. *Methods in Ecology and Evolution*. doi:
 915 [10.1111/2041-210X.12896](https://doi.org/10.1111/2041-210X.12896)
- 916 113. Verhagen, W., Kukkala, A. S., Moilanen, A., van Teeffelen, A. J., & Verburg, P. H., 2017.
 917 Use of demand for and spatial flow of ecosystem services to identify priority areas. *Conservation*
 918 *Biology*. doi: [10.1111/cobi.12872](https://doi.org/10.1111/cobi.12872)
- 919 114. Wallace, K. J., 2007. Classification of ecosystem services: problems and solutions. *Biological*
 920 *conservation*, 139(3-4), 235-246. doi: [10.1016/j.biocon.2007.07.015](https://doi.org/10.1016/j.biocon.2007.07.015)
- 921 115. Wenny, D. G., DeVault, T. L., Johnson, M. D., Kelly, D., Sekercioglu, C. H., Tomback, D.
 922 F., & Whelan, C. J., 2011. The need to quantify ecosystem services provided by birds. *The*
 923 *Auk*, 128(1), 1-14. doi: [10.1525/auk.2011.10248](https://doi.org/10.1525/auk.2011.10248)
- 924 116. White, C., Halpern, B. S., & Kappel, C. V., 2012. Ecosystem service tradeoff analysis reveals
 925 the value of marine spatial planning for multiple ocean uses. *Proceedings of the National Academy of*
 926 *Sciences*, 109(12), 4696-4701. doi: [10.1073/pnas.1114215109](https://doi.org/10.1073/pnas.1114215109)

927

928 **Appendix**

929

930 **Formulae and equations**

931 Eq. (A) *Hotspot analysis detail*

932 The G_i^* statistic was calculated according to Mitchel (2005) as follows:

$$933 \quad G_i^*(d) = \frac{\sum_j w_{ij}(d)x_j}{\sum_j x_j} \quad (1)$$

934

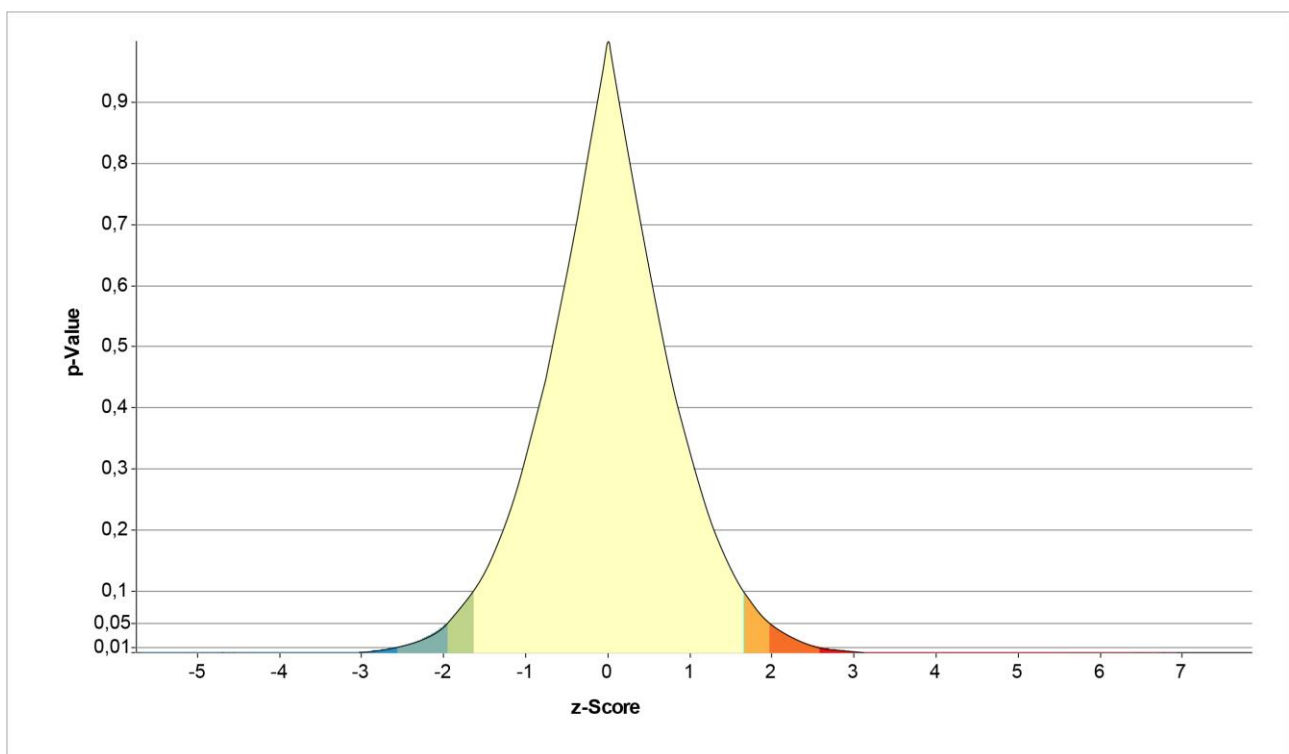
935 where:

936 i = cell;
 937 j = point within d of i ;
 938 d = fixed distance determined by the Polygon Contiguity (Rook case) spatial correlation;
 939 w_{ij} = binary spatial weight matrix corresponding to 1 if cell fall within d , or 0 if not;
 940 x_j = sum of ecosystem services values for each grid cell.

941

942 **Figures**

943



944

z-score	p-value	Confidence level
< -1.65 or > +1.65	< 0.10	90%
< -1.96 or > +1.96	< 0.05	95%
< -2.58 or > +2.58	< 0.01	99%

945

946 Fig. (A). Getis-Ord-Gi* value representation related to the obtained results. It combines both the z-scores
 947 and p-values resulting from the Hotspot analysis.

948

949 **Tables**

950

951 Table (A). ES hotspot and coldspot areas, expressed in both number of grid cells and Km², and related
 952 percentage coverage area resulted from the joint hotspot analysis (Total), and the hotspot analysis carried out
 953 on each marine domain separately (Surface, Water column, and Seafloor). The hotspot and coldspot areas are
 954 distinguished on the base of their confidence level (90%, 95%, 99%). The sum of the coverage percentage
 955 areas of statistically significant hotspot and coldspot, with confidence level $\geq 95\%$, was calculated per each
 956 hotspot analysis. The percentage coverage area of each hotspot and coldspot is calculated on the study area,
 957 which corresponds to about 139.160 Km².

HotSpot Total	Counted cells (n°)	Summed area (Km²)	Coverage on Adriatic area (%)
Coldspot $\geq 95\%$			19.3%
ColdSpot 99%	18861	18.365,79	13.2%
ColdSpot 95%	8584	8.436,79	6.1%
ColdSpot 90%	4977	4.641,13	3.3%
Not significant	78288	75.659,05	54.4%
Hotspot 90%	6256	6.228,23	4.5%
Hotspot 95%	8988	8.934,54	6.4%
Hotspot 99%	17014	16.897,09	12.1%
Hotspot $\geq 95\%$			18.5%
Hotspot Surface	Counted cells (n°)	Summed area (Km²)	Coverage on Adriatic area (%)
Coldspot $\geq 95\%$			18.9%
ColdSpot 99%	17137	16.645,72	12.0%
ColdSpot 95%	9717	9.607,55	6.9%
ColdSpot 90%	3915	3.888,84	2.8%
Not significant	86568	83.507,88	60.0%
Hotspot 90%	3803	3.760,84	2.7%
Hotspot 95%	6026	5.978,76	4.3%
Hotspot 99%	15802	15.773,18	11.3%
Hotspot $\geq 95\%$			15.6%
Hotspot Water Column	Counted cells	Summed area (Km²)	Coverage on Adriatic area (%)

Coldspot \geq 95%			16.8%
ColdSpot 99%	12831	11.083,88	8.0%
ColdSpot 95%	13342	12.310,86	8.8%
ColdSpot 90%	8036	7.681,4	5.5%
Not significant	79824	79.152,28	56.9%
Hotspot 90%	3585	3.584,95	2.6%
Hotspot 95%	6496	6.495,4	4.7%
Hotspot 99%	18854	18.854	13.5%
Hotspot \geq 95%			18.2%
Hotspot Seabed	Counted cells	Summed area (Km²)	Coverage on Adriatic area (%)
Coldspot \geq 95%			20.3%
ColdSpot 99%	27532	27.031,3	19.4%
ColdSpot 95%	1345	1.270,67	0.9%
ColdSpot 90%	614	579.11	0.4%
Not significant	85883	83.007,86	59.6%
Hotspot 90%	6595	6.581,25	4.7%
Hotspot 95%	6595	6.560,64	4.7%
Hotspot 99%	14404	14.131,94	10.2%
Hotspot \geq 95%			14.9%
