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

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## Abstract

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

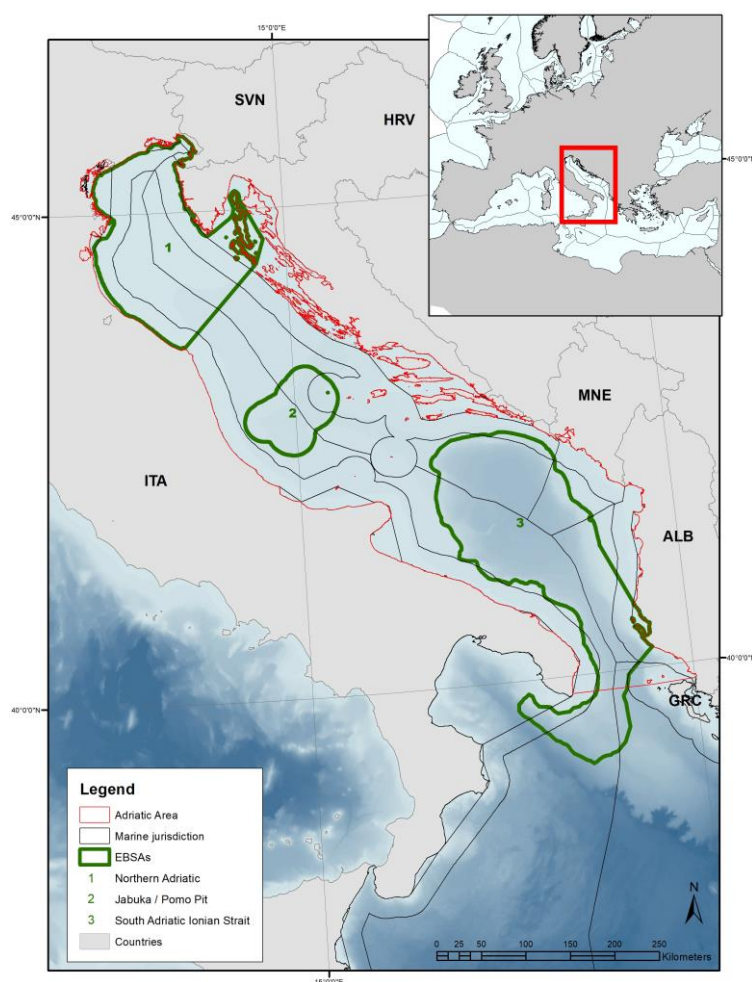
### 116 *2.1 Study area*

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 km<sup>2</sup>) with respect to the MPAs in other parts of the Mediterranean  
132 (Rodríguez-Rodríguez et al. 2016). In the study area, of about 139160 km<sup>2</sup>, 32 MPAs were designated (Med-  
133 PAN, MAPAMED GIS database; [www.medpan.org](http://www.medpan.org)). In particular, the Italian territorial waters count 4 MPAs,

134 with an average area of 17,8 km<sup>2</sup>, while the remaining ones belong to Slovenia, counting 2 MPAs (average  
 135 area 0,18 km<sup>2</sup>), Croatia (17 MPAs with an average size of 51,7 km<sup>2</sup>), Montenegro (only 1 MPA, 110 km<sup>2</sup> in  
 136 size), and Albania (8 MPAs, with average size 114,7 km<sup>2</sup>) (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](http://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](http://www.medpan.org) for MPAs; sources:

[www.cbd.int](http://www.cbd.int) for EBSAs). ITA = Italy; SVN = Slovenia; HRV = Croatia; BIH = Bosnia-Herzegovina; MNE = Montenegro; ALB = Albania; GRC = Greece.

## 2.2 Operational approach for mapping supporting ES for MSP processes

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

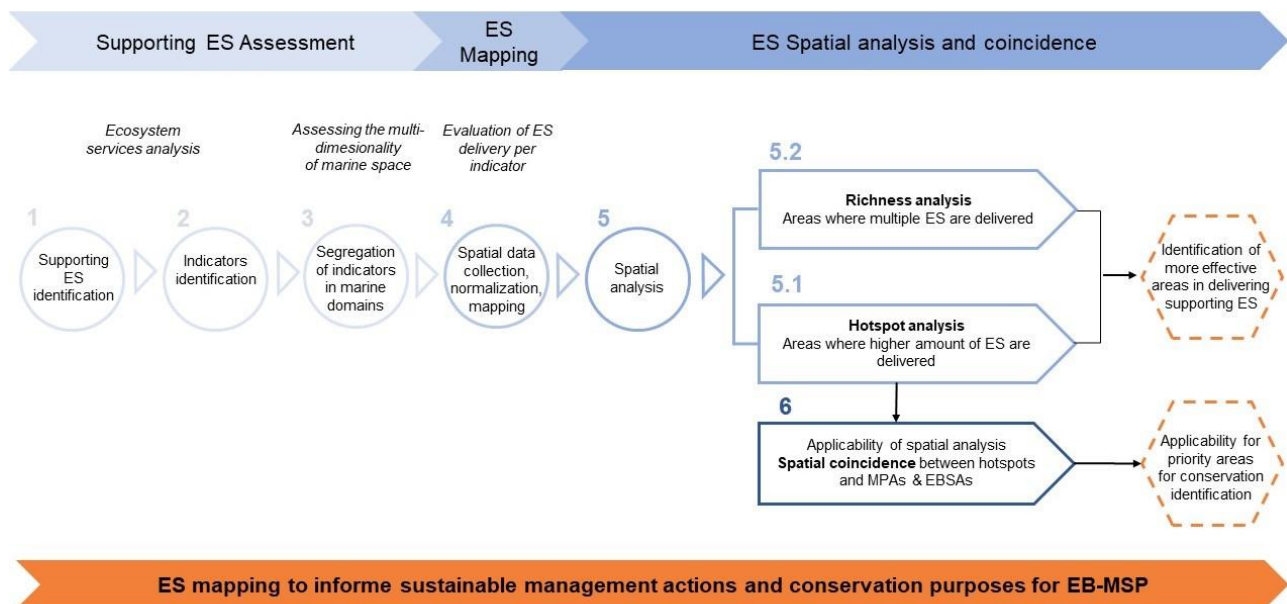


Fig. 2 Methodological framework for mapping supporting ES delivered from the marine environment. Steps 1, 2, 3 and 4 indicate the stages to carry out before step 5 that consists in applying the spatial analyses 5.1 and 5.2, and before step 6 to reach the main outputs.

### 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

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

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

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

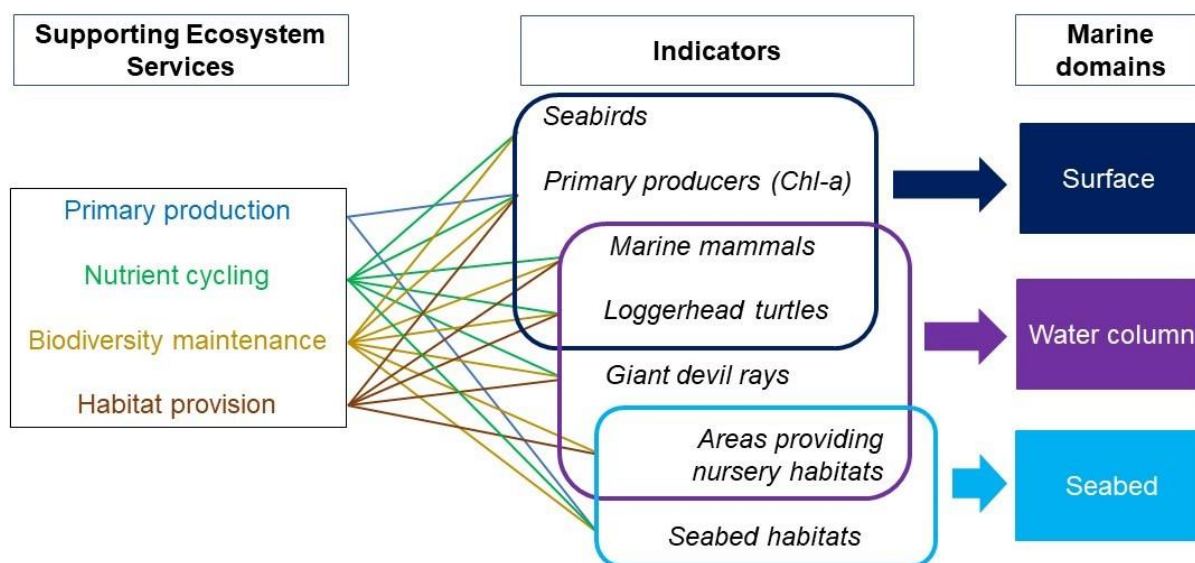
202 In step 3, each of the indicators were associated to a specific marine domain (surface, water column, seabed).  
 203 Segregation among domains was based on life behaviour and spatial distribution of the marine components,  
 204 as described in Table 2.

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/unknown), 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 <sup>2</sup>	EMODnet
Seabirds	Number of individuals/20 km <sup>2</sup>	Adriplan dataportal
Giant devil ray	Number of individuals/20 km <sup>2</sup>	Adriplan dataportal
Loggerhead turtles	Number of individuals/20 km <sup>2</sup>	Adriplan dataportal
Primary producers	Chlorophyll-a, average annual value mg m <sup>-3</sup>	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

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

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

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

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

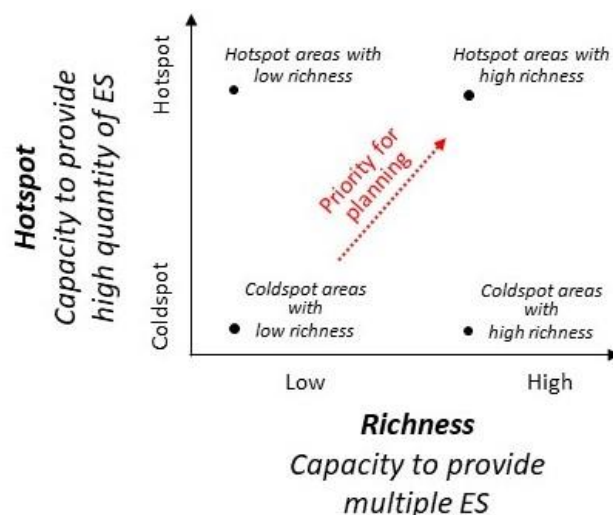


Fig. 4 Conceptual relationship between Hotspot and Richness analyses. The application of both the analyses allow the identification of marine areas with the highest delivery capacity of multiple ES

#### 2.2.6. Step 6: Spatial coincidence

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

### 3. Results

#### 3.1 ES Hotspot areas distribution

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

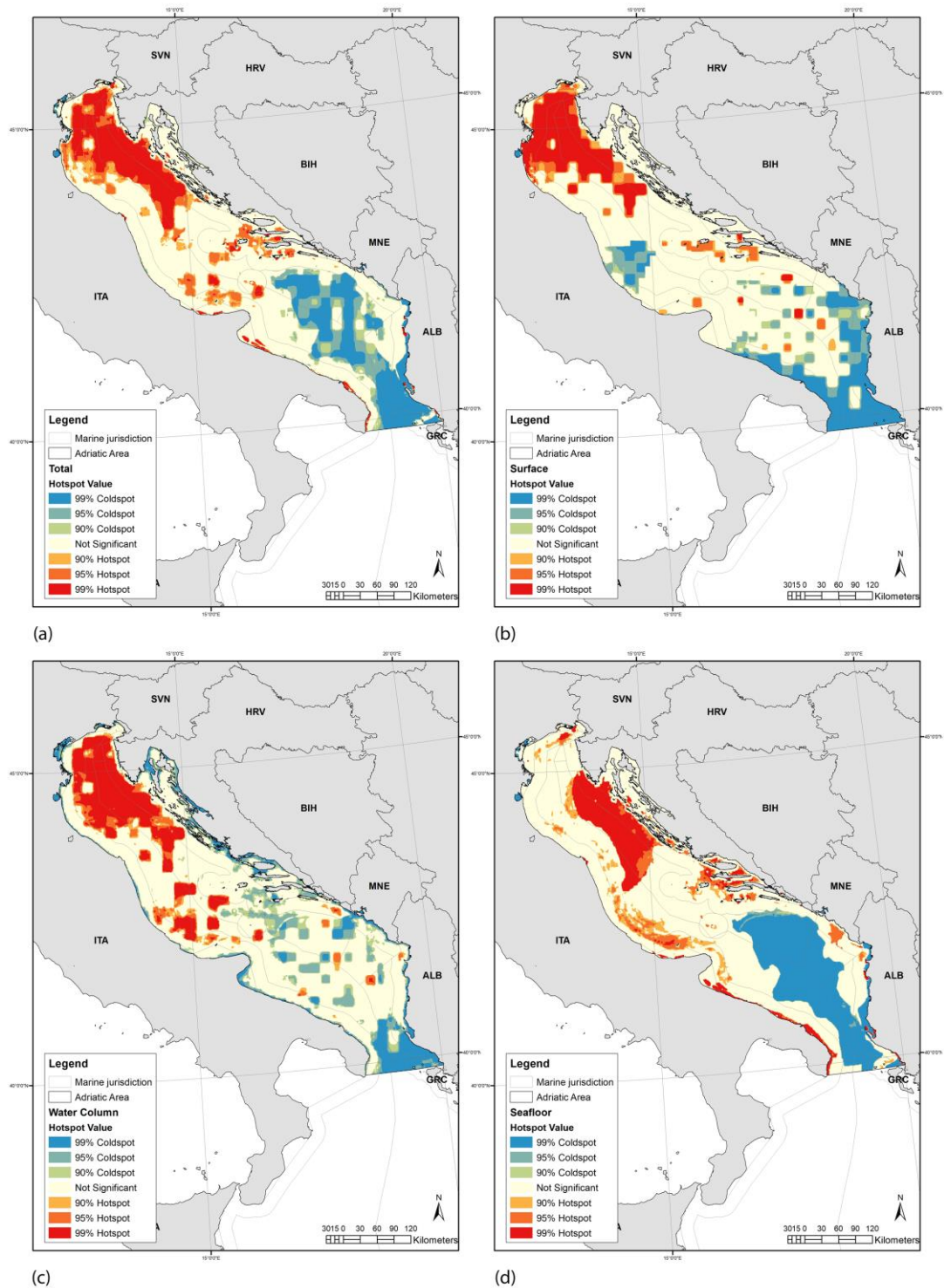
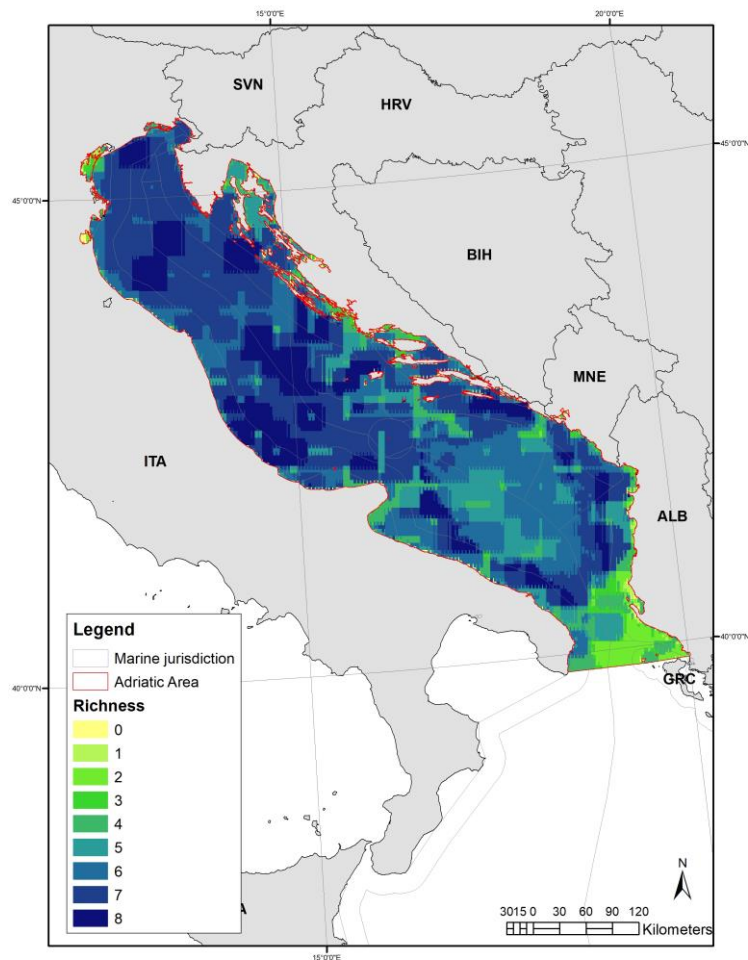


Fig.5 Identified hotspot and coldspot areas. Map (a) Total hot and cold spot areas not distinguishing the marine domains; map (b) Surface hot and cold spot areas; map (c) Water Column hot and cold spot areas; map (d) Seabed hot and cold spot areas. Red areas (core hotspots) represent distribution values corresponding to Getis-Ord-Gi\* values equal to  $p=0.01$ , 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 distribution values corresponding to Getis-Ord-Gi\* values equal to  $p=0.01$ , blue areas equal to  $p=0.05$ , and light blue areas equal to  $p=0.1$ .

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

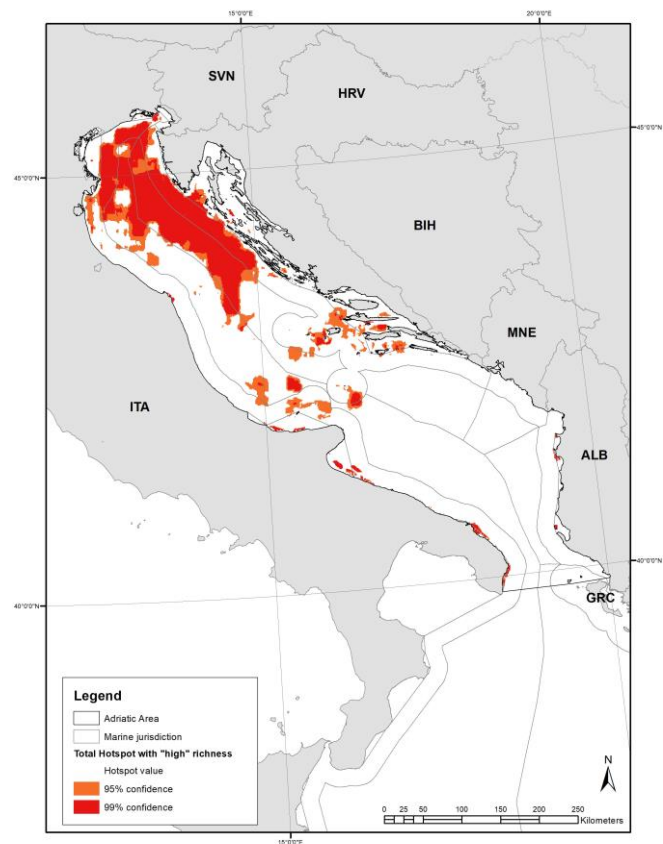
355 3.3 Areas of higher and lower effectiveness in supporting ecosystem services delivery

356

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

359

360



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.

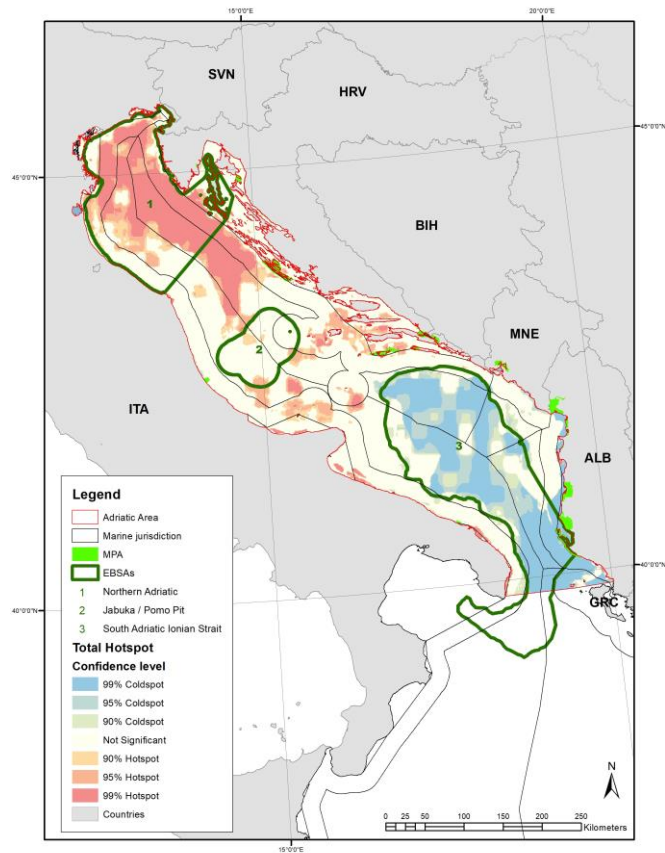
364

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 km<sup>2</sup>. 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).

374



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		
Hotspot total	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %
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	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %
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%

<b>Hotspot water column</b>	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	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%
<b>Hotspot seabed</b>	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	Spatial coincidence %	Cells n°	Area (km <sup>2</sup> )	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%

## 4. Discussion

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

### 4.1 Including supporting services in planning the marine space

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

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

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

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## Appendix

### Formulae and equations

Eq. (A) Hotspot analysis detail

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

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

where:

936  $i$  = cell;

937  $j$  = point within  $d$  of  $i$ ;

938  $d$  = fixed distance determined by the Polygon Contiguity (Rook case) spatial correlation;

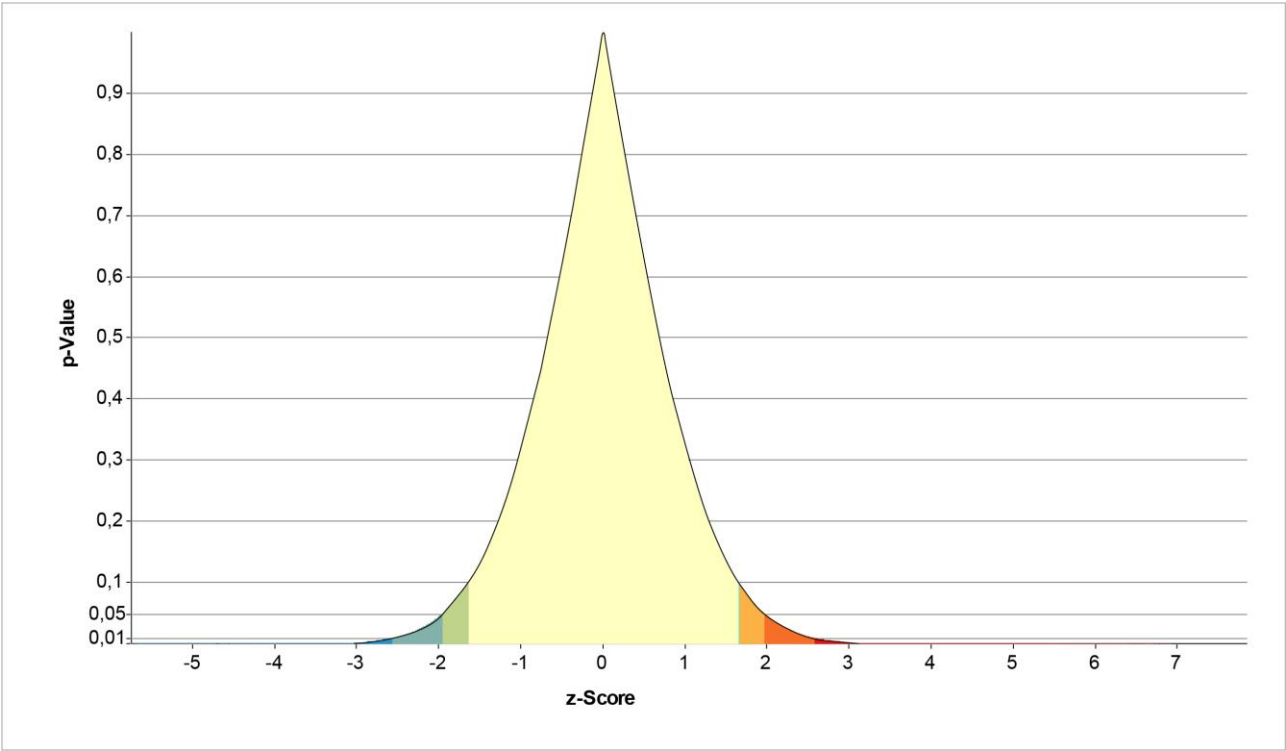
939  $w_{ij}$  = binary spatial weight matrix corresponding to 1 if cell fall within  $d$ , or 0 if not;

940  $x_j$  = sum of ecosystem services values for each grid cell.

941

942 **Figures**

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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**

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951 Table (A). ES hotspot and coldspot areas, expressed in both number of grid cells and Km<sup>2</sup>, 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 Km<sup>2</sup>.

<b>HotSpot Total</b>	<b>Counted cells (n°)</b>	<b>Summed area (Km<sup>2</sup>)</b>	<b>Coverage on Adriatic area (%)</b>
Coldspot $\geq 95\%$			<b>19.3%</b>
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 $\geq 95\%$			<b>18.5%</b>
<b>Hotspot Surface</b>	<b>Counted cells (n°)</b>	<b>Summed area (Km<sup>2</sup>)</b>	<b>Coverage on Adriatic area (%)</b>
Coldspot $\geq 95\%$			<b>18.9%</b>
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 $\geq 95\%$			<b>15.6%</b>
<b>Hotspot Water Column</b>	<b>Counted cells</b>	<b>Summed area (Km<sup>2</sup>)</b>	<b>Coverage on Adriatic area (%)</b>

Coldspot $\geq 95\%$			<b>16.8%</b>
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 $\geq 95\%$			<b>18.2%</b>
<b>Hotspot Seabed</b>	<b>Counted cells</b>	<b>Summed area (Km<sup>2</sup>)</b>	<b>Coverage on Adriatic area (%)</b>
Coldspot $\geq 95\%$			<b>20.3%</b>
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 $\geq 95\%$			<b>14.9%</b>